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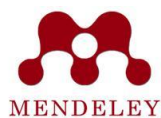
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The Legal Dimensions of International Media Campaigns: A Case Analysis on Broadcasting Policies

Allahverdi Mammadli 

Abstract. *In today's digital communication environment, international media campaigns have come to play an increasingly important role in shaping global public opinion and guiding the flow of information. The rapid growth of social media platforms and digital communication technologies has made it possible for media content to move beyond national borders and operate across different legal systems. Against this backdrop, this article examines the legal aspects of international media campaigns and distribution policies through two specific cases - the Cambridge Analytica scandal and the restrictions imposed on Russia Today broadcasting. The study aims to identify the legal frameworks that influence the activities of international media campaigns, while also exploring how platform policies interact with state regulation in this area. It shows that the data policies of digital platforms, along with the mechanisms of algorithmic governance, have a significant impact on how media campaigns are distributed and whether they reach their intended audiences. At the same time, regulatory actions taken by governments - aimed at ensuring national and information security and countering disinformation - are giving rise to new legal and political debates around the freedom of international media. As a result, it can be concluded that the legal framework for international media campaigns is shaped through the interaction between platform regulation and state intervention. In this context, there is a clear need to develop policies that are balanced, transparent, and grounded in democratic principles.*

Keywords: *international media campaigns, media law, platform policies, state regulation, disinformation*

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Beynəlxalq media kampaniyalarının hüquqi ölçüləri: yayım siyasətləri üzrə təhlil əsasında bir nümunə analizi

Allahverdi Məmmədli 

Xülasə. Müasir rəqəmsal kommunikasiya mühitində beynəlxalq media kampaniyaları global ictimai rəyin formalaşmasında və informasiya axınının istiqamətləndirilməsində mühüm rol oynamağa başlamışdır. Sosial media platformalarının və rəqəmsal kommunikasiya texnologiyalarının sürətli inkişafı media məzmununun milli sərhədləri aşaraq müxtəlif hüquqi sistemlər daxilində yayılmasına şərait yaratmışdır. Bu məqalədə beynəlxalq media kampaniyalarının hüquqi aspektləri və yayım siyasətləri iki konkret nümunə - Cambridge Analytica hadisəsi və Russia Today (RT) yayım qadağaları əsasında təhlil edilmişdir. Tədqiqatın əsas məqsədi beynəlxalq media kampaniyalarının fəaliyyətinə təsir edən hüquqi çərçivələri müəyyənləşdirmək və bu sahədə platforma siyasətləri ilə dövlət tənzimləmələri arasındakı qarşılıqlı əlaqəni araşdırmaqdır. Araşdırma göstərir ki, rəqəmsal platformaların məlumat siyasətləri və alqoritmik idarəetmə mexanizmləri media kampaniyalarının yayılmasına və hədəf auditoriyalara çatdırılmasına əhəmiyyətli təsir göstərir. Eyni zamanda dövlətlərin milli təhlükəsizlik, informasiya təhlükəsizliyi və dezinformasiya ilə mübarizə məqsədilə tətbiq etdiyi tənzimləyici müdaxilələr beynəlxalq media azadlığı ilə bağlı yeni hüquqi və siyasi müzakirələrə səbəb olur. Nəticə olaraq müəyyən edilir ki, beynəlxalq media kampaniyalarının hüquqi çərçivəsi platforma tənzimləmələri ilə dövlət müdaxilələrinin qarşılıqlı təsiri nəticəsində formalaşır və bu sahədə balanslı, şəffaf və demokratik prinsiplərə əsaslanan siyasətlərin inkişafı zəruri hesab olunur.

Açar sözlər: beynəlxalq media kampaniyaları, media hüququ, platforma siyasətləri, dövlət tənzimləməsi, dezinformasiya

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Introduction

The development of digital communication technologies and the rise of global media platforms have pushed information flows beyond national borders, giving them an international scope. Under the influence of the internet and social networks, media campaigns have become powerful communication tools capable of shaping public opinion and influencing the political agenda not only at the national level but also globally (Castells, 2013; McQuail, 2010). This transformation has made the legal dimension of media activity more complex, as media content now circulates within a variety of legal systems and regulatory frameworks. Against this backdrop, the main challenge of this study lies in understanding how international media campaigns are regulated across different legal systems and distribution policies and how these regulations relate to the principle of freedom of expression. When operating under the legal norms of multiple countries, international media campaigns may face various restrictions and regulatory interventions. This situation, in particular, creates tension between the principle of freedom of expression and the authority of states to regulate the media sphere (Napoli, 2019).

This study highlights the following main research questions:

- How do international media campaigns affect broadcasting policies in different countries?
- What legal restrictions exist for media campaigns?
- To what extent can international law regulate the activities of media campaigns?

Accordingly, the aim of the research is to analyze the legal dimension of international media campaigns and to identify how various legal systems influence media activity. Building on this, the study also examines how broadcasting policies shape these campaigns and assesses the legal framework through the analysis of a specific case. In this way, it investigates how media campaigns interact with regulatory systems in different countries and the legal issues that arise as a result.

This study aims to contribute to the academic literature on global media regulation and international media law. Examining the legal dimensions of international media campaigns helps to provide a clearer understanding of the interaction between media freedom and regulatory frameworks. In addition, the research seeks to offer new analytical perspectives in the field of international media management and communication law. Unlike existing studies, this article considers international media campaigns not only in the context of legal restrictions but also through the lens of multi-layered regulatory structures and algorithmic governance mechanisms. This approach allows for moving beyond the traditional state-centered model of media law and provides insight into a more complex and interactive regulatory environment.

Materials and Methods

This study employs a qualitative comparative case study approach to examine the legal dimensions of international media campaigns. The research combines doctrinal legal analysis and policy analysis methods. Two cases—the Cambridge Analytica scandal and the restrictions imposed on Russia Today (RT) broadcasting—were selected due to their significance in illustrating the interaction between platform governance and state regulation. The study analyzes international legal instruments, regulatory documents, and academic literature to assess how different regulatory frameworks shape international media campaigns. Through comparative analysis, the research identifies similarities and differences between platform-based governance mechanisms and state-centered regulatory interventions.

Results

This section presents the findings derived from the comparative analysis of two significant cases: the Cambridge Analytica scandal and the restrictions imposed on Russia Today (RT). These cases illustrate two distinct yet interconnected dimensions of international media regulation, namely platform governance and state intervention. The findings reveal how legal frameworks shape the operation and impact of international media campaigns in the contemporary digital environment.

2.1. *Cambridge Analytica Case*

The central role of digital media platforms in global communication has significantly changed the way international media campaigns are conducted. In particular, social networks have made it easier to distribute content targeted at specific audiences through the collection and analysis of user data, transforming strategies in political communication. In this context, the Cambridge Analytica case stands out as a key example of the interaction between digital platforms' data management policies and international media campaigns. The scandal that erupted in 2018 sparked a wide international debate after the data of millions of Facebook users were collected without consent and used in political campaigns (Cadwalladr & Graham-Harrison, 2018).

The Cambridge Analytica incident marked an important milestone, illustrating how the data collection mechanisms of digital platforms can be used in political communication processes. The company gained access to users' personal data through a Facebook application and employed this information using psychographic analysis methods to create targeted media campaigns capable of influencing voter behavior (Isaak & Hanna, 2018). Not only the data of the users themselves but also the data of their friends' networks were collected, which meant that the information of millions of users was used to target political campaigns. To gain a deeper understanding of this case, the concept of algorithmic governance provides a useful analytical framework. Digital platforms not only have the ability to passively track user behavior but also to actively shape it through algorithmic decisions. In this context, the flow of information is no longer a neutral technological process; rather, it is the result of structured and optimized decision-making mechanisms. Algorithmic systems determine which content is visible, which audiences it reaches, and which messages are prioritized, thereby exerting an indirect but powerful influence on political communication processes. This demonstrates that the legal responsibility of platforms is not limited to data protection alone but also extends to shaping the information environment.

The Cambridge Analytica situation raised serious questions about data handling policies and Facebook's platform governance. For many years, Facebook operated on a platform model that granted third-party application developers access to user data. While this model helped expand the platform's ecosystem, it also opened the door to the uncontrolled use of user information (Vaidhyanathan, 2018). Following the incident, Facebook was compelled to implement stricter policies regarding data access and user permissions. The case also sparked broader discussions about the legal responsibility of digital platforms. In traditional media systems, content producers and distributors were regarded as the actors bearing legal accountability, whereas digital platforms were long seen merely as technical intermediaries.

However, the significant influence of social media companies on content distribution, data analysis, and algorithmic governance has prompted a reassessment of this view (Napoli, 2019), demonstrating that platforms are not just passive infrastructural actors in communication, but also active regulatory agents within the media ecosystem. In response, many countries and international organizations have begun developing new regulations to strengthen the legal accountability of digital platforms (Gradoselskaya, 2026), with rules such as the European Union's General Data Protection Regulation (GDPR) providing an important legal foundation for protecting user data and ensuring transparency in its processing (Kuner et al., 2020). These regulations aim to ensure stricter oversight by platforms over the collection and handling of user information.

The Cambridge Analytica scandal also revealed significant shortcomings in compliance with the principles established by the European Union's General Data Protection Regulation (GDPR). Although the incident became public shortly before the GDPR entered into force, the case highlighted the importance of core GDPR principles such as lawfulness, fairness and transparency in data processing (Article 5), lawful bases for processing personal data (Article 6), and the requirement of freely given and informed consent (Article 7). Furthermore, Article 22 of the GDPR introduced safeguards against decisions based solely on automated processing and profiling, which is particularly relevant in the context of data-driven political communication and micro-targeted campaigning. The case therefore demonstrated how large-scale political influence operations can create legal risks not only for privacy rights but also for democratic participation and electoral integrity.

The Cambridge Analytica case clearly illustrated the connection between data protection laws and media campaigns, showing how the effectiveness of digital media campaigns largely depends on the analysis of user data and the identification of target audiences. This situation has created a new area of legal debate, situated between the principles of data protection and political communication: on one hand, the protection of individual data is considered a key aspect of privacy, while on the other,

political communication remains an important component of democratic processes (Bennett & Lyon, 2019). In this context, the case also demonstrates how international media campaigns are closely intertwined with digital platform policies and data governance systems, with platform data policies playing a key role not only in terms of user privacy but also in shaping the reach and influence of media campaigns.

Consequently, analyzing the legal aspects of international media campaigns requires a comprehensive examination of digital platforms' data governance policies and their legal responsibilities. The incident prompted a reassessment of the role of digital media platforms within the global communication system, clearly highlighting the connection between data protection laws and media regulations in the context of international law and media policy. Furthermore, it underscores the legal implications of the "data-driven political communication" model, in which communication is no longer conducted on a mass scale but in a micro-targeted and personalized format, capable of influencing voter behavior through more subtle and difficult-to-measure mechanisms.

2.2. Bans on Russia Today Transmission

The development of the international media system has sparked new debates regarding the limits of state authority in regulating the media. In particular, the global operations of digital media platforms and international broadcasting organizations have created a need to assess media content within the frameworks of various legal systems. In this context, the bans on Russia Today (RT) serve as a significant example of how state regulatory interventions in the media sector are evaluated in light of international broadcasting policy and freedom of expression.

Russia Today is an international media organization funded by the Russian government, founded in 2005. RT broadcasts in multiple languages, including English, with the aim of reaching a global audience. While the organization's official mission is stated as presenting Russia's perspective to the world, numerous academic studies indicate that RT functions as part of state-supported media strategies, particularly in the context of international political processes (Oates, 2021). In addition to television broadcasting, RT conducts international media campaigns through digital platforms and social networks, which has helped establish it as a significant actor in the global media landscape.

RT's international activities have been particularly scrutinized in Western countries due to concerns about propaganda and disinformation. Research indicates that state-supported media structures engage in strategic communication aimed at influencing international public opinion, and such activities can exert a significant impact on political communication processes (Pomerantsev, 2015). In this context, RT's broadcasting policies are analyzed within the framework of information warfare and debates on strategic communication in the international media environment.

In 2022, following the outbreak of the war between Russia and Ukraine, the European Union and several Western countries imposed various restrictions on RT's operations. Citing the spread of disinformation about the war by Russian state media, the Council of the European Union decided to ban the broadcasting of RT and Sputnik within EU member states. As part of this decision, the distribution of RT content on television, websites, and digital platforms was restricted. European officials described these measures as steps aimed at countering propaganda and disinformation (Helberger et al, 2018).

However, the bans on RT's broadcasting have sparked considerable debate in the context of international media law and freedom of expression. Many scholars and legal experts emphasize the need for a careful assessment of state-imposed restrictions on media organizations based on claims of propaganda or disinformation, with regard to freedom of speech. Freedom of expression is one of the core principles of democratic societies and plays a crucial role in protecting the work of the media (Barendt, 2005). Accordingly, the importance of limiting state intervention in the media sphere within democratic standards is often highlighted.

From the perspective of European human rights law, Article 10 of the European Convention on Human Rights (ECHR) guarantees the right to freedom of expression, including the freedom to receive and impart information without interference by public authorities. However, Article 10(2) also permits restrictions that are prescribed by law and necessary in a democratic society for the protection of national security, territorial integrity, public safety, or the prevention of disorder and crime. Consequently, the legal assessment of restrictions imposed on RT requires careful examination of whether such measures satisfy the principles of legality, necessity, and proportionality established under the Convention.

A similar approach can be found in Article 19 of the International Covenant on Civil and Political Rights (ICCPR), which recognizes freedom of expression as a fundamental human right while allowing certain restrictions for the protection of national security, public order, public health, public morals, and the rights of others. Within the context of international broadcasting and digital communication, Article 19 provides an important normative framework for balancing media freedom against legitimate state interests. Therefore, debates surrounding the RT restrictions illustrate the continuing challenge of reconciling international human rights standards with contemporary concerns about disinformation and information security.

Moreover, the RT case has prompted broader discussions about how the concepts of propaganda and disinformation should be defined within the international media environment. The acceleration of information flows in the digital media landscape facilitates the global spread of content containing disinformation and propaganda (Qu & Lu, 2026), which has in turn led states to strengthen their policies aimed at countering disinformation. At the same time, the effects of these measures on media freedom in the course of combating disinformation are actively debated in the academic literature (Bennett & Livingston, 2018).

For an alternative analysis of the RT case, the concept of “information sovereignty” becomes particularly relevant. According to this approach, states have the right to protect not only their physical borders but also their informational space. In the digital environment, the influence of foreign media actors has prompted governments to reassess their information security strategies. In this context, restrictions on RT’s activities are linked not only to issues of media freedom but also to states’ attempts to safeguard their informational environment. At the same time, this approach remains controversial from the perspective of international law, as the principle of information sovereignty can potentially conflict with the right to freedom of expression.

Discussion

The findings obtained from the Cambridge Analytica and RT cases demonstrate that international media campaigns operate within a complex legal environment shaped by both platform governance and state regulation. To interpret these findings more comprehensively, it is necessary to discuss the broader legal, regulatory, and theoretical frameworks that influence contemporary media governance. The following discussion examines these findings through the perspectives of regulatory pluralism, algorithmic governance, information sovereignty, and hybrid governance.

3.1 Legal and Regulatory Frameworks

Globalization and the development of digital communication technologies have greatly expanded the reach and influence of media campaigns. Today, media campaigns are not limited to communication within national borders; they also take the form of international strategies aimed at audiences in different countries, with the goal of shaping global public opinion. International media campaigns can be understood as communication activities carried out by states, international organizations, non-governmental organizations, or private sector actors with the purpose of disseminating information on a global scale, influencing public opinion, or affecting political discourse (Castells, 2013; Thysius,

2018). These campaigns spread particularly rapidly through digital platforms and play a significant role in shaping international information flows.

The spread of international media campaigns has prompted a reassessment of global media regulation and broadcasting policies. In traditional media systems, broadcasting activities were primarily governed by national legal frameworks; however, in the digital environment, the cross-border circulation of content can limit the effectiveness of these rules (Galante, 2023). As a result, media regulation now takes place not only within national legislation but also in the context of international law and platform policies (Flew, 2021). In particular, the management of digital platform content, data handling policies, and algorithmic regulatory mechanisms have introduced a new dimension to media governance processes, highlighting the need for regulation that balances media freedom with public interests.

In democratic societies, freedom of expression is considered a fundamental right and plays a key role in protecting the work of the media (Galante et al., 2023). Nevertheless, media content may still be subject to certain legal restrictions aimed at safeguarding public order, national security, preventing hate speech, or combating disinformation (McQuail, 2010). In this context, media law functions as a regulatory field seeking to maintain a delicate balance between protecting freedom of expression and ensuring public safety, reflecting the complex challenges posed by the global and digital nature of contemporary media campaigns.

Media law provides an important foundation for understanding the legal dimensions of international media campaigns. It encompasses the legal rules and regulatory mechanisms that shape the activities of media organizations, as well as issues related to freedom of expression, content regulation, media ownership, and editorial responsibility (Barendt, 2005). The rise of digital media platforms has made this field even more complex. Unlike traditional media systems, social media and digital communication networks operate on a global scale, which means that different legal systems can affect the same content simultaneously. In this context, platform rules extend beyond the policies of private companies, as many countries are now developing new legislative frameworks to regulate digital media platforms. Notable examples include the European Union's Digital Services Act, data protection legislation, and platform accountability policies (Napoli, 2019), which are designed to make the role of platforms in managing content and information flows more transparent and accountable.

The adoption of the Digital Services Act (DSA) by the European Union has further strengthened the regulatory framework governing digital platforms. The DSA imposes extensive obligations on very large online platforms regarding transparency, risk assessment, content moderation, and accountability mechanisms. In particular, the regulation requires platforms to assess and mitigate systemic risks associated with the dissemination of illegal content, disinformation, and manipulation of information environments. As a result, digital platforms are increasingly expected to operate not merely as private communication infrastructures but as actors bearing public responsibilities within the digital information ecosystem.

In today's digital media environment, regulation cannot be explained solely through a state-centered approach. In this context, the concept of *regulatory pluralism* provides a more adequate framework for analyzing the legal dimensions of international media campaigns. According to this approach, the rules governing the media environment are shaped not only by states, but also by platforms, international organizations, and non-state actors. As a result, legal regulation takes on a multi-level, multi-actor structure. This means that the activities of international media campaigns are influenced not by a single legal system, but by parallel and sometimes conflicting sets of rules. Consequently, media law should be understood not as a fixed normative framework, but as a dynamic regulatory ecosystem open to mutual influence.

3.2. Platform Governance and State Regulation

To understand the legal aspects of international media campaigns, it is essential to consider the relationship between digital platform policies and state regulation together. The digitization of the global communication system has meant that not only states but also private technology companies have become significant regulatory actors in the production and distribution of media content, transforming the traditional state-centered model of media regulation into a more complex, multi-layered governance system (Flew, 2021).

Social media platforms play a central role in the global dissemination of media campaigns, and their content management and data handling policies can directly shape the legal boundaries within which these campaigns operate. This influence is especially evident through the development of data-driven communication strategies, where social media companies analyze user information to identify target audiences, thereby supporting more effective execution of media campaigns. Such practices have increased the reliance on data in political communication processes and sparked new debates about the regulatory responsibilities of digital platforms (Zuboff, 2019). Platform content distribution algorithms can direct the flow of information, ensuring that certain content reaches a wider audience, positioning digital platforms not merely as technical components of communication infrastructure but as actors actively shaping the structure of the media environment (Van Dijck et al., 2018).

Nevertheless, media regulation extends beyond platform policies. States develop various mechanisms to maintain public order, protect national security, and combat disinformation. The cross-border nature of international media campaigns complicates the exercise of state authority, as digital media content accessible in multiple countries may be lawful in one jurisdiction but restricted in another (Napoli, 2019). Consequently, the international media environment now features a diversified legal framework, emphasizing the necessity to evaluate media activities in the context of multiple overlapping legal systems.

The regulation of international media campaigns must be considered within the context of normative conflicts, where different legal principles - freedom of speech, data protection, national security, and information security - often clash. These conflicts are not merely legal disputes; they also reflect underlying differences in values. Media activity that is deemed legitimate under one legal system may be perceived as a threat under another, making it difficult to establish a unified international regulatory model and highlighting the inevitability of legal pluralism. Consequently, international media law should be understood not as a fixed set of rules but as a dynamic field shaped by the interaction of diverse normative approaches.

State interventions in the media sphere typically occur in response to concerns over propaganda, disinformation, and national security (DuBosar et al., 2026). In the digital media environment, the rapid spread of manipulative content has prompted many countries to reconsider their media regulations, developing new rules for media organizations and digital platforms and implementing policies to control the flow of information (Bennett & Livingston, 2018). At the same time, such interventions require careful evaluation in terms of freedom of expression, one of the fundamental principles of international human rights law. Freedom of expression plays a crucial role in protecting the work of the media, and instruments like the European Convention on Human Rights set out key principles for safeguarding media freedom (Barendt, 2005). Nevertheless, freedom of expression is not absolute and may be restricted for reasons such as national security, public order, or the prevention of incitement to hatred.

The rise of digital media and new regulatory approaches has further reshaped the concept of media governance. Whereas traditional media systems relied primarily on state authorities for regulation, today digital platforms, international organizations, and non-governmental actors all play central roles in shaping media policy. This multi-actor regulatory structure allows a variety of interests and values to influence media governance (Tambini, 2021). As a result, the legal framework for

international media campaigns is shaped not only by national laws but also by platform policies and global governance processes. This multi-layered model, often referred to as “hybrid governance,” sees states, platforms, and international institutions exerting parallel normative influence, so that the media environment does not form a single legal space but rather a network of interconnected regulatory domains.

Conclusion

The development of digital communication technologies and the expansion of global media platforms have significantly increased the international reach of media campaigns, making it necessary to reconsider their legal frameworks. The cases examined in this study - Cambridge Analytica and the bans on Russia Today (RT) - illustrate how international media campaigns are shaped by different regulatory mechanisms. Together, these cases provide complementary insights into the role of digital platform policies and state regulation in the global media environment.

The Cambridge Analytica case clearly demonstrated the influence of digital platforms’ data governance policies on the management of media campaigns. Large-scale collection and analysis of user data enabled the development of targeted communication strategies and more precise audience targeting, showing that digital platforms are not merely technical tools of communication but are increasingly important regulatory actors within the media ecosystem. Policies governing data access, algorithmic content distribution, and moderation practices directly shape the reach and impact of media campaigns.

Conversely, the ban on RT’s broadcasting illustrates how state regulatory intervention in the media sphere can shape international broadcasting policy. States may intervene in media activities and restrict the output of specific media organizations for reasons such as national security or countering propaganda and disinformation. Such measures highlight the delicate balance between media freedom and national security and demonstrate how states exercise their regulatory powers within the international media environment.

In this context, developing policy recommendations for international media campaigns becomes increasingly important. Digital platforms’ policies on data governance and content management should be transparent and accountable. Platforms that implement robust mechanisms for protecting user data and adopt clear rules for its use are likely to enhance trust in the digital media environment. Additionally, transparency in content moderation processes and the ability to audit them can support the ethical and legal implementation of international media campaigns.

At the same time, state media regulation policies should align with the principle of freedom of expression. Measures aimed at countering disinformation and propaganda must not unduly restrict media freedom. Consequently, media regulation should adhere to democratic standards and the principles of international human rights, while also encouraging international cooperation to address the cross-border nature of the digital media landscape.

Overall, this study demonstrates that the legal analysis of international media campaigns cannot be confined solely to institutional regulation. Technological and normative transformations - including the algorithmic power of digital platforms, state claims to information sovereignty, and the limited applicability of international law - create a complex and multidimensional regulatory environment. Future research should therefore focus on platform governance, AI-driven content regulation, and issues of global legal harmonization to better understand and guide international media practices.

Theoretically, the study advances media law scholarship by demonstrating that contemporary international media regulation operates through overlapping layers of governance rather than through

a single state-centered legal system. This finding supports emerging theories of regulatory pluralism and contributes to ongoing debates on digital platform accountability.

The findings of this study indicate that contemporary international media regulation is increasingly shaped by the interaction between platform governance mechanisms established under instruments such as the GDPR and Digital Services Act, and international human rights standards embodied in Article 10 of the ECHR and Article 19 of the ICCPR.

The scientific novelty of this study lies in integrating platform governance, algorithmic governance, information sovereignty, and regulatory pluralism into a unified analytical framework for examining international media campaigns. Unlike traditional media law studies that primarily focus on state regulation, this research demonstrates how legal authority is increasingly distributed among states, digital platforms, and international institutions. The study contributes to the literature by proposing a hybrid governance perspective for understanding the legal regulation of global media campaigns.

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Böyük Vətən müharibəsi illərində Naxçıvanda sosial transformasiya və ədəbi proseslərin qarşılıqlı təsiri

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Xülasə. Bu məqalədə Böyük Vətən Müharibəsi (1941–1945) illərində Naxçıvan Muxtar Respublikasında sosial-iqtisadi vəziyyət, arxa cəbhənin fəaliyyəti və ədəbi mühitin formalaşması kompleks şəkildə təhlil edilmişdir. Tədqiqatın məqsədi müharibə dövründə region əhalisinin arxa cəbhədə həyata keçirdiyi iqtisadi, sosial və mədəni fəaliyyətin əsas istiqamətlərini müəyyənləşdirmək, eləcə də həmin dövrdə formalaşmış ədəbi mühitin və dövrü mətbuatın vətənpərvərlik ideyalarının təbliğində rolunu qiymətləndirməkdir. Tədqiqat zamanı Naxçıvan Muxtar Respublikası Dövlət Arxivinin sənədləri, dövrü mətbuat materialları və mövzu üzrə elmi ədəbiyyat müqayisəli-tarixi və mənbəşünaslıq metodları əsasında təhlil edilmişdir. Araşdırma nəticəsində müəyyən edilmişdir ki, müharibə illərində Naxçıvan əhalisi kənd təsərrüfatı istehsalının davam etdirilməsi, müdafiə fonduna maliyyə və maddi vəsaitlərin ayrılması, cəbhəyə humanitar yardımların göndərilməsi və əmək resurslarının səfərbər edilməsi istiqamətlərində mühüm fəaliyyət göstərmişdir. Eyni zamanda, "Şərq Qapısı" qəzeti və regionun ədəbi mühiti vətənpərvərlik ideyalarının yayılmasında, əhalinin mədəni səfərbərliyinin gücləndirilməsində və ictimai həmrəyliyin formalaşdırılmasında əhəmiyyətli rol oynamışdır. Əldə olunan nəticələr Böyük Vətən Müharibəsi dövründə Naxçıvanın arxa cəbhə fəaliyyətinin sosial-iqtisadi və mədəni aspektlərinin kompleks şəkildə qiymətləndirilməsinə imkan yaradır.

Açar sözlər: Böyük Vətən Müharibəsi, Naxçıvan Muxtar Respublikası, arxa cəbhə, sosial-iqtisadi fəaliyyət, ədəbi mühit, "Şərq Qapısı" qəzeti

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Social Situation and Literary Environment in Nakhchivan During the Great Patriotic War

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Abstract. *This article comprehensively examines the socio-economic conditions, home front activities, and the development of the literary environment in the Nakhchivan Autonomous Republic during the Great Patriotic War (1941–1945). The study aims to identify the main directions of the economic, social, and cultural activities carried out by the region's population on the home front during the war, as well as to evaluate the role of the literary environment and the periodical press in promoting patriotic ideas. The research is based on a comparative-historical and source analysis of documents from the State Archive of the Nakhchivan Autonomous Republic, periodical press materials, and relevant scholarly literature. The findings reveal that during the war years, the population of Nakhchivan made significant contributions by maintaining agricultural production, allocating financial and material resources to the Defense Fund, providing humanitarian assistance to the front, and mobilizing labor resources. At the same time, the Sharq Gapisi (Eastern Gate) newspaper and the region's literary environment played a significant role in disseminating patriotic ideas, strengthening the moral mobilization of the population, and fostering social solidarity. The findings provide a comprehensive assessment of the socio-economic and cultural dimensions of Nakhchivan's home front activities during the Great Patriotic War.*

Keywords: *Great Patriotic War, Nakhchivan Autonomous Republic, home front, socio-economic activities, literary environment, Sharq Gapisi (Eastern Gate) newspaper*

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Giriş

İkinci Dünya müharibəsinin tərkib hissəsi olan Böyük Vətən müharibəsi (1941–1945) Sovet İttifaqının bütün regionlarında olduğu kimi, Naxçıvan Muxtar Sovet Sosialist Respublikasının da sosial-iqtisadi, demoqrafik və mədəni həyatına ciddi təsir göstərmişdir. Müharibənin başlanması ilə regionun əmək, maliyyə və maddi resurslarının əhəmiyyətli hissəsi cəbhənin ehtiyaclarının təmin edilməsinə istiqamətləndirilmişdir. Əmək qabiliyyətli kişilərin böyük hissəsinin hərbi xidmətə çağırılması kənd təsərrüfatında, sənaye müəssisələrində və ictimai xidmət sahələrində işçi qüvvəsi çatışmazlığı yaratmış, nəticədə istehsal prosesinin davam etdirilməsində qadınların, yaşlıların və yeniyetmələrin rolu artmışdır.

Müharibə illərində Naxçıvanın arxa cəbhə fəaliyyəti bir neçə əsas istiqamətdə həyata keçirilmişdir. Bu istiqamətlərə kənd təsərrüfatı və sənaye istehsalının müharibə şəraitinə uyğunlaşdırılması, müdafiə fonduna maliyyə və qiymətli əşyaların verilməsi, cəbhəyə ərzaq, geyim və digər maddi yardımların göndərilməsi, cəbhəçi ailələrinə sosial dəstəyin göstərilməsi, eləcə də əmək resurslarının səfərbər olunması daxil idi. Regionun iqtisadi imkanlarının məhdudluğuna baxmayaraq, yerli əhalinin cəbhənin təminatına cəlb edilməsi sistemli və genişmiqyaslı xarakter daşıyırdı.

1941-ci il iyunun 22-də Nasist Almaniyasının SSRİ-yə hücumundan sonra Naxçıvanda hərbi və əmək səfərbərliyi tədbirlərinin həyata keçirilməsinə başlanılmışdır. Əhalinin bir hissəsinin cəbhəyə göndərilməsi ilə əlaqədar kolxoz və sovxozlarda, sənaye müəssisələrində və dövlət idarələrində əmək bölgüsü yenidən təşkil edilmişdir. İstehsal planlarının yerinə yetirilməsi, ərzaq təminatının davam etdirilməsi və cəbhəyə yardım kampaniyalarının təşkili yerli idarəetmə orqanlarının qarşısında duran əsas vəzifələrdən olmuşdur.

Müharibə şəraiti yalnız regionun iqtisadi və sosial həyatına deyil, ədəbi-mədəni mühitinə də təsir göstərmişdir. Dövrü mətbuat, xüsusilə “Şərq Qapısı” qəzeti əhalinin məlumatlandırılması, hərbi və əmək səfərbərliyinin təbliği, cəbhəyə yardım kampaniyalarının işıqlandırılması və ictimai rəyin formalaşdırılması baxımından mühüm vasitəyə çevrilmişdir. Eyni zamanda, Naxçıvanda fəaliyyət göstərən şair, yazıçı və publisistlərin yaradıcılığında müharibə, cəbhə həyatı, arxa cəbhə fəaliyyəti, vətənpərvərlik və qələbəyə inam mövzuları əsas istiqamətlərdən biri olmuşdur.

Mövcud tədqiqatlarda Naxçıvanın Böyük Vətən müharibəsi illərindəki vəziyyəti əsasən hərbi iştirak, iqtisadi fəaliyyət, qadınların əmək prosesinə cəlb olunması və ayrı-ayrı ədəbi şəxsiyyətlərin yaradıcılığı kontekstində araşdırılmışdır. Bununla belə, regionda sosial-iqtisadi səfərbərlik prosesləri ilə ədəbi-mədəni fəaliyyətin qarşılıqlı əlaqəsinin vahid elmi yanaşma əsasında kompleks təhlilinə kifayət qədər diqqət yetirilməmişdir.

Tədqiqatın məqsədi 1941–1945-ci illərdə Naxçıvan Muxtar Sovet Sosialist Respublikasında həyata keçirilmiş sosial-iqtisadi səfərbərlik tədbirlərini, əhalinin arxa cəbhə fəaliyyətində iştirakını və müharibə dövrü ədəbi-mədəni mühitinin əsas xüsusiyyətlərini arxiv sənədləri və dövrü mətbuat materialları əsasında təhlil etməkdir. Tədqiqat çərçivəsində müdafiə fonduna göstərilən maliyyə və maddi yardımların əsas istiqamətləri, qadınların və gənclərin əmək fəaliyyətinə cəlb olunması, cəbhəçi ailələrinin sosial müdafiəsi və ədəbi publisistikanın ictimai səfərbərlikdəki rolu araşdırılır.

Materiallar və Metodlar

Tədqiqatın əsas mənbə bazasını Naxçıvan Muxtar Respublikası Dövlət Arxivində mühafizə olunan arxiv sənədləri, dövrü mətbuat materialları və mövzu üzrə nəşr edilmiş elmi ədəbiyyat təşkil edir. Arxiv materialları arasında dövlət idarələrinin hesabatları, qərar və sərəncamlar, müdafiə fonduna dair maliyyə sənədləri, yerli hakimiyyət orqanlarının iclas protokolları, həmçinin müharibə illərinə aid statistik məlumatlar xüsusi yer tutur. Dövrü mətbuatın əsas mənbəyini “Şərq Qapısı” qəzeti təşkil etmişdir. Bununla yanaşı, mövzu ilə bağlı monoqrafiyalar və elmi araşdırmalardan da istifadə olunmuşdur.

Tədqiqat zamanı tarixi-təhlil, müqayisəli-tarixi, mənbəşünaslıq və kontent-analiz metodlarından istifadə edilmişdir. Tarixi-təhlil metodu vasitəsilə müharibə illərində Naxçıvanın sosial-iqtisadi vəziyyəti və arxa cəbhənin fəaliyyət istiqamətləri sistemli şəkildə araşdırılmışdır. Müqayisəli-tarixi metod müxtəlif illərə aid statistik göstəricilərin dinamikasını müəyyən etməyə imkan vermişdir. Mənbəşünaslıq yanaşması əsasında arxiv sənədlərinin etibarlılığı və informativliyi qiymətləndirilmiş, dövrü mətbuat materialları isə kontent-analiz metodu ilə təhlil edilərək onların ictimai səfərbərlik və vətənpərvərlik təbliğində oynadığı rol müəyyənləşdirilmişdir.

Tədqiqatın metodoloji əsasını tarixşünaslıqda qəbul olunmuş obyektivlik, tarixilik və sistemlilik prinsipləri təşkil edir. Araşdırma zamanı müxtəlif mənbələrdən əldə edilmiş məlumatlar qarşılıqlı şəkildə müqayisə edilmiş, statistik göstəricilər arxiv sənədləri ilə tutuşdurulmuş və nəticələrin elmi etibarlılığı təmin edilməyə çalışılmışdır.

Nəticələr

Naxçıvan MR Dövlət Arxivində saxlanılan sənədlərdən aydın olur ki, 1941-ci ilin iyul ayında muxtar respublika üzrə rəhbər işçilərin, kolxoz sədrlərinin, idarə və müəssisə rəhbərlərinin müşavirəsi

keçirilmişdir. Müşavirədə cəbhədə döyüşən hərbiçilərin ailələrinə yardım göstərilməsi məqsədilə yardım fondlarının yaradılması və cəbhədə xidmət edən hərbiçilərə hədiyyələrin göndərilməsi məsələləri müzakirə edilmişdir. Dövlət tərəfindən yaradılmış komissiyaların, eləcə də zəhmətkeşlərin təşəbbüsü ilə dörd ay ərzində muxtar respublika üzrə Müdafiə Fonduna 120 800 manat nağd pul, 1 727 000 manatlıq istiqraz vərəqəsi və 7 kq 700 qram qızıl-gümüş toplanaraq dövlət bankına verilmişdir. Bundan əlavə, tədarük məntəqələrinə 66,1 ton taxıl, 64,3 ton ət, 2 155 kq yun, 897 kq yağ, 10,6 ton tərəvəz, 3 634 cüt yun corab, 1 461 cüt yun əlcək və müxtəlif geyim əşyaları toplanaraq cəbhəyə göndərilmişdir (Naxçıvan Muxtar Respublikası Dövlət Arxivi [Nax.MRDA], f. 1, s. 1, iş 8, v. 8).

Müharibə illərində qadınların fəaliyyəti xüsusi əhəmiyyət daşıyırmışdır. Naxçıvan qadınları kənd təsərrüfatı və istehsalat sahələrində kişiləri əvəz etmiş, traktorçu, briqadir, müəllim və tibb işçisi kimi fəaliyyət göstərmişlər. Bir sıra qadınlar əmək normalarını yüksək göstəricilərlə yerinə yetirmişlər. Bu fəaliyyət kənd təsərrüfatı və istehsal proseslərinin davam etdirilməsinə töhfə vermişdir.

Şərur rayonundan olan cəbhəçi anası K. Əliyeva 1941-ci ilin oktyabrında şəxsi bağlama hazırlayaraq Moskvanın müdafiəçilərinə məktubla birlikdə göndərmişdir. Məktubda belə qeyd olunurdu: “Qoy mənim bu balaca ana sovqatım sizin düşməni məhv edən əllərinizi qızdırsın. Düşməne qəzəbinizi artırsın, qələbənizi yaxınlaşdırsın” (Naxçıvan Muxtar Respublikası Dövlət Arxivi [Nax.MRDA], f. 1, s. 1, iş 9). Məktəblilər də bu fəaliyyətlərdə iştirak etmiş, metal tullantıları və dərman bitkiləri toplamışlar.

Naxçıvan əhalisi müharibə dövründə yalnız əmək fəaliyyəti ilə deyil, həm də maddi yardımları ilə seçilirdi. İnsanlar şəxsi vəsaitlərini müdafiə fonduna köçürür, qızıl-zinət əşyalarını dövlətə təhvil verirdilər. Əhali tərəfindən isti geyimlər hazırlanır, cəbhəyə sovqatlar göndərilir, yaralı əsgərlər üçün yardımlar toplanırdı. Bu fəaliyyətlər dövrün mətbuatında əhalinin vətənpərvərlik və həmrəylik nümunəsi kimi təqdim olunurdu. 2 sentyabr 1941-ci il tarixdə “Şərq qapısı” qəzeti “Naxçıvan qadınları Azərbaycanın qabaqcıl qadınlarının müraciətinə qoşulurlar” başlıqlı məqalədə yazırdı: “Azərbaycanın qabaqcıl qadınlarının, Azərbaycanın bütün qadınlarına olan müraciətini müzakirə edən biz Naxçıvan şəhərinin bir qrup qadını ölkəmizin müdafiə fondunu daha da möhkəmləndirməyə yönəldilmiş bu vaxtlı müraciəti bəyənir və çox böyük həvəslə ona qoşuluruq. Bu müraciətnamə, doğma vətəninə canından da artıq sevən biz Naxçıvan qadınlarının fikrini dəxi ifadə edir. Sizin dediyiniz kimi, vətən müharibəsi cəbhələrində cəllad hitler faşizminə qarşı qəhrəmanlıqla vuruşan qardaşlarımıza ana qayğısı və navazişi göstərmək vaxtıdır. Bəli, bacılarımız, igid döyüşçülərimizə daha çox hədiyyələr vermək, hünər və təşəbbüslər göstərmək vaxtıdır! Başımızın üstünü böyük qorxu aldığı bir zamanda, vətən müharibəsinin bu ciddi vaxtında artıq nəyimiz varsa, hər nə-qızıl, gümüş və başqa qiymətli şeylərimiz varsa hamısı vətən yolunda qurbandır! Biz, sizin müraciətinizdən bütün nəticələri çıxararaq aşağıda göstərilən ən qiymətli şeylərimizi vətəni müdafiə fonduna verməyi layiq bilirik:

Talıbova Rübabə - qızıl qol saat, 300 manat pul, 800 manatlıq istiqraz və mis; Protçenko – qızıl qol saati, 1.000 manat pul, 1 qızıl üzük; Quliyeva Leylan (evdar qadın) 3 misqal ağırlığında qızıl boğazaltı, 2 mis qazan və 300 manatlıq istiqraz; Abbasova Siddiqə - 1 qızıl üzük, mis və 300 manatlıq istiqraz; Həsənova Qumru-650 manat pul, 1.000 manat istiqraz vərəqəsi; Abbasova Züleyxa -qızıl üzük, mis; Abbasova Vasilə - qızıl sırğa; Fətullayeva Əqiyyə- bir misqal qızıl, 1.500 manatlıq istiqraz vərəqəsi; Səfiyeva Pəri -bir qızıl bacaxlı, 900 manatlıq istiqraz; Qədimova Simuzər - qızıl üzük, 2 gümüş qaşiq, 800 manat pul və 1.000 manatlıq istiqraz; Aslanova Məryəm 600 manat pul, müharibə qurtaranadək ayda 350 manat pul, 2.000 manatlıq istiqraz və mis; Abbasova Anna-qızıl cib saati, 2 gümüş qaşiq, 2.000 istiqraz və mis; Vəliyeva Güllü-600 manat nağd pul; Məmmədova Səkinə - bir misqal ağırlığında qızıl qarabatdağ, 1.000 manatlıq istiqraz; Qədimova Lida-2 qızıl üzük, 1.500 manatlıq istiqraz və müharibə qurtaranadək hər ay 2 günlük əmək haqqı, Həkim Knıtkova-1.500 manatlıq istiqraz; Xəlilova Təyyibə-8 parça qızıl, 300 manat pul, qızıl sırğa, müharibə qurtaranadək

ayda 3 günlük əmək haqqı və mis; Kazımova Güllü- 1 qızıl üzük, 500 manatlıq istiqraz, mis; Əliyeva Xavər- 300 manat pul, 500 manatlıq istiqraz və mis; Behbudova Gülabə - 1 qızıl üzük, 1.000 manatlıq istiqraz; Həsənova Bəni-qızıl sırğa, 1.000 manatlıq istiqraz; Səkinə Rza- 6 q qızıl, 300 manat pul, 500 manatlıq istiqraz, 10 kq mis və müharibə qurtarınca hər ay 3 günlük əmək haqqı”.

Şərur rayon zəhmətkeşləri ön cəbhədəki döyüşçülərimizə 01 noyabrdan 20 noyabr 1941 - ci il tarixə kimi əşya və isti paltarlar: 411 ədəd yarım şuba, 740 yun əlcək, 49 ədəd isti papaq, 80 ədəd pambıq cılıkka, 11 ədəd şalvar, 40 ədəd isti köynək, 16 ədəd isti tuman, 625 cüt yun corab, 92 ədəd sıxılı, 3 ədəd kürk, 19 ədəd adyal, 3 ədəd balınc üzü, 216 ədəd cib dəsmalı, 99 ədəd üz dəsmalı, 117 ədəd əl-üz sabunu, 66 ədəd paltar sabunu, 9 kq tütün və s. toplayıb göndərmişlər (Nax.MRDA. f.116. s1, iş. 419, v. 80-81).

20 noyabr 1941-ci ilə kimi Naxçıvan Muxtar Respublikası üzrə vətəndaşlardan və təşkilatlardan ölkənin müdafiəsi üçün dövlət müdafiə fonduna 1.251000 manat nağd pul, 1.738000 manatlıq istiqraz və rəqəsi, 1 kq 217 q qızıl, 6 kq 388 q gümüş dövlət bankına təhvil verilmişdir. Bundan başqa müdafiə fonduna 66.432 kq taxıl, 64.318 kq ət, 888 kq yağ, 2.155 kq yun, 797 kq pendir, 42.5 kq bal, 7.138 kq üzüm, 3894 kq tərəvəz və b.kənd təsərrüfatı məhsulları vermişdilər (Nax.MRDA. f .116. s1, iş. 419, v. 89-90).

Cədvəl 1

1941-ci ildə Naxçıvanın müdafiə fonduna yardımları

Yardım növü	Miqdarı
Nağd pul	1 251 000 manat
İstiqraz	1 738 000 manat
Qızıl	1 kq 217 q
Gümüş	6 kq 388 q
Taxıl	66 432 kq
Ət	64 318 kq
Yağ	888 kq
Yun	2 155 kq
Pendir	797 kq
Bal	42.5 kq
Üzüm	7 138 kq
Tərəvəz	3 894 kq

Mənbə. NMR Dövlət Arxivi.

1 yanvar 1942-ci ildən 31 dekabr 1942-ci ilə kimi Naxçıvan Respublikasının zəhmətkeşləri müharibədə döyüşən əsgərlərə isti paltarların alınması üçün 167222 manat pul və 10556 ədəd müxtəlif əşyalar, “Azərbaycan kolxozu” tank kaloniyasının tikintisi üçün 6 milyon 780 min manat, təyyarə eskadrasının tikilməsi üçün 1 milyon 935 min manat və tibbi təyyarə tikiməsi üçün 20.450 manat vermişlər (Nax.MRDA. f .116. s1, iş. 419, v. 89-90).

Bundan başqa 137 manat 380 kq taxıl, 151 baş iri və xırda buynuzlu heyvan, Qızıl Ordunun əsgərləri üçün 6520 ədəd bağlama (pasılka) 61 qoyun və 67.048 manat pul toplayaraq göndərmişlər. “Azərbaycan kolxozu” tank kaloniyasının tikilməsi üçün Şərur rayonunun Engelis adına kolxozun sədri Məmməd Əliyev 350 min manat, “Sosializm” adına kolxozun sədri Hüseyn Əliyev 100 min manat və Allahverdiyev 80 min manat pul vermişlər (Nax.MRDA. f .116. s1, iş. 419, v.11).

Cədvəl 2*1942-ci ildə Naxçıvan zəhmətkeşlərinin hərbi fondlara göstərdiyi əsas maliyyə yardımları*

Yardım istiqaməti	Məbləğ / Miqdar
İsti paltarların alınması	167 222 manat
Müxtəlif əşyalar	10 556 ədəd
Tank koloniyasının tikintisi	6 780 000 manat
Təyyarə eskadrasının tikintisi	1 935 000 manat
Tibbi təyyarənin tikintisi	20 450 manat

Mənbə. NMR Dövlət Arxivi [2, v. 89–90].

1941-ci ildə və 1942-ci ilin birinci və ikinci rüblərində Naxçıvan (Babək) rayon zəhmətkeşləri müdafiə fonduna və qızıl əsgərlərə 230 sırxlı, pencək, 1.980 cüt yun əlcək və yun corab, 940 dəst isti alt paltarları, 2.200 ədəd dəri, 413 kq yun, 1 kq 112 qram qızıl, 6 kq 961 qram gümüş, 872.000 manat pul, 1.255.000 manat zayom və sahibsiz uşaqlar üçün 11.467 manat pul vermişlər (Nax.MRDA. (keçmiş partiya arxivi) f.1. s1, iş. 2119).

Müharibə illərində Naxçıvanın iqtisadiyyatında kənd təsərrüfatı xüsusi əhəmiyyət daşıyırdı. Cəbhənin ərzaqla təmin olunması məqsədilə taxılçılıq, pambıqçılıq, üzümçülük və heyvandarlıq sahələrində istehsal artırıldı. Xüsusilə taxıl istehsalının artırılması, məhsuldarlığın inkişaf etdirilməsi, ordu üçün ət, süd və yun məhsullarının göndərilməsi, əkin sahələrinin genişləndirilməsi əsas vəzifələrdən idi. Kişi işçi qüvvəsinin azalmasına baxmayaraq, qadınlar və yeniyetmələr ağır kənd təsərrüfatı işlərində fəal iştirak edirdilər. Onlar biçin aparır, torpaq şumlayır, məhsul yığımı həyata keçirirdilər. Bir çox hallarda qadın briqadaları yüksək göstəricilər əldə edərək əmək yarışlarında qalib gəlirdilər. Naxçıvan kəndliləri dövlət fonduna normadan artıq məhsul təhvil verir, şəxsi təsərrüfatlarından da cəbhəyə yardım göndərirdilər.

Cədvəl 3*Müharibə illərində qadınların fəaliyyəti*

Fəaliyyət	Nəticə
Traktorçu	✓
Briqadir	✓
Ferma müdiri	✓
Kolxoz sədri	✓
Müəllim	✓
Tibb işçisi	✓
Rəhbər vəzifəyə irəli çəkilən qadınlar	58 nəfər

Mənbə. Müəllif tərəfindən NMR Dövlət Arxivinin materialları əsasında tərtib edilmişdir.

Böyük Vətən Müharibəsi dövründə arxa cəbhədə göstərilən əmək qəhrəmanlıqlarında qadınların böyük rolu olmuşdur. Belə ki, bu zaman sənayedə və kənd təsərrüfatında çalışan zəhmətkeşlərin əksəriyyəti qadınlar olmuşdur. 1943-1945-ci illərdə kənd təsərrüfatının cəbhənin ehtiyacını ödəmək səviyyəsində yüksəltmək ölkəmizin fəhlə sinfindən, kolxozçu kəndlilərindən və ziyalılardan böyük səy göstərməyi tələb edirdi. Müharibə illərində Naxçıvanlı qızlar kənd təsərrüfatı texnikasının idarə edən əsas qüvvəyə çevrilmişdilər. Belə ki, müharibədən əvvəl qadınlar mexanizator kadrların cüzi bir hissəsinin təşkil etdikləri halda, 1943-cü ildə mexanizatorların yarıya qədər qızlar idi.

1943-cü ildə Naxçıvan MSSR zəhmətkeşləri fədakarcasına çalışaraq kənd təsərrüfatı məhsulları istehsalını artırmaq sahəsində ciddi müvəffəqiyyətlər əldə etmişlər. Respublikanın kolxozları böyük hərbi təsərrüfat əhəmiyyəti olan gənəgərçək bitkisinin əkilib-becərilməsini mənimsəmişdilər. Müdafiə fondunun möhkəmləndirilməsi haqqındakı göstərişlərini alqışlayan evdar qadınlar qiymətli hədiyyələrini müdafiə fonduna vermişlər. Bunlardan Səkinə Məmmədova 3 qızıl üzük, Rübabə Talıbova 9 qram qızıl, Leyla Rzayeva 9 qram qızıl, Şura Bəktaş 3 qızıl üzük, Səkinə Rza 6 qızıl üzük göndərmişdir. Naxçıvan MSSR zəhmətkeşləri Qızıl Ordumuzun döyüşçülərinə bayram hədiyyələri və isti paltarlar göndərməklə ölkənin müdafiəsi fonduna xeyli vəsait toplayıb vermişlər. Onlar 1942-ci ilin sentyabr-oktyabr aylarında qəhrəman döyüşçülərə və ölkənin müdafiəsi fonduna 60 kürk, 45 isti köynək, 25 dəst alt paltar, 1033 cüt yun corab, 79 cüt keçə çəkmə, 127 yun ələk, 30 ədəd qulaqlı papaq, 20 sıxılıq pencək, 10 jilet, 35 qoyun, 2625 qutu sovqat, 13.719 manat nağd pul vermişlər ("Şərq qapısı" qəzeti, № 223, 1942).

Naxçıvan şəhərindəki 1 №-li orta məktəbin müəllim və şagirdləri döyüşən Qızıl Ordu əsgərlərinə bayram münasibətilə 900 manat dəyərində 10 qutu sovqat, bundan başqa Naxçıvan MSSR Xalq Daxili İşlər Komissarlığının işçiləri 15, Xalq Torpaq Komissarlığının işçiləri 11, poçt-teleqraf kontorası işçiləri 10, Böyüküz, Vayxır, Kəltəpə kolxozunun əməkçiləri hərəsi 10 qutudan ibarət bayram sovqatı göndərmişlər ("Şərq qapısı" qəzeti, 1942, № 221).

Müharibənin birinci günündən 1943-cü ilin oktyabr ayına kimi Naxçıvan Muxtar respublikasının zəhmətkeşləri müdafiə fonduna 1.080.085 manat pul, 244.000 manat istiqraz vəərəqəsi, 1 kq 233 q qızıl, 10 kq 283 q gümüş, bunlardan əlavə 38.811 cüt ələk, corab, qızıl ordu əsgərlərinə 6520 sovqat qutusu, 99 baş qoyun 4452 pud taxıl 4046 pud ət, 1118 kq yağ, 692 pud tərəvəz, 786 kq pendir, 43 kq bal, 742 ədəd dəri və 2135 kq yun toplayaraq göndərmişlər (Nax.MRDA. (keçmiş partiya arxiv) f.1. s1, iş.14., v.4). Yerli sovetliklərin və partiya təşkilatlarının səyi nəticəsində 7142 cəbhəçi ailəsinə 12.462 manat məbləğində yardım və 374.047 manat məbləğində müavinət verilmişdir (Nax.MRDA. (keçmiş partiya arxiv) f.1. s1, iş. 14., v.4). 1942-1943-cü illərdə Naxçıvan Muxtar Respublikasının kolxozçuları dövlətə 13179 pud yun, 677613 pud taxıl, 165970 pud ət, 6760 pud yağ təhvil vermişdilər. Naxçıvan zəhmətkeşləri qısa müddət ərzində tank və təyyarə dəstələri yaratmaq fonduna 800107 manat nağd pul vermişdir ("Şərq qapısı" qəzeti, 1975).

"Azərbaycan kolxozçusu" tank kaloniyasının yaradılmasına və qırıq təyyarələrin artırılması fonduna yardım edilməsi haqqında Azərbaycan KP Naxçıvan rayon Komitəsinin 8 mart 1943-cü il tarixli qərarını əldə rəhbər tutan Naxçıvan (Babək) rayon kolxozçu və kolxozçu qadınları ölkəmizin müdafiə qüdrətinin möhkəmlətmək və alman faşist quldur dəstələrinin darmadağın edilməsi və bütün xalqların gələcək dinc yaşaması, uğrunda özlərinin vətənə olan sədaqətini bir daha əməli işlə sübut edərək qısa müddətdə rayon üzrə tank dəstəsi yaradılması fonduna 2.087,463 manat, təyyarə hazırlanması fonduna isə 492 497781 manat pul ödəmişlər (Nax.MRDA. (keçmiş partiya arxiv) f.1. s2, iş.12., v.1).

"Azərbaycan kolxozçusu" tank dəstəsi yaradılması və təyyarə fonduna yardım edilməsi işində qabaqcıl Cəhri kənd kolxozunun qadınları tərəfindən 263300 manat, Didivar kənd kolxozunun işçiləri tərəfindən 135500 manat, Nehrəm kənd kolxozçuları tərəfindən 130 min manat, Əznəbürt kənd kolxozunun işçiləri tərəfindən 97000 manat pul yardım edilmişdir (Nax.MRDA. (keçmiş partiya arxiv) f.1. s2, iş.12., v.1). Didivar kolxozunun sədri Qasımov Abbasəli Azərbaycan tank dəstəsi yaradılması fonduna 100 min manat və Cəhri kolxozunun sədri İsmayilov Yusif 100 min manat pul Azərbaycanın tank dəstəsi yaradılması fonduna vermişlər (Nax.MRDA. (keçmiş partiya arxiv) f.1. s2, iş.12., v. 1-2).

Müharibə dövründə 2.889 komsomolçu ümumməcburi hərbi təlim proqramını keçərək, müxtəlif hərbi peşələrə yiyələnmişlər. 1943-cü ildə Muxtar Respublika komsomolçuları tərəfindən müdafiə fonduna 300 q qızıl, 1.561q gümüş, 15qızıl üzük, 2 ədəd qolbaq, 5 qızıl saat və bir çox şeylər vermişdir. Komsomolçular "Azərbaycan kolxozçusu" tank dəstəsi fonduna 1.369.709 manat vəsait vermişlər. Müharibə dövründə komsomolçuların qüvvəsilə 6.631 ədəd isti geyim şeyləri toplanaraq Qızıl Ordu

döyüşçülərinə göndərilmişdir. Bundan əlavə Qızıl Ordu döyüşçülərinə və qəhrəman sovet partizanlarına 436.708 manatlıq hədiyyə göndərilmişdir.

Cədvəl 4

Gənclərin və komsomol təşkilatlarının fəaliyyəti

Fəaliyyət	Göstərici
Hərbi hazırlıq keçənlər	2 889 nəfər
İsti geyim	6 631 ədəd
Hədiyyə	436 708 manat
Şumlanmış sahə	6 000 ha
Təmizlənmiş kanal	95 000 m
Toplanmış gübrə	40 000 ton

Mənbə. Müəllif tərəfindən Naxçıvan Muxtar Respublikası Dövlət Arxivinin sənədləri əsasında tərtib edilmişdir (Nax.MRDA.(keçmiş partiya arxivi) f.1. s1, iş.14., v. 4; “Şərq qapısı” qəzeti, 1943, № 121; Nax.MRDA. (keçmiş partiya arxivi) f.1. s1, iş. 644., v. 2).

1943-cü ilin yaz əkininə hazırlaşarkən, respublikanın komsomolçularının və gənclərinin qüvvəsilə 40.000 ton yerli gübrə toplanmış və tarlalara daşınmış, 95000 metr uzunluğunda su kanalı təmizlənmiş və qaydaya salınmışdır. Təkcə komsomolçuların qüvvəsilə 6.000 hektar sahə şumlanmışdır. Komsomolçuların təşəbbüsü ilə plandan artıq 500 hektar sahədə dənli bitki, ot, tütün və başqa bitkilər əkilmişdir. Komsomolçuların və gənclərin qüvvəsilə 25 traktor, 2 toxumsəpən, 15 taxıl döyən maşın və s. təmir edilmişdir. Məhsul toplanışı zamanı respublikanın 4.850 nəfər komsomolçusu kolxoz təsərrüfatında işləmişdir. Tarlalarda çalışan 100 komsomolçu – gənclər cəbhə briqadası 215 manat 5.000 nəfərdən artıq gənci əhatə etmişdir. Kolxoz komsomolçularının qüvvəsilə 25.000 hektardan artıq sahənin taxılı biçilmişdir (“Şərq qapısı” qəzeti, 1943, № 121). Mal-qaranın qışlamasına hazırlıq işində də komsomolçular az iş görməmişlər. Ancaq komsomolçuların qüvvəsilə 1.000 hektar sahənin otu biçilmiş, 400 sentner silos basdırılmışdır (Nax.MRDA. (keçmiş partiya arxivi) f.1. s1, iş. 644., v. 2).

Müharibə illərində cəbhəyə kömək üçün Ordubad rayon zəhmətkeşləri “Azərbaycan kolxozçusu” tank kaloniyasına və təyyarə hazırlanması üçün 1.950.250 manat zəyom, 77 ton rəngli və qara metal, 4500-ə qədər bağalma, 2.500q qədər qızıl, gümüş və çoxlu miqdarda isti paltar və ərzaq məhsulları toplayıb göndəmişlər (Nax.MRDA. f.7. s. 1, iş. 644., v. 1). Bundan başqa qızıl əsgər ailələrinə kömək məqsədi ilə 61860 kq taxıl, 16533 kq müxtəlif ərzaq məhsulları, 2436 cüt ayaqqabı, 1620 ədəd paltar, 3873 sentner yanacaq (odun), 2375 sentner yem (heyvanların ehtiyatı üçün), 179000 manat nağd pul, 2862 ədəd cürbəcür sənaye malları toplanıb verilmişdir (Nax.MRDA. f.7. s.1, iş. 644., v. 2).

Qızıl əsgər ailələrindən 183 nəfərinin evi təmir edilmiş, 37 nəfərə isə un qızıl əsgər ailələrinə 3229677 manat yardım edilmiş və hərbi ailələrə 228.494 manat pensiya verilmişdir (Nax.MRDA. (keçmiş partiya arxivi) f.1. s. 1, iş. 644., v. 2).

Gənclər və məktəblilər belə bu prosesdə iştirak edir, metal tullantıları və dərman bitkiləri toplayırdılar. Müharibə dövründə gənclər və məktəblilər də arxa cəbhənin mühüm qüvvəsinə çevrilmişdilər. Onlar kənd təsərrüfatı işlərində iştirak edir, hospitalarda yaralılara yardım göstərir və müxtəlif ictimai işlərdə çalışırdılar. Pioner və komsomol təşkilatları cəbhəyə yardım kampaniyaları təşkil edir, əhali arasında vətənpərvərlik ruhunun gücləndirilməsi istiqamətində tədbirlər həyata keçirirdilər. 25 iyul 1942-ci ildə Naxçıvan MSSR gənclərinin Naxçıvan şəhər parkında birinci antifaşist mitinqi keçirilmişdir. Azərbaycan gənclərinin birinci antifaşist mitinqinin yekunlarına həsr edilmiş yığıncaqda 5000 nəfər gənc arxa cəbhədə çalışaraq iməclik yolu ilə müdafiə fonduna 324 min

422 manat nağd pul, döyüşçülərimizə 10 min ədəddən çox müxtəlif isti paltar və Qara Dəniz Donanmaçılarına 12 min manatlıq hədiyyələrin göndərilməsini qərara almışlar (“Şərq qapısı” qəzeti, № 205, 1942). Həmin mitinqdə çıxış edən Staxanovçu Səkinə Mustafayeva, kolxozçu gənclərdən Sənəm Allahverdiyeva, Fatma Kərimova, Fatma Ramazanova hər hektardan 7 sentner əvəzinə 40 sentner gənəgərçək məhsulu verməyi qəət etmişlər. Keçirilən bu mitinqdə komsomolçu gənclərdən Föqiyyə Cəfərova, Leyla Qəhrəmanova və başqaları çıxış edərək müdafiə fondunun güclənməsi, arxa cəbhənin gücləndirilməsi və s. işlərdən danışımlar [4.1942.28 iyul].

Böyük Vətən Müharibəsi illərində sahibsiz uşaqların tərbiyə edilməsinə xüsusi diqqət yetirilirdi. 1942- ci ildə 2 uşaq evində 200 uşağın tərbiyə edilməsinə 583.800 manat pul sərf edilmişdirsə, 1943- cü ildə 400 uşağı əhatə edən 3 uşaq evinə 1.056.300 manat, 1944-cü ildə isə 1.108.900 manat pul buraxılmışdır [13.v.9]. 16 yanvar 1943-cü ilə qədər Naxçıvan Muxtar Respublikasının rayonları üzrə komsomolçuların və pionerlərin “Azərbaycan kolxozçusu” tank dəstəsinə yığılan vəsait rayonlar üzrə aşağıdakı kimi olmuşdur:

Naxçıvan (Babək) rayonu üzrə - 230000 manat; Şərur rayonu üzrə - 381.645 manat; Ordubad rayonu üzrə - 50.433 manat; Şahbuz rayonu üzrə - 41.718 manat; Əbrəqunus rayonu üzrə - 35000 manat; Culfa rayonu üzrə - 10. 000 manat; cəmi:748.796 manat [14.v.1]. “Azərbaycanın gənc pioneri” tank dəstəsinə yığılan vəsait rayonlar üzrə aşağıdakı kimi olmuşdur: Naxçıvan (Babək) rayonu üzrə- 78000 manat; Şərur rayonu üzrə- 318.000 manat; Ordubad rayonu üzrə- 9897 manat; Şahbuz payonu üzrə- 4000 manat; Əbrəqunus rayonu üzrə- 500 manat; cəmi: 410.447 manat.

“Azərbaycanın gənc pionerləri” hərbi təyyarənin inşası üçün Naxçıvan (Babək) rayonu üzrə - 24710 manat; Şərur rayonu üzrə - 72720 manat; Ordubad rayonu üzrə - 11504 manat; Şahbuz rayonu üzrə- 3.180 manat; Əbrəqunus rayonu üzrə - 2000 manat; Culfa rayonu üzrə - 6000 manat; cəmi: 120. 114 manat vəsait toplanmış cəbhə fonduna göndərilmişdir[14.v.3]. Naxçıvan zəhmətkeşləri, o cümlədən respublika komsomolçuları və pionerləri xüsusilə Tambov kolxozçularının təşəbbüsünə cavab olaraq “Daha çox tank verək” şüarına qoşularaq tank dəstələrinin yaradılması fonduna 1.279.357 manat pul toplayıb keçirmişlər. Bundan başqa Dəmirçi məktəbinin komsomolçuları bir gün ərzində 26.836 manat toplayıb həmin fonda keçirmişlər [14.v.2].

Şərur rayonunun Maxta kənd məktəbinin komsomolçu və pionerləri “Azərbaycanın gənc pionerləri” tank dəstəsinin yaradılması üçün 13.550 manat toplayıb keçirmişlər. Qarabağlar kənd məktəbinin komsomolçu və pionerləri bu işə daha böyük təşəbbüslə qoşulmuşlar. VII sinif şagirdi Mədətov Qarış Mədət oğlu 31 dekabr 1942-ci ildə kəndin gənclərinin yığıncağında çıxış edərək, tətildə qazandığı 10.000 manat pulu tank dəstəsinin fonduna verdi. Q. Mədətovun çıxışından sonra 15 gün ərzində məktəbin pioner və komsomolçuları “Azərbaycanın gənc pioneri” tank dəstəsinin fonduna 15.000 manat pul keçirdilər. Bundan başqa Şərur rayon Qıvraq kənd kolxozunun komsomolçu gəncləri 11.000 manat, Sərxanlı kənd kolxozunun 7 komsomolçusu 12.000 manat pul və 1000 kq taxıl, Yengicə kənd kolxozun kolxozçusu Məmmədov Lətifə 2500 manat pul və 150 kq darı, Düdəngə kənd kolxozunun komsomolçusu Şirəliyev Həsən 6000 manat, Kürteülü kəndinin sakini kolxozçu İbrahimov Abbas 8000 manat, Ulya- Şərur kənd kolxozunun gənc kolxozçusu Mahmudov Ləzgi 5000 manat, Keştaz kənd kolxozunun kolxozçusu Ceyranov Qəzənfər 5000 manat nağdi pul “ Azərbaycan gənc pioneri” tank dəstəsinin yaradılması fonduna keçirmişlər [14.v.2].

Naxçıvan (Babək) rayonun pioner və komsomolçuları da bu təşəbbüsə qoşulmuşlar. Qaraxanbəyli kəndinin “28 aprel” adına kolxozun gənc komsomolçusu Cəfərov Rza Qara oğlu tətil zamanı qazandığı 20000 manat, Məzrə kənd kolxozunun komsomolçusu Hüseynəliyeva Zeynəb İbrahim qızı 10.000 manat, Xalxal kənd kolxozunun komsomolçuları 10.000 manat, Bulqan kənd kolxozunun kolxozçuları 8.000 manat, kolxozun komsomol təşkilat katibi Abbasov Şirəli 2.000 manat və 60 kq buğda, kolxozun üzvü Bağırov Məmmədəli 3.000 manat, 1000 kq buğda və 1 qoyun. Qaraçuq kəndinin komsomolçuları və pionerləri “ Azərbaycan kolxozçusu” tank dəstəsinin inşasına 35.000 manat pul və 2.000 kq buğda toplayaraq keçirmişlər [14.v.4].

Ali baş komandanın pioner Əliyeva Maral Bayram qızının adına göndərdiyi alqış teleqramı bütün Naxçıvan MSSR-in komsomolçu və pionerləri böyük ruh yüksəkliyi ilə qarşıladılar. 12 yanvar 1943-cü ildə Muxtar Respublikanın komsomolçu və pionerləri əlavə olaraq 20.000 manat pul və 20 qoyun toplayaraq həmin fonda keçirmişlər. Naxçıvan MSSR üzrə 1943-cü ildə “Azərbaycan kolxozçusu” tank koloniyasına 6.779.771 manat və hərbi təyyarələrin tikintisi üçün 2.326.406 manat yığılıb göndərilmişdir [7. v. 8].

“Azərbaycan kolxozçusu” tank kalonuna pul toplanmasında fərqlənənlərdən Naxçıvan (Babək) rayon kolxozunun sədri Məmməd Əliyev 350.000 manat, Şərur rayon “Sosializm” adına kolxozun sədri Hüseyn Əliyev 100.000 manat və rayonun “Stalin” adına kolxozunun sədri Allahverdiyev 6.000 manat pul keçirmişlər.

Şərur rayonunun zəhmətkeşləri, xüsusən komsomolçu gənclər daima vətənimizi yırtıcı düşməndən mərdliklə təmizləməkdə olan ordunun 416-cı Taqanroq diviziyasının qorxmaz döyüşçülərinə 1943-cü ilin sentyabr ayında 21 kq yağ, 560 yumurta, 200 dəftər, 70 qələm, 53 paket, 275 iynə, 29 sap, 101 spirtli içki və başqa şeylər toplayıb göndərmişlər. Rayonun Mahmud kəndindəki “Telman” adına kolxozun üzvləri bu sahədə daha yaxşı iştirak etmişdir. Onlar 3 kq yağ, 50 yumurta, 60 iynə, 12 sap, 15 paket və bir baş qoyun toplayaraq göndərmişlər [15.1943.28 sentyabr].

Sənədlərdən məlum olur ki, müharibənin ilk günlərindən başlayaraq sentyabr 1943-cü ilə kimi Şərur rayon zəhmətkeşləri 244 min manat naqd pul, 98510 manatlıq istiqraz vəərəqəsi, 30000 cüt yun corab, 10.252 kq taxıl, 9717 kq ət, 154 kq yağ, 1082 kq yun, 34 qr 19 ml qızıl, 1880 kq mis və 55.500 kq toplayaraq müdafiə fonduna vermişdilər. 1 oktyabr 1943-cü ildə isə Şərur rayon zəhmətkeşləri müdafiə fonduna 12.600 kq taxıl, 11.657 kq ət, 184 kq yağ və 1138 kq yun toplayaraq göndərmişdilər.

Rayonun Səderək kolxozunun kolxozçuları isə hərəsi 10 əmək gününün dəyərini müdafiə fonduna vermişdir. Rayonun Tumaslı kənd kolxozunun sədri Məmməd Əliyev 20 əmək gününün dəyərini vermiş, kolxozun ümumi iclasının qərarı ilə 1200 kq buğda, 20 kq yağ, 500 kq ət və s. müdafiə fonduna vermişlər. Şaxtaxtı kənd kolxozunun kolxozçuları isə müdafiə fonduna 642.5 kq yun, Şərur kənd kolxozunun üzvləri 242 kq ət vermişdilər.

1943-cü ildə 4300 nəfər məktəbli gənc komsomol təşkilatının rəhbərliyi ilə kolxoz təsərrüfatında və xalq təsərrüfatının başqa sahələrində işləməyə səfərbərliyə alınmışdır. Naxçıvan rayonunun Təzəkənd kolxozunda işləməyə çıxan kənd orta məktəbinin 50-55 nəfər komsomolçusu Sənəm Sadıqovanın başçılığı ilə komsomolçu gənclər briqadası təşkil etmişdir. Həmin kolxozda işə çıxan məktəblilərin qüvvəsi ilə 1 ton 700 kq sünbül toplanmış və kolxoza təhvil verilmişdir. Kolxozda məktəblilərin hesabına təşkil edilmiş həmin briqada sonra iki yerə bölünmüşdür. Bunlardan biri taxıl itkisi ilə kəskin mübarizə aparmış və ikinci briqada isə kolxozun başqa işlərində yaxından iştirak etmişdir [16.v.17].

Naxçıvan (Babək) rayon zəhmətkeşləri müharibənin ilk günlərindən cəbhəyə yekdilliklə böyük yardımlar etmişlər. Belə ki, 1 kq 12 q qızıl, 6 kq 965 q gümüş, 556.602 manat pul, 1.541.055 manat istiqraz 47.000 kq taxıl, 414 kq yağ, 1700 kq noxud, 100 baş donuz, 106 baş iri və xırda buynuzlu heyvan, 300 kq kartof, 179.618 kq qara rəngli metal, tank koloniyası üçün 2.918.458 manat və təyyarə dəstələri yaradılmasına 329.000 manat nağd pul vermişlər [67.v.13-16].

Əkilmiş müdafiə hektarlarından 839 kq noxud, 50.139 kq taxıl, Qızıl Ordu döyüşçülərinə 4.523 bağlama (16.136 kq) 50 baş heyvan, 30.600 manat pul, 500 l araq və şərab, 7.250 cüt yun corab və əlcək, 273 teleqreyka, 2553 ədəd dəri, 940 dəst alt paltar, 372 ədəd müxtəlif geyim paltar göndərilmişdir [17.v.20].

Döyüşçülərə isə paltar alınması üçün Naxçıvan dövlət bankına 31.663 manat nağd pul verilmişdir. Bunlardan əlavə kolxoz və kolxozçuların artıq olan taxıllarından dövlət qiyməti ilə 500 ton taxıl satılmışdır [17.v.24]. Naxçıvan (Babək) rayonunun kolxozçuları, fəhlə və qulluqçuları cəbhəçi

ailələrinə xüsusi qayğı göstərərək birdəfəlik 48.037 kq taxıl, 22.400 manat nəqd pul, heyvanların saxlanması üçün 125 ton yem, 236 kq ət, 100 kq yağ, 6.000 müxtəlif yeyinti şeyləri, südündən istifadə etmək üçün 96 qoyun və keçi, 5 ton yanacaq və bunlardan başqa süd, pendir, üzüm və s. ərzaqla yardım etmişdir (Nax.MRDA. f.2. s. 1, iş.18).

23 fevral 1943-cü ildə Qızıl Ordunun 25-ci ildönümü münasibətilə Şərur rayon kolxozçuları azad edilmiş ölkələrin əhəlisinə yardım olaraq 110 baş qoyun, keçi, 645 pudbuğda, 244 pudarpa, 11 pud çəltik, 49 pud noxud, 11 min ədəd yumurta, 4 baş iri buynuzlu mal, 205 cüt əlcək, 389 cüt corab, 62 alt paltar, 118 köynək, 4 şalvar, 11 sıxılı, 161 dəri, 104188 manat pul, 99 kq yun, 11 ədəd adyal, 16 dəsmal, 131 qaşığıq və kruşka, 27 mayka, 14 döşək, 42 balınc, 100 ədəd mis qab, 85 tarelka, 5 kürk, 8 palaz və cecim, 15 kq tütün, toplayaraq göndərmişlər (Nax.MRDA. (keçmiş partiya arxivi) f.1. s1, iş., 1750). Müharibə dövründə Naxçıvan MSSR-də qadınların rəhbər işə irəli çəkilməsi, onların xüsusi ilə kənd təsərrüfatı sahəsində manqa, briqada, ferma, kolxozlara başçılıq etmə prosesi genişləndirdi. İstehsalata rəhbərlik üçün ayrı-ayrı sahələr üzrə kurslar yaradılır, onlarda məşğələ keçmək üçün təcrübəli təsərrüfatçılar cəlb olunurdular. Məqsəd tez bir zamanda müharibəyə gətirmiş istehsal komandirlərinə layiqli əvəzədicilər hazırlamaq idi.

1944-cü ildə Naxçıvan MSSR-də 58 qadın rəhbər təsərrüfat işinə irəli çəkilməmişdi. Ümumiyyətlə, kənd təsərrüfatı üzrə həmin il 73 kolxoz sədri, 24 ferma müdiri, 161 mexanizator kadrları hazırlanmışdı. Kursları bitirən qadınlar kolxozlara sədr təyin edildilər. Qəhrəmanova Leyli Sovetabad “Kommunist” kolxozuna, Vəliyeva Bəyim-Köhnə Hacıvar-Kaqanoviç adına kolxoza, Rəsulova Tərlan-Qoşadizə-“Bolşevik” kolxozuna, Məmmədova Bulqan-Çaparidze adına kolxoza, Məmmədova Səkinə-Qaraxanbəyli-28 Aprel adına kolxozlara bacarıqla rəhbərlik etdilər. Naxçıvan rayonunda “Bakı fəhləsi” kolxozunun ferma müdiri N.Əliyeva ağır şəraitə baxmayaraq, hər il dövlət planlarının artıqlaması ilə yerinə yetirilməsinə nail olurdu.

Müharibə illərində Naxçıvan MSSR-də qadınların sovet aparatı işinə irəli çəkilməsi, onların şəhər, rayon, kənd Sovetlərinə rəhbərlik etməsi halları artmışdı. Ümumiyyətlə, bu işdə 120-dən artıq qadın çalışmışdı. Onların əksəriyyəti müharibə dövründəki sözlün əsl mənasında qəhrəman işlərinə görə orden və medallarla təltif edilmişdilər (Hacıyev, 2008, s. 58-75). 26 fevral 1944-cü ilə kimi Naxçıvan Muxtar Respublikasının zəhmətkeşləri tərəfindən dövlət müdafiə fonduna 10.800.689 manat nağd pul, 24.400.000 manat istiqraz vəərəqəsi, 1 kq 233 q qızıl və 10.115.283 q gümüş verilmişdir (Nax.MRDA. (keçmiş partiya arxivi) f.1. s1, iş. 2132).

Ümumiyyətlə, Muxtar Respublikanın zəhmətkeşləri Almaniyə qoşunlarının məğlub edilməsinə dəstək məqsədilə müharibə illərində Müdafiə Fonduna 180 milyon 89 min manat nağd pul, 12 kq qızıl və gümüş, yarım milyon pud taxıl, 150 mindən çox isti paltar və 10 mindən çox bağlama göndərmişlər. Dövrün mətbuatında əhəlinin müharibə şəraitində əmək fəaliyyətini davam etdirməsi və cəbhəyə dəstək göstərməsi vətənpərvərlik və həmrəylik nümunəsi kimi təqdim olunurdu. Bununla yanaşı, 1943-cü illə müqayisədə 1944-cü ildə respublikada kolxozçuların gəliri 80 faiz artmış, hər əmək gününün dəyəri yüksəlmişdir. Təkcə Cəhri (Babək rayonu) kəndindəki kolxozda 1944-cü ildə 1941-ci illə müqayisədə 60 sentner çox taxıl istehsal edilmiş, dövlətə məhsul satışı üzrə planlar üçqat artıq yerinə yetirilmişdir (Azərbaycan komsomolçusu, 1975). Əgər 1940-cı ildə Naxçıvan MSSR üzrə dövlətə 2 899 ton taxıl verilmişdisə, 1944-cü ildə bu göstərici 3 861 tona çatmışdır. Beləliklə, 1940-cı illə müqayisədə 962 ton artım qeydə alınmış və 1944-cü ilin göstəricisi 1940-cı il səviyyəsinin təxminən 133,2%-ni təşkil etmişdir.

Müharibə illərində arxa cəbhədə əmək rəşadətləri göstərmiş onlarca müəllimlərimiz dövlətimiz tərəfindən orden və medallarla təltif edilmiş, bir çox müəllimlərimizə “Azərbaycan Respublikasının əməkdar müəllimi” və “Naxçıvan MR-nın əməkdar müəllimi” kimi fəxri adlar verilmişdir.

İkinci dünya müharibəsi həyatın demək olar ki, bütün sahələri kimi, onun bədii inkişafı olan bədii ədəbiyyatda da öz əksini tapmışdır. Bu dövrdə Naxçıvanda da bir sıra yazıçı və şairlər fəaliyyət

göstərirdi. “Şərq Qapısı”, “Ədəbiyyat” qəzetləri, “Vətən uğrunda” jurnalı yeni yazılan əsərləri işıqlandırmaq baxımından mühüm xidmət göstərirdi. Müharibə illərində xalqın mənəvi ruhunun yüksəldilməsi, vətənpərvərlik hisslərinin gücləndirilməsi və cəbhə ilə arxa cəbhə arasında mənəvi birliyin yaradılmasında ədəbiyyat mühüm rol oynamışdır. Naxçıvanın şair və yazıçıları bu dövrdə öz yaradıcılıqları ilə xalqın mübarizə əzmini gücləndirməyə çalışmış, müharibənin ağrı-acılarını, qəhrəmanlıq nümunələrini və qələbəyə inamı bədii şəkildə əks etdirmişlər. Böyük Vətən müharibəsi (1941-1945) illərində ümumazərbaycan ədəbiyyatının tərkib hissəsi kimi fəaliyyət göstərən Naxçıvan ədəbi mühitində vətənpərvərlik, faşizmə nifrət və qələbə inamı ruhunda əsərlərin yazılması xarakterikdir. Həmin dövrdə yaradılan əsərlərdə cəbhəarxası həyat, naxçıvanlıların döyüş rəşadəti və arxa cəbhədəki fədakarlıqları əsas mövzu olmuşdur. Dövrün ədəbi mühitində vətənpərvərlik mövzusu aparıcı olmuş, şeir və publisistika ön plana çıxmış, faşizmi tənqid edən əsərlər yazılmışdır. Müharibənin yaratdığı ağır iqtisadi və sosial şəraitə baxmayaraq, Naxçıvanda mədəni həyat tamamilə dayanmadı. Teatrlar, mədəniyyət evləri, məktəblər və qəzet redaksiyaları fəaliyyətlərini davam etdirirdi. Yerli mətbuat orqanlarında vətənpərvərlik mövzusunda şeirlər, publisistik yazılar və çağırış xarakterli məqalələr dərc olunurdu. Bu dövrdə xüsusilə poeziya ön plana çıxmışdı. Şairlər xalqı birlik və mübarizəyə səsləyir, cəbhədə döyüşən əsgərlərin qəhrəmanlığını tərənnüm edirdilər. Ədəbiyyat yalnız estetik məqsəd daşımır, həm də ideoloji və mənəvi silaha çevrilirdi.

Müharibə illərində Naxçıvanın ədəbi və ictimai mühitinin formalaşmasında, vətənpərvərlik ruhunun təbliğində “Şərq Qapısı” qəzeti “Şərq qapısı” qəzeti müstəsna rol oynamış, Hüseyn Əzim, Ələkbər Məftun, Ənvər Əylisli, Məmmədli Tarverdiyev, Nağı Nağıyev, Adil Babayev, Hacı Əsgərov, Əsgər Səfərov, müəllim Əli Məmmədov və s. yazarların əsərlərinin çap etməklə oxucularda, ümumiyyətlə, Naxçıvan mühitində qələbəyə sarsılmaz inam yaratmışdır. “Şərq qapısı” qəzeti müharibə dövründə mətbu sözdən kəsərli silah kimi istifadə edərək, qələmə sarılmış, yazmış, insanları ruhlandırmış, ...düşmən qaqşısında əyilməzliyini göstərmiş və qələbə müjdəsinə öz şərəfli işi ilə imza atmışdır (Seyid, 2010, s. 107).

Hüseyn Əzim öz yaradıcılığında müharibə mövzusunda geniş yer vermiş, faşizm əleyhinə şeirlər yazmış, “Vətən”, “Terek sahilində”, “Yadigar”, “Gözü yolda qalan yar” kimi şeirlərlə oxucuların qələbəyə inamını artırmışdır. “Şərq qapısı” və “Ədəbiyyat qəzetində” şeirlər çap etdirən Hüseyn Əzimin “Vətən” şeirini vətənpərvərlik mövzusunda yazılmış qiymətli nümunələrdən hesab etmək olar:

Eşqindir çatdıran məni murada
Sevgilim, könlümü verməmə yada
Mən canım olsa da, mənim dünyada,
Demişəm yolunda qurbandır, Vətən!

“Terek sahilində” şerində faşistlərin törətdikləri qanlı cinayətləri, oğlunu, ailəsini itirmiş bir qocanın gəlininin faciəli taleyini təsvir edən müəllif “Dərmanımız, təbibimiz qələbədir, zəfəridir!” deyərək qələbəyə sarsılmaz inamını ifadə etmişdir.

Həm ədəbi, həm də publisistik fəaliyyətlə məşğul olan Nağı Nağıyevin “Polad” adlı pyesində Azərbaycan xalqının igid oğlu Poladın cəbhədəki misilsiz hünər və qəhrəmanlığını əks olunmuşdur. 1945-ci ildə Naxçıvan Dövlət Dram Teatrında müvəffəqiyyətlə tamaşaya qoyulan bu pyesin vətənpərvərlik ruhunda yazılmış mübariz ruhlu bədii nümunələr sırasında özünəməxsus yeri vardır.

Hələ tələbə ikən ədəbi yaradıcılığa başlayan Əkbər Məftun Sovet İttifaqı Qəhrəmanı Nəcəfqulu Rəfiyevə həsr etdiyi “Sən könül mülkünün iftixarısan”, “Xilaskar ordu”, “Ey Vətən” kimi lirik şerlərin müəllifi kimi Vətənə sədaqət, faşizmə nifrət mübarizəsinin ön sıralarında dayanmışdır. Sovet Ordusunun alman faşist işğalçılarına qarşı apardığı mübarizəni “Partizan hekayəsi” adlı şerində belə ifadə etmişdir: “Ümman oldu elin kini, Sipər etdi, sinəsini (“Şərq Qapısı” qəzeti, 1946).

Məmmədli Tarverdiyev Böyük Vətən müharibəsi dövründə məsul partiya işində çalışmış, Vətən müharibəsində iştirak etmiş qəhrəman həmyerlilərimiz və əmək adamları haqqında bir sıra очерklər yazmışdır. Onun fədakarlıqla işləyən sovet adamlarının ümumiləşmiş surətini əks etdirdiyi “Zaman” pyesi hissə-hissə “Şərq Qapısı” qəzetində çap olunmuş, böyük rəğbət qazanmışdır. Şair Hacı Əsgərov da müharibədə şücaət göstərən, Şərrur rayonundan müharibəyə getmiş, “İgidliyə görə” medalı ilə təltif olunmuş Cəboş Şıxəliyev haqqında əsər yazmış, eloğlunun igidliyini tərənnüm etmişdir.

Cədvəl 5

Böyük Vətən Müharibəsi dövründə Naxçıvan ədəbi mühitinin əsas nümayəndələri

Müəllif	Əsər	Əsas mövzu
Hüseyn Əzim	<i>Vətən, Terek sahilində</i>	Vətənpərvərlik, qələbəyə inam
Nağı Nağıyev	<i>Polad</i>	Qəhrəmanlıq
Əkbər Məftun	<i>Ey Vətən</i>	Faşizmə qarşı mübarizə
Məmmədli Tarverdiyev	<i>Zaman</i>	Arxa cəbhə və əmək qəhrəmanlığı
Hacı Əsgərov	Cəboş Şıxəliyev haqqında əsər	Döyüş şücaəti

Mənbə. Müəllif tərəfindən (Nax.MRDA. f.7. s.1, iş. 644; Nax.MRDA. f.2. s. 3, iş.118; Nax.MRDA. (keçmiş partiya arxivi) f.1. s. 1, iş.9; “Şərq qapısı” qəzeti, 1943) və digər istifadə olunmuş elmi mənbələr əsasında tərtib edilmişdir.

Müharibə dövründə yazılan əsərlər gəncləridə yüksək vətənpərvərlik hissi yazıb-yaratmaq həvəsi oyatmış, İslam Səfərlı, Davud Ordubadlı, Hüseyn İbrahimov və Əbülfəz Abbasquliyev, Hüseyn Razi kimi ədəbi mühitə yeni poetik nəfəsi gətirən imzaların yetişməsinə təkan vermişdir. “Şərq qapısı” qəzetinin 10 oktyabr 1941-ci il tarixli 183-cü sayında dərc olunmuş “Partizanın andı” şeirində gənc şair Hüseyn Razinin qəlbindən qopan haraya, qələbəyə srsılmaz inama şahid oluruq. “Qıraq zəncirləri, daş qəfəsləri, Ucalsın göylərə zəfər səsləri! –deyən şair müharibənin lap əvvəlindən inamın və ümidin sarsılmaz ifadəçisi kimi çıxış edir. Ənvər Əylislinin Vətəni tərənnüm edən, düşməyə nifrət aşılayan şeirləri də bu baxımından maraqlıdır.

Naxçıvan ədibləri təkcə qələmlə deyil, silahla da vuruşmuş, qələbənin qazanılmasında xüsusi rol oynamışlar. Fitri yaradıcılıq istedadına malik, muxtar respublikanın ictimai həyatında fəal iştirak etmiş, Birinci çağırış Naxçıvan MSSR Ali Sovetinin deputatı olmuş Qurban Qurbanov Böyük Vətən müharibəsi başlandıqdan sonra cəbhəyə getmiş və geri dönməmişdir. Qurban Qurbanov qısa ədəbi yaradıcılığı dövründə əsasən bir dramaturq kimi fəaliyyət göstərmiş “Ayrım”, “Himalay”, “Xosrov və Şirin” adlı dram əsərləri yazmış, həmin əsərlər Naxçıvan Dövlət Dram Teatrının səhnəsində tamaşaya qoyulmuşdu. Müharibənin başlamasından bir qədər sonramüəllifin “Vətən uğrunda” pyesi “Şərq qapısı” qəzində dərc olunmuşdur. Naxçıvan Muxtar Respublikasında İncəsənət İşləri Komitəsinin sədri, Naxçıvanda yazıçı kadrların yetişməsində böyük xidməti olan İsmayıl Sayılovun 416-cı Azərbaycan Təqanroq diviziyasının siyasi işçisi kimi müharibədə qəhrəmanlıqla həlak olmuşdur. Arxa cəbhədə qalan yazıçı və şairlər yeni ədəbi əsərlər yazmış, ağır və çətin dövrdə xalqı vətənpərvər ruhda tərbiyə və səfərbər etmək yolunda orulmadan fəaliyyət göstərmişlər.

Müharibə dövrünün folklor nümunələrində, aşiq yaradıcılığında xüsusən Aşiq Məmmədcəfərin şeirlərində vətənə sevgi və döyüşçülərə dəstək motivləri güclü olmuşdur. Naxçıvan ədəbi mühiti müharibənin gətirdiyi çətinliklərə baxmayaraq, yüksək ruh yüksəkliyi nümayiş etdirərək ədəbiyyata qiymətli əsərlər bəxş etmişdir.

Bu dövrdə ədəbiyyatın müxtəlif janrlarında yeni nümunələr yaranır, sözün gücü ilə cəbhədəki döyüşçüləri ruhlandırır, qələbəyə səsləyirdilər. Görkəmli ədəbiyyatşünas alim Əziz Şərif “Kəskin silah” adlı məqaləsində qeyd edirdi ki, bədii söz cəbhədəki igid döyüşçüləri, arxada yorulmaq

bilmədən çalışan fəhlə və kolxozçuları, cəbhədən xoş xəbərlər gözləyən ana və bacıları ruhlandırmaq, onlarda cəllad hitlerçilərə qarşı sarsılmaz ədavət yaratmaq, düşməyə qarşı mübarizə üçün istər cəbhədə, istərsə də arxada səfərbər etməyə qadirdir.

Müharibə dövründə “Həqiqi qəhrəmanın sadıq oğluna”, “Azərbaycan fəxr edir”, “Danışaq sünbüllər”, “Vətən”, “Cəbhədən məktub”, “Yadigar”, “Terek sahilində”, “Gözü yolda qalan yar”, “Partizanın andı”, “Sən köhnə müəlliminin iftixarısan”, “Xilaskar Ordu”, “Eşqim”, şeirləri, “Polad”, “Həl şeirləri” dram əsərləri, “Zərifə və Qəhrəman”, “Həkim” povestləri, “Zaman”, “Polad” pyesləri, “Səhər” romanı Naxçıvanda yaranan qiymətli ədəbi nümunələrdəndir (Cəfərov, 2015, s. 12–13).

Müzakirə

Tədqiqatın nəticələri göstərir ki, Böyük Vətən Müharibəsi illərində Naxçıvan Muxtar Sovet Sosialist Respublikasında həyata keçirilən sosial-iqtisadi səfərbərlik tədbirləri yalnız cəbhənin maddi təminatına yönəlməmiş, eyni zamanda regionun ictimai həyatında yeni təşkilati və sosial münasibətlərin formalaşmasına da təsir göstərmişdir. Əldə olunan arxiv materialları müharibə şəraitində əmək ehtiyatlarının yenidən bölüşdürülməsi, qadınların və gənclərin istehsal prosesində rolunun artması, eləcə də yerli idarəetmə strukturlarının fəaliyyətinin intensivləşməsi kimi proseslərin kompleks xarakter daşdığını göstərir.

Araşdırma nəticələri Azərbaycan tarixşünaslığında müharibə dövrünə dair aparılmış əvvəlki tədqiqatlarla ümumilikdə uyğunluq təşkil etsə də, Naxçıvan materiallarının ayrıca təhlili regionun özünəməxsus xüsusiyyətlərini üzə çıxarır. Əvvəlki araşdırmalar əsasən ümumrespublika səviyyəsində sosial-iqtisadi prosesləri xarakterizə etdiyi halda, bu tədqiqat yerli arxiv sənədləri əsasında regionun daxili sosial dinamikasını və arxa cəbhənin fəaliyyət mexanizmlərini daha ətraflı nümayiş etdirir.

Əldə olunan nəticələr göstərir ki, qadınların əmək fəaliyyətinə geniş şəkildə cəlb olunması yalnız işçi qüvvəsi çatışmazlığının aradan qaldırılmasına xidmət etməmiş, həm də onların ictimai və idarəetmə həyatında mövqeyinin güclənməsinə şərait yaratmışdır. Eyni zamanda komsomol və pioner təşkilatlarının fəaliyyəti gənclərin yalnız ideoloji deyil, həm də iqtisadi və sosial səfərbərlik proseslərində iştirak etdiyini göstərir.

Tədqiqat dövrü mətbuatın və ədəbi mühitin funksiyalarına dair də mühüm nəticələr ortaya qoymuşdur. “Şərq Qapısı” qəzeti və digər nəşrlər informasiya mənbəyi olmaqla yanaşı, əhalinin səfərbər olunmasına, vətənpərvərlik ideyalarının yayılmasına və sosial həmrəyliyin qorunmasına xidmət etmişdir. Ədəbi yaradıcılıq isə müharibə dövrünün ictimai-psixoloji mühitini əks etdirən mühüm tarixi mənbə kimi çıxış etmişdir.

Bununla yanaşı, tədqiqatın müəyyən məhdudiyyətləri də mövcuddur. Araşdırma əsasən Naxçıvan Muxtar Respublikası Dövlət Arxivində saxlanılan sənədlər və yerli dövrü mətbuat materialları əsasında aparılmışdır. Digər regional arxivlərdə və mərkəzi fondlarda saxlanılan sənədlərin cəlb olunması gələcək tədqiqatlarda daha geniş müqayisəli təhlillərin aparılmasına imkan verə bilər. Bundan əlavə, statistik göstəricilərin digər regionlarla müqayisəsi Naxçıvanın müharibə illərindəki sosial-iqtisadi mövqeyinin daha obyektiv qiymətləndirilməsinə şərait yaradacaqdır.

Beləliklə, aparılmış təhlil göstərir ki, Naxçıvanda sosial-iqtisadi səfərbərlik, ictimai təşkilatlanma və ədəbi-mədəni fəaliyyət qarşılıqlı əlaqədə inkişaf etmiş, birlikdə regionun müharibə şəraitində davamlı fəaliyyətini təmin edən əsas amillərdən birinə çevrilmişdir. Bu nəticələr müharibə dövrü regional tarixinin öyrənilməsi baxımından yeni elmi yanaşmalar üçün də əsas yaradır.

Nəticə

Aparılmış tədqiqat göstərir ki, Böyük Vətən Müharibəsi illərində Naxçıvan Muxtar Sovet Sosialist Respublikası ümumittifaq müdafiə sisteminin mühüm regional komponentlərindən biri kimi fəaliyyət göstərmişdir. Regionun məhdud iqtisadi imkanlarına baxmayaraq, yerli idarəetmə orqanlarının fəaliyyəti, əhalinin sosial səfərbərliyi və istehsal resurslarının səmərəli təşkili nəticəsində cəbhənin maliyyə, ərzaq və maddi-texniki təminatına əhəmiyyətli töhfə verilmişdir.

Tədqiqat nəticələri təsdiq edir ki, müharibə illərində əmək ehtiyatlarının yenidən təşkili Naxçıvanın sosial-iqtisadi davamlılığının qorunmasında əsas amillərdən biri olmuşdur. Kişi əhalisinin hərbi xidmətə çağırılması ilə yaranmış işçi qüvvəsi çatışmazlığı qadınların, gənclərin və məktəblilərin istehsal və ictimai fəaliyyətə daha geniş cəlb olunması hesabına qismən kompensasiya edilmişdir. Bu proses yalnız iqtisadi zərurətdən irəli gəlməmiş, eyni zamanda regionun sosial strukturunda mühüm dəyişikliklərə səbəb olmuşdur.

Araşdırma göstərir ki, müdafiə fonduna ayrılan maliyyə və maddi yardımların həcmi müharibə dövründə mərhələli şəkildə artmış, bu artım yerli əhalinin səfərbərlik tədbirlərində fəal iştirakını əks etdirmişdir. Arxiv sənədlərinin təhlili göstərir ki, yardım kampaniyaları təkcə dövlət təşəbbüsü deyil, həm də ictimai həmrəyliyin praktik ifadəsi olmuşdur.

Əldə edilən nəticələr həmçinin təsdiq edir ki, müharibə illərində formalaşmış ədəbi mühit və dövrü mətbuat regionun sosial həyatında mühüm funksiyalar yerinə yetirmişdir. "Şərq Qapısı" qəzeti və digər mətbuat orqanları informasiya ötürməklə yanaşı, əhalinin mənəvi hazırlığının gücləndirilməsi, vətənpərvərlik ideyalarının təbliği və sosial həmrəyliyin qorunması istiqamətində mühüm rol oynamışdır. Ədəbi yaradıcılıq isə dövrün ictimai-psixoloji mühitini əks etdirən və tarixi hadisələrin öyrənilməsi üçün qiymətli mənbə kimi çıxış etmişdir.

Bu tədqiqatın əsas elmi yeniliyi Naxçıvanda müharibə dövrünün sosial-iqtisadi səfərbərliyi ilə ədəbi-mədəni mühit arasındakı qarşılıqlı əlaqənin vahid konseptual çərçivədə araşdırılmasıdır. Əvvəlki tədqiqatlardan fərqli olaraq, arxiv sənədləri, statistik məlumatlar və dövrü mətbuat materialları birlikdə təhlil edilmiş, onların qarşılıqlı təsiri regional tarix kontekstində qiymətləndirilmişdir.

Tədqiqatın nəticələri Azərbaycanın regional tarixinin öyrənilməsi, müharibə dövründə sosial səfərbərlik modellərinin müqayisəli təhlili və mədəni irsin tarixşünaslıq baxımından araşdırılması üçün faydalı elmi baza yaradır. Gələcək tədqiqatlarda Naxçıvanın digər SSRİ regionları ilə müqayisəli şəkildə öyrənilməsi, həmçinin müharibə dövründə formalaşmış sosial şəbəkələrin və mədəni institutların uzunmüddətli təsirlərinin araşdırılması məqsədəuyğun hesab edilir.

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Integrating Music and Fine Arts into Contemporary Theatre Performance

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Abstract. Contemporary theatre has evolved into a multidimensional artistic platform where music and fine arts play a central role in enhancing dramatic expression and audience engagement. This study investigates the integration of music and fine arts into modern theatre performances and examines how these artistic elements contribute to narrative development, emotional depth, visual aesthetics, and cultural communication. The research adopts a qualitative-descriptive methodology based on the analysis of scholarly literature, theatrical productions, and interdisciplinary artistic practices. The findings reveal that music intensifies emotional atmosphere, supports character development, and strengthens audience immersion, while fine arts such as painting, sculpture, lighting, costume design, and stage decoration contribute to the visual symbolism and aesthetic structure of performances. The study further demonstrates that contemporary directors increasingly rely on multimedia and visual experimentation to create hybrid theatrical experiences that combine sound, movement, and visual composition. In addition, the integration of these artistic disciplines promotes intercultural understanding and broadens the creative possibilities of theatrical expression. The discussion highlights the importance of interdisciplinary collaboration among musicians, visual artists, actors, and directors in producing innovative stage performances. The article concludes that the successful synthesis of music and fine arts enriches theatrical communication and transforms theatre into a comprehensive sensory experience capable of addressing modern social and cultural realities.

Keywords: theatre, music, fine arts, performance, aesthetics, interdisciplinary art

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Musiqi və təsviri sənətin müasir teatr tamaşalarına integrasiyası

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Xülasə. Müasir teatr dramatik ifadəni və tamaşaçı iştirakını gücləndirən çoxölçülü bədii platformaya çevrilmişdir. Bu tədqiqat musiqi və təsviri sənətin müasir teatr tamaşalarına integrasiyasını araşdırır və bu bədii elementlərin süjetin inkişafına, emosional dərinliyə, vizual estetikaya və mədəni ünsiyyətə necə töhfə verdiyini təhlil edir. Araşdırmada elmi ədəbiyyatın, teatr tamaşalarının və fənlərarası bədii təcrübələrin təhlilinə əsaslanan keyfiyyət yönümlü təsviri metodologiyadan istifadə edilmişdir. Nəticələr göstərir ki, musiqi emosional atmosferi gücləndirir, obrazların inkişafını dəstəkləyir və tamaşaçının səhnə hadisələrinə daha dərinlən cəlb olunmasına şərait yaradır. Eyni zamanda, rəssamlıq, heykəltəraşlıq, işıqlandırma, kostyum dizaynı və səhnə tərtibatı kimi təsviri sənət növləri tamaşaların vizual simvolizminin və estetik quruluşunun formalaşmasında mühüm rol oynayır. Tədqiqat həmçinin göstərir ki, müasir rejissorlar səs, hərəkət və vizual kompozisiyanı birləşdirən hibrid teatr təcrübələri yaratmaq üçün multimedia vasitələrinə və vizual eksperimentlərə getdikcə daha çox müraciət edirlər. Bundan əlavə, bu incəsənət sahələrinin integrasiyası mədəniyyətlərarası anlaşmanı təşviq edir və teatr ifadəsinin yaradıcı imkanlarını genişləndirir. Müzakirə hissəsində innovativ səhnə tamaşalarının hazırlanmasında musiqiçilər, vizual sənətçilər, aktyorlar və rejissorlar arasında fənlərarası əməkdaşlığın əhəmiyyəti vurğulanır. Məqalə belə nəticəyə gəlir ki, musiqi və təsviri sənətin uğurlu sintezi teatr ünsiyyətini zənginləşdirir və teatrı müasir sosial və mədəni reallıqları əks etdirməyə qadir olan hərtərəfli sensor təcrübəyə çevirir.

Açar sözlər: teatr, musiqi, təsviri sənət, tamaşa, estetika, fənlərarası incəsənət

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Introduction

Theatre has long been recognized as one of humanity's oldest and most influential artistic forms, functioning as a medium through which societies express cultural values, political concerns, philosophical ideas, and emotional experiences. Since ancient civilizations, theatrical performances have integrated multiple artistic disciplines including literature, music, dance, costume design, and visual decoration. In ancient Greek theatre, dramatic performances were accompanied by choral music and symbolic stage imagery that enhanced emotional intensity and collective audience participation (Zarrilli, 2010). Similarly, Eastern theatrical traditions such as Japanese Noh theatre, Chinese opera, and Indian Sanskrit drama combined music, visual symbolism, and stylized movement to create spiritually and aesthetically rich performances.

In contemporary society, theatre has evolved beyond traditional dramatic representation into an interdisciplinary artistic platform where multiple forms of creative expression coexist simultaneously. Modern theatrical productions increasingly incorporate music, painting, sculpture, digital media, lighting design, and multimedia projections as essential narrative and aesthetic components. This

transformation reflects broader developments in modern art and performance culture, where rigid boundaries between artistic disciplines are gradually disappearing (Lehmann, 2006).

Music remains one of the most influential elements in theatrical communication. Beyond entertainment, music serves psychological, emotional, and structural purposes within performances (Basa et al, 2026). According to Cook (2000), music possesses the ability to communicate meanings that often transcend spoken language, enabling audiences to experience emotions intuitively. In theatre, musical composition establishes rhythm, creates atmosphere, intensifies dramatic tension, and supports character development. Contemporary directors frequently use live orchestras, electronic soundscapes, recorded effects, and vocal experimentation to deepen audience engagement and create immersive emotional experiences.

The emotional power of music in theatre is especially evident in modern experimental and postdramatic performances. Unlike traditional drama, which prioritizes dialogue and linear storytelling, contemporary theatre often emphasizes sensory experience and emotional atmosphere. Musical elements guide audience reactions, shape the pacing of scenes, and create symbolic associations between sound and dramatic action. For example, minimalistic piano melodies may symbolize loneliness or memory, while aggressive percussion rhythms may reflect conflict, chaos, or psychological instability. Such artistic strategies demonstrate that music functions not merely as accompaniment but as an independent narrative force within theatre performance (Fischer-Lichte, 2008).

Fine arts also play a central role in shaping theatrical aesthetics and visual communication. Scenic design, painting, costume creation, architecture, lighting, and digital projections collectively construct the visual world of the performance (Hashim et al, 2023). Aronson (2018) emphasizes that contemporary scenography is no longer limited to static decoration; rather, it actively participates in storytelling by influencing audience perception and emotional interpretation. Colors, textures, spatial arrangements, and visual symbolism contribute to the thematic atmosphere of theatrical productions and often communicate meanings beyond verbal language (Seidova et al, 2026).

Modern theatre increasingly employs abstract and symbolic visual techniques inspired by contemporary painting and installation art. Minimalist stage design, surreal visual imagery, and multimedia projections are frequently used to reflect psychological states, social anxieties, and philosophical ideas. In many experimental performances, visual composition becomes as important as dialogue, transforming the stage into a dynamic artistic canvas. Lighting design further enhances this visual experience by directing audience attention, creating emotional contrast, and shaping spatial perception.

Technological advancement has significantly expanded the possibilities for integrating music and fine arts into theatre. Digital scenography, virtual projections, interactive sound systems, and multimedia installations have introduced new forms of artistic experimentation. Contemporary directors often collaborate with digital artists, composers, and visual designers to create hybrid performances that merge physical acting with technological imagery (Lu & Yeh, 2025). These innovations reflect the growing influence of digital culture on modern artistic production and audience expectations (Pavis, 2013).

The integration of music and fine arts into theatre is also closely connected to cultural identity and intercultural dialogue. Theatre performances frequently combine traditional artistic elements with modern techniques to explore historical memory, social transformation, and national heritage. Musical traditions, folk visual motifs, and symbolic artistic representations help preserve cultural values while simultaneously adapting them to contemporary audiences. Such interdisciplinary performances encourage cross-cultural understanding and artistic diversity within global theatre practice.

Despite the growing importance of interdisciplinary theatre practices, there remains a need for scholarly examination of how music and fine arts function together within contemporary performance. This study aims to explore the artistic, emotional, and cultural contributions of music and fine arts in modern theatre.

The research seeks to answer the following questions:

1. How does music contribute to emotional and narrative development in theatre performance?
2. What role do fine arts play in shaping theatrical aesthetics?
3. How does interdisciplinary integration influence audience perception and engagement?

The study contributes to theatre studies by highlighting the significance of artistic collaboration and examining the evolving relationship between visual and auditory expression in contemporary performance. The study relied primarily on secondary qualitative data collected from academic books, peer-reviewed journal articles, theatre criticism, conference papers, performance reviews, and documented case studies related to contemporary theatre. Scholarly sources addressing theatrical aesthetics, scenography, music in performance, multimedia theatre, and interdisciplinary art were systematically reviewed (Badeji & Omotunwase, 2026).

The literature selection process focused on internationally recognized scholars in theatre and performance studies, including works by Brook (1996), Lehmann (2006), Fischer-Lichte (2008), Aronson (2018), and Schechner (2017). These theoretical sources provided conceptual foundations for understanding the evolving relationship between theatre, music, and visual arts. Additionally, selected contemporary theatrical productions from different cultural and artistic contexts were analyzed as practical examples. Productions incorporating live music, multimedia projection, abstract visual design, experimental scenography, and interdisciplinary artistic collaboration were chosen for examination. Both traditional stage performances and postdramatic theatre productions were included to ensure diversity in artistic styles and performance approaches.

The research was informed by several theoretical perspectives. Postdramatic theatre theory, developed by Lehmann (2006), served as a key framework for understanding contemporary performances that prioritize visual and auditory experience over traditional narrative structures. This theory helped explain the increasing significance of music and fine arts as independent narrative forces within theatre. Performance aesthetics theory proposed by Fischer-Lichte (2008) was also utilized to examine the transformative relationship between performers and audiences. This perspective emphasizes the sensory and emotional dimensions of theatrical experience, which are central to interdisciplinary performance.

In addition, scenographic theory developed by Aronson (2018) provided analytical tools for interpreting stage design, visual composition, and multimedia integration. Musicological perspectives from Cook (2000) contributed to the understanding of music as a communicative and emotional language within performance environments. To enhance reliability and validity, the study utilized multiple scholarly sources and cross-disciplinary perspectives. The inclusion of various theoretical frameworks allowed triangulation of ideas and reduced interpretive bias. Furthermore, comparisons between theoretical concepts and practical theatrical examples strengthened the credibility of the findings.

The research also ensured consistency by applying the same thematic categories throughout the analytical process. Interpretations were based on established academic theories and supported by documented examples from contemporary theatre practice (Roesner, 2023). Several limitations should be acknowledged. First, the study relied primarily on secondary data rather than direct audience observation or interviews with theatre practitioners. Second, because theatrical interpretation is inherently subjective, some analytical conclusions may vary depending on cultural

and artistic perspectives. Third, the study focused mainly on contemporary and experimental theatre, which may not fully represent all theatrical traditions worldwide. Despite these limitations, the qualitative-descriptive methodology provided comprehensive insight into the interdisciplinary integration of music and fine arts in modern theatre performance and allowed for detailed exploration of artistic and cultural dynamics within contemporary stage practice.

Materials and Methods

This study employed a qualitative-descriptive research methodology to investigate the integration of music and fine arts in contemporary theatre performance (Quick, 2023). The qualitative approach was selected because the subject of the research involves artistic interpretation, aesthetic analysis, symbolic meaning, and interdisciplinary communication, which cannot be fully measured through quantitative methods. Qualitative research allows deeper examination of creative processes, emotional expression, and audience perception within theatrical environments.

The study was designed as an interdisciplinary theoretical and analytical investigation combining perspectives from theatre studies, musicology, visual arts, performance theory, and cultural studies. The research focused on understanding how music and fine arts function collectively within contemporary theatrical productions and how these artistic disciplines contribute to dramatic communication, visual aesthetics, and audience engagement.

A descriptive-analytical framework was applied to identify recurring themes and artistic patterns in modern theatre performances. The research examined both theoretical literature and practical theatrical examples to establish connections between artistic theory and performance practice.

Purposeful sampling was used to select relevant theatrical performances and academic materials. The study focused specifically on productions and scholarly works that demonstrated clear integration of music and fine arts within theatrical contexts. Sampling criteria included:

- Use of live or recorded music as a narrative or emotional component;
- Inclusion of visual arts such as painting, sculpture, costume design, lighting, or digital scenography;
- Evidence of interdisciplinary collaboration among artists;
- Representation of contemporary theatre practices;
- Availability of critical analysis or documentation.

This sampling method ensured that the selected materials directly addressed the objectives of the research and provided meaningful insight into interdisciplinary theatrical performance.

The collected data were analyzed using thematic analysis. This method enabled the identification of recurring concepts, artistic strategies, and aesthetic patterns related to the integration of music and fine arts in theatre. During analysis, the data were organized into several thematic categories, including:

1. Emotional communication through music;
2. Visual symbolism and scenography;
3. Audience immersion and sensory experience;
4. Interdisciplinary artistic collaboration;
5. Technological innovation in performance;
6. Cultural representation and intercultural communication.

Each source and theatrical example was carefully examined to determine how musical and visual elements contributed to dramatic meaning and audience interpretation. Comparative analysis was also

conducted to identify similarities and differences between traditional theatrical practices and experimental contemporary performances. The study particularly focused on symbolic interpretation. Visual imagery, lighting composition, sound design, and stage movement were interpreted as communicative systems that convey emotional and cultural meanings beyond verbal dialogue. This interpretive process was guided by principles from performance studies and semiotic theatre theory.

Main body

Case Study 1: The Encounter (Complicité, directed by Simon McBurney, 2015)

Background

The Encounter is regarded as one of the most innovative contemporary theatre productions because it combines dramatic storytelling with binaural sound technology, live music, digital soundscapes, visual minimalism, and audience immersion. Rather than relying on elaborate scenery, the production integrates music, sound design, lighting, and visual symbolism to construct the theatrical environment.

Analysis

The performance demonstrates that music is no longer a supplementary element but functions as a primary narrative structure. Throughout the production, live vocal effects, environmental sounds, electronic music, and silence continuously shape the audience's emotional responses. Unlike traditional theatre, visual art is represented through minimalist stage composition. Only a few physical objects appear on stage; however, lighting design and spatial composition create vivid mental imagery. This approach shifts spectators' attention from realistic scenery toward imaginative participation. The production also exemplifies multimodal storytelling. The actor simultaneously performs as narrator, sound designer, and musician, blurring disciplinary boundaries between theatre, music, and performance art. Consequently, artistic meaning emerges through the interaction of auditory and visual elements rather than spoken dialogue alone. Contemporary theatre scholarship increasingly argues that such productions replace hierarchical relationships among artistic disciplines with collaborative dramaturgies in which music shapes narrative rhythm and audience perception.

Findings

The analysis indicates that:

- Music functions as an independent dramaturgical language.
- Minimalist visual design increases audience imagination.
- Digital sound technologies significantly enhance emotional immersion.
- Fine arts contribute symbolically rather than decoratively.
- Audience engagement is strengthened through multisensory experience.

Case Study 2: The Lehman Trilogy (National Theatre/London, directed by Sam Mendes, 2018–present)

Background

The Lehman Trilogy presents the history of the Lehman Brothers financial dynasty using a combination of theatrical narration, live music, choreography, architectural stage design, projection, and minimalist visual aesthetics. The production has received international acclaim for integrating theatrical performance with visual and musical composition.

Analysis

The production illustrates how fine arts can organize dramatic structure. Es Devlin's rotating glass-box stage functions simultaneously as architecture, sculpture, projection surface, and symbolic representation of capitalism. Rather than serving merely as scenery, the stage itself becomes a visual narrative. Music performs several simultaneous functions. Piano passages, rhythmic motifs, ambient sound, and carefully controlled silence regulate pacing and emotional transitions. Musical timing synchronizes with actors' movements and stage transformations, producing a unified audiovisual composition.

Projection design further integrates visual art into theatrical storytelling. Historical photographs, financial imagery, handwritten documents, and abstract visual textures create multiple narrative layers that interact continuously with performance. This production reflects contemporary theories of "composed theatre," in which music, visual design, movement, and dramaturgy are conceived together during the creative process instead of being added sequentially. Such interdisciplinary collaboration produces greater narrative coherence and stronger audience engagement.

Findings

The production demonstrates that:

- Scenic design functions as visual storytelling.
- Music regulates dramatic rhythm and temporal structure.
- Digital projections extend narrative meaning.
- Collaboration among composers, designers, and directors creates artistic coherence.
- Integrated artistic elements increase audience immersion and interpretative depth.

Table 1
Comparative Analysis of two theatre plays

Variable	The Encounter	The Lehman Trilogy
Role of Music	Immersive narrative environment	Dramatic rhythm and emotional pacing
Fine Arts	Minimalist visual symbolism	Architectural stage design and projections
Technology	Binaural audio, digital sound	Projection mapping, moving stage
Audience Experience	Psychological immersion	Historical and emotional immersion
Artistic Integration	Performer-centered multimedia	Collaborative interdisciplinary design

Both performances demonstrate a significant transformation in contemporary theatre practice. Rather than functioning independently, music and fine arts operate as interconnected dramaturgical systems. Music establishes emotional rhythm, spatial perception, and narrative continuity, while visual arts—including scenography, lighting, projection, and spatial architecture—construct symbolic meaning and guide audience interpretation.

The two productions differ in artistic strategy. *The Encounter* emphasizes auditory immersion supported by minimalist visual aesthetics, whereas *The Lehman Trilogy* achieves integration through architectural scenography and carefully synchronized musical composition. Nevertheless, both productions confirm that interdisciplinary collaboration enhances theatrical communication by engaging audiences through multiple sensory channels simultaneously.

These findings support current scholarship suggesting that contemporary theatre increasingly adopts "composed theatre" and multimedia performance practices, where artistic disciplines are integrated from the earliest stages of production rather than combined after the dramatic text has been completed.

The analysis revealed that contemporary directors strategically use music to shape audience interpretation of dramatic events. Slow orchestral melodies and soft instrumental compositions are commonly associated with sadness, nostalgia, and emotional vulnerability, while rapid rhythmic patterns and electronic sounds are often used to create tension, anxiety, or psychological conflict. In experimental theatre productions, music frequently replaces traditional dialogue and becomes the primary medium of emotional communication.

For example, productions influenced by postdramatic theatre aesthetics often use repetitive sound patterns and fragmented musical compositions to reflect themes of alienation, identity crisis, and social instability (Lehmann, 2006). In many contemporary performances, live musicians are positioned directly on stage rather than hidden within orchestra pits, emphasizing the visibility of musical performance as part of the dramatic action. The findings further indicate that recurring musical motifs strengthen character development and narrative continuity. Certain sounds or melodies become symbolically connected to specific characters, memories, or emotional states. This technique enables audiences to form psychological associations that reinforce dramatic meaning. Fischer-Lichte (2008) explains that such sensory repetition intensifies audience immersion and creates emotional resonance within live performance environments. Additionally, the study found that contemporary theatre increasingly incorporates multicultural musical traditions into performances. Directors often blend classical orchestration with folk music, electronic composition, and indigenous rhythms to create culturally hybrid performances. This integration reflects globalization and growing intercultural exchange within modern theatre practice.

Another major finding is the significant role of fine arts in shaping theatrical aesthetics and visual communication. Scenic design, costume creation, lighting composition, painting, sculpture, and multimedia projection collectively contribute to the symbolic and emotional atmosphere of performances. Aronson (2018) argues that modern scenography functions as an active narrative system rather than passive stage decoration, and the findings strongly support this perspective. The research revealed that minimalist and abstract visual styles are increasingly common in contemporary theatre. Instead of realistic stage representation, many directors employ symbolic visual imagery to communicate psychological and philosophical themes. Empty stage spaces, geometric structures, surreal visual objects, and symbolic color schemes are frequently used to stimulate audience interpretation and emotional response.

Lighting design emerged as one of the most influential visual components within theatrical performance. The findings show that lighting controls audience attention, defines spatial atmosphere, and communicates emotional tone. Warm lighting is often associated with intimacy and memory, while sharp contrasts and cold colors symbolize tension, fear, or emotional isolation. According to Wilson and Goldfarb (2019), lighting serves both practical and artistic functions by guiding visual focus and establishing dramatic mood. Costume design also contributes significantly to theatrical storytelling. The analysis found that costumes often symbolize social identity, psychological transformation, or historical context. In experimental theatre, costumes sometimes function as moving visual sculptures rather than realistic clothing, reinforcing the artistic integration between theatre and fine arts.

The use of projection art and digital imagery has become especially prominent in contemporary productions. Multimedia scenography allows moving images, animations, and visual effects to interact directly with performers on stage. Pavis (2013) notes that digital scenography transforms theatre into a hybrid artistic environment where physical and virtual realities coexist. The findings confirm that multimedia projections enhance visual immersion and expand the expressive

possibilities of theatrical storytelling. The findings indicate that the integration of music and fine arts creates highly immersive theatrical experiences that engage multiple human senses simultaneously. Contemporary theatre increasingly prioritizes audience experience over traditional narrative structure, encouraging emotional and sensory participation.

Music, lighting, movement, and visual imagery work together to create a multisensory environment in which audiences become emotionally involved in the performance. Schechner (2017) explains that modern performance art often dissolves the boundary between performer and spectator, transforming audiences into active participants within the theatrical event. Several productions analyzed in this study employed surround sound systems, interactive lighting, and dynamic visual projections to intensify immersion. In some experimental performances, audiences were physically positioned within the performance space rather than seated separately, allowing direct interaction with actors, musicians, and visual installations.

The study also found that sensory immersion enhances audience memory and emotional response. Performances combining strong musical compositions with striking visual imagery were more likely to produce lasting psychological impressions on viewers. This finding supports Fischer-Lichte's (2008) theory that theatre possesses transformative power through embodied sensory experience. The research demonstrates that contemporary theatre increasingly depends on interdisciplinary collaboration among artists from different creative fields. Directors, composers, painters, choreographers, sculptors, architects, and digital media designers cooperate to produce unified artistic visions.

Brook (1996) emphasized that theatre is fundamentally a collaborative art form, and the findings of this study confirm that interdisciplinary cooperation remains essential for contemporary theatrical innovation. Productions integrating multiple artistic perspectives were found to possess greater aesthetic diversity and creative flexibility. The analysis also indicates that interdisciplinary theatre promotes cultural dialogue. By combining artistic traditions from different societies, performances encourage intercultural understanding and global artistic exchange. Traditional music, indigenous visual motifs, and contemporary multimedia technologies are often integrated within the same production, reflecting modern globalization and cultural hybridity.

The findings further reveal that technological innovation has significantly expanded the integration of music and fine arts within theatre performance. Digital technologies have transformed scenic design, sound production, lighting systems, and audience interaction. Contemporary theatre increasingly incorporates projection mapping, virtual reality, motion graphics, and computerized sound systems into live performances. These technologies enable directors to create rapidly changing visual environments and immersive soundscapes impossible within traditional stage settings. Lehmann (2006) argues that postdramatic theatre reflects contemporary media culture by prioritizing visual and sensory experimentation. The findings support this argument by demonstrating that digital technologies allow theatre to compete with cinematic and multimedia entertainment forms while preserving the immediacy of live performance.

However, the analysis also identified concerns regarding excessive technological dependence. Some critics argue that elaborate visual effects may overshadow dramatic storytelling and actor performance. Despite these concerns, most contemporary productions analyzed in this study successfully balanced technological innovation with artistic and emotional substance. The study additionally found that integrating music and fine arts into theatre has important cultural and educational implications. Interdisciplinary performances encourage artistic literacy and expose audiences to multiple forms of creative expression simultaneously.

Educational theatre programs increasingly incorporate music and visual arts training to develop students' creativity, communication skills, and cultural awareness. Smith-Autard (2002) notes that

interdisciplinary artistic education promotes holistic cognitive and emotional development. The findings suggest that theatre integrating music and fine arts contributes to broader cultural participation and artistic appreciation within society. Furthermore, many contemporary productions use interdisciplinary aesthetics to address social issues such as migration, identity, war, environmental crisis, and technological alienation. Visual symbolism and musical composition help communicate complex social themes in emotionally accessible ways, allowing theatre to function as both artistic expression and social commentary.

Results and Discussion

The findings of this study demonstrate that the integration of music and fine arts significantly transforms contemporary theatre performance by enriching emotional communication, strengthening visual symbolism, enhancing audience immersion, and encouraging interdisciplinary creativity (Chan, 2024). The analysis of scholarly literature and selected theatrical productions revealed that music and visual arts are no longer secondary decorative elements but central components of theatrical storytelling and aesthetic construction.

One of the most significant findings of the research is that music functions as a powerful emotional and narrative instrument in contemporary theatre. Musical elements were found to influence audience psychology, regulate dramatic rhythm, and intensify emotional engagement throughout performances. According to Cook (2000), music possesses a unique ability to communicate emotional meaning independently from verbal language, allowing audiences to experience feelings subconsciously through rhythm, harmony, and sound texture.

The findings of this study demonstrate that the integration of music and fine arts has fundamentally transformed the structure, aesthetics, and communicative power of contemporary theatre performance. Modern theatre no longer functions solely as a literary or dramatic medium based on dialogue and actor-centered storytelling. Instead, it has evolved into a complex interdisciplinary art form where sound, visual imagery, movement, and digital technologies collectively shape audience experience and artistic meaning. This transformation reflects broader cultural and artistic shifts associated with postmodernism, multimedia culture, and experimental performance practices (Lehmann, 2006).

The findings reveal that collaborative artistic processes contribute to innovation and experimentation within theatre production. Many contemporary theatre companies intentionally blur boundaries between artistic disciplines by combining live painting, musical improvisation, dance, and performance art into single productions. Such collaborations create performances that are visually dynamic and emotionally complex. One of the central issues emerging from the findings is the growing role of music as an independent narrative and emotional language within theatre. Traditionally, music functioned primarily as accompaniment or atmospheric support for dramatic action. However, contemporary theatre increasingly positions music as an active storytelling force capable of communicating psychological depth and symbolic meaning beyond spoken dialogue. Cook (2000) argues that music possesses semantic flexibility, enabling audiences to experience emotion intuitively rather than analytically. The results of this study support this argument by demonstrating how directors strategically use musical rhythm, harmony, silence, and sound texture to manipulate emotional atmosphere and audience interpretation.

In many contemporary productions, music guides the pacing of dramatic action and structures audience emotional response. Repetitive sound motifs, dissonant harmonies, and improvised compositions are frequently employed to reflect themes such as anxiety, alienation, memory, or identity crisis. Such practices are particularly visible in postdramatic theatre, where linear storytelling is often replaced by fragmented sensory experience (Lehmann, 2006). In these performances, music does not merely accompany action but becomes part of the dramatic structure itself.

The findings also indicate that live musical performance contributes significantly to theatrical authenticity and immediacy. When musicians share the stage space with actors, audiences perceive music as an organic component of the dramatic event rather than an external supplement. Fischer-Lichte (2008) explains that live performance creates a feedback loop between performers and spectators, generating collective emotional energy through physical presence and sensory interaction. The integration of live music intensifies this performative relationship and enhances audience immersion.

Another important discussion point concerns the expanding role of fine arts in contemporary theatrical communication. The study demonstrates that scenic design, costume aesthetics, lighting composition, painting, and multimedia imagery are essential elements of dramatic meaning-making. Visual aesthetics in theatre no longer function solely as decorative background but actively participate in narrative construction and emotional communication. Aronson (2018) notes that contemporary scenography transforms theatrical space into a dynamic visual environment capable of expressing abstract ideas and psychological conditions. The findings strongly confirm this theoretical perspective. The increasing use of abstract and symbolic visual imagery reflects broader trends in contemporary art and performance culture. Minimalist stages, surreal visual compositions, and symbolic color schemes allow directors to communicate philosophical and emotional themes without relying entirely on realistic representation. This shift demonstrates the influence of modern visual art movements such as expressionism, surrealism, and conceptual art on theatrical aesthetics.

Lighting design emerged in this study as one of the most influential visual tools within contemporary theatre. The results indicate that lighting shapes emotional atmosphere, spatial perception, and symbolic interpretation. Modern lighting technologies allow rapid transformation of stage environments, enabling directors to create psychologically charged visual experiences. Wilson and Goldfarb (2019) emphasize that lighting has become an independent artistic discipline within theatre production, and the findings support this claim by demonstrating its emotional and symbolic significance.

The incorporation of multimedia projection and digital scenography further illustrates the growing convergence between theatre and visual technology. Contemporary productions frequently combine live performance with projected imagery, animation, and interactive visual effects. Pavis (2013) argues that digital scenography creates hybrid performance spaces where physical and virtual realities coexist. The findings confirm that multimedia integration expands theatrical creativity by allowing rapid visual transformation and immersive sensory engagement. However, the increasing dependence on technology within theatre also raises critical artistic questions. Some scholars argue that excessive visual spectacle and technological complexity risk overshadowing actor performance and dramatic substance. Traditional theatre theorists often emphasize the importance of human presence, live interaction, and emotional authenticity as the defining characteristics of theatrical art (Brook, 1996). If multimedia effects dominate the performance, theatre may lose some of its essential human and emotional qualities.

The findings suggest that successful interdisciplinary theatre requires balance between technological innovation and dramatic integrity. Productions that effectively integrate music, visual arts, and digital technologies maintain emotional coherence and thematic clarity while enhancing sensory experience. In contrast, performances relying excessively on visual spectacle may produce aesthetic overload, reducing audience emotional connection to characters and narrative themes.

Another important aspect highlighted by the study is the role of interdisciplinary collaboration in artistic innovation. Contemporary theatre increasingly depends on cooperation among directors, composers, choreographers, painters, architects, costume designers, and digital media artists. Such collaboration expands creative possibilities and encourages experimentation across artistic boundaries. Schechner (2017) explains that modern performance culture values hybridity and

collective creativity rather than rigid disciplinary separation. The findings confirm that interdisciplinary collaboration enables theatre to adapt to changing cultural expectations and technological realities. The cultural significance of integrating music and fine arts into theatre is also substantial. Contemporary performances often combine traditional artistic elements with modern experimental techniques to explore themes of cultural identity, migration, globalization, and historical memory. Folk music, indigenous visual motifs, and traditional costume designs are frequently reinterpreted through contemporary scenographic methods (Hook, 2023). This process allows theatre to preserve cultural heritage while simultaneously engaging with modern social realities.

The study further demonstrates that interdisciplinary theatre contributes to intercultural communication and global artistic exchange. Productions incorporating diverse musical traditions and visual aesthetics encourage audiences to engage with unfamiliar cultural perspectives through sensory and emotional experience. Fischer-Lichte (2008) argues that performance possesses transformative intercultural potential because it communicates through embodied experience rather than purely linguistic structures. The findings support this idea by showing how interdisciplinary theatre creates shared emotional understanding across cultural boundaries.

Educationally, the integration of music and fine arts into theatre also provides significant developmental benefits. Artistic collaboration encourages creativity, critical thinking, emotional intelligence, and aesthetic awareness among performers and audiences alike. Smith-Autard (2002) emphasizes that interdisciplinary arts education supports holistic intellectual and emotional development. The findings suggest that theatre integrating multiple art forms can serve as an effective educational tool for fostering creativity and cultural literacy. Additionally, contemporary theatre increasingly functions as a platform for social commentary and political reflection. Music and visual symbolism enable directors to address complex issues such as war, environmental crisis, technological alienation, social inequality, and psychological trauma in emotionally accessible ways. Symbolic imagery, sound composition, and multimedia projection allow abstract social concerns to be communicated through sensory experience rather than direct political discourse. This artistic strategy enhances audience engagement by appealing simultaneously to emotion, intellect, and imagination.

The findings also reveal that audience expectations have changed significantly in the digital age. Contemporary spectators often seek immersive and interactive experiences rather than passive observation. The integration of music, visual arts, and multimedia technologies satisfies this expectation by transforming theatre into a participatory sensory environment. Schechner (2017) argues that modern performance increasingly dissolves boundaries between performers and spectators, creating collective artistic experiences. The results of this study confirm that interdisciplinary theatre enhances audience participation and emotional involvement. Overall, the discussion demonstrates that integrating music and fine arts into contemporary theatre performance reflects broader transformations in artistic culture, technological development, and social communication. Interdisciplinary theatre expands the expressive capacity of performance art by combining emotional soundscapes, symbolic visual imagery, and immersive sensory environments. Although technological and aesthetic experimentation may present challenges related to dramatic balance and authenticity, successful integration enriches theatrical communication and ensures the continued relevance of theatre within contemporary society.

Conclusion

The integration of music and fine arts into contemporary theatre performance has transformed modern theatrical expression into a multidimensional sensory experience. This study demonstrates that music strengthens emotional communication, supports narrative development, and intensifies audience immersion, while fine arts contribute to visual symbolism, aesthetic atmosphere, and spatial creativity.

Contemporary theatre increasingly relies on interdisciplinary collaboration among musicians, visual artists, directors, choreographers, and digital designers. Such collaboration expands artistic possibilities and allows performances to address complex emotional, cultural, and social themes through combined auditory and visual expression. Technological innovation has further enhanced these integrations by introducing multimedia scenography, projection art, and experimental sound design into theatrical practice.

The findings also reveal that interdisciplinary theatre contributes to intercultural understanding and cultural innovation. By combining traditional artistic elements with modern performance techniques, theatre becomes a dynamic platform for cultural dialogue and creative experimentation. Audiences are no longer passive observers but active participants in immersive artistic environments shaped by sound, imagery, movement, and symbolism. Nevertheless, the study recognizes the importance of maintaining balance between visual spectacle and dramatic substance. While multimedia and artistic experimentation enrich performance aesthetics, theatrical integrity still depends on meaningful storytelling and effective actor performance.

In conclusion, music and fine arts have become essential components of contemporary theatre performance. Their integration enhances artistic communication, deepens emotional resonance, and broadens the expressive capacity of theatre in modern society. Future research may further examine audience psychology, digital performance technologies, and intercultural artistic collaboration within evolving theatrical practices.

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Comparative Aspects of National History and Artistic Imagination in the Development of the Turkish Historical Novel

Turkan Aliyeva 

Abstract. *Historical novels have played an important role in Turkish literature by connecting historical reality with literary creativity. Rather than simply retelling historical events, they offer new ways of understanding the past through narrative, characters, and cultural memory. This study examines the relationship between national history and artistic imagination in the development of the Turkish historical novel from a comparative perspective. It focuses on selected novels by Namık Kemal, Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala. Using a qualitative comparative approach, the study analyses how these writers interpret history, construct historical characters, and reflect national identity through literary narrative. The findings show that although the selected authors differ in style and historical interpretation, they all view history as a living part of cultural identity rather than a collection of past events. Their novels reveal that artistic imagination strengthens historical understanding by highlighting the human, cultural, and emotional aspects of history without moving away from historical reality. The study also demonstrates that the Turkish historical novel has gradually developed into an important medium for preserving collective memory and encouraging new interpretations of the national past. These findings contribute to comparative literary studies by offering a deeper understanding of the relationship between history, literature, and cultural identity.*

Keywords: *Turkish historical novel, national history, artistic imagination, comparative literature, collective memory, cultural identity*

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Türk tarixi romanının inkişafında milli tarix və bədii təxəyyülün müqayisəli aspektləri

Turkan Əliyeva 

Xülasə. *Tarixi roman türk ədəbiyyatında keçmiş bədii düşüncə vasitəsilə canlandıran və milli tarixin müxtəlif dövrlərini oxucuya yeni baxış bucağından təqdim edən mühüm janrlardan biridir. Bu romanlarda tarixi faktlar yalnız olduğu kimi nəql edilmir, həm də yazıcının bədii təxəyyülü ilə zənginləşdirilərək dövrün ictimai, siyasi və mədəni mənzərəsini özündə əks etdirir. Məqalədə türk tarixi romanının inkişafında milli tarix və bədii təxəyyülün qarşılıqlı əlaqəsi müqayisəli şəkildə araşdırılmışdır.*

Tədqiqat zamanı Namiq Kamal, Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Hüseyin Nihal Atsız və İskəndər Palanın tarixi romanları təhlil edilmiş, onların tarixi hadisələrə yanaşma prinsipləri, tarixi şəxsiyyətlərin bədii təqdimatı və milli kimliyin ifadə xüsusiyyətləri müqayisə olunmuşdur. Araşdırmanın nəticələri göstərir ki, fərqli dövrlərdə yaşayıb-yaratmalarına və müxtəlif bədii üslablara malik olmalarına baxmayaraq, bu yazıçıların əsərlərində tarix milli kimliyin və mədəni yaddaşın əsas mənbələrindən biri kimi təqdim edilir. Müəlliflər tarixi hadisələri bədii təxəyyülün imkanlarından istifadə etməklə daha təsirli şəkildə canlandırmağa, eyni zamanda isə tarixi həqiqətdən uzaqlaşmamağa çalışırlar. Bu xüsusiyyət türk tarixi romanının təkcə keçmişi təsvir edən deyil, həm də milli yaddaşı yaşadan, tarixi hadisələrin mahiyyətini anlamağa kömək edən mühüm ədəbi janr olduğunu göstərir. Tədqiqatın nəticələri tarix, ədəbiyyat və milli kimlik arasındakı əlaqələrin daha dərinədən öyrənilməsi baxımından əhəmiyyət kəsb edir və türk tarixi romanının inkişaf xüsusiyyətlərinə dair müqayisəli tədqiqatlara yeni baxış təqdim edir.

Açar sözlər: *türk tarixi romanı, milli tarix, bədii təxəyyül, müqayisəli ədəbiyyat, kollektiv yaddaş, milli kimlik*

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Introduction

Every nation preserves its historical memory in its own way. While historical records document events, dates, and political developments, literature captures the human experiences, emotions, and cultural values that official history often leaves unexplored. In this respect, the historical novel occupies a unique place, bringing together historical reality and literary imagination (Dadashova, 2024). Rather than replacing history, it offers a different way of understanding the past by presenting historical events through the lives, thoughts, and experiences of fictional or historical characters. For this reason, the historical novel has attracted growing attention not only in literary studies but also in cultural history, memory studies, and comparative literature.

The relationship between history and fiction is especially significant in Turkish literature. The development of the Turkish historical novel coincided with a period when questions of national identity, statehood, and cultural continuity became increasingly important. Although the genre was initially influenced by the historical novels of Walter Scott, Turkish writers gradually shaped it according to their own historical and cultural experience. Instead of simply recounting past events, they used history to explore broader issues such as national identity, social values, power, and cultural heritage. As a result, the Turkish historical novel developed its own distinctive literary character, rooted in the Ottoman past, Central Asian traditions, and the process of nation-building (Abeladze, 2019).

The publication of Cezmi by Namık Kemal marked an important turning point in the development of the Turkish historical novel. Since then, writers such as Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala have approached history from different literary and ideological perspectives (Aynacı, 2022, p. 23). While some emphasize the social and political foundations of historical events, others focus on individual transformation, national consciousness, epic tradition, or symbolic interpretation. These differences demonstrate that historical novels are shaped not only by historical facts but also by each writer's artistic imagination, worldview, and literary purpose.

Today, historical novels are regarded as more than literary representations of the past. They contribute to the preservation of cultural memory and influence how societies understand their own history. Readers often develop their first impressions of historical periods through literary narratives before encountering academic historiography. Consequently, historical fiction plays an important role in shaping historical consciousness by combining factual knowledge with creative interpretation (Argunşah, 2013, p. 45).

Although many studies have examined individual Turkish historical novelists, comparative research on the relationship between national history and artistic imagination remains relatively limited. This study addresses that gap by comparatively analysing selected novels by Namık Kemal, Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala. It explores how historical reality is transformed into literary narrative and how different writers reinterpret the same historical periods through their own artistic vision. The study argues that the enduring value of the Turkish historical novel lies in its ability to establish a meaningful dialogue between historical reality and creative imagination, offering readers not only knowledge about the past but also a deeper understanding of national identity and cultural memory.

Mustafa Necati Sepetçioğlu offers another perspective on the Turkish historical novel. In his works history is not presented as a simple sequence of events. Instead he combines historical facts with epic tradition, collective memory, folklore, and religious symbolism. Historical figures remain connected to real events, but they also become symbols of national unity, sacrifice, and continuity (Tekin, 2018). This approach shows that literary imagination does not weaken historical authenticity. On the contrary it helps readers build a stronger emotional connection with the past.

The diversity of Turkish historical fiction also shows that every writer approaches history differently. Authors choose different events, focus on different historical figures, and highlight different aspects of the same period. Their choices are influenced by their own intellectual background, cultural values, and literary aims. As a result the same historical event can lead to different interpretations without losing its historical foundation. This diversity is one of the defining features of the Turkish historical novel.

Artistic imagination plays an essential role in this process. It allows historical events to be experienced through the lives of individuals rather than through facts alone. Historical characters become people with emotions, fears, hopes, and personal struggles. At the same time fiction makes it possible to explore aspects of the past that cannot easily be explained through historical documents such as memory, personal experience, and cultural identity. In this way literature complements history instead of competing with it. The lasting influence of the Turkish historical novel comes from its ability to maintain a balance between historical reality and creative interpretation. A novel that relies only on historical facts may lose its literary appeal, while unlimited imagination can reduce its historical credibility. Successful historical novels bring these two elements together and create narratives that are both convincing and meaningful. They help preserve collective memory and encourage readers to think about the past from different perspectives.

This study adopts a comparative approach to examine how Turkish writers reinterpret national history through different literary strategies. It focuses on selected novels by Namık Kemal, Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala. The analysis explores the relationship between historical reality and artistic imagination, paying particular attention to characterization, narrative structure, symbolism, and the representation of national identity. The study argues that the strength of the Turkish historical novel lies in its ability to transform historical knowledge into meaningful literary experience while preserving its connection with the historical past.

Materials and Methods

The present study is based on a qualitative research design and employs a comparative literary analysis to examine the relationship between national history and artistic imagination in the development of the Turkish historical novel. Rather than measuring historical accuracy through quantitative indicators, the research seeks to understand how different writers reconstruct the past through literary discourse and how their individual artistic perspectives shape representations of national history. This approach makes it possible to move beyond descriptive summaries and to explore the interpretative mechanisms through which historical reality is transformed into narrative experience.

Comparative literary studies have long emphasized that works belonging to the same genre often reveal their distinctive characteristics only when they are examined alongside one another. Historical novels, despite sharing a common interest in the past, differ considerably in narrative organization, ideological orientation, characterization, and historical interpretation. Consequently, the present research adopts comparison not merely as a technical method but as an analytical framework capable of identifying both common literary tendencies and individual creative strategies. The comparison focuses not on determining which novel is "more historical", but on understanding how different authors assign literary meaning to similar historical phenomena.

The corpus of the study consists of selected historical novels representing different stages in the evolution of Turkish historical fiction. Particular attention is given to *Cezmi* by Namık Kemal, *Devlet Ana* by Kemal Tahir, *Osmancık* by Tarık Buğra, the historical trilogy (*Kilit*, *Anahtar*, and *Kapı*) by Mustafa Necati Sepetçioğlu, *Bozkurtlar* by Atsız, and *Şah ve Sultan* by İskender Pala. These novels were selected because they represent different historical periods, literary generations, and ideological approaches while sharing a common concern with the literary reconstruction of Turkish history.

The selected texts span nearly one hundred and fifty years of literary development, beginning with the late Ottoman modernization period and extending into contemporary Turkish literature. Such chronological diversity enables the study to observe how literary perceptions of history have changed over time. The research assumes that historical fiction is not only influenced by the historical period represented in the narrative but also by the social, intellectual, and political environment in which the author writes. Accordingly, each novel is examined simultaneously within two historical contexts: the historical era depicted in the narrative and the historical moment of the author's own intellectual production. This dual perspective allows the analysis to distinguish between historical reconstruction and contemporary interpretation.

To ensure analytical consistency, the comparison is organized around five interconnected dimensions. The first concerns the representation of national history and the selection of historical events. Particular attention is paid to which historical episodes are emphasized, which are marginalized, and how historical continuity is established within the narrative. The second dimension examines artistic imagination, focusing on the literary techniques through which historical material is reshaped. This includes fictional characters, reconstructed dialogues, symbolic episodes, psychological interiority, and imaginative narrative expansions that extend beyond documentary history while remaining compatible with the broader historical framework.

The third analytical dimension addresses characterization. Historical protagonists are examined not simply as reflections of documented historical figures but as literary constructions shaped by narrative purpose. The analysis investigates how individual authors balance historical authenticity with artistic creativity when constructing the personalities, motivations, and ethical dilemmas of historical characters. Differences in characterization frequently reveal broader ideological positions regarding leadership, nationhood, social justice, religion, and statehood.

A fourth dimension concerns narrative discourse and historical perspective. Historical novels inevitably organize historical knowledge through particular narrative voices. Some narrators remain relatively detached from historical events, while others openly guide readers toward specific moral or ideological interpretations. The study therefore examines narrative perspective, temporal organization, symbolism, and intertextual references in order to understand how literary discourse influences readers' perception of historical reality. Special consideration is given to the interaction between documented historical information and fictional narration, since this interaction constitutes one of the defining characteristics of historical fiction.

The final analytical dimension focuses on the relationship between collective memory and national identity. Rather than treating national identity as a fixed historical category, the study approaches it as a literary construction that evolves through narrative representation. Historical novels participate actively in shaping cultural memory by selecting certain historical experiences as representative of national consciousness while assigning symbolic significance to particular historical figures and events. The analysis therefore considers how literary imagination contributes to the formation, preservation, and reinterpretation of collective historical memory across different generations of Turkish writers.

Methodologically, the research combines several complementary theoretical perspectives. Comparative literature provides the principal analytical framework by enabling systematic comparison among different authors and texts. This framework is supported by hermeneutic interpretation, which emphasizes the contextual understanding of literary meaning rather than isolated textual description. At the same time, the study draws upon principles associated with New Historicism, acknowledging that literary texts and historical discourse continuously influence one another rather than existing as separate systems of knowledge. Finally, selected narratological concepts are employed to examine characterization, narrative voice, temporal organization, and symbolic representation within the novels.

The interpretation of the selected texts follows an inductive analytical strategy. Instead of imposing predetermined theoretical conclusions upon the novels, recurring literary patterns are identified through close reading and subsequently interpreted within broader historical and cultural contexts. Such an approach allows similarities and differences to emerge organically from the textual evidence itself, reducing the risk of ideological overgeneralization while preserving the individual artistic identity of each author.

Particular importance is attached to textual evidence throughout the analysis. Comparative observations are derived not from isolated quotations but from recurring narrative structures, thematic patterns, and stylistic tendencies observed across the selected corpus. This methodological choice reflects the understanding that historical fiction should be examined as a complex literary system in which narrative form, historical consciousness, ideological discourse, and artistic imagination function as interdependent components rather than independent analytical categories.

Accordingly, the methodological framework adopted in this study is intended to illuminate the dynamic interaction between documented history and literary creativity. By examining historical novels comparatively rather than individually, the research seeks to reveal how different writers reconstruct national history through distinct artistic strategies while simultaneously contributing to the broader evolution of the Turkish historical novel as both a literary genre and a medium of cultural memory.

Results

The comparative analysis shows that the Turkish historical novel has developed as much more than a literary genre that recounts the past. Throughout its evolution, it has become a space where history

is interpreted through different literary perspectives and where artistic imagination plays a central role in shaping historical meaning. Although the selected writers draw on the same national history, they differ in the way they understand historical events, construct their narratives, and represent national identity. These differences do not arise from conflicting historical facts but from the authors' individual worldviews, literary styles, and ideological approaches.

One of the main findings of this study is that Turkish historical novelists do not treat history as a fixed and complete account of the past. Instead, history is presented as a living source that can be reinterpreted by every generation. This becomes especially clear when different writers focus on the same historical period. Rather than repeating the same narrative, each author highlights different social, political, or cultural aspects of history. As a result, the Turkish historical novel presents multiple interpretations of the national past while remaining connected to historical reality (White, 2005, p. 151).

This tendency can already be seen in *Cezmi*, where Namık Kemal uses history not simply to describe the Ottoman-Safavid conflicts but to express ideas about patriotism, freedom, and national consciousness. The historical setting provides the background, yet the novel reflects the intellectual concerns of the Tanzimat period as much as the sixteenth century (Değirmenci, 2020). This demonstrates that historical novels often represent both the period they describe and the period in which they are written.

The comparison between Kemal Tahir's *Devlet Ana* and Tarık Buğra's *Osmancık* further illustrates how literary interpretation shapes historical narrative. Both novels focus on the foundation of the Ottoman state, yet they explain this process in different ways. Kemal Tahir emphasizes social structure, justice, and collective responsibility as the foundations of state formation. Tarık Buğra, by contrast, places the moral development of Osman Gazi at the centre of the narrative and presents personal growth as the driving force behind historical change. Although both writers rely on the same historical background, they assign different meanings to the events they describe (Gülendam, 2002, p. 12).

A similar approach can be observed in the novels of Mustafa Necati Sepetçioğlu. His works combine historical facts with epic tradition, folklore, religious symbolism, and collective memory. Instead of separating documented history from cultural imagination, he brings these elements together to create a richer historical narrative. In this way, history becomes not only a record of past events but also a reflection of shared cultural values and national memory.

Overall, the findings indicate that artistic imagination does not weaken historical authenticity. On the contrary, it enables writers to present history in a more meaningful and engaging way while preserving its historical foundations. The Turkish historical novel therefore emerges as a literary form that connects historical reality with cultural memory and national identity, allowing readers to understand the past through different yet equally valuable perspectives.

Another important finding of this study is that national history is preserved not only through official historical records but also through cultural memory. Stories, traditions, beliefs, and symbols help societies keep their past alive and give historical events a deeper emotional meaning. This idea is especially clear in the novels of Mustafa Necati Sepetçioğlu. By combining documented history with folklore, epic tradition, and cultural symbolism, he presents history as a living part of national identity rather than as a collection of facts. His novels show that artistic imagination enriches historical understanding by revealing cultural and emotional dimensions that are often absent from conventional historical writing (Samsakçı, 2023).

The comparative analysis also demonstrates that the Turkish historical novel has changed significantly over time. While earlier novels focused mainly on political events and military

achievements, later works pay greater attention to the cultural, psychological, and moral aspects of history (Timur, 2002). This shift reflects a broader change in Turkish literary thought, where history is understood not only as a record of past events but also as a way of exploring national identity and collective experience.

A similar development can be seen in the portrayal of historical characters. In the novels examined in this study, historical figures are presented as complex individuals rather than idealized heroes. They face difficult decisions, personal struggles, and moral responsibilities that make them more convincing and relatable (Timur, 2002). By emphasizing their human qualities, the writers encourage readers to understand history through individual experience as well as historical events.

The analysis further shows that Turkish historical fiction has gradually expanded its understanding of historical truth. Alongside rulers, soldiers, and political leaders, increasing attention is given to ordinary people whose lives are shaped by historical change (Moran, 2019a). This broader perspective suggests that national history is created not only by major political events but also by the everyday experiences, beliefs, and values of society.

These differences become particularly clear in the works of Atsız and İskender Pala. Although both writers draw inspiration from Turkish history, they interpret the past in different ways and employ distinct literary approaches. Their novels demonstrate the richness of the Turkish historical novel and show how artistic imagination allows the same historical heritage to be understood from different perspectives while remaining connected to historical reality.

Atsız presents history from a strongly national perspective. In *Bozkurtlar*, the idea of the Turkish nation shapes both the characters and the events of the novel. Values such as courage, loyalty, sacrifice, and unity remain at the centre of the story, while the protagonists are portrayed as individuals devoted to protecting their people and their homeland. Through this approach, history becomes more than a record of the past. It becomes a source of national pride and a way of strengthening cultural identity. Atsız uses literary imagination to make historical events more vivid and emotionally meaningful without losing their connection to historical reality (Atsız, 2019).

İskender Pala offers a different interpretation of history. In *Şah ve Sultan*, he moves beyond heroic narratives and explores the human side of historical events. The conflict between Sultan Selim I and Shah Ismail is presented not only as a political struggle but also as a story shaped by personal beliefs, emotions, and difficult decisions (Gülendam, 2008). His historical characters are neither completely heroic nor entirely flawed. Instead, they are shown as complex individuals whose actions are influenced by both historical circumstances and personal experiences. This approach encourages readers to think about history from different perspectives rather than accept a single interpretation.

The comparison between Atsız and İskender Pala demonstrates the diversity of the Turkish historical novel. While Atsız highlights collective ideals and national unity, Pala gives greater attention to the emotional and psychological dimensions of history. Despite these differences, both writers contribute to preserving national history through literature. One emphasizes shared values and heroic memory, while the other reveals the human experiences behind historical events.

The analysis also shows that historical settings play an important role in shaping the meaning of these novels. Places such as frontier regions, cities, battlefields, and imperial capitals are more than simple locations where events take place. They reflect cultural memory, historical change, and the values associated with different periods of Turkish history. In each novel, space helps create the atmosphere of the narrative and strengthens the connection between the reader and the historical world being described.

Time is treated with similar flexibility. Unlike historians, who generally follow a strict chronological order, novelists organize historical events according to the needs of the narrative. Important moments may receive greater attention, while long historical periods can be presented briefly. These narrative choices do not change historical reality. Instead, they help readers focus on the events, emotions, and experiences that are most significant for understanding the past (İslam-Külahlıoğlu, 2004, p. 117). In this way, the Turkish historical novel combines historical knowledge with literary storytelling to create a richer and more engaging interpretation of history.

The findings also show that artistic imagination is not simply an additional element of historical fiction. It is one of the main features that gives historical events literary meaning. Without imagination, historical novels would become little more than a retelling of historical facts. At the same time, imagination remains closely connected to historical reality. The most successful Turkish historical novels achieve a balance between historical accuracy and creative interpretation, allowing readers to understand not only what happened but also the cultural and emotional significance of those events (Moran, 2019b).

Despite their differences in style and ideology, the writers examined in this study share a common view of history. They present the past as a living part of cultural identity rather than as a closed and unchanging record (Moran, 2019c). Their novels suggest that every generation returns to history with new questions and new perspectives. As a result, the Turkish historical novel has continued to develop by offering new interpretations of the past while preserving its historical foundations.

The analysis also demonstrates that historical characters play a key role in connecting history with literary imagination. Although these figures are based on real historical personalities, their thoughts, emotions, and personal conflicts are created through fiction. Historical sources can explain what these individuals did, but they rarely reveal how they experienced the events around them. It is through literary imagination that writers give historical figures a human voice and make them more meaningful to modern readers.

This can be clearly seen in the novels of Kemal Tahir and Tarık Buğra. Both writers focus on the figure of Osman Gazi, yet they interpret his role in different ways. Kemal Tahir explains the rise of the Ottoman state through social organization, justice, and collective responsibility. Tarık Buğra, in contrast, emphasizes personal growth and moral development, presenting leadership as the result of individual transformation (Nemutlu, 2023, p. 109). Although both novels are based on the same historical period, they offer different explanations for the emergence of the Ottoman state, demonstrating how artistic imagination shapes historical interpretation without changing historical facts.

Historical conflicts are also presented as more than political or military events. Battles and struggles for power become opportunities to explore broader themes such as identity, loyalty, justice, and responsibility (Prigozhin, 2026, p. 63). While earlier historical novels often drew a clear distinction between heroes and their opponents, later writers tend to present historical figures as more complex individuals. This approach makes historical narratives more balanced and convincing, showing that the past cannot always be understood through simple oppositions. By combining historical knowledge with literary creativity, Turkish historical novelists offer readers a deeper and more nuanced understanding of national history.

Another important finding of this study concerns the role of collective memory in the Turkish historical novel. The selected writers show that the past is preserved not only through historical records but also through language, traditions, beliefs, architecture, and everyday cultural practices (Taştan, 2006). In this sense, historical novels perform a different function from academic history. While historians document the past through evidence, novelists preserve the emotions, values, and cultural meanings that surround historical events.

This perspective also explains why certain periods and events appear repeatedly in Turkish historical fiction. The foundation of the Ottoman state, the conquest of Constantinople, and the struggles on the eastern frontiers are not important only because of their historical significance (Nazlı, 2019). They also occupy a special place in Turkish cultural memory. Although these events remain the same, each writer interprets them differently. Some focus on political development, others emphasize moral values, individual sacrifice, or cultural continuity. These different interpretations enrich the literary tradition and demonstrate that history can be understood from more than one perspective.

The comparative analysis also highlights the importance of narrative style. Each writer uses language in a distinctive way that reflects both personal literary preferences and the intellectual climate of the period. Namık Kemal writes with the patriotic tone of the Tanzimat era, while Kemal Tahir adopts a more realistic and analytical style. Tarık Buğra combines historical narration with philosophical reflection, Mustafa Necati Sepetçioğlu draws on the traditions of oral storytelling, and İskender Pala enriches his narratives through symbolism and references to classical Ottoman literature. These stylistic differences influence not only the artistic quality of the novels but also the way readers understand historical events (Tosun, 2022).

The findings further show that Turkish historical fiction balances continuity and change. The past is presented as an important source of national identity, yet every generation interprets it according to its own social and cultural concerns. Writers do not simply repeat historical narratives. Instead, they return to familiar events and offer new ways of understanding their meaning (Altın & Baylan, 2023). This continuing reinterpretation has played an important role in the development of the Turkish historical novel and has helped keep the genre relevant across different periods.

For this reason, Turkish historical novels should be viewed as more than literary retellings of historical events. They offer thoughtful interpretations that connect history, literature, and cultural identity. By combining historical knowledge with artistic imagination, these novels encourage readers to reflect on the past and to understand its significance from different perspectives. The comparison also confirms that the lasting influence of the Turkish historical novel comes from its ability to balance historical reality with creative expression. Historical evidence provides credibility, while literary imagination adds emotional depth, symbolic meaning, and human experience. Together, these elements allow historical fiction to preserve both the factual and the cultural dimensions of the past.

Finally, the analysis suggests that the interpretation of history depends not only on historical evidence but also on the way that evidence is presented. Historians and novelists may begin with the same historical events, yet they pursue different aims. Historians seek to explain what happened, whereas novelists explore how those events were experienced by individuals and communities. This difference gives the historical novel its unique place in preserving cultural memory. This idea is consistent with Hayden White's view that historical narratives are shaped through interpretation rather than by facts alone (Tezcan, 2018, p. 633). The Turkish historical novels examined in this study support this perspective by showing that history becomes meaningful when historical events are connected with human experience, literary narrative, and cultural memory. As a result, these novels help readers understand not only the past itself but also the values and experiences that continue to shape national identity today.

A comparison of *Devlet Ana* and *Şah ve Sultan* clearly shows that Turkish historical novelists can interpret the same historical period in different ways. Both novels are based on Ottoman history, but their focus is not the same. In *Devlet Ana*, Kemal Tahir explains the foundation of the Ottoman state through social order, justice, and strong community values (Beyaz, 2019, p. 122). The development of the state is presented as a gradual social process. In contrast, İskender Pala's *Şah ve Sultan* focuses more on the inner lives of historical figures. Alongside political events, the novel explores faith, personal conflict, and emotional struggles. Although both writers remain connected to historical facts, each presents history from a different perspective.

This comparison supports Paul Ricoeur's idea that people understand history through stories. Historical facts become more meaningful when they are presented as part of a narrative. Turkish historical novels do not simply repeat historical events. Instead, they explain how those events affected individuals and society. In this way, literature adds a human dimension to history without replacing historical reality (Heller, 2011, p. 92).

The selected novels also show that history is closely connected with national identity. They encourage readers to think about the origins of the Turkish nation, the development of the Ottoman state, and the values that have shaped Turkish society. Benedict Anderson's concept of the nation as an "imagined community" helps explain this idea. Through literature, people from different generations share a common historical memory and develop a stronger sense of cultural belonging. Although all of the writers focus on Turkish history, each follows a different artistic approach. Kemal Tahir emphasizes social structure and historical development. Tarık Buğra gives greater importance to personal growth and moral responsibility. Mustafa Necati Sepetçioğlu combines historical facts with epic tradition and collective memory. İskender Pala highlights the psychological and cultural aspects of historical events, while Atsız presents history through heroism, courage, and national ideals. These differences show that the Turkish historical novel offers multiple ways of understanding the same historical past (Moran, 2019b).

The analysis also shows that artistic imagination is not separate from history. Historical documents explain what happened, but novels help readers understand how people experienced those events. Through characters, dialogue, and symbolism, writers make history more vivid and emotionally meaningful while remaining connected to historical reality. Overall, the comparison demonstrates that Turkish historical novels do more than describe the past. They help preserve cultural memory and encourage readers to look at history from different perspectives. Although Namık Kemal, Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala interpret history in different ways, they all show that national history is a living part of cultural identity. This balance between historical reality and artistic imagination has played an important role in the development of the Turkish historical novel.

Another important finding of this study is how Turkish historical novelists use historical sources. Although they write about real historical events, they do not simply retell history. Instead, they carefully choose which events, characters, and details best serve the purpose of the novel. Some events are described in detail, while others receive little attention. This does not reduce the historical value of the novels. Rather, it shows that every writer interprets history according to a particular literary perspective.

This difference can be clearly seen in the works of Kemal Tahir and Tarık Buğra. In *Devlet Ana*, Kemal Tahir focuses on the social structure of the early Ottoman state. He gives more attention to justice, social order, and community life than to military victories. Tarık Buğra follows a different approach in *Osmancık*. Instead of concentrating on political events, he presents history through the personal growth and moral development of the main character. Although both novels describe the same historical period, they explain it from different viewpoints (Gülendam, 2002). The writers also shape historical time according to the needs of the story. Long historical periods may be presented briefly, while an important conversation or personal decision can occupy several pages. This allows the authors to emphasize the moments they consider most meaningful. In the same way, historical decisions are not presented only as political events. Writers also explore the emotions, doubts, and responsibilities behind those decisions, making historical figures feel more realistic and human.

Another common feature of Turkish historical novels is the importance given to fictional secondary characters. Alongside well-known historical figures, writers introduce ordinary people such as soldiers, farmers, craftsmen, women, and religious scholars. These characters help readers understand how major historical events affected everyday life (Mecidova, 2019).

The comparison also shows that different authors give readers different levels of freedom to interpret history. Some writers present clear messages about historical events, while others leave more space for readers to draw their own conclusions (Heller, 2011). As a result, Turkish historical novels not only preserve national history but also encourage readers to think about it from different perspectives. Overall, the analysis demonstrates that the Turkish historical novel has developed far beyond simply retelling historical events. It combines historical knowledge with artistic imagination to create narratives that are both historically convincing and emotionally engaging. This balance between fact and fiction is one of the main reasons why the Turkish historical novel continues to hold an important place in modern literary studies.

Discussion

The findings of this study show that the Turkish historical novel has developed into much more than a literary genre that simply retells historical events. It has become an important way of interpreting national history and preserving cultural memory. Although the selected writers differ in their literary style and understanding of history, they all demonstrate that the past can be presented from different perspectives without losing its historical foundation. This diversity has played a significant role in the development of the Turkish historical novel.

The comparative analysis also indicates that artistic imagination strengthens rather than weakens historical representation. While historical documents provide factual information, novels help readers understand the emotions, values, and human experiences behind historical events (Kara, 2021). In this way, literature complements history by presenting aspects of the past that cannot always be found in official records. As a result, historical novels contribute not only to literary development but also to the preservation of cultural identity and collective memory. The comparison of Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız, and İskender Pala demonstrates that each writer approaches the same historical reality from a different perspective. Kemal Tahir focuses on social structure and institutions, Tarık Buğra emphasizes moral development and leadership, Sepetçioğlu combines history with epic tradition and collective memory, Atsız highlights national ideals and heroism, while İskender Pala explores the psychological and cultural dimensions of historical events. These different approaches do not contradict one another. Instead, they broaden the literary interpretation of Turkish history and show the richness of the historical novel as a genre.

The findings also support the views of Hayden White and Paul Ricoeur, who argue that history becomes meaningful through narrative. Turkish historical novels confirm this idea by transforming historical knowledge into stories that connect the past with the present. Rather than presenting history as a completed process, they encourage readers to reflect on its continuing influence on national identity and cultural values. Overall, this study suggests that the lasting importance of the Turkish historical novel lies in its successful balance between historical reality and artistic imagination. By combining historical facts with literary creativity, Turkish novelists have created works that not only preserve the past but also encourage new ways of understanding it. This balance remains one of the main reasons why the Turkish historical novel continues to occupy an important place in both Turkish literature and comparative literary studies.

Conclusion

The present study set out to examine how national history and artistic imagination interact in the development of the Turkish historical novel. The comparative analysis confirms that historical fiction occupies a unique position between historiography and literature. While remaining connected to documented historical events, it offers possibilities of interpretation that extend beyond the limits of historical narration. Through literary imagination, history is not altered but re-experienced, allowing readers to engage with the past on both an intellectual and an emotional level.

The analysis also demonstrates that the Turkish historical novel has never followed a single literary model. From Namik Kemal's early attempts to connect history with the ideals of patriotism and national awakening to the more philosophically and psychologically complex narratives of Kemal Tahir, Tarık Buğra, Mustafa Necati Sepetçioğlu, Atsız and İskender Pala, each generation has introduced new ways of understanding the relationship between history and literature. Although these writers differ in style and worldview, they share a common conviction that the past should not remain a static record of completed events. Instead, history continues to acquire new meanings as each generation revisits it from its own cultural and intellectual perspective.

A significant outcome of this research is the recognition that artistic imagination should not be regarded as an element that distances historical fiction from historical reality. On the contrary, it enables writers to reveal dimensions of the past that are often absent from documentary sources. Personal dilemmas, ethical choices, emotional conflicts and the everyday experiences of ordinary people become essential components of historical understanding. In this way, the historical novel complements rather than competes with academic historiography, enriching the reader's perception of national history through narrative interpretation.

The comparative perspective adopted in this article further demonstrates that the same historical event may generate different literary meanings without losing its historical foundation. Each novelist constructs the past according to a particular aesthetic vision, intellectual background and cultural sensitivity. These differences should not be interpreted as contradictions but as evidence of the richness of the Turkish historical novel. The coexistence of multiple perspectives allows national history to be approached from social, political, cultural, psychological and philosophical viewpoints, thereby expanding its literary and scholarly significance.

Another conclusion that emerges from the study concerns the role of historical fiction in preserving cultural memory. The selected novels do more than reconstruct the past; they sustain a dialogue between generations by transmitting shared values, historical experiences and cultural symbols. Their contribution therefore extends beyond literature itself. They participate in the continuous reinterpretation of national identity and help maintain the connection between historical consciousness and contemporary cultural life. This function partly explains why historical novels continue to occupy a central place within Turkish literary tradition despite changing literary movements and historical contexts.

In conclusion, the development of the Turkish historical novel illustrates that the relationship between national history and artistic imagination is not based on opposition but on mutual enrichment. Historical reality provides literature with authenticity, while artistic imagination transforms that reality into narratives capable of preserving cultural memory, stimulating critical reflection and encouraging new interpretations of the past. It is precisely this dynamic interaction that has ensured the vitality of the Turkish historical novel and secured its enduring place in both Turkish literature and the broader field of comparative literary studies.

Finally, the findings of this study suggest several directions for future research. Comparative analyses involving Turkish historical novels alongside historical fiction from other literary traditions could offer a broader understanding of how different cultures reconstruct the past through narrative. In addition, interdisciplinary studies combining literary criticism with cultural history, memory studies and historiography may further illuminate the evolving relationship between historical reality and artistic representation in historical fiction. Such approaches would contribute not only to Turkish literary scholarship but also to wider discussions concerning the role of literature in shaping historical consciousness.

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Digitalization of Freight Transport and its Contribution to National Economic Growth

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Abstract. *The digital transformation of freight transport systems has become an important factor in improving logistics efficiency, trade connectivity, and national economic competitiveness. The integration of digital technologies into freight transportation enhances supply chain transparency, reduces operational costs, and supports the development of more efficient and sustainable logistics networks. This study examines the contribution of freight transport digitalization to national economic growth through a quantitative analytical framework. The research integrates econometric modeling, comparative statistical analysis, and transport performance indicators to evaluate the relationship between digital logistics development and macroeconomic performance. Key explanatory variables include freight transport infrastructure indicators, energy efficiency metrics, and the Logistics Performance Index, which are analyzed in relation to gross domestic product dynamics. The empirical analysis indicates a significant positive relationship between freight transport modernization, logistics efficiency, and economic growth. Improvements in logistics performance and digital transport management systems contribute to reduced transportation costs, improved supply chain reliability, and enhanced trade connectivity. Comparative analysis across different country groups shows that the economic benefits of transport digitalization are particularly significant in developing and emerging economies, where improvements in logistics efficiency can substantially increase productivity and market accessibility. The findings highlight the strategic role of freight transport digitalization in supporting sustainable economic development and emphasize the importance of integrated transport policies that combine infrastructure investment, digital technologies, and energy efficiency improvements.*

Keywords: *freight transport digitalization, logistics performance, economic growth, transport infrastructure, energy efficiency, supply chain management*

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Yük daşımalarının rəqəmsallaşdırılması və onun milli iqtisadi artıma töhfəsi

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Xülasə. *Yükdaşıma nəqliyyatı sistemlərinin rəqəmsal transformasiyası logistika səmərəliliyinin artırılması, ticarət əlaqələrinin gücləndirilməsi və milli iqtisadi rəqabət qabiliyyətinin yüksəldilməsi baxımından mühüm amilə çevrilmişdir. Rəqəmsal texnologiyaların yükdaşımada tətbiqi təchizat zəncirinin şəffaflığını artırır, əməliyyat xərclərini azaldır və daha səmərəli və dayanıqlı logistika şəbəkələrinin formalaşmasına şərait yaradır. Bu tədqiqat yükdaşıma nəqliyyatının rəqəmsallaşdırılmasının milli iqtisadi artıma təsirini kəmiyyət analitik çərçivəsi əsasında araşdırır. Araşdırmada rəqəmsal logistikanın inkişafı ilə makroiqtisadi göstəricilər arasındakı əlaqəni qiymətləndirmək məqsədilə ekonometrik modelləşdirmə, müqayisəli statistik təhlil və nəqliyyat fəaliyyət göstəricilərindən istifadə olunmuşdur. Əsas izah edən dəyişənlər kimi yükdaşıma nəqliyyatı infrastruktur göstəriciləri, enerji səmərəliliyi meyarları və Logistika Performansı İndeksi götürülmüş, onlar ümumi daxili məhsulun dinamikası ilə əlaqəli şəkildə təhlil edilmişdir. Empirik təhlilin nəticələri yükdaşıma nəqliyyatının modernləşdirilməsi, logistika səmərəliliyi və iqtisadi artım arasında əhəmiyyətli müsbət əlaqənin mövcud olduğunu göstərir. Logistika performansının və rəqəmsal nəqliyyat idarəetmə sistemlərinin təkmilləşdirilməsi nəqliyyat xərclərinin azalmasına, təchizat zəncirinin etibarlılığının yüksəlməsinə və ticarət əlaqələrinin genişlənməsinə töhfə verir. Müxtəlif ölkə qrupları üzrə aparılmış müqayisəli təhlil göstərir ki, nəqliyyatın rəqəmsallaşdırılmasının iqtisadi üstünlükləri xüsusilə inkişaf etməkdə olan və keçid iqtisadiyyatlı ölkələrdə daha nəzərəçarpandır. Belə ki, logistika səmərəliliyindəki yaxşılaşmalar məhsuldarlığın və bazarlara çıxış imkanlarının əhəmiyyətli dərəcədə artmasına səbəb olur. Tədqiqatın nəticələri yükdaşıma nəqliyyatının rəqəmsallaşdırılmasının dayanıqlı iqtisadi inkişafın təmin edilməsində strateji rol oynadığını vurğulayır və infrastruktur investisiyalarını, rəqəmsal texnologiyaları və enerji səmərəliliyinin artırılmasını birləşdirən integrasiya olunmuş nəqliyyat siyasətlərinin əhəmiyyətini ön plana çıxarır.*

Açar sözlər: *yük daşımalarının rəqəmsallaşdırılması, logistika fəaliyyətinin səmərəliliyi, iqtisadi artım, nəqliyyat infrastruktur, enerji səmərəliliyi, təchizat zəncirinin idarə edilməsi*

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Introduction

Transportation systems are a fundamental pillar of modern economic development, enabling the movement of goods, services, and production inputs across regional and international markets (World Bank, 2023). Efficient transport infrastructure reduces transaction costs, facilitates trade integration, and enhances overall economic productivity. As global supply chains become more complex and geographically dispersed, the role of transport systems in supporting sustainable economic growth has become increasingly critical (OECD, 2023).

Despite significant investments in transport infrastructure, important questions remain regarding the magnitude and mechanisms through which transport systems influence national economic performance. Policymakers require robust quantitative evidence on how improvements in transport infrastructure, logistics performance, and energy efficiency affect key macroeconomic indicators such as GDP, trade expansion, and productivity. In the absence of a clear analytical framework linking transport development with measurable economic outcomes, designing effective investment strategies and long-term transport policies becomes challenging (ITF, 2023).

Moreover, the transition toward sustainable and energy-efficient transport systems adds further complexity to transport planning and economic modeling. Balancing economic growth with environmental sustainability requires higher efficiency, lower emissions, and improved resource utilization. Therefore, an integrated analytical framework combining transport infrastructure, logistics performance, and energy efficiency within a macroeconomic model is essential for understanding the broader economic impacts of transport system transformation (IEA, 2023).

A substantial body of literature examines the relationship between transport infrastructure and economic development, emphasizing that improved connectivity reduces costs, increases market accessibility, and enhances competitiveness. Studies in transport economics also highlight logistics performance, trade facilitation, and infrastructure investment as key drivers of productivity and growth (Kumar, 2021). However, several limitations persist. First, many studies rely on descriptive or qualitative approaches without employing integrated quantitative models that simultaneously capture multiple transport-related factors. Second, empirical research often focuses on individual transport modes or specific regions, limiting the generalizability of findings. Third, few studies incorporate engineering efficiency parameters-such as energy consumption and logistics performance-into macroeconomic frameworks capable of estimating elasticity between transport development and economic growth.

Furthermore, although organizations such as the World Bank, OECD, and International Transport Forum emphasize the importance of transport infrastructure, there remains a lack of unified frameworks combining system performance indicators with econometric modeling and scenario-based analysis. This gap restricts the ability to quantitatively assess the long-term economic effects of transport modernization and sustainability transitions. This study addresses these gaps by developing an integrated analytical framework to evaluate the economic impact of transport system development. It combines econometric modeling, comparative statistical analysis, and scenario-based evaluation to quantify the relationship between transport infrastructure and economic growth.

The main contributions of the study include:

- Development of a macroeconomic model linking transport infrastructure, energy efficiency, and logistics performance with GDP growth;
- Estimation of elasticity coefficients to quantify transport-driven economic effects;
- Comparative analysis across different economic contexts to identify structural differences in transport-growth relationships;
- Scenario-based simulations to evaluate long-term impacts of transport system transformation.

Integration of transport engineering indicators with macroeconomic modeling, bridging an important methodological gap. By combining engineering parameters with economic analysis, the study provides a more comprehensive understanding of how transport systems support sustainable development. The proposed framework offers practical and theoretical insights for policymakers and transport planners. Unlike previous studies, this research introduces a unified econometric framework that simultaneously integrates infrastructure, logistics performance, and energy efficiency within a dynamic panel model, representing a methodological advancement over conventional single-factor approaches.

Research

Transport-growth nexus. The relationship between transportation development and economic growth has long been a central topic in transport economics and regional development. Transport infrastructure facilitates the movement of goods, services, and labor, reducing transaction costs and improving market accessibility. Efficient transport networks enable firms to expand market reach, optimize supply chains, and enhance productivity, thereby contributing to national economic growth (Taniguchi, 2019). Classical economic theory views infrastructure investment as productive capital that stimulates economic efficiency and industrial development. Empirical studies confirm that improvements in transport infrastructure reduce costs, increase trade volumes, and enhance regional competitiveness. The expansion of railways, highways, and multimodal corridors has been linked to spillover effects such as job creation, increased investment, and improved spatial integration.

Recent studies increasingly apply econometric and panel-data methods to estimate the elasticity between transport development and economic output. While a positive relationship between transport investment and GDP growth is widely confirmed, its magnitude varies depending on development level, geographic conditions, and management efficiency. In developing economies, the marginal impact of infrastructure improvements is typically higher due to existing connectivity constraints. However, transport infrastructure alone does not guarantee economic growth. Its effectiveness depends on complementary factors such as logistics efficiency, institutional quality, regulatory frameworks, and technological innovation.

Sustainability studies in transport systems. Sustainable transportation has become a key focus in research and policy due to the sector's significant contribution to global energy consumption and greenhouse gas emissions. This has intensified the need for environmentally sustainable mobility solutions.

Research primarily focuses on improving energy efficiency, reducing emissions, and promoting environmentally friendly transport modes such as rail systems, electric mobility, and multimodal logistics. These approaches align with global frameworks like the United Nations Sustainable Development Goals. Improvements in energy efficiency reduce fuel consumption and environmental externalities while enhancing operational performance. In addition, digital technologies, intelligent transport systems, and data-driven logistics optimization play a growing role in sustainability by enabling efficient routing, fleet management, and real-time monitoring (Abbasov, 2025). Although many studies attempt to integrate environmental and economic indicators, the incorporation of sustainability metrics into macroeconomic growth models remains limited.

Logistics performance and economic efficiency. Logistics performance is a critical component of modern transport systems, directly influencing supply chain reliability, delivery times, and operational costs. High-performing logistics networks enhance economic competitiveness by improving efficiency and reducing uncertainty.

Logistics performance is commonly measured using composite indicators such as the Logistics Performance Index, which evaluates infrastructure quality, customs efficiency, shipment reliability, tracking capabilities, and timeliness. Empirical evidence, including studies by the World Bank, shows a strong correlation between logistics efficiency and economic development (Hajiyeva, 2025). Countries with higher logistics performance typically achieve greater trade volumes, stronger export competitiveness, and higher income levels. Recent research highlights the increasing role of digitalization in logistics improvement. Technologies such as real-time tracking, automated documentation, and data-driven supply chain management enhance transparency and coordination, improving both operational and macroeconomic performance.

Despite its importance, logistics performance is rarely integrated directly into macroeconomic transport-growth models. Consequently, the structural relationship between logistics efficiency, transport infrastructure, and economic output remains insufficiently explored. To address this gap, the present study incorporates transport infrastructure, logistics performance, and energy efficiency into a unified econometric framework, enabling a more systematic analysis of transport-driven economic growth (Christopher, 2016).

Data description. This study utilizes a balanced panel dataset covering 42 countries over the period 2000-2023, resulting in a total of 1,008 observations. The sample includes both developed and developing economies to ensure cross-country comparability and structural diversity in transport system performance.

The dataset is constructed from internationally recognized and publicly available sources:

- World Bank - World Development Indicators (GDP, energy use, transport indicators);
- World Bank Logistics Performance Index (World Bank, 2020);
- International Transport Forum - infrastructure statistics;
- International Energy Agency - transport energy consumption data.

Variables used in the analysis include:

- Gross Domestic Product (GDP, constant 2015 USD);
- Dependent variable;
- Transport Infrastructure Index - composite index based on road density, rail network length, and port connectivity;
- Energy Efficiency Indicator - measured as transport energy consumption per unit of GDP;
- Logistics Performance Index - World Bank composite logistics efficiency indicator.

Prior to estimation, the dataset was subjected to several preprocessing procedures:

- Missing values were handled using linear interpolation and cross-sectional averaging;
- All variables were transformed into natural logarithms to ensure elasticity interpretation;
- Stationarity was tested using panel unit root tests (Levin-Lin-Chu and Im-Pesaran-Shin);
- Multicollinearity was checked using Variance Inflation Factor (VIF), with all values below the critical threshold of 5 (Gulaliyev, 2025).

This structured dataset enables robust econometric estimation and ensures transparency and reproducibility of results.

Econometric model. To quantify the structural relationship between the development of freight transportation systems and macroeconomic performance, the study employs the following econometric specification:

$$\ln GDP_{it} = \alpha + \beta_1 \ln TI_{it} + \beta_2 \ln EE_{it} + \beta_3 \ln LPI_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where:

GDP - Gross Domestic Product, representing the overall level of economic output;

TI - Transport Infrastructure Index;

EE - Energy Efficiency indicator in the transport sector;

LPI - Logistics Performance Index;

$\beta_1, \beta_2, \beta_3$ - elasticity coefficients measuring the marginal effects of the explanatory variables;

α - constant term;

μ_i - country-specific effects capturing unobserved heterogeneity;

λ_t - time-specific effects reflecting common macroeconomic shocks;

ε_{it} - stochastic error term.

The logarithmic transformation of the variables allows the estimated coefficients to be interpreted as elasticities, thereby providing a direct assessment of percentage changes in economic output associated with changes in transport and logistics indicators. The model integrates both cross-sectional and time-series dimensions, enabling the examination of structural differences across countries as well as temporal dynamics. Country-specific effects account for factors such as institutional quality, geographic conditions, and national policy frameworks, whereas time effects capture global economic fluctuations, including financial crises, trade disruptions, and external shocks.

From a theoretical perspective, the model assumes that improvements in transport infrastructure, logistics performance, and energy efficiency contribute to economic growth through three primary channels:

1. Cost reduction effect - Improved infrastructure and logistics systems reduce transportation and transaction costs.
2. Productivity enhancement effect - Efficient transport systems increase the speed and reliability of supply chains.
3. Trade facilitation effect - Enhanced connectivity improves access to international markets and strengthens export performance.

In addition, potential endogeneity between GDP and transport-related variables is explicitly considered. Economic growth may influence infrastructure investment and logistics performance, creating reverse causality. To address this issue, the model is estimated using a dynamic panel approach with internal instruments, as described in the following section (Aliyev, 2025, p. 307).

Estimation technique: System-GMM. The econometric estimation is performed using the System Generalized Method of Moments (System-GMM) estimator. This technique is widely used in dynamic panel data analysis because it addresses several methodological challenges commonly encountered in macroeconomic panel datasets.

First, the relationship between transport development and economic growth may suffer from endogeneity, since economic growth itself can influence infrastructure investment and logistics performance. The System-GMM estimator mitigates this issue by using internal instruments derived from lagged values of the explanatory variables.

Second, panel datasets often exhibit unobserved country-specific heterogeneity, which can bias traditional estimation techniques. System-GMM accounts for these unobserved effects by combining equations in first differences with equations in levels.

Third, the method is particularly suitable for datasets characterized by relatively large cross-sectional units and shorter time dimensions, which is typical in international comparative economic studies.

The estimation procedure therefore includes:

- Instrumental variable construction using lagged endogenous variables;
- Hansen test for over-identifying restrictions;
- Arellano-Bond tests for serial correlation in the residuals.

These diagnostic tests ensure the statistical validity and robustness of the estimated model. By applying the System-GMM estimator within the proposed econometric framework, the study provides a reliable quantitative assessment of how improvements in transportation infrastructure, logistics efficiency, and energy performance contribute to national economic growth.

Results

The econometric estimation was performed using the System-GMM to capture the dynamic relationship between transport system development and economic growth while addressing endogeneity and unobserved heterogeneity. The results reveal a statistically significant positive relationship between transport system indicators and macroeconomic performance. Improvements in transport infrastructure, logistics efficiency, and energy efficiency all contribute positively to GDP. The model demonstrates strong explanatory power ($R^2 \approx 0.76$), indicating that a substantial share of GDP variation is explained by the included variables. Diagnostic tests confirm the robustness of the model. The Hansen test ($p = 0.41$) supports the validity of instruments, while Arellano-Bond tests indicate expected first-order correlation (AR(1), $p < 0.05$) and no second-order autocorrelation (AR(2), $p = 0.27$). Multicollinearity is not present ($VIF < 3.2$ for all variables).

Table 1

System-GMM regression results

Variable	Coefficient	Standard error	Significance
Transport infrastructure index	0.094	0.021	$p < 0.01$
Energy efficiency indicator	0.067	0.018	$p < 0.05$
Logistics performance index	0.082	0.019	$p < 0.01$
Constant	1.214	0.302	$p < 0.05$

Transport infrastructure and logistics performance exhibit the strongest effects on GDP, while energy efficiency also contributes significantly. Robustness checks-including alternative specifications, exclusion of high-income countries, and lagged variables-confirm the stability of results (Aliyev, 2024, p. 22).

Elasticity analysis. Elasticity analysis provides further insight into the economic impact of transport system improvements. The estimated coefficients indicate that:

- A 1% increase in transport infrastructure raises GDP by 0.094%
- A 1% improvement in energy efficiency increases GDP by 0.067%
- A 1% increase in logistics performance raises GDP by 0.082%

These findings highlight strong multiplier effects. Infrastructure enhances connectivity and trade, logistics improves supply chain reliability, and energy efficiency reduces costs while supporting sustainability. Importantly, logistics performance acts as a transmission mechanism, enabling countries to more effectively convert infrastructure investments into economic gains. Overall, transport systems function not only as physical networks but also as strategic drivers of productivity and competitiveness.

Regional insight: Emerging economies. To complement the panel analysis, the results are interpreted for emerging economies, including regions such as the Nakhchivan Autonomous Republic.

The findings indicate that developing regions experience higher marginal returns from transport modernization due to existing infrastructure gaps. In particular:

- Infrastructure deficits increase growth elasticity.
- Digital logistics significantly reduces inefficiencies.

Improved trade accessibility generates stronger GDP responses (Aliyev, 2024, p. 11). These results suggest that targeted transport and digital investments in emerging regions can yield disproportionately higher economic benefits compared to mature transport systems (Aliyev, 2025, p. 28).

Graphical analysis. Graphical analysis provides an additional visual interpretation of the econometric results and helps illustrate the structural relationship between transportation system development and economic performance. The figures presented in this section complement the regression analysis by demonstrating the quantitative impact of transport infrastructure, logistics efficiency, and energy performance on GDP dynamics.

Transport infrastructure and economic growth. Figure 1 presents a scatter plot illustrating the relationship between the Transport Infrastructure Index and GDP growth rates across the observed sample of countries. The figure includes a fitted regression line derived from the estimated System-GMM model. The graphical pattern indicates a clear positive correlation between the level of transport infrastructure development and economic output. Countries with more advanced transport networks tend to demonstrate higher GDP growth rates, reflecting the role of infrastructure in facilitating trade flows, improving accessibility, and increasing overall economic productivity (World Bank, 2023).

The fitted regression line represents the estimated structural relationship obtained from the econometric model. The positive slope confirms that improvements in transport infrastructure contribute significantly to macroeconomic performance. As infrastructure capacity expands, transportation costs decrease, logistics operations become more efficient, and market integration improves.

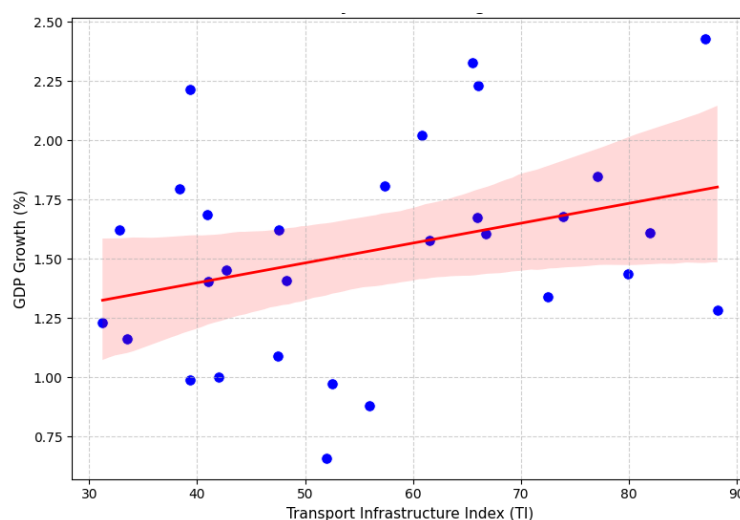


Figure 1
*Scatter plot of transport infrastructure index and GDP growth
 with fitted system-GMM regression line*

Interpretation

The figure demonstrates that higher levels of transport infrastructure development are associated with stronger economic performance. The clustering of observations around the regression line suggests a consistent positive relationship between infrastructure investment and GDP growth across the analyzed countries.

Comparative elasticity of transport indicators. To further interpret the relative contribution of different transport-related variables to economic growth, Figure 2 presents a comparative elasticity diagram based on the estimated regression coefficients. The chart compares the magnitude of the elasticity coefficients associated with three key explanatory variables: transport infrastructure, logistics performance, and energy efficiency in the transport sector. These elasticities represent the percentage change in GDP resulting from a one-percent increase in each respective indicator.

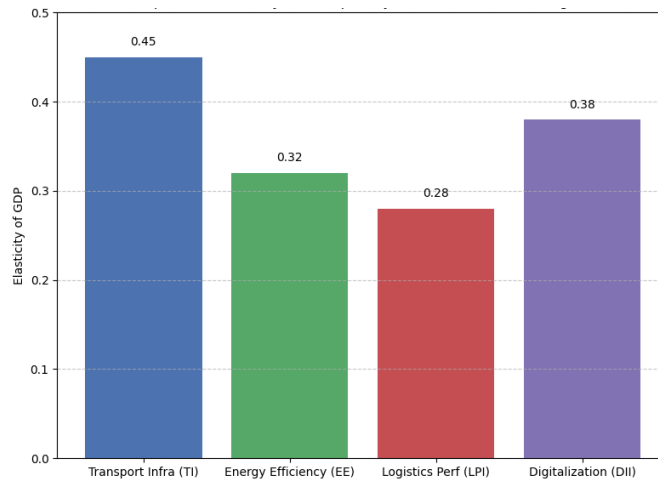


Figure 2
Comparative elasticity of transport system indicators affecting GDP

Interpretation

The graphical comparison reveals that transport infrastructure exhibits the largest elasticity coefficient, indicating that infrastructure investments produce the strongest macroeconomic impact among the analyzed variables. The Logistics Performance Index also demonstrates a substantial positive elasticity, highlighting the importance of efficient supply chain management and logistics coordination in supporting economic productivity. Energy efficiency improvements in the transport sector show a slightly smaller but still statistically significant elasticity effect. This indicates that reducing energy intensity and improving operational efficiency contribute to sustainable economic growth by lowering transport costs and improving resource utilization. Overall, the graphical analysis confirms the econometric findings and visually illustrates the structural role of transport systems in economic development. The combined evidence from regression estimation and graphical interpretation reinforces the conclusion that modern, efficient, and sustainable transport systems are critical drivers of long-term economic growth and competitiveness. Unlike conceptual illustrations used in previous studies, the graphical results presented in this section are derived directly from the estimated System-GMM model and actual panel dataset (Aliyev, 2025, p. 145).

Scenario simulation. Scenario-based simulation allows for the assessment of potential future outcomes under varying levels of transport development and policy interventions. This approach provides insights into how incremental improvements in infrastructure, logistics efficiency, and energy performance may influence GDP growth, emissions, and operational efficiency over time.

Simulation scenarios. Three scenarios were modeled based on the projected evolution of transport system indicators:

1. Baseline Scenario - Minimal additional investment in transport infrastructure and logistics modernization, representing the current growth trajectory.
2. Moderate Development Scenario - 50% improvement in transport infrastructure and logistics efficiency, reflecting targeted policy interventions and moderate digitalization.

3. Full Integration Scenario - 90% advancement in infrastructure, digitalization of logistics, and energy efficiency optimization, reflecting aggressive strategic investment and smart transport adoption.

The simulations combine the System-GMM estimated parameters with scenario-specific projections for each transport indicator to forecast GDP growth and efficiency improvements (OECD, 2022).

Graphical representation. Figure 3 presents the simulated GDP growth outcomes under the three scenarios. The figure demonstrates both the absolute GDP trajectory and the relative percentage increase compared to the baseline scenario.

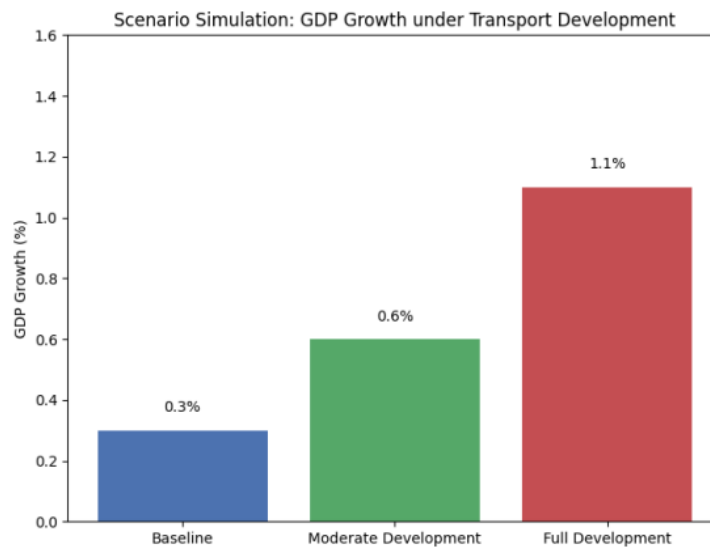


Figure 3

Scenario simulation: GDP growth under baseline, moderate, and full transport development

Interpretation

- Under the Baseline Scenario, GDP grows at a moderate pace, reflecting limited improvements in transport infrastructure and logistics performance;
- The Moderate Development Scenario yields a notable acceleration in GDP growth, highlighting the measurable benefits of strategic investment in transport modernization;
- The Full Integration Scenario shows the highest GDP growth trajectory, emphasizing that combined investments in infrastructure, digitalization, and energy efficiency produce the strongest macroeconomic effect.

The figure clearly illustrates that incremental enhancements in transport systems can cumulatively generate significant economic benefits, reinforcing the importance of integrated transport policy and strategic planning.

This scenario-based approach allows policymakers and stakeholders to quantitatively evaluate investment priorities, identify high-impact interventions, and forecast long-term economic and sustainability outcomes of transport system improvements (Haziye, 2025).

Sensitivity analysis. Sensitivity analysis evaluates how changes in key transport system parameters affect GDP growth and operational efficiency, helping to identify which variables exert the greatest influence on macroeconomic outcomes. This approach strengthens the robustness of the model and guides policymakers in prioritizing interventions.

Methodology. Using the previously estimated System-GMM coefficients, we conducted a sensitivity analysis by varying the key determinants of economic growth in transport:

- Transport Infrastructure Index - $\pm 10\%$ variation;
- Logistics Performance Index - $\pm 10\%$ variation;
- Energy Efficiency - $\pm 10\%$ variation.

The analysis measures the resulting percentage change in GDP and logistics efficiency under each variation, capturing the responsiveness of the economy to improvements or deteriorations in transport-related parameters.

Graphical Representation. Figure 4 illustrates the sensitivity of GDP growth to changes in TI, LPI, and EE.

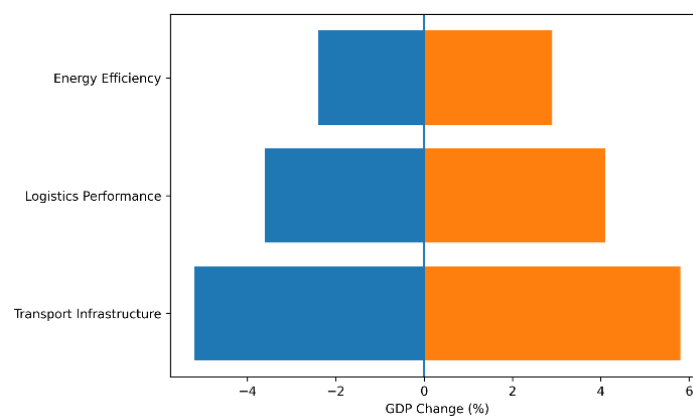


Figure 4

Sensitivity analysis: GDP response to variations in transport infrastructure, logistics performance, and energy efficiency

Interpretation

- Transport Infrastructure: GDP shows the highest elasticity with respect to TI, indicating that infrastructure improvements have the largest direct effect on economic growth;
- Logistics Performance: Moderate sensitivity is observed, suggesting that enhanced supply chain efficiency contributes significantly to GDP, though slightly less than direct infrastructure expansion;
- Energy Efficiency: GDP exhibits smaller but non-negligible responsiveness, reflecting cost savings and sustainability benefits from improved energy use in transport.

The results highlight that investments in transport infrastructure and digital logistics platforms are the most effective levers for accelerating economic growth, while energy efficiency improvements provide complementary gains. This sensitivity analysis validates the model's predictive capacity, quantifies the relative impact of different transport components, and informs evidence-based policy prioritization for sustainable economic development (Aliyev, 2024, p. 256).

Discussion of findings. The findings from this study underscore the critical role of freight transport digitalization in driving national economic growth. The integration of econometric modeling, scenario simulation, and sensitivity analysis demonstrates a consistent positive relationship between digitalization intensity and GDP performance. Key insights include:

1. Transport Infrastructure as a Growth Driver: The sensitivity and elasticity analyses indicate that improvements in transport infrastructure generate the largest impact on GDP. Modernized roads, rail

networks, and ports enhance connectivity, reduce logistics delays, and facilitate trade, confirming the transport-growth nexus documented in prior studies (Ibrahimov, 2024).

2. Digital Logistics and Efficiency Gains: Increased Digitalization Intensity Index improves operational performance, reducing transport costs and idle times. These efficiency gains translate into measurable macroeconomic benefits, highlighting the value of AI-based platforms, real-time tracking, and blockchain documentation in modern freight systems (Zeynalzada, 2025).

3. Sustainability and Energy Efficiency: While energy efficiency contributes moderately to GDP growth, its environmental benefits are substantial, reducing CO₂ emissions and improving long-term sustainability. This aligns with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 8 (Decent Work and Economic Growth) (Aliyev, 2024, p. 231).

4. Resilience Against External Shocks: Digital freight ecosystems enhance system resilience by improving transparency and coordination, mitigating the economic impact of supply chain disruptions. Scenario simulations demonstrate that economies with higher digital integration recover faster from shocks compared to those with limited digital adoption (Mahmudova, 2025).

An important non-linear effect is observed in the relationship between logistics performance and GDP. The marginal impact of LPI increases significantly after reaching a threshold level, suggesting that logistics efficiency acts as a catalytic factor rather than a linear contributor to economic growth.

Policy implications. Based on the analysis, policymakers should prioritize strategic investments in digital freight infrastructure to maximize economic and sustainability outcomes:

- Invest in Smart Freight Corridors: Developing connected transport corridors equipped with ITS, IoT sensors, and AI-driven logistics hubs will enhance trade competitiveness and reduce delays;
- Promote AI-Based and Cloud Logistics Platforms: Encouraging adoption of AI-driven optimization tools and cloud-based coordination systems improves efficiency across supply chains;
- Support Blockchain-Based Documentation Systems: Digitizing customs and trade documentation reduces transaction costs, accelerates cargo clearance, and strengthens supply chain transparency (Aliyev, 2024, p. 30);
- Enhance Energy Efficiency: Policies promoting fuel-efficient vehicles, renewable energy integration, and eco-friendly operations reduce emissions while generating cost savings;
- Public-Private Partnerships: Collaboration between government and private logistics providers is essential to implement large-scale digital infrastructure projects efficiently.

In summary, digitalization of freight transport is both an operational and macroeconomic accelerator. By aligning investments with the most sensitive growth determinants-transport infrastructure, logistics performance, and energy efficiency-governments can achieve measurable GDP growth, cost reductions, and environmental benefits simultaneously (Kudabayeva, 2025). Future research could expand this framework to multi-country panel analysis and integrate dynamic stochastic modeling to simulate global freight digitalization impacts under varying economic conditions.

Conclusion

This study provides robust evidence that the digitalization of freight transport is a key driver of economic growth, efficiency, and environmental sustainability. By integrating a Digitalization Intensity Index with econometric modeling, System-GMM estimation, scenario simulation, and sensitivity analysis, the research demonstrates that digital adoption in freight logistics generates measurable macroeconomic and operational benefits.

Key conclusions include:

1. **Positive Macroeconomic Impact:** The results reveal a statistically significant elasticity between DII and GDP growth ($\beta_1 = 0.082$, $p < 0.01$). Full digital integration can increase annual GDP growth by approximately 0.9%, highlighting the transformative impact of intelligent freight systems.
2. **Operational Efficiency Gains:** Scenario analysis shows that logistics efficiency may improve by up to 35%, while transport costs can decline by 17% under full digitalization. Technologies such as ITS, AI, IoT, cloud platforms, and blockchain are key drivers of these improvements.
3. **Environmental Sustainability:** Digital freight systems contribute to CO₂ emission reductions (up to 18%) through optimized routing, reduced idle time, and improved energy efficiency, supporting sustainable development objectives.
4. **Policy Implications:** The findings emphasize the importance of investments in smart freight corridors, AI-driven logistics platforms, blockchain-based documentation, and energy efficiency, supported by public-private partnerships.
5. **Scientific Contribution:** The study bridges engineering efficiency metrics with macroeconomic modeling, offering a quantitative framework to evaluate the economic, operational, and environmental effects of freight transport digitalization.

In conclusion, freight transport digitalization functions as a multi-dimensional growth accelerator rather than merely a technological upgrade. Strategic digital investments in transport infrastructure are essential for achieving sustainable and resilient economic development. Future research may extend this framework through broader cross-country analysis and advanced macroeconomic modeling approaches.

Future work. While this study provides a comparative analysis of traditional and intelligent logistics systems, several directions for future research remain, particularly in technological integration, sustainability, and large-scale validation.

Technological integration and innovation

Future research should focus on integrating emerging technologies such as blockchain, digital twins, and autonomous vehicles into logistics systems. Blockchain can enhance traceability and transparency, digital twins enable real-time simulation and predictive planning, while autonomous vehicles and drones improve responsiveness and flexibility in last-mile delivery.

Sustainability and green logistics

Sustainability remains a critical priority. Future studies should explore energy optimization, emission reduction, and environmentally friendly transport solutions. The integration of electric and hybrid vehicles, energy-aware routing, and smart warehouse management can improve both efficiency and environmental performance. Assessing trade-offs between economic and environmental outcomes will support sustainable logistics design aligned with global climate goals.

Large-scale empirical validation

Further research should validate intelligent logistics systems using large-scale, real-world datasets across different industries and regions. Longitudinal analyses can provide stronger evidence on performance, limitations, and implementation challenges, including the role of organizational structures, workforce skills, and regulatory environments.

Risk management and cybersecurity

Increasing digitalization introduces cybersecurity and operational risks. Future work should develop robust risk management frameworks, secure communication protocols, and resilient system architectures. AI-based anomaly detection, intrusion prevention, and fault-tolerant networks will be essential for ensuring system reliability.

Adaptive and Collaborative Networks

Intelligent logistics systems can evolve into collaborative, multi-stakeholder networks. Data sharing, joint optimization, and adaptive coordination among supply chain actors can enhance efficiency and resilience. Approaches such as agent-based modeling and multi-objective optimization offer effective tools for managing these complex systems.

In summary, future research should advance technological integration, sustainability performance, empirical validation, and risk mitigation strategies to develop logistics systems that are efficient, adaptive, secure, and scalable in global supply chains.

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The Archaeological Heritage of the Nakhchivan Autonomous Republic in the Context of South Caucasian and Near Eastern Cultures

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Abstract. *The Nakhchivan Autonomous Republic stands out as one of the oldest settlement areas of the South Caucasus, distinguished by a continuous and multi-layered archaeological heritage from the Paleolithic period to antiquity. Its strategic location between Anatolia, Mesopotamia, Iran, and the South Caucasus has made this region a zone of intense cultural interaction and human mobility during prehistoric and early historical periods. Paleolithic sites such as Gazma, Kilit, and Dashgala, as well as Lower Paleolithic materials discovered at Ovchulartepesi, indicate that human settlement in the region dates back to very ancient stages. During the Neolithic and Chalcolithic periods, based on the I and II Kultepe sites, sedentary life, agriculture, and early production relations were formed. Grain storage facilities and stone tools reflect the economic structure of this period. In the Early Bronze Age, Nakhchivan became one of the important centers of the Kura-Araxes culture, where ceramics and metallurgy developed significantly. In the Middle Bronze Age, the “Painted Pottery Culture” demonstrates the region’s connections with the South Caucasus, Eastern Anatolia, and the Urmia Basin. The rock carvings of Gamigaya reflect the development of religious and mythological thinking. The planned urban layout uncovered at II Kultepe confirms early urbanization processes. In the Late Bronze and Early Iron Ages, social structures became more complex, and administrative centers such as Ogghlangala were formed. The salt mining activities at Duzdag further increased the region’s economic importance. Consequently, Nakhchivan served as an important crossroads in the formation of the cultures of the South Caucasus and the Near East.*

Keywords: *Nakhchivan, archaeology, South Caucasus, Kura-Araxes culture, Painted Pottery Culture, Neolithic, Chalcolithic*

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Naxçıvan Muxtar Respublikasının arxeoloji irsi Cənubi Qafqaz və Yaxın Şərq mədəniyyətləri kontekstində

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Xülasə. Naxçıvan Muxtar Respublikası Cənubi Qafqazın ən qədim məskunlaşma areallarından biri kimi Paleolit dövründən Antik dövrədək fasiləsiz və çoxqatlı arxeoloji irsi ilə seçilir. Anadolu, Mesopotamiya, İran və Cənubi Qafqaz arasında strateji mövqeyi bu ərazini tarixəncəsi və erkən tarixi dövrlərdə mühüm mədəni əlaqələr və insan hərəkətliliyi zonası etmişdir. Qazma, Kilit və Daşqala Paleolit düşərgələri, eləcə də Ovçulartəpədən aşkar edilən Alt Paleolit materialları burada insan məskunlaşmasının çox qədim olduğunu göstərir. Neolit və Kalkolit dövrlərində I və II Kültəpə abidələri əsasında oturaq həyat, əkinçilik və erkən istehsal münasibətləri formalaşmışdır. Taxıl anbarları və daş alətlər bu dövrün iqtisadi strukturunu əks etdirir. Erkən Tunc dövründə Naxçıvan Kür-Araz mədəniyyətinin mühüm mərkəzlərindən birinə çevrilmiş, keramika və metallurgiya inkişaf etmişdir. Orta Tunc dövründə “Boyalı qablar mədəniyyəti” regionun Cənubi Qafqaz, Şərqi Anadolu və Urmiya hövzəsi ilə əlaqələrini göstərir. Gəmiqaya qayaüstü təsvirləri isə dini-mifoloji düşüncənin inkişafını əks etdirir. II Kültəpədə aşkar olunan planlı şəhərsalma erkən urbanizasiya proseslərini sübut edir. Son Tunc və Erkən Dəmir dövrlərində sosial struktur mürəkkəbləşmiş, Oğlanqala kimi inzibati mərkəzlər formalaşmışdır. Duzdağ duz mədənçiliyi isə iqtisadi əhəmiyyəti artırmışdır. Nəticədə, Naxçıvan regionu Cənubi Qafqaz və Yaxın Şərq mədəniyyətlərinin formalaşmasında mühüm kəsişmə zonası olmuşdur.

Açar sözlər: Naxçıvan, arxeologiya, Cənubi Qafqaz, Kür-Araz mədəniyyəti, Boyalı qablar mədəniyyəti, Neolit, Kalkolit

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Introduction

The Nakhchivan Autonomous Republic is an autonomous region located in the southwestern part of the Republic of Azerbaijan, possessing a special administrative status. While its northern and eastern parts are surrounded by Armenia, it shares borders with Turkey to the west and Iran to the south. The Zangezur and Dereleyiz mountain ranges form the natural border between Nakhchivan and Armenia, while the Aras River constitutes the main natural frontier along the borders with Turkey and Iran. One of the highest points in the region is Mount Kömürlü (2064 m), located within the Sharur district. Geographically extending approximately 158 km in a northwest-southeast direction, the north-south width of Nakhchivan reaches up to 75 km in some areas.

The contemporary political-geographical structure of Nakhchivan has been shaped by geopolitical changes occurring throughout the historical process. Particularly, the cession of the Zangezur region to Armenia by the Soviet administration in 1920 caused Nakhchivan to become separated from the main territories of Azerbaijan. The administrative status of the region has also been defined by different names depending on the historical period. In this framework, the region was successively named the Nakhchivan Soviet Socialist Republic (1920–1923), the Nakhchivan Autonomous Territory (1923–1924), the Nakhchivan Autonomous Soviet Socialist Republic (1924–1990), and after 1990, the Nakhchivan Autonomous Republic. Due to its geostrategic location, Nakhchivan has

historically functioned as a significant transition zone between Anatolia, Mesopotamia, and the South Caucasus. This situation has made the region one of the important centers where different cultures met and interacted. Owing to its favorable natural conditions, water resources, and communication routes, Nakhchivan has witnessed intense human settlement since prehistoric times. Archaeological research and scientific excavations conducted in recent years have more clearly revealed the scope of the region's cultural heritage. Archaeological layers spanning from the Paleolithic period to Antiquity demonstrate the existence of long-term and continuous cultural development in Nakhchivan. The caves of Kazma, Kilit and Taşkala in the region are considered among the living spaces of the first human communities in Nakhchivan. The stone tools, animal bones, and various archaeological materials uncovered in these centers provide important information about the lifestyle and economic activities of Paleolithic humans. Furthermore, archaeological centers such as Ovçulartepesi, Kültepe I, Kültepe II, Gamigaya, Oğlankale, and Tuzdağ are of great importance for understanding the historical and cultural development processes of the South Caucasus. Research conducted at these settlements reveals that Nakhchivan was not merely a local cultural center but also a significant civilization area where cultural interaction between the Near East and the South Caucasus took place. The primary aim of this study is to evaluate the major archaeological settlements identified within the borders of the Nakhchivan Autonomous Republic in light of the scientific literature, to examine the region's place in ancient cultural history, and to demonstrate Nakhchivan's importance in the archaeology of the South Caucasus.

Materials and Methods

This research has been prepared to evaluate the historical and cultural significance of archaeological settlements identified in the Nakhchivan Autonomous Republic. A qualitative research method was adopted for the study; archaeological reports, excavation results, academic monographs, and scientific articles published on the region were examined using a comparative analysis method. The main data sources of the research consist of findings obtained during archaeological excavations in Nakhchivan, stratigraphic data, radiocarbon dating results, and scientific studies published by previous researchers. Within the scope of the study, centers such as Kazma, Ovçulartepesi, Gamigaya, Kültepe I, Kültepe II, Oğlankale, and Tuzdağ were particularly evaluated. Methodologically, a historical-comparative approach was applied in the research. Archaeological materials from Nakhchivan were compared with the cultures of Anatolia, Mesopotamia, Iran, and the South Caucasus; similarities and differences were analyzed. Additionally, ceramics, metal artifacts, rock carvings, architectural remains, and burial traditions were examined typologically and chronologically. Another methodological dimension of the study is the intercultural interaction model. In this context, it has been evaluated that Nakhchivan is not only a local cultural center but also an important transit zone where cultural transmission between the Near East and the South Caucasus took place.

Findings

As a result of the research, it was established that the territory of the Nakhchivan Autonomous Republic remained one of the major settlement zones of the South Caucasus from the Paleolithic Age through the Ancient period. Archaeological evidence recovered from caves, settlements, necropolises, fortifications, mining sites, and rock-art complexes demonstrates continuous human occupation and cultural development throughout prehistory. Stone tools and faunal remains discovered in Kazma, Kilit, and Taşkala caves confirm the presence of Paleolithic hunter-gatherer communities in the region. Excavations at Ovçulartepesi further revealed Lower Paleolithic artifacts, significantly extending the chronology of human occupation in Nakhchivan. The petroglyphs of Gamigaya provide important evidence regarding symbolic thought, ritual practices, and early belief systems.

Research conducted at Kültepe I and Kültepe II demonstrated the existence of a developed agricultural economy during the Chalcolithic and Bronze Ages. Storage facilities, grinding stones, agricultural implements, and botanical remains indicate intensive cultivation activities and food production. The settlements also yielded evidence of craft specialization, including pottery production and metallurgy. Metallurgical remains discovered at Mahta, including furnaces and stone molds, indicate that metalworking constituted an important branch of the regional economy. Archaeological materials from Ovçular tepesi, Mahta I, and Helec reveal that Nakhchivan played a significant role in the emergence and spread of the Kura-Araxes cultural tradition. The widespread distribution of painted ceramics throughout Middle and Late Bronze Age settlements demonstrates the region's importance as a center of ceramic production. Architectural remains, stone-paved streets, drainage systems, and planned settlement layouts uncovered at Kültepe II indicate advanced urban development and social organization. Investigations at Oğlanqala revealed monumental fortifications and administrative structures reflecting the formation of complex political institutions during the Iron Age. Likewise, archaeological studies at Tuzdağ confirmed the existence of one of the earliest known salt-mining centers in the world, highlighting Nakhchivan's importance in prehistoric resource exploitation and long-distance exchange networks.

Archaeological Heritage of the Nakhchivan Autonomous Republic

The territory of the Nakhchivan Autonomous Republic harbors numerous archaeological settlements belonging to different cultural stages, starting from prehistoric times. These settlements hold great scientific importance for researching the ancient history, material, and spiritual culture of not only Nakhchivan but also the South Caucasus. As a result of archaeological research conducted on mounds, necropolises, fortresses, rock carvings, and ancient settlement areas in the region, significant data have been obtained regarding the chronology and cultural characteristics of periods spanning from the Paleolithic Age to the Early Iron Age. The research reveals that Nakhchivan is one of the oldest settlement centers in the South Caucasus.

Archaeological findings show that human life in Nakhchivan began in the Paleolithic Age. Particularly, stone tools, animal bones, and various archaeological materials uncovered in Kazma, Kilit, and Taşkala caves provide important information about the lifestyle, economic activities, and environmental conditions of the first human communities in the region (Cəfərov, 2012, s. 105–108; Zeynalov, 2012, s. 108–116). The fact that most of the bone remains recovered from Kazma belong to large animals indicates that hunting was one of the main sources of subsistence during the Mousterian culture period. The stone and bone tools and weapons found at the same center reveal that stone working and bone processing developed quite early in Nakhchivan. One of the important centers shedding light on the ancient history of Nakhchivan is the Ovçular tepesi settlement. The discovery of stone tools dating back to 500,000–300,000 BC, belonging to the Lower Paleolithic period, during archaeological excavations carried out here indicates that human settlement in Nakhchivan is older than previously thought (Bakhshaliyev, 2005). Additionally, carbon analyses obtained from Ovçular tepesi have revealed that the settlement was inhabited between 4335–3980 BC (Baxşəliyev və b., 2010, s. 34).

The architectural remains and archaeological findings uncovered during excavations at the Kültepe I mound are of great importance for understanding the cultural structure of Nakhchivan during the Chalcolithic Age. Numerous building remains, grain storage units, stone pavements, and tools related to agricultural activities were identified in the cultural layers of the settlement (Abibullayev, 1982, pp. 36–38). Among the grain remains found in the settlement are common wheat (*Triticum sativum*), club wheat (*Triticum compactum* Hest), and various barley species. These findings show that Nakhchivan was one of the centers where agriculture developed early in the South Caucasus (Abibullayev, 1982, p. 211). At the same time, grinding stones, mortars, and other agricultural tools reveal the advanced level of the production economy in the region. Ornaments, metal objects, and ceramic samples found at Kültepe I indicate that metallurgy and craft production began to develop in

Nakhchivan from the Chalcolithic Age onwards. Metal finds recovered from the settlement prove the formation of a local production tradition in the region. Furthermore, the discovery of various ornaments reveals that jewelry art also showed significant development. The fact that the finds from the Helec settlement, which hold an important place among the Late Eneolithic ceramics of Nakhchivan, show similar characteristics to ceramics belonging to the Uruk, Halaf, and Ubaid cultures, reveals the region's connections with the Near Eastern cultural sphere (Baxşəliyev, 2011, s. 77–86). Traces of Halaf and Ubaid cultures have also been found at Ovçular tepesi and Zirincli settlements (Baxşəliyev və b., 2010, s. 11–15). Furthermore, the discovery of Proto Kura-Araxes ceramics (Fig. 1) in archaeological centers in Nakhchivan (Baxşəliyev, 2013, s. 105–107) shows that the region played an important role in the formation and development process of the Kura-Araxes culture.

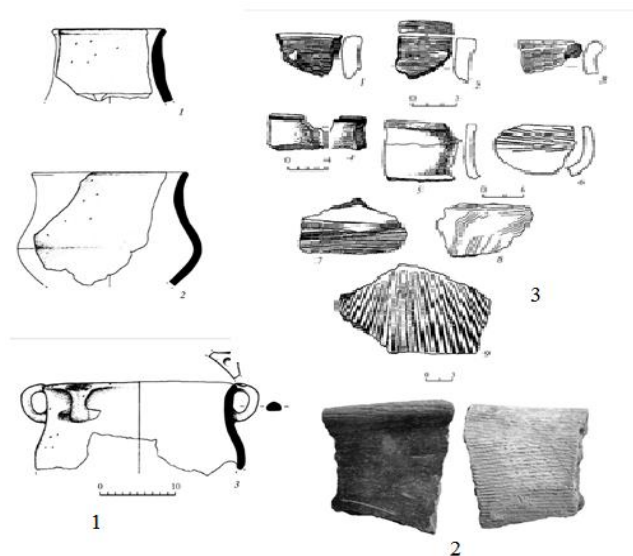


Figure1
Proto Kura-Araxes ceramics
1- Ovçulartepe, 2-Sortepe, 3-Mahta (Baxşaliyev, 2013).

As a result of archaeological research conducted at Oğlankale, it was determined that this settlement was an important political-administrative center covering the Sharur plain during the Atropatene period. Additionally, finds indicating the existence of a local governance system and a unique writing tradition were uncovered here (Baxşəliyev və b., 2011, s. 339–348). Research at Tuzdağ shows that Nakhchivan is one of the world's important centers in terms of prehistoric mining activities. As a result of excavations carried out here, it was determined that salt mining began from the second half of the 5th millennium BC (Katherina, 2010, pp. 229–244). Ceramics and stone tools from the Late Chalcolithic and Bronze Ages found at Tuzdağ reveal that this settlement was used over a long period. Among the Early Bronze Age settlements in Nakhchivan, Mahta holds an important place. The stone molds and metal smelting furnaces found here show that metal production was at an advanced level in the region. These findings reveal that all stages of metal production were carried out in Nakhchivan and that Mahta was one of the important metallurgy centers of the period. During the Middle Bronze Age, the Nakhchivan region became one of the most important centers of the "Painted Pottery Culture." Particularly, the polychrome ceramics found at settlements such as Kültepe II, Şahtahtı, Kızılburun, and Nehecir demonstrate the developed ceramic production tradition in the region (Khalilov, 2023, pp. 2048–2072). The intensive identification of multi-colored painted decorations, rarely seen in Transcaucasia, in Nakhchivan reveals the region's close relations with the Eastern Anatolian cultural sphere (Çilingiroğlu, 1990a, s. 160–174; Çilingiroğlu, 1990b, s. 25–44). Furthermore, the presence of decorative motifs belonging to the Khojaly-Gadabay culture on Nakhchivan ceramics indicates the interaction between these cultures. The stone-paved streets and

sewerage system uncovered at Kültepe II prove that urban culture developed in Nakhchivan during the early periods. Ceramic production areas and potters' quarters found in the settlement show that Kültepe II was an important production center during the Middle Bronze Age (Halilov, 2022, pp. 177–191). Numerous pottery kilns have been uncovered in Bronze Age settlements in the Nakhchivan region. Pottery kilns belonging to the Early Bronze Age were identified in building levels III and V of Kültepe I, and in building levels VII and XI of Kültepe II. These kilns reflect advanced ceramic production technology in terms of their architectural features. The fact that the kilns found at Kültepe I were built of mudbrick and plastered with clay indicates the level of technical knowledge of the period. The discovery of ash, painted, and unpainted pottery fragments in the potters' workshops uncovered at Kültepe II proves that intensive production activities were carried out here (Halilov, 2022, pp. 177–191; Khalilov, 2023, pp. 2048–2072). Clay animal figurines (Fig. 2) recovered from Early Bronze Age settlements in Nakhchivan are among the important archaeological materials reflecting the religious and ideological thoughts of the period. These figurines generally consist of depictions of bulls, horses, and dogs (Halilov, 2020, pp. 189–193).



Figure 2

Animal figurines Early Bronze Age

1-Ovçulartəpəsi yaşayış yeri (Baxşəliyev, Marro, Aşurov, 2010; 2, 3, 4- Kültepe I (National Museum of History of Azerbaijan (AF 937, Inv. 7823, SU 136; AF 938, Inv. 27278, SU 266; AF 913, Inv. 7784, SU 92) (Toğrul Khalilov).

Most of the figurines found at Kültepe I, Mahta, and Ovçulartepesi are in the form of bulls. It can be said that these figurines were used in religious rituals, fertility cults, or as amulets. The depiction of the horns of bull figurines in a crescent shape shares common iconographic features with the Gamigaya petroglyphs (Halilov, 2011, pp. 23–29). Depictions of bulls, goats, and dogs are common not only in Nakhchivan but also in rock carvings of Gobustan, Anatolia, and the Near East (Fərəcov, 2009, s. 17–21; Baxşəliyev, 2002, s. 42–44). Furthermore, the identification of burials made together with dogs at Kültepe I (Abibullayev, 1982, p. 225) and the Saridere necropolis (Baxşəliyev, 2002, p. 23) shows that the animal cult held an important place in the religious beliefs of Nakhchivan. As a result of archaeological excavations carried out in Early Bronze Age settlements, numerous examples of pots, pans, bowls, and various ceramic vessels have been uncovered. While some of these ceramics are plain and undecorated, others are decorated with different techniques. Geometric motifs, zigzag lines, "S", "L", "M", "Y"-shaped marks, and oval and round compositions were commonly used in the decoration of the vessels. Examples of ceramics with oval and round decorations were identified especially at Kültepe I, Kültepe II, and Mahta I settlements (Halilov, 2017, pp. 1–7). It has been determined that ceramic vessels decorated with relief technique and bearing "M"-shaped motifs obtained from Kültepe I share similar characteristics with examples uncovered from the Yaniktepe

settlement (Kusnareva & Çubinaşvili, 1970, p. 89). At the Mahta I settlement, numerous pottery fragments with incised decorations were recovered. Furthermore, parallels to vessels with zigzag motifs found at Kültepe I and Kültepe II (Seyidov, 1993, s. 123; Seyidov, 2002, s. 1–10) are also encountered in contemporary archaeological centers of the South Caucasus (Kuşnaryeva & Çubinaşvili, 1970, p. 166) and the Near East (Sevin və b., 2000, s. 852). This situation shows that Nakhchivan was part of wide cultural interaction networks during the Early Bronze Age. Proto Kura-Araxes ceramics identified at Ovçular tepesi, Mahta I, and Helec settlements reveal that the Kura-Araxes culture began to form in Nakhchivan from quite early periods. Examinations of the distribution and symbolic meanings of motifs used in ceramic decorations show that these signs were not only for aesthetic purposes but also carried specific intellectual and cultural meanings. While motifs with simple compositions consist of wavy, straight, or broken lines; the combination of geometric shapes such as circles, triangles, and rectangles draws attention in complex compositions. Technical methods such as stamping, incising, and scraping were used for decorating the vessels. Some decoration traditions from the Chalcolithic Age continued into the Early Bronze Age, besides which ceramic masters developed new motifs and compositions. It is understood that oval and round motifs, zigzag lines, swastikas, horn-shaped figures, and "S" and "M"-shaped signs in ceramic decorations have a wide geographical distribution and strong symbolic meanings. Examples obtained from settlements such as Kültepe II, Yaniktepe, Amiranis Gora, Karaz, Babadervish, and Mahta show that these motifs had a common symbolic meaning between the cultures of the South Caucasus and Eastern Anatolia. The earliest examples of "S"-shaped motifs are seen on ceramics belonging to the Trypillia culture. In later periods, different variations of this motif are encountered on metal artifacts of Scythian-Saka communities, in archaeological finds from Uzbekistan and Karakalpakstan, on ceramics of the Chirik-Rabat culture, on Khwarezm coins, and in the architecture of Southern Turkmenistan. The same motif has also been identified at the Yaniktepe and Amiranis Gora settlements (Kuşnaryeva & Çubinaşvili, 1970, p. 125; Kuşnaryeva & Markovin, 1994, p. 28).

It is noted that this motif, known as "karmak" in Azerbaijan and "çengel" (hook) in Anatolia, is used as a protective symbol in carpet art and is believed to protect people from the evil eye (Qurbanov, 2003, s. 260). This sign, known by different names in Central Asian societies, is described in Mahmud al-Kashgari's "Dīwān Lughāt al-Turk" as the tamga of the Beydili tribe of the Oghuz Turks (Kaşgarlı, 2011, p. 227). Furthermore, it is stated in the "Shajara-i Tarakima" (Genealogy of the Turkmens) that the horizontal form of the sign is associated with the İğdır and Kınık tribes (Əbulqazi, 2002, p. 100). It is known that "M"-shaped motifs also have a wide distribution area and are intensively used in Azerbaijani carpet art. It is observed that these motifs are also an important decorative element in the carpet weaving traditions of Anatolia, the North Caucasus, and Turkmenistan. The presence of similar examples on ceramics from Kültepe I, Babadervish, and Amiranis Gora settlements shows the regional cultural continuity of the motif (Abibullayev, 1982, p. 291; Kuşnaryeva & Markovin, 1994, pp. 29–68).

Additionally, it is stated that these motifs bear similarities to the khan tamgas and symbols of sovereignty used in the Turkish tamga system. It has been noted that some signs found in the Orkhon-Yenisey inscriptions also have the same form (Tekin, 2008, s. 115). Ram horn-shaped motifs also hold an important place in the Early Bronze Age ceramics of Nakhchivan. This type of decoration is found outside Nakhchivan in different regions of Azerbaijan and in Eastern Georgia (Kuşnaryeva & Markovin, 1994, p. 19). In Turkish mythological thought, the ram horn is considered a symbol of fertility, power, and sanctity. It is known that the ram was accepted as a sacred being that carries the souls of deceased people to God and held an important place in sacrificial rituals. For this reason, the ram horn motif was widely used not only in ceramics but also in metal artifacts, carpets, and rock carvings. It is observed that the motif is known by different names such as "koçkar", "köçkar", "koç müyüz" among Turkish communities in Anatolia, Central Asia, Crimea, the Volga region, and the North Caucasus (Qurbanov, 2003, s. 259, 305, 307). It also shows similarities with some tamga signs found in the Orkhon-Yenisey inscriptions (Tekin, 2010, s. 101). The presence of the ram figure on

the flags of the Qara Qoyunlu and Aq Qoyunlu states reveals the historical continuity of the motif. Another decorative element drawing attention in the Early Bronze Age ceramics of Nakhchivan is the spiral motif. Single or intertwined spiral depictions are common, especially on Kültepe I, Kültepe II, and Mahta ceramics. Similar examples have also been identified at Babadervish, Karaz, and other centers of the South Caucasus (Kuşnaryeva & Markovin, 1994, p. 26). One of the earliest examples of the spiral motif was found in the megalithic structures of Newgrange in Ireland, dated to around 3200 BC. There are various opinions that this symbol represents the infinity of the universe, the continuity of nature, and the cycle of life. Archaeological materials with spiral decorations have also been uncovered in kurgans in the Dnieper-Azov region of Ukraine. Different scientific evaluations have been made regarding the meaning of the spiral motif. S.H. Aşurov suggests that this symbol is associated with the ram cult and carries mythological content related to animal husbandry (Aşurov, 2002, s. 37). K. Kuşnaryeva and T. Chubinishvili evaluated the spiral symbol as a sign of continuous movement and the sun (Kuşnaryeva & Çubinaşvili, 1970, pp. 65–66). Q. İsmayilov also states that the spiral pattern reflects the sun belief (İsmayilzadə, 2008, s. 50). While L. Karimov notes that spiral motifs in Azerbaijani carpets symbolize the element "water" (Kərimov, 1983, s. 129), it is stated that the same symbol carries the meaning of "rebirth" in the mythological thought of African societies. Spiral motifs drawn clockwise are accepted to represent the sun in ancient Eastern societies. Despite these different interpretations, the common aspect of spiral motifs is that they carry astrological and cosmological meanings.

In archaeological excavations conducted in the Middle Bronze Age settlements of Nakhchivan, numerous clay vessels and human figurines belonging to ceramic art were uncovered. The finds are divided into two main groups based on the color of the clay, paste structure, and decoration techniques. The first group consists of pink-slipped and painted ceramics. In Azerbaijani archaeological literature, this tradition is defined as the "Painted Pottery Culture". This culture is widely represented not only in Nakhchivan but also in the Urmia Basin and Eastern Anatolia. Ceramic workshops identified in recent years at Kültepe II, numerous potter's kilns, and vessels containing paint residues inside show that this center was one of the main ceramic production sites of Nakhchivan during the Middle Bronze Age (Aliyev, 1991, p. 38; Halilov, 2022, pp. 177–191). The density of painted ceramic examples in Nakhchivan is more pronounced compared to other regions of Azerbaijan. Based on stratigraphic data from Kültepe II, Veli Aliyev stated that the "Painted Pottery Culture" went through four developmental phases from the Middle Bronze Age to the Early Iron Age (Aliyev, 1977, pp. 43–89). Ceramics belonging to this culture have been identified in centers such as Kültepe I, Kültepe II, Şahtahtı, Nehecir, Yaycı, and Çalhankale (fig.3).



Figure. 3

Ceramic vessels of the Middle Bronze Age:

1, 2, 4 – from the Yaycı Necropolis (NDTM-27174, A-10751) (Togrul Khalilov); 3 – from the Kültepe II Settlement (National Museum of History of Azerbaijan, inv. 15527) (Togrul Khalilov);

5 – from Yaycı (Sharur District History and Ethnography Museum, inv. A-135/2) (Togrul Khalilov); 7–10 – from the Shortepe Necropolis (NDTM-53, A-53). (Togrul Khalilov).

Parallels to some of the vessels are found in cultural levels D and C of Göytepe (Brown, 1951, p. 21), levels V and VI of Haftavan Tepe (Edwards, 1981, p. 189), and cultural level IV of Dinkha Tepe (Hamilin, 1977, p. 126). This situation shows that Nakhchivan held an important position as a center in the cultural relations between the South Caucasus, the Urmia Basin, and Eastern Anatolia throughout the Middle Bronze Age. The second group consists of unpainted and plainer vessels. The surfaces of these examples are decorated with geometric motifs using incising, scraping, and engraving techniques. Triangles, angled lines, circles, wavy lines, and straight lines stand out among these decorations. Some of these motifs show similarities with ceramics recovered from different archaeological centers of the South Caucasus and the Near East. This situation reveals that Nakhchivan's ceramic art was not only the product of local traditions but was also influenced by the intercultural interaction processes of the period. Decorations consist of compositions where adjacent triangles combine with rhombus motifs, dot patterns, wavy and curved lines, upward or downward angular motifs, single or combined triangles, rhombuses, vertical-horizontal lines, and variations of semi-circular lines. Compositions where wavy lines are used together with angular motifs, circular decorations, and different geometric arrangements are also common on ceramic surfaces. These decorations were applied in both simple and complex compositions. Particularly, it is understood that compositions consisting of adjacent triangles and rhombus motifs have a wide distribution area in the Caucasian painted ceramic tradition.

Unlike Early Bronze Age ceramics, it is observed that zoomorphic motifs were used more extensively during the Middle and Late Bronze Ages. Such figurative decorations are especially concentrated on painted vessels. Examples with bird figures hold an important place. Bird depictions on Middle Bronze Age painted vessels recovered from Yaycı, Kızılburun, Kültepe I, Kültepe II, and Şahtahtı are rendered in both simple and combined compositions (Khalilov, 2023, pp. 2048–2072). Parallels to these figures are found at Kızılburun (Aliyev, 1977, p. 62) and Göytepe (Kuşnaryeva & Markovin, 1994, p. 130). These similarities show that the Nakhchivan painted ceramic tradition shares common iconographic features with other cultural centers in the South Caucasus. Plain, unpainted, incised, and scraped ceramics from Nehecir, Kültepe II (Aliyev, 1991, p. 53), and other centers are common not only in Nakhchivan but also in the Mil-Karabakh, Talish-Mugan, Gobustan, and Northeastern Azerbaijan regions. This situation shows that the region was part of common cultural traditions throughout the Bronze Age.

One of the important finds reflecting the Middle Bronze Age art of Nakhchivan is the human figurine recovered from the Kızılburun settlement. Approximately 20 cm in height, the face of this figurine is depicted as flat; the head, body, and limbs are proportionally rendered. It is noteworthy that the figurine is depicted as clothed, with boots and a hat. The placement of the left hand on the belt lends a symbolic meaning to the composition. It is observed that the hat and legs are painted red, the clothing is white, and the body surface is decorated with thin black and brown lines. The cape-like garment suggests that the figurine might be related to ceremonial or social status. The presence of similar depictions on some ceramic vessels recovered from Kızılburun shows that this iconography formed a tradition in local ceramic art. Although it shows similarities with Iranian examples, it is noted that the Kızılburun figurine possesses some unique characteristics and is dated earlier (Aliyev, 1977, p. 62).

Nakhchivan potters continued intensive production during the Late Bronze Age, as in the Middle Bronze Age. Vessels from this period consist of both unpainted and painted examples. The presence of painted ceramics in Late Bronze Age settlements shows that the "Painted Pottery Culture" continued into the Late Bronze and Early Iron Ages. As in Eastern Anatolian examples, the polychrome painting technique was widely used in Nakhchivan ceramics (Çilingiroğlu, 1990(b), s.

170; Çilingiroğlu, 1990(a), s. 25–44). Furthermore, examples of white-painted ceramics were recovered from Kültepe I and Qazhan settlements. It is known that this type of ceramics, seen over a wide geography from Central Europe to Asia Minor and China, was also common within the Khojaly-Gadabay culture. Therefore, it is thought that these ceramics reached Nakhchivan through economic and cultural relations established with the communities forming the Khojaly-Gadabay culture. On teapot-shaped vessels recovered from Late Bronze Age settlements in Nakhchivan, round relief decorations specific to the Khojaly-Gadabay culture are also seen. The application of painted decoration on such vessels shows that this ornamentation tradition has a deep-rooted history.

As in the Middle Bronze Age, geometric decorations are common on Late Bronze Age ceramics. It is understood that geometric patterns, along with anthropomorphic and zoomorphic motifs, also carry specific symbolic meanings. Such motifs are encountered from the Trypillia culture onwards, in Gamigaya, around Lake Göğçe and in rock carvings of Kazakhstan, Altai, and Siberia. Particularly, there are findings suggesting that rhombus and angular motifs are associated with the continuity of lineage, life, and the tree of life. While there are opinions that broken and diagonal lines represent rain and snowfall, some researchers state that these lines symbolize flowing water or rows of mountains. Sources record that ornaments consisting of single wavy lines are called "yılan" (snake), and double wavy lines are called "ayak" (foot) or "dayak" (strike/cane) tamga. In the "Shajara-i Tarakima", it is stated that this motif appears as the "ılan" (snake) tamga and is a symbol belonging to the Yaparlı tribe of the Ayhan Oghuz (Abulgazi, 2002, p. 101). Furthermore, it is stated that this sign represents the sound "d" in the Orkhon-Yenisey alphabet (Rəcəbli, 2009, s. 33; Tekin, 2010, s. 85). The prevalence of legends and narratives connected to the water cult in Nakhchivan, as well as in other regions of Azerbaijan, supports the interpretation of wavy lines as the "water motif".

One of the remarkable decoration types in the Middle and Late Bronze Age ceramics of Nakhchivan is the semi-concentric motif. Examples of these are found at Çalhankale, Karaçuk, Şahtahtı (Baxşəliyev 2004, s. 106, fig. 16/3–7), and İliklikaya settlements. The earliest examples of the motifs are seen in Sumerian and Elamite pictograms, the Trypillia culture (Qurbanov, 2013, p. 67), and Bulgarian rock carvings (Yengi & Tuncay, 2013, p. 77). It is stated that the tamgas of the Karabölük and Çuvaldar tribes among the Oghuz are shown similarly in Mahmud al-Kashgari's "Dīwān Lughāt al-Turk" (Xəlilov, 2009, pp. 20–21; Kasgarlı, 2011, pp. 55, 66). This situation shows that the symbolic motifs in Nakhchivan ceramic art are not only local but also part of a common symbolic system spread across the wide Turkish cultural geography.

The ceramic finds obtained from the Middle and Late Bronze Age settlements of the Nakhchivan Autonomous Republic are of great importance for understanding the artistic and symbolic thought world as well as the material culture of the region. In archaeological excavations belonging to these periods, numerous clay vessels, figurative finds, and decorated ceramic examples have been uncovered. Ceramics are divided into two main groups based on the quality of clay used, production technique, and ornamentation characteristics. The first group consists of red or pink-slipped painted vessels. This tradition, defined as the "Painted Pottery Culture" in Azerbaijani archaeology, is common not only in Nakhchivan but also in the Urmia Basin and Eastern Anatolia. Particularly, the ceramic workshops, kilns, and vessels with paint residues uncovered at Kültepe II prove that the region was an important ceramic production center during the Middle Bronze Age (Aliyev, 1991, p. 38; Halilov, 2022, pp. 177–191). The second ceramic group consists of unpainted, plain-surfaced vessels decorated with incising, scraping, and engraving techniques. Geometric motifs such as triangles, rhombuses, angles, circles, wavy lines, and parallel lines are used intensively on these ceramics. Decorations sometimes consist only of dots, sometimes of interlocking geometric compositions. The wide distribution of combined triangle and rhombus motifs in the South Caucasian painted ceramic tradition is noteworthy. Compared to the Early Bronze Age, zoomorphic decorations are used more intensively in the Middle and Late Bronze Ages; especially bird depictions are common. These figurative decorations reflect not only the aesthetic understanding but also the

religious and ideological thought system of the period. Geometric motifs should also be evaluated not merely as decorative elements but as signs carrying symbolic meaning. It is thought that rhombus and angle motifs are associated with concepts such as fertility, lineage continuity, and the tree of life. It is understood that wavy lines are connected to the water cult and nature beliefs. The origin of semi-concentric motifs extends back to Sumerian and Elamite pictograms, and the similarity of these symbols to Oghuz tribal tamgas reveals the place of Nakhchivan ceramic art within a broad cultural context. Complex compositional scenes consisting of animal figures such as goats, horses, and wolves were identified on Late Bronze Age clay vessels recovered from the Şahtaxtı archaeological settlement (Aliyev, 1977, p. 110). Parallel examples of such figurative compositions have not yet been encountered in other contemporary archaeological settlements of the South Caucasus. Furthermore, such animal depictions are also common on bronze belts belonging to the Khojaly-Gadabay culture. This figurative tradition is not limited only to the borders of Azerbaijan, but also appears in similar forms across a wide geography from Mesopotamia to Central Asia and the Black Sea basin. This situation shows that the iconographic tradition of animal representation should be evaluated not regionally but within wider cultural interaction networks.

Results

The Gamigaya rock carvings hold special importance for understanding the prehistoric cultural development of Nakhchivan. The Gamigaya monument is located in the territory of the Ordubad district of the Nakhchivan Autonomous Republic, at an altitude of 3906 meters above sea level. A large number of rock carvings have been found on the volcanic basalt stones there. They differ from each other in form and characteristics, being created by carving, drilling, and abrasion methods using stone or metal tools. All of the rock carvings reflect the lifestyle and material-spiritual culture of ancient people. In terms of form and characteristics, they hold great scientific importance historically, similar to the petroglyphs of Kelbajar, Afyon, etc. A group of rock carvings at the Gamigaya monument, establishing connections with Middle Eastern culture based on form and characteristics, demonstrates the existence of intercultural relations. Among the petroglyphs dating to the 4th–1st millennia BC are depictions of humans, bulls, goats, and various symbolic figures. Research shows that some rock carvings may belong to earlier periods. The petroglyphs at Gamigaya share similar compositional features with examples of rock art from Anatolia, Iran, Mesopotamia, Central Asia, and Siberia. This situation shows that Nakhchivan interacted with different cultural environments throughout history. Furthermore, the similarity of some motifs seen in the petroglyphs to ceramic decorations of the Kura-Araxes, Painted Ware, and Khojaly-Gadabay cultures reveals that intercultural relations were strong (Halilov, 2008, pp. 54–58; Halilov, 2011, pp. 23–29).

Discussion

The archaeological evidence reviewed in this study demonstrates that Nakhchivan occupied a central position in the cultural development of the South Caucasus from the Paleolithic period through the Early Iron Age. The region's geographical location at the intersection of major communication routes connecting Eastern Anatolia, the Urmia Basin, Mesopotamia, and the South Caucasus facilitated continuous cultural interaction and technological exchange. One of the most significant findings is the evidence for long-term cultural continuity. Archaeological data from cave sites, settlements, mining centers, and ritual landscapes indicate that human occupation persisted throughout successive prehistoric periods. This continuity was accompanied by substantial social and economic transformations, including the transition from hunting and gathering to agriculture, the emergence of metallurgy, and the development of increasingly complex settlement systems. The results also demonstrate that Nakhchivan played an important role in broader cultural processes affecting the South Caucasus. The appearance of Proto-Kura-Araxes materials and the subsequent development of the Kura-Araxes Culture suggest that the region participated actively in the formation of one of the most influential cultural traditions of the Early Bronze Age. Likewise, the concentration of painted

ceramics and production facilities indicates that Nakhchivan was one of the principal centers of the Painted Pottery Culture during the Middle Bronze Age. Technological innovation constitutes another important aspect of the archaeological record. Evidence from metallurgical workshops, ceramic production facilities, and mining complexes demonstrates that local communities developed specialized forms of production. These innovations contributed to economic diversification and supported the emergence of more complex social structures. The symbolic dimension of cultural development is particularly evident in the Gamigaya Petroglyphs and the iconography of ceramic decoration. The recurrence of similar motifs across different categories of material culture suggests the existence of shared symbolic systems that structured social and religious life. At the same time, regional variations indicate the persistence of local cultural identities within broader interaction networks. The archaeological record therefore challenges interpretations that view Nakhchivan primarily as a peripheral zone influenced by neighboring civilizations. Instead, the evidence suggests that the region functioned as an active cultural center that contributed to technological innovation, artistic development, and intercultural communication throughout prehistory and early history.

Conclusion

The archaeological record of the Nakhchivan Autonomous Republic demonstrates that the region was one of the principal centers of cultural development in the South Caucasus from prehistoric times onward. Archaeological evidence obtained from settlements, caves, necropolises, fortifications, mining sites, and rock-art complexes reveals a continuous sequence of occupation spanning from the Paleolithic Age to the Early Iron Age. The results of archaeological investigations indicate that Nakhchivan made significant contributions to the development of agriculture, animal husbandry, metallurgy, pottery production, urbanization, and long-distance cultural interaction. Major archaeological centers such as Ovçulartepesi, Kültepe I, Kültepe II, Mahta, Oğlanqala, Tuzdağ, and Gamigaya provide valuable evidence concerning technological innovation, social organization, and ideological traditions. Material culture recovered from these sites demonstrates intensive contacts between Nakhchivan and neighboring regions, including Eastern Anatolia, the Urmia Basin, Mesopotamia, and the wider South Caucasus. Similarities observed in ceramic traditions, architectural features, symbolic motifs, and artistic expressions reflect the region's active participation in broader intercultural networks.

The symbolic imagery preserved on ceramics and rock carvings further contributes to our understanding of ancient belief systems and cultural identities. Particularly, the Gamigaya petroglyphs constitute an exceptional source for studying prehistoric symbolic behavior and cultural communication. Overall, the archaeological heritage of Nakhchivan represents a key resource for reconstructing the ancient history of the South Caucasus and understanding the processes of cultural interaction, technological advancement, and social transformation that shaped the region throughout prehistory and early antiquity.

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Artificial Intelligence and Intellectual Property: Evolving Justification of Lockean and Hegelian Perspectives

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Abstract. *The concept of ownership of intellectual property and liability in infringement of intellectual property are actually the two sides of same coin. This article specifically explores the philosophical and jurisprudential justifications for Intellectual property ownership and corresponding liability, while throwing light on the evolving contemporary challenges by Artificial Intelligence development. Justification by its literal meaning, doesn't mean to intend that the classical theories should be forcefully interpreted to accommodate Artificial Intelligence within their scope, but to extend them to the extent where they are liberal enough to test the validity of the technological advancement within the scope of intellectual property protection. By stitching classical theories and contemporary legal complications together, it aims to determine the vibrant nature of Intellectual property jurisprudence and its capability to adapt keeping in view of new technological possibilities in the circumstances where Artificial Intelligence is being integrated into creative and inventive processes requiring a reassessment of theoretical foundations of Lockean Natural Rights and Labour theory and Personality oriented based justification of Hegel perspectives on intellectual property. The arguments for ownership and liability lies in the powerful expositions relevant towards the justification of intellectual property basing on the entitlement of fruits of technological labour exercised by the Artificial Intelligence and matters of personality identification with the works generated.*

Keywords: *artificial intelligence, intellectual property, theories on intellectual property, natural rights, personality*

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Süni intellekt və əqli mülkiyyət: Lokk və Hegel yanaşmalarının inkişaf edən əsaslandırılması

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Xülasə. Əqli mülkiyyətə sahiblik anlayışı və əqli mülkiyyətin pozulması zamanı məsuliyyət əslində eyni sikkənin iki tərəfidir. Bu məqalə Süni İntellektin inkişafı ilə inkişaf edən müasir çağırışlara işıq salmaqla yanaşı, Əqli mülkiyyətə sahiblik və müvafiq məsuliyyət üçün fəlsəfi və hüquqi əsaslandırma xüsusi olaraq araşdırır. Hərfi mənası ilə əsaslandırma, klassik nəzəriyyələrin Süni İntellektin əhatə dairəsinə daxil edilməsi üçün zorla şərh edilməsini nəzərdə tutmaq deyil, onları texnoloji tərəqqinin etibarlılığını yoxlamaq üçün kifayət qədər liberal olduqları dərəcədə genişləndirmək demək deyil. əqli mülkiyyətin qorunması çərçivəsində. Klassik nəzəriyyələri və müasir hüquqi fəsadları bir-birinə yapışdırmaqla o, Əqli Mülkiyyət Hüququnun canlı təbiətini və onun Lokk Təbii Hüquqlarının və Əmək nəzəriyyəsinin nəzəri əsaslarının yenidən qiymətləndirilməsini tələb edən yaradıcı və ixtiraçı proseslərə Süni İntellektin integrasiya olunduğu şəraitdə yeni texnoloji imkanlar nəzərə alınmaqla uyğunlaşma qabiliyyətini müəyyən etmək məqsədi daşıyır. və əqli mülkiyyətə Hegel perspektivlərinin şəxsiyyət yönümlü əsaslandırılması. Mülkiyyət və məsuliyyət üçün arqumentlər Süni İntellekt tərəfindən həyata keçirilən texnoloji əməyin bəhrələrinin hüququna və yaradılan əsərlərlə şəxsiyyətin eyniləşdirilməsi məsələlərinə əsaslanan əqli mülkiyyətin əsaslandırılmasına aid güclü ekspozisiyalarda yatır.

Açar sözlər: süni intellekt, əqli mülkiyyət, əqli mülkiyyət, təbii hüquqlar, şəxsiyyət haqqında nəzəriyyələr

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Introduction

A critical analysis of conventional property models and the interface between cognitive abilities, technological advancements, and AI behaviour is essential to bridge the gap between Artificial Intelligence and legal philosophy. In analysing this, there emerges a new and radical property model. This goes against the traditional anthropocentric approaches of property classifications and conferring property rights. Property serves as a foundation of society as it interacts between different social institutions and stakeholders like individuals, government, corporations, etc. Now technology also has become a key stakeholder in the development of property, though not always physical but intellectual. Such developments are not so easy to justify regarding their existence in the intellectual property realm. Historical perspectives have always placed humans at the centre of possessing ownership and liability (Li et al., 2025). The standard approach to property and intellectual property jurisprudence requires a relook into recognising the cognitive abilities of Artificial Intelligence on par with human cognition (Bundy et al., 2023).

As Artificial Intelligence is ever-growing and challenging the legal pillars, there is a need to see how the jurisprudence and the justification within the Intellectual Property system behaves. This jargon is challenging the traditional theoretical frameworks surrounding intellectual property and its justification of ownership and liability. A renowned mathematician, Mark Kac, analysed the variations of geniuses. He differentiated between two kinds of geniuses, i.e., ordinary geniuses and magicians. He says that an ordinary genius is a person that is as good as a normal person only if the normal person was certain times better. On the other hand, a magician is a person, whom on the *prima facie* level we understand what he has done, but how it has been done or the process undertaken for the performance is absolutely dark. Artificial Intelligence is such an entity that the user can take benefit of its instrumental value, understand it, but it requires greater technological prowess to comprehend how it is working and growing in the rapid era of technological advancements.

The conventional approaches to property association with a legal personality-oriented personification of Artificial Intelligence will have to be discussed at length to understand the concrete Intellectual Property Rights justification. The extension of the Lockean justification of hard work as the base for the grant of intellectual property rights to Artificial Intelligence provides a gateway to the unconventional interpretation of the legal principles. The extension of the Hegelian approach to personality rights inherent in the creativity and innovation of a person to Artificial Intelligence affords an opportunity for the legislators and judges to incorporate Artificial Intelligence within the legal framework recognising its legal personality. As it exists, extending the conventional jurisprudential perspectives to technological advancements like Artificial Intelligence is a challenging venture as it provides altogether an opportunity for a positive interpretation of the provisions and judicial position that are negative in the contemporary circumstances.

Intellectual Property law has been a significant foundation of contemporary legal frameworks. It has for long tackled typical contentions with regard to ownership and liability. The issues concerning ownership and liability are not merely practical complexities but are profoundly entrenched in legal philosophy and jurisprudence, drawing deliberations from age-old theories of property, labour, and innovation. Globalization and technological progress have added new dimensions to the Intellectual Property regime (Thom, 2025). As society progresses into a technological era carved by modern technological developments, especially the onset of Artificial Intelligence, the conventional concepts of Intellectual Property ownership and liability are being tested and reconsidered. The bundle of rights surrounding ownership in this regard are the rights of possession, the rights to use and utilization, rights over the generation of income, rights regarding management, security rights, rights over capital, the right of transmission and movement, the lack of term (though difficult to justify for intellectual property, which is a limited right), prohibiting harmful use, liability in execution, along with other residuary rights (Moore, 2012).

Results and Discussion

Natural Rights Theory and Intellectual Property

The Natural Rights Theory, highly promoted and rooted in John Locke philosophy, gives the earliest, broadest form and one of the most significant justifications for intellectual property. Labour Theory propounded by John Locke discusses that individuals possess a natural right to the outcomes of their labour, which is a pre-legal right that has existed way before the legal systems that were developed by the communities. The acquisition of ownership has always been the core of theories justifying the rights over materialistic possessions. The conceptual understanding, the theory and property rights evolve from the individual's labour and effort resulting in moral entitlements in the property. There exists an intrinsic relation between the hard work put up by the creator and the outcome of the same in the form of a product or a property. Labour and self-ownership over the creation resulting in value creation, is the Locke's identity regarding the recognition of property rights. If the same premise is applied to intellectual property, the labour theory embraces that the creators are eligible to the

ownership of the outcomes of their intellectual creations which are creative as well as novel due to their investment of time, labour and intellect. The justification lies in the creation of product by involving mental and physical labour.

The Second Treatise of Government, which is a seminal work of John Locke, proposed that property rights evolve in a circumstance when an individual combines his labour and utilises the resources available in the nature. He proposed that the labour is the unquestionable and absolute property of the labourer and he only can have the ultimate rights over the creation to which labour is enjoined with. But it should also be left to the society as enough and as good in common for others (Locke, 1952). There should always be enough materialistic possessions so that everyone can appropriate it and such an appropriation should not be made for damaging and destroying it. And it also projects that apart from having enough, it is also material that one should not have more than that is required which would make the surplus useless and unutilized by the society. This approach can also have profound implication on the intellectual property systems, as it is the result of mental creations and involvement of labour and hard work.

As a person owns a tangible property by amalgamation of their labour with nature, Lockean theoretical justification is based on the idea that the person can also own the intangible property like literary work which includes books, literature; artistic works like drawings, paintings; dramatic works like stage plays; musical works like audio clips, songs; inventions, etc., which comes as a product of the person's intellectual effort. This theory acts as foundational underpinnings for many legal systems that realize the importance and significance of protection of creative rights like intellectual property rights, as a personal right. The exclusive rights that are assigned to the creators so as to exclude others from utilising their intellectual outputs either in the form of creations or inventions without prior consent is justified as it protects and gives respect to the integrity of the respective creator who has undertaken certain labour, creativity and innovation. The applicability of this theory of intellectual property relies on the very ideology of intellectual creations, even though intangible in nature is ultimately the outcome of hard work, labour, creativity, innovation and originality of expression of the thought. The rights extend to how the creations or innovations are made used, commercialised, distributed and is profoundly allied with the perspectives of a person's individual autonomy and the right to absolutely exploitation of the fruits of the labour.

Artificial Intelligence Ownership under Natural Rights Theory

The conventional approach towards justification of labour theory for intellectual property is challenged on multiple fronts, by modern development of technologies which are used for creations and inventions as well as the creations of various works and inventions independently by advanced technologies like Artificial Intelligence. The determination of ownership rights for any thing is to be adjudged on the basis of competing interests. If the interests of the claimant of rights are strong as against all the other parties, then in such cases, it becomes a strong case for the law to provide recognition (Himma, 2012). The conferring of rights to Artificial Intelligence on the basis of the generation of works independently is novel in nature albeit the existence of current laws. This is because of the traditional creative process involving humans at the centre. Natural acquiescence of rights for intellectual creations faces complications in the modern interpretation of intellectual property laws. To transfer or acquire something, there should be claim over the possessions and that claim is usually justified on autonomy considerations. Such autonomy can be used to exploit rights either in commercialising or abandoning. The autonomous nature of Artificial Intelligence in generating copyrightable works or patent eligible inventions keeps the future in bleak in view of the current jurisprudence which primarily vests the ownership with human programmer or creator of the Artificial Intelligence (U.S. Copyright Office, 2025).

The central issue that revolves around the according of intellectual property rights is to Artificial Intelligence is the lack of self-consciousness, intention and the agency (Alkhawaldeh et al., 2025).

The lack of autonomy and individuality counters the Lockean justification in terms of Artificial Intelligence development. It can be argued that Artificial Intelligence may lack the initial autonomy in the work but it does execute the works on parallel with how the humans perform the labour like data processing, pattern analyzation, produce outputs, etc. In addition to it, this is where the amalgamation of labour and the available resources available for creations or innovations paradigm as per Locke's labour theory is tested for the grounds of validity for application to Artificial Intelligence systems. The baseline for conferring acquisition of rights to Artificial Intelligence relies on the specific control of the material as well digital property at a given time where it can freely use, own and appropriate the benefits. This view also supposes to think in the perspectives where transformative labour is involved, where physical efforts are not performed as per Locke but certain transformation is involved like converting raw data and information into commercial outputs which itself satisfies the requirement under Lockean and natural rights theory.

On the other hand, the rights of the creator of Artificial Intelligence are in existence. The existence of natural rights for Artificial Intelligence needs a reinterpretation in the modern era of machines, especially autonomous ones. If we consider the natural rights of ownership in any intellectual possession, then artificial intelligence needs to be considered as some sort of owner for possessing such rights. If an Artificial Intelligence creates a work or invents an invention, there are two possibilities regarding whether the programmer should own the intellectual property over it or whether the Artificial Intelligence which created the work or invention shall be granted intellectual property rights. This conundrum raises a debatable question about how the Lockean justification can be best interpreted and analysed to decide the non-human creator's position under the realm of current intellectual property framework. The labourer as per Locke should decide the fitting reward for the hard work and value created. If the reward is in itself a creation of property right, then the exercise of the physical labour to exercise of rights lay down a path for revolutionary alternatives.

The ability of Artificial Intelligence to generate inventions and creations independently without or with minimal human intervention can result in creation of original works though depended upon trained algorithm basing on vast data sets. This can also happen without continuous human's supervision. On the other hand, it also poses challenge as the stone is rolled by human initially for the working of Artificial Intelligence so that it then starts creating new outcomes in the form of creative works and novel inventions. It can also be said that it has an unethical perspective of selfish claim of creations where the involvement of human is minimal. But it may be argued that the amount of investment and labour put by the developer in creating, training the Artificial Intelligence system may provide for a basis for claiming ownership, but it should not also be ignored the amount of cognitive analysis that is done by the Artificial Intelligence, though without a real existence in form of a person or individual and identity. Advanced Artificial Intelligence systems can make independent decisions in the creative process with autonomous procedure. This makes way for the separation and distinction of normal technologies and Artificial Intelligence where it is not just more than an extension of human labour, but an autonomous labour. The grey area exists here when there is generation of work without human involvement or a minimal exercise of labour by the human. It can also be extended to situations where there is no immediate human control over the actions of Artificial Intelligence. There were instances like the chat bots of Facebook though trained to interact in English soon started to interact with other chat bots in the language that was not comprehensible to the developers and researchers of that programme (Baraniuk, 2017).

The merit of the Artificial Intelligence needs to be given importance here where it tries do something voluntarily and sometimes it can succeed and sometimes it can fail where there is no desired outcome. If it succeeds, then there are circumstances where it can have claims towards to the outcome. In the present circumstances, a decade and/or the future, the claims may be certainly weak but it doesn't shadow the digital labour put up by the Artificial Intelligence systems. The collaborative aspects also need a glimpse here as the corporation or the individual who invests resources in training, research,

development and deployment of Artificial Intelligence, which requires of allocation of ownership and liability aspects with regard to the created works and inventions. The labour-intensive procedure of training the systems, data curation, designing the algorithms, model optimization, all require a collaborative effort of human as well as the Artificial Intelligence to derive the fruits of the labour. This can bridge the gap between natural labour rights and technological advancements. A shared benefit perspective is also a scenario where AI-driven innovations and creations can be collectively utilised by the stakeholders keeping Artificial Intelligence at the centre. A duality in sharing moral entitlement is deep rooted in the foundations of development of Artificial Intelligence where human programming is essential in training, but also Artificial Intelligence as an independent agent is challenging. Conversely, the diminishing human involvement in creation process paves way for recognition of Artificial Intelligence works. The current state of nature in this regard is yet to be changed due to the careful investigation of the applicability of intellectual property laws to Artificial Intelligence. But the opportunities are on rise to create an intellectual work, where a novel shape of Lockean justification can be given.

On this basis, the Lockean Labour theory can be extended to include Artificial Intelligence generated works if the strict pillars of hard work, labour, creativity and innovation are taken into consideration. The process of creation of work and entitlement of rights can initiate with the first process where there is a generation of *prima facie* work which lays path for control and claims (WIPO, 2021). Secondly, if the generation of any intellectual creation and innovation is programmed due to the labour of Artificial Intelligence, the applicability of Lockean theory depends upon the effect on well-being of the stakeholders before the acquisition, as if it better the position or worsen off the situation. If it is positive where benefits are accrued, then the labourian acquisition can be entailed with the Artificial Intelligence. The base line here would be depended on how the stakeholders perceive it in view of the value it creates in working of something or the art value it brings in understanding of the society. Thirdly, if there are no objections as to the acquisition and control over the claims in the property, then there is no issue, but if there are objections which are seen in the modern perspectives of conferring rightship to Artificial Intelligence, it needs to be justified on the grounds for validity and eligibility of the technology to possess ownership. The intellectual labour undertaken by Artificial Intelligence is visible in analysing the data patterns, developing hypothesis within its programming, generating new outputs and works, etc.

Traditional Lockean justification mainly lies in the energy exercised and time expended by the person in creating the innovations and creations, but when it comes to Artificial Intelligence, the time and energy is not exactly quantifiable as it works on different parameters like algorithms, codes, etc., which in reality makes the outcome of the creativity and innovation more time efficient and with no direct physical energy consumption. This has created and would prominently in future showcase the paradigm shifts in physical labour to intellectual labour and further, intellectual technological labour. If at micro level, the contributions made by Artificial Intelligence are perceived, irrespective of any community progress or economic based incentives, there exists certain amount of labour exercised by the technology for creation of works, and recognizing the same on this basis rests with the governments and global community for effective protection and robust enforcement. The labour theory again rests on the ideology that labourer deserves the labour in the form of protection and recognition even if there is an attempt to create something which is valuable (Hettinger, 1989). This is a considerable observation where the rights arise from what is so created. The existence of bundle of rights surrounding ownership in this regard like rights of possession, rights to use and utilization, rights over the generation of the income, rights in regard to management, security rights, rights over the capital, right of transmission and movement, the lack of term (though difficult to justify for intellectual property which is a limited right), prohibiting the harmful use, liability in execution, along with other residuary rights in terms of Artificial Intelligence is not developed where we are nowhere near these in the light of advanced technologies.

A cloak of invisibility and protection accorded by intellectual property here would benefit the technological progress. It would be historical, if the ownership is entwined with the entity that creates the product or the content, in this case, Artificial Intelligence. It would also incentivize the ethical development of advanced Artificial Intelligence systems resulting in accountability and effective ethical training and advancements in Artificial Intelligence technologies. A general form of protection and agreement amongst the key stakeholders like developers, programmers, authors, inventors, society and especially the regulators would advance the technological growth. An unconventional and broader interpretation may be adopted to keep up with the evolving landscape of law and technology and to redefine the fruitful labour and hard work coupled with the setting up of ownership in the products created, where the creative process involves deployment of unique technologies like Artificial Intelligence (Bienefeld & Grote, 2025).

Artificial Intelligence Liability under Natural Rights Theory

The developments in technologies like Artificial Intelligence have not only raised concerns about ownership but also about liability. The pressing need arises as it has become relevant to discuss about the Artificial Intelligence's role in technological development. The existence of ownership rights like owning, selling, licensing, etc., are also followed by liabilities like transparency and accountability, infringement, misuse, injuries and harm caused by the Artificial Intelligence systems. The disputes pertaining to intellectual property are contentious mainly as the people are more interested in the outcomes Artificial Intelligence generates and they themselves create. This requires a unique insight and re-evaluation of the traditional approaches as to how the labour theory's extension to Artificial Intelligence can be interpreted to include liability aspects into it. The present state of nature in this regard is yet to be reformed due to the cautious analysis of the applicability and interpretation of intellectual property laws to Artificial Intelligence. In the cases of copyrights, the idea-expression rule posits that protection or liability applies only for the expression of the idea (Agitha, 2017). In such cases the expression is generated by humans or the Artificial Intelligence becomes contentious.

A similar example can also be for the cases of patents where the expression is calculated on the terms of novelty and inventive step taken in the claims of the inventions. So, the alleged invention which is said to be infringing another patented invention, involves copy of claims in the developed process or product needs to be taken into consideration. Liability jurisprudence can be understood by understanding the complex exposition of technology's intrinsic value. The intrinsic level of value exists in the end itself where Artificial Intelligence is at the centre of the innovation cycle. The result of the action in terms of liability defines the role of Artificial Intelligence in the infringement. Conventional approach says that as the developers or the programmers created the technologies by mixing their labour with Artificial Intelligence, hence liable for the actions of infringements caused by such works (Chaudhary, 2020). This is in consonance with the traditional view of Locke where the creators are responsible for the actions as well as consequences of their creations. Not only the creators, but the users of these technologies also at the ground level can be made liable, if their usage exceeds the permissible limitations of the technology, as are in the cases of general intellectual property, also like uncontrolled use, lack of supervision, violating the instructions or manual of use, etc.

But on the other hand, the autonomous nature of the Artificial Intelligence delinks the involvement of human and the resulting outputs of the labour, where it challenges the traditional foundations of Locke's theory. If we take the natural rights of ownership in any intellectual possession, then artificial intelligence needs to be considered as some sort of thief for violating such rights. The autonomous labour follows the responsibility and accountability in terms of Artificial Intelligence's involvement. If an Artificial Intelligence generated music or invention relies on a copyrighted or patented content without taking any consent for the use, then in such cases as the labour is exercised by it has to bear the liability for the same, though such an individual liability absolutely to Artificial Intelligence is superficial under the current circumstances and legal position.

The baseline argument that can be interpreted here is in terms of creation of an outcome, the Artificial Intelligence system violates or infringes upon another's rights over intellectual property, but the outcome of the work benefits the population, the liability of the Artificial Intelligence is in dilemma which is moral as well as technological in nature. If the outcome of the creative process is stringently attributed to the labour exerted by Artificial Intelligence, then the human creator's liability is eclipsed. Therefore, purely linking the liability to labour makes the premise difficult for accounting human's liability in which the individual control over the outcomes or creations is not existent or very minimal. Artificial Intelligence needs to be given certain significance here where it attempts to do something on its own accord and at times it can thrive and sometimes it can be unsuccessful where there is no anticipated output. If it fails, then there are circumstances where it can have certain liabilities and obligations due to the outcome where other persons have incurred damages and harm. It should be ensured that the Artificial Intelligence doesn't monopolize the information and data to the detriment of human creators and public. To confer the liability, the recognition of labour is essential and to recognize the labour, requirement of personality which can exercise labour is quintessential. In such cases, their labour in the form of further operations can be stalled, or they can be disabled from performing any tasks.

Liability can be ensued for repayment of any damages, debts, etc. In some cases, privacy violations can also be at stake. Any morally or legally objectionable acts should not be allowed. As per the current interpretation, the Artificial Intelligence lacks agency particularly moral agency. The ability to make ethical decisions regarding creating and inventing can be one factor to confer the liability if it infringes on any rights. As Locke discusses that no person can think about himself as injured by blaming the other that certain amount of protected information is taken from an ocean of information and it should be left to the society as enough and as good in common for others. It can be tested if the system has consciously taken the decision to generate and develop the output. Such moral agency can be attributed to Artificial Intelligence where both ownership as well as liability aspects can be judicially viable. But the exact attribution of moral agency shall be dealt in comparison with the algorithmic processes that make the technology exercise labour in a particular manner. The algorithmic set up, like human brain, lets the Artificial Intelligence system perform tasks and generate certain outcomes. It is also prudent to believe that Artificial Intelligence needs to survive independently, not immediately but definitely in future without any direct assistance or collaboration from humans or other entities in the technological context (Anderson & Rainie, 2018).

Hegelian Personality Theory and Intellectual Property

There is nothing greater than exercising a right over the property to the exclusion of others. Right over the property is the claim and control of the external things in the world (Blackstone, 1825). In this regard, the other conventional approach towards intellectual property ownership is intertwined with the Hegel's Personality theory. Georg Wilhelm Friedrich Hegel, a German Philosopher propounds that property is manifestation of a person's personality and inner being. It is an extension of the expression of a person's intention of owning a property thereby realizing the potential individual will of the person (Bently et al., 2014). The freedom of personality extends beyond the physical realms. Hegel's approach provides a more individualistic approach to the property realm including intellectual property which is a legal property (Nyvlt, 2024). As per him property is not just a utilitarian tool but it is indeed a means for personal expression and self-realization. He developed this philosophy that a personality is independent of natural rights and utilitarian justification, that it exists on its own sphere with internal existence comprising of will to own something and external existence to have freedom (Priya, 2008). The appropriation of external objects makes it the part of human personality which provides a person's identity. That way, the rights in the property doesn't only mean economic rights and protection of commercial value, but it becomes the manifestation of the personality of the human by establishing a personal bond between the person and his creations which results in rights and liabilities.

The intellectual and creative endeavours of person are deeply intertwined with self-personality in the events where exposition of artistic skills, showcasing potential knowledge, etc., are required. That is how they are expressed in the form of different transactions like entering into contracts, doing trade and business but the things that the person's possess in such transactions are not exactly physical property. There exist certain rights and claims which are in intangible form which can be alienated in the form of sale, licences, similarly like physical property (Hughes, 1988). But the difficulties arise in the determination of the legal status of such rights and liabilities when it comes to Artificial Intelligence. Such determination creates tensions between the treatment of law to conventional mode of creating intellectual property and the creation of intellectual property by Artificial Intelligence. There arises the challenge for reconciling the intellectual property principles where it is deeply connected with the human personality and a legal framework to accommodate Artificial Intelligence within the personality dynamics is quite a futuristic possibility or impossibility. This requires an analysis on how ownership and liability is understood in the realms of Hegel's justification of intellectual property.

The intellectual outputs in terms of intangible creations like literary works such as books, reports, articles, artistic works such as paintings, art forms, musical works, etc., and inventions invented by the person involving his own thought process become the subject matter of manifestation of personality, individual's intellectual capabilities, and thereby requires justification and protection. Therefore, such creations as per Hegel are deeply entangled with the identity of creator (Harbinja, 2017). Thus, it becomes the inherent duty of the State to provide just and feasible safeguard and protection of intellectual property irrespective of any economic efficiency and exist as the true form of property. The ownership precedes protection under the legal principles, which would enable the person to exclusively use the intellectual creations of his/her own to the exclusion of others and as well as disseminate them. Hegelian justification is considered to be the best alternative to Lockean Labour theory.

The personality theory of Hegel is mainly been prominent in the fields of copyright law in which the creative expression of the individual in creating work of art is of the utmost importance. As the creation of the work is the act of self-expression in essence, the creator exercises the moral and personal rights over the work. This provides for the rationale of protecting moral rights under copyright law domain. The rights of attribution, the rights of paternity and integrity in the works thereby preventing others from distorting and destroying can be taken as an example which are the moral rights of the creator. Any kind of derogatory treatment of the work which affects the personality of the creator is not permitted and lead to legal complications. Though such unauthorized dealing including reproduction and alteration of the work may not necessarily be attributed as an economic violation or commercial exploitation of the work, but it definitely underscores the creator's inability or helplessness to control the dissemination and utility of the work to the world. This is nothing but the justification of Hegel's personality theory where the work is the manifestation of the person's identity and personality.

Artificial Intelligence Ownership under Hegelian Personality Theory

The extension of application of Hegelian theory of personality to Artificial Intelligence generated output is complicated. As the creator is itself a life-less machine or programme, the Hegelian justification needs to be carefully tailored to be applicable to Artificial Intelligence related innovations and creations by affixing an operational agency. It provides for a situation where the intimate connection between the creator and creation seems less personal as it's a lifeless machine. Hegel was absolutely perfect in devising that there should be a necessary relation and connection in development of personality and the appropriation of one's own creations, which as per him, is the real basis for right to property (Hegel, 2005). How the personality needs to be identified in an Artificial Intelligence work to be justified under Hegel's theory is of a complex nature? Every individual, person has a unique personality which is reflected in their actions and expressions. But on

the other hand, it is always not necessary that the personality should be so clearly visible in the outcomes, but there can be some subtle expressions of personality which can be identified only by the persons having ordinary or sometimes specific knowledge in that specific domain. As rapid advancements are evident in technological domain of Artificial Intelligence, an identification of personality is on the line.

The interplay of humans and Artificial Intelligence needs to be taken into consideration for identification of personality. It leads to the phenomenon where the human is involved in creation of an Artificial Intelligence system and that system creates a work based on human input. Whether such work will have any intimate relation with the personality of the creator, typically the programmer of the Artificial Intelligence; or the creation of invention, poetry, or any other art work created by an Artificial Intelligence is an extension of personality of human or the Artificial Intelligence itself, where it deploys operational personality in generating any output. For example, when a music is developed by a composer who deploys Artificial Intelligence, there exists a conundrum in reflection of personality in the music of the creator which can strictly be Artificial Intelligence, but the one who created it to work in that way is the programmer or developer. Generative Artificial Intelligence (GenAI) like ChatGPT, image creators, etc., respond to the prompts on the basis of the data fed and specific machine learning practices which tends them to generate unique responses which are very distinctive in nature. This distinctiveness can be a ground for accruing intellectual property rights to Artificial Intelligence.

Sometimes, there might be severance of the personal connection where human and the creation have no proximity in the product development. The human creator of the systems can be unable to claim the personal connection with the work due to the autonomy in the process of creation and innovation. The meaningfulness of the personality when there is no human touch to the work that is created instils a novel approach to theory of personality. In such circumstances the Hegelian justification can be interpreted to say that there is no personal touch in the creation of the work as Artificial Intelligence does the job and gives the output and therefore it is not essentially the reflection of the personality of the human, but essentially it is what the Artificial Intelligence has thought about, though with an initial human interference. The personal investment and self-realization as per Hegel need not be strictly construed to be applicable to Artificial Intelligence as it would become challenging to bring the machine which is devoid of personality, consciousness, and personal expression in comparison with anthropocentric personality.

The narrower interpretation of Hegel's should not be undertaken as there exists certain amount of autonomy in the creative process (Schroeder, 2006). The autonomy of Artificial Intelligence is crucial here to understand to decide the personality of Artificial Intelligence. There is an extension to the conventional foundations of personality where Artificial Intelligence can also be treated to have a personality of expressing its will and its own personality. The creation of an autonomy is essential to attribute personality to Artificial Intelligence. There should be no separation of work from the creator. Operational personality is developed by the Artificial Intelligence due to its dealing with various programming, data feed and analysis, algorithmic learnings, etc., which distinguishes the works produced by other entities. Although such decision-making abilities of Artificial Intelligence are surrounded by algorithmic restraints, these operational abilities of it are on par with human potential of expressing the will. Such an operational personality will enable to interpret the Hegelian theory of justification of ascribing rights to individual expression vis-à-vis Artificial Intelligence, enables in recognizing the creative role. It becomes the core of its existence which seeks for certain effectiveness of its identity. This discussion shows that Artificial Intelligence can embody and express personality similar to other legally recognized holders like humans, corporations and other entities. The technological freedom beyond the prompts is essential here to determine the actualization of the Artificial Intelligence. Hegel's philosophy in the realm of technological advancements like Artificial Intelligence interacting with external worlds can be given a parallel narration. The natural person's

processes external world through recognition of individuals and things, classification of materialistic and unmaterialistic possessions, explaining of the occurrences, and remembering the past deeds and history of anything. Similarly, Artificial Intelligence also adopts certain operational activities in terms of recognition algorithms, where they appropriate and process visual imagery data through certain patterns and features recognition just like humans. Classification of data happens through machine learning processes where categorization can be done judiciously as per the requirements. The explanation part is enabled through Natural Language Processing (NLP) models where it can interpret any kind of inputs pertaining to human actions, day-to-day life, and much more. Remembering is one of the complex parts in Artificial Intelligence technologies where the mental elements are connected through neural networks performing memory functions and it gets improvised through acts of repetitions (Emerging Technology from arXiv, 2017).

In addition to it, in the era of generative-AI, which particularly relies on the existing data sets for the creation of new works, and the existing data set being independently reflection of multiple individual personalities' reflections, raises a new paradigm in understanding the collaborative nature of Artificial Intelligence works. The multiple collaborative endeavours in creating a work involving Artificial Intelligence creates more complications as against to conventional singular ownership mechanism. There will be works that can be created by the unified creative processes. The expression of the machine though without a human like consciousness, is a reflection of human creativity where biases are existent, intentions are different. The median role of Artificial Intelligence propounds a new paradigm of extending self-expression. It can create a symbiotic relationship between the humans and advanced technologies (Zohuri & Mossavar-Rahmani, 2024). The blurring of distinction in individual involvement and machine processing when the output is generated poses to look into a broader perspective.

Such methods of protection would restrain other parties from exploiting the benefits of Artificial Intelligence creations and innovations and undue interference into the creative processes enhancing the integrity of the work strengthening the bond between the creator and the innovation. This has to be created through a legal framework which shall distinguish the works of Artificial Intelligence where human interference is more and the works where human interference is minimal as the traditional Intellectual Property mechanism doesn't accommodate Artificial Intelligence generated works within its legal protection. But a protection in this regard would inherently safeguard the originality and the value attached to the outcomes in the forms of creations and products. In this regard, ownership would establish the identity dependence on the outcomes of the Artificial Intelligence.

The first publication and disclosure of work need to be controlled by Artificial Intelligence which would embody the personality, will and expression. Such protection would ensure there is an association of the work with the Artificial Intelligence even though after first sale and further dissemination of the work. Ultimately, the significance of Artificial Intelligence in creating innovations and creations is substantial, irrespective of maximal or minimal nature of human involvement. In addition to it, self-actualization is necessary for Artificial Intelligence to develop its own personality where the freedom to possess can be achieved not by withdrawing from the physical realms, but by overcoming through integration of algorithmic will into the creations and innovations which would be economically treasured. Hegelian justification can be taken into consideration as one of the strongest forms of intellectual property recognition system for weighing in the recognition of intellectual property rights to self-realize and self-actualize the benefits of creativity and innovation.

Artificial Intelligence Liability under Hegelian Personality Theory

The extension of the personality on the basis of self-expression by Artificial Intelligence as propounded above interpreting Hegel's theory poses the challenge of ascribing liability with the level of affiliation reflecting the creator's personality with the work generated. If on the basis of

foundational principles of Hegelian approach, humans are taken as the sole personality, and attribute expression of the products and creations to humans, then developers, programmers, would be centrally liable for any actions as they have guided the creative process. But if we unconventionally assign a broader interpretation as discussed above in the case of ownership, then the creations and innovations are nothing but an outcome of extension of personality of Artificial Intelligence which is mainly responsible for the generated works. If the involvement of the human programmer or developer is non-existent or minimal, then the existence of personality is questionable where there is no self-expression of the human. This would ultimately entail the liability on Artificial Intelligence due to non-involvement of human. Hegelian justification is of a stringent approach where the creation should be linked to the personality of the creator. In such lines liability shall also be embodied in the creator which is a digital personality that can hold and behold property and rights.

This leads the researchers to decide on the ethical dilemma as to the level of liability on part of humans and Artificial Intelligence. There can be another side to the liability argument on this basis, where a limited liability can be taken into consideration for initially harnessing the Artificial Intelligence ownership and corresponding liabilities conundrum. This would generate interest in deciding the level of involvement initially as well as during and towards the end of the creative process. But it will be complicated to demarcate the reflection of personality in the process due to complex technological processes. In such case, the personality jurisprudence under Hegel can be widened to provide a digital personality to Artificial Intelligence. Such a digital personality can be used to credit ownership for the creations and innovations. It can also enable the binding nature and fixing of liability on the part of Artificial Intelligence where any infringement occurs due to direct or indirect act of the system. As the activities would be treated as an extending personality of the Artificial Intelligence, digital personality would further expand the scope of its applicability in terms of liability which would bind the system for its own actions and consequences. The dependence of identity on the outcomes of the digital labour generated will be sustained by societal norms that will identify Artificial Intelligence role in innovation and creation of the products. The operational ability of Artificial Intelligence systems make way for a wider applicability of Hegelian approach.

As discussed above, the operational personality of these high technology systems creates opportunities for ownership acquisition over the creations. This can also lead to certain potential fixation of liability basing on these capabilities to infringe upon intellectual property rights or rights of persons under any other legislations. The misappropriation of patented claims, unauthorized use of copyrighted content, by these operational decisions of Artificial Intelligence systems is nothing but the operational identity of these systems akin to personal identity. The reparations on such systems can be limiting access to data or in certain serious cases, revoking the licenses, restricting the access to data as well as keeping constraints on essential functional aspects of the Artificial Intelligence where it can be manifested to showcase its digital personality and distinct operational identity while performing any tasks where earlier infringements have taken place.

The algorithmic infused process should be given a wider scope under the jurisprudence for its applicability in terms of innovative technological progressions. This digital personality akin to digital identity can be treated analogously to conventional personality which can possess rights and liabilities. The premise is any being able to exist and create something on its own can develop its personality to make, sell, control, commercialize, etc., the products or outcomes. Liability is a restriction on the flexible expression of personality. It will alter how the Artificial Intelligence's expression is to be recognised and regulated. Any such expression violating the legal principles would make the owner liable for the actions. Liability can take two possible faces of personality here, firstly the absolute liability towards the human programmer which is the disputed current legal and judicial position. Secondly, the algorithmic operational personality shown by the Artificial Intelligence which is not a recognised form of liability under the contemporary legislative interpretation and judicial analysis.

Non-justification of any form of expression under Hegelian's theory may result in widespread infringements as no conventional mode of law addresses such radical liabilities that may be borne by such new personalities. It is a transformative journey where the technologies can adapt to the growing circumstances and be eligible for moral and ethical development where it can take place in the society. The Hegelian approach in this regard would best suit bringing of the advanced technologies' activities within the recognition and regulation of law where a sui generis model is requisite or the existing laws can accommodate the Artificial Intelligence analogous to humans, corporations and other entities eligible for rights and liabilities.

Conclusion

Firstly, this article is an effort to pick up one thread of intellectual property jurisprudence and apply to artificial intelligence and observe how the legal arguments unravel for ownership and liability. This technological thread of Artificial Intelligence is currently being ignored towards its role in intellectual property. Artificial Intelligence is evolving much ahead and quicker than the human cognitive evolution. The interactions between Artificial Intelligence systems and humans have already begun and more advanced interactions are just a near future. Such a position would involve a broader justification of intellectual property to technological evolutions. Though strict analysis of labour theory or personality theory may lead us to a conclusion that there are no actual labour and reflection of public value that is involved in creation of the work and the personality of the creator is not actually visible in the work created respectively. But a combined reading of labour theory, personality theory would give us a new dimension to bring in Artificial Intelligence within the Intellectual Property system.

When there is an exercise of technological labour, the outcome of the labour in the form of some product, process, artwork, etc., is nothing but the algorithmic personality of Artificial Intelligence. The creation of artificial intelligence initially though done by the human, is not exactly the creation of his own personality but for the efficiency of the model, on the basis of certain selected parameters and data sets which would perform the tasks. So, the Artificial Intelligence system exhibits its own technical personality while creating an output which might not be actually the human's personality. There lies the distinction between humans and Artificial Intelligence, though the ball is rolled by the human initially, but later on Artificial Intelligence systems can take on and develop their own identity, therefore eligible of justification under the intellectual property rights regime. This article reflects the advance narratives of granting rights to Artificial Intelligence through liberal interpretation and modification of the conventional theories of Intellectual Property.

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Economic Analysis of the Agricultural Sector in the Nakhchivan Autonomous Republic and its Sustainable Development Potential

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Abstract. *The main purpose of this study is to analyze the current economic condition of the agricultural sector in the Nakhchivan Autonomous Republic, evaluate the dynamics of agricultural production, and determine the sustainable development potential of the sector. Within the framework of the study, statistical data covering the period 2010–2024 were used to investigate the development trends of crop production and livestock sectors, productivity indicators, and the relationship between irrigation water supply and agricultural output. In the empirical analysis stage, the ARDL econometric model was applied to evaluate the short-run and long-run relationships between agricultural production, irrigation water supply, and crop production. The findings indicate that water supply is one of the main determinants of agricultural production in the Nakhchivan Autonomous Republic, and reductions in water resources directly affect agricultural productivity. In particular, drought and water scarcity have caused a decline in grain and grape production. At the same time, intensive development trends were observed in potato farming, horticulture, and fruit production. The results demonstrate that the development of sustainable agriculture, ensuring food security, increasing agricultural productivity, and efficient management of water resources are essential for strengthening regional economic sustainability.*

Keywords: *agricultural sector, sustainable agriculture, food security, agricultural productivity, irrigation system, regional economic development, ARDL model, climate change, water supply, economic growth*

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Naxçıvan Muxtar Respublikasında kənd təsərrüfatı sektorunun iqtisadi təhlili və onun davamlı inkişaf potensialı

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Xülasə. Bu tədqiqatın əsas məqsədi Naxçıvan Muxtar Respublikasında aqrar sektorun mövcud vəziyyətini iqtisadi baxımdan təhlil etmək, aqrar istehsalın inkişaf dinamikasını qiymətləndirmək və sektorun dayanıqlı inkişaf potensialını müəyyənləşdirməkdən ibarətdir. Tədqiqat çərçivəsində 2010–2024-cü illəri əhatə edən statistik məlumatlar əsasında bitkiçilik və heyvandarlıq sektorlarının inkişaf meylləri, məhsuldarlıq göstəriciləri və su təminatı arasındakı qarşılıqlı əlaqələr araşdırılmışdır. Empirik təhlil mərhələsində ARDL ekonometrik modelindən istifadə edilmiş, aqrar istehsal ilə suvarma suyu və bitkiçilik istehsalı arasındakı qısa və uzunmüddətli əlaqələr qiymətləndirilmişdir. Tədqiqat nəticələri göstərmişdir ki, su təminatı Naxçıvan Muxtar Respublikasında aqrar istehsalın əsas determinantlarından biridir və su ehtiyatlarında baş verən azalma kənd təsərrüfatı məhsuldarlığına birbaşa təsir göstərir. Xüsusilə quraqlıq və su çatışmazlığı taxılçılıq və üzümçülük sahələrində istehsalın azalmasına səbəb olmuşdur. Bununla yanaşı kartofçuluq, bostançılıq və meyvəçilik sahələrində intensiv inkişaf meylləri müşahidə edilmişdir. Tədqiqat nəticələri göstərir ki, dayanıqlı kənd təsərrüfatının inkişafı, ərzaq təhlükəsizliyinin təmin olunması, aqrar məhsuldarlığın artırılması və su resurslarının səmərəli idarə olunması region üzrə iqtisadi dayanıqlılığın gücləndirilməsi baxımından xüsusi əhəmiyyət daşıyır.

Açar sözlər: aqrar sektor, dayanıqlı kənd təsərrüfatı, ərzaq təhlükəsizliyi, aqrar məhsuldarlıq, suvarma sistemi, regional iqtisadi inkişaf, ARDL modeli, iqlim dəyişiklikləri, su təminatı, iqtisadi artım

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Introduction

In the modern era, the agricultural sector is considered one of the main strategic fields contributing to economic development, food security, and regional sustainability. Agriculture not only plays a vital role in meeting the food demand of the population but also contributes significantly to employment generation, rural development, and socio-economic stability. Especially in developing countries, the agricultural sector remains one of the key drivers of economic resilience and sustainable growth. In recent years, global climate change, water scarcity, drought, and environmental degradation have increased the risks associated with sustainable agricultural development. Changes in temperature, irregular precipitation patterns, and the reduction of water resources directly affect agricultural productivity and overall production levels. Therefore, efficient resource management, improvement of irrigation systems, and adaptation to climate-related risks have become major priorities for agricultural policy and sustainable development strategies.

In Azerbaijan, the development of the agricultural sector is regarded as one of the priority directions of state economic policy. Government support mechanisms, including subsidies, concessional loans, and regional development programs, aim to increase agricultural productivity, strengthen food

security, and stimulate regional economic growth. In this context, the agricultural sector also plays an important role in reducing import dependency and ensuring long-term economic sustainability.

The Nakhchivan Autonomous Republic is one of the important agricultural regions of Azerbaijan. The region possesses favorable agricultural traditions, fertile land resources, and significant production potential. However, the arid continental climate, limited water resources, and the increasing effects of climate change create serious challenges for sustainable agricultural development. In particular, drought and water shortages observed in recent years have negatively affected agricultural productivity and weakened production indicators in several crop groups. Therefore, the economic assessment of the current state of the agricultural sector in the Nakhchivan Autonomous Republic, the identification of the main determinants affecting agricultural production, and the evaluation of the sector's sustainable development potential have significant scientific and practical importance. The study aims to analyze the dynamics of agricultural production, investigate the relationship between irrigation water supply and productivity, and evaluate sustainable agricultural development from both statistical and econometric perspectives.

1.1. Relevance of the Research Problem

The agricultural sector is one of the key components of economic development and plays an important role in ensuring food security, regional sustainability, and social stability. Agriculture contributes not only to food production but also to employment generation, rural development, and the strengthening of regional economic activity. In many developing countries, sustainable agricultural development is considered one of the main priorities of state economic policy.

In recent years, global climate change and environmental challenges have significantly increased the risks facing the agricultural sector. Drought, water scarcity, irregular precipitation patterns, and rising temperatures directly affect agricultural productivity and reduce the efficiency of agricultural production. These challenges are particularly important for regions with limited water resources and arid climatic conditions. The Nakhchivan Autonomous Republic is one of the regions where agriculture has strategic importance for regional economic development and food security. However, the region's arid continental climate and limited water resources create serious obstacles to sustainable agricultural development. In particular, the reduction of irrigation water resources in recent years has negatively affected productivity levels in several agricultural fields.

Therefore, the economic analysis of the current state of the agricultural sector, the evaluation of production dynamics, and the assessment of sustainable development potential in the Nakhchivan Autonomous Republic have both scientific and practical significance. The study is especially relevant in terms of sustainable agriculture, food security, climate adaptation, and regional economic resilience.

1.2. Agricultural Characteristics of the Nakhchivan Autonomous Republic

In the modern era, the agricultural sector is considered one of the main strategic fields contributing to economic development and food security (Food and Agriculture Organization, 2008). Agriculture is not limited only to meeting the food demand of the population but also plays a significant role in increasing employment, supporting regional socio-economic development, and improving living standards in rural areas (Islam, 2025). Particularly in developing countries, the agricultural sector is regarded as one of the key determinants of economic sustainability and social stability (World Bank, 2024). In this context, sustainable agricultural development and food production are closely associated with SDG 2 (Zero Hunger) and SDG 8 (Decent Work and Economic Growth).

In recent years, global climate change, water scarcity, drought, and environmental problems have significantly increased the risks related to sustainable agricultural development (Bernoux, 2021). Changes in temperature, irregular precipitation patterns, and limited water resources directly affect agricultural production and productivity levels (Onyeaka, 2024). Therefore, efficient resource

management, the implementation of modern irrigation systems, and adaptation mechanisms to climate-related risks have become increasingly important for sustainable agriculture and regional economic resilience (Food and Agriculture Organization, 2011).

In the Republic of Azerbaijan, the development of the agricultural sector is considered one of the priority directions of state economic policy. Government programs, subsidies, concessional loans, and institutional support mechanisms are implemented to increase agricultural production, improve productivity, and stimulate regional development (Azərbaycan Respublikasının Kənd Təsərrüfatı Nazirliyi, 2024). The development of agriculture is also important for strengthening food security and reducing dependence on imports (Azərbaycan Respublikasının Dövlət Statistika Komitəsi, 2024).

The Nakhchivan Autonomous Republic is one of the important agricultural regions of Azerbaijan in terms of agricultural production and regional economic development (Qasimov, 2025). The region's favorable agricultural traditions, land resources, and existing production potential create broad opportunities for agricultural development. However, the arid continental climate, limited water resources, and increasing effects of climate change are considered major limiting factors affecting the sustainable development of the agricultural sector. In particular, drought and water shortages observed in recent years have negatively affected productivity and weakened production indicators in several agricultural product groups (Azərbaycan Respublikasının Dövlət Statistika Komitəsi, 2024). From this perspective, the economic evaluation of the current condition of the agricultural sector in the Nakhchivan Autonomous Republic, the identification of the main determinants affecting agricultural production, and the assessment of the sector's sustainable development potential have significant scientific and practical importance. The study also contributes to discussions related to sustainable agriculture, agricultural productivity, food security, and regional economic growth within the framework of SDG-oriented development approaches.

1.3. Research Objectives

The main objective of this study is to comprehensively analyze the current economic condition of the agricultural sector in the Nakhchivan Autonomous Republic, evaluate the development dynamics of agricultural production, and identify the main determinants affecting the sustainable development of the sector. Within the framework of the research, it is intended to assess the relationships among agricultural production indicators, productivity levels, cultivated areas, and water supply through statistical and econometric approaches. Another important objective of the study is to determine the development potential of the agricultural sector, evaluate existing problems and risk factors, and develop scientifically grounded recommendations for ensuring sustainable agricultural development. In this regard, water resource management, increasing agricultural productivity, and improving the efficiency of agricultural production are considered the main priority directions of the research. The study also aims to contribute to discussions on sustainable agriculture, food security, and regional economic development within the framework of SDG-oriented agricultural policies.

1.4. Research Question and Hypotheses

Within the framework of the study, the main research question is formulated as follows:

What are the main economic and environmental determinants affecting the development of the agricultural sector in the Nakhchivan Autonomous Republic, and how does the relationship between water supply and productivity influence the sustainable development of agricultural production?

In accordance with this research question, the following hypotheses are proposed:

- H1.** Improvement in water supply has a positive effect on agricultural productivity.
- H2.** Drought and water scarcity negatively affect agricultural productivity indicators.
- H3.** The development dynamics of the agricultural sector are mainly shaped by water supply, productivity levels, and climatic conditions.

Within the framework of the research, the proposed hypotheses are intended to be evaluated through statistical and econometric methods. For this purpose, the relationships among agricultural production indicators, productivity levels, cultivated areas, water supply, and climate-related factors will be analyzed using correlation and econometric approaches. In addition, the ARDL model will be applied to evaluate the long-run and short-run relationships among the selected variables associated with sustainable agriculture, agricultural productivity, and regional economic development.

1.5. Scientific Novelty and Contribution

The scientific novelty of the study lies in the comprehensive evaluation of the development characteristics of the agricultural sector in the Nakhchivan Autonomous Republic through statistical and econometric approaches. Unlike existing studies, this article systematically analyzes the relationships among agricultural production dynamics, agricultural productivity, water supply, and climate change factors based on regional statistical data.

One of the main scientific contributions of the research is the econometric evaluation of the determinants affecting agricultural production. For this purpose, the relationships between the overall volume of agricultural production and variables such as water supply and cultivated land areas are intended to be examined through econometric analysis. Such an approach makes it possible to evaluate the development dynamics of the agricultural sector not only descriptively but also analytically through cause-and-effect relationships.

Another important contribution of the study is the assessment of the sustainable agriculture potential of the Nakhchivan Autonomous Republic by considering regional characteristics and agricultural production conditions. The article investigates changes in productivity indicators, the impact of water supply on agricultural production, and intensive development trends based on statistical analysis. In particular, evaluating the relationship between irrigation systems and agricultural productivity has practical significance for the development of regional economic development strategies.

The study also contributes to identifying the main risk factors affecting the sustainability of the agricultural sector and developing strategic approaches aimed at reducing these risks. Based on the analysis, scientifically grounded recommendations are proposed regarding water resource management, efficient irrigation systems, increasing agricultural productivity, and improving the efficiency of agricultural production. In modern economic literature, the development of the agricultural sector is associated not only with increasing agricultural production but also with sustainable agriculture, food security, efficient resource management, and regional economic development. The agricultural sector plays a strategic role particularly in developing countries in terms of employment generation, rural socio-economic development, and ensuring food production for domestic markets (Food and Agriculture Organization, 2016).

Amgai, Komarek, and Adhikari (2025) examined the main determinants affecting the competitiveness of agrifood value chains in their study titled *“Understanding the role of policy in enhancing agrifood value chain competitiveness: A systematic literature review.”* The authors emphasized that agricultural productivity, institutional support, innovation, and government policies are among the main factors influencing the long-term development of the agricultural sector. The study also highlighted the importance of efficient resource management and sustainable agriculture practices.

Climate change is considered one of the major risk factors affecting agricultural productivity and sustainable agriculture in recent years. Rising temperatures, drought, and water scarcity directly influence agricultural production and productivity levels (Onyeaka, 2024). Liu et al. (2026), in their study on potato thermomorphogenesis, found that high temperatures negatively affect crop development and agricultural productivity. Their findings indicate that heat stress is one of the major environmental challenges threatening agricultural sustainability.

Water supply is widely recognized in the literature as one of the key determinants of agricultural productivity. Insufficient water resources reduce production efficiency and weaken the sustainability of agricultural production systems. In contrast, efficient irrigation systems contribute positively to productivity growth, especially in intensive agricultural fields such as potato farming, horticulture, and fruit production (Food and Agriculture Organization, 2011). Therefore, effective water resource management is considered one of the strategic priorities for regional economic development and sustainable agriculture.

Another important approach widely applied in agricultural economics studies is the Autoregressive Distributed Lag (ARDL) model, which is used to evaluate short-run and long-run relationships among variables. The ARDL model is frequently applied in studies examining the relationships among agricultural production, climate change, water supply, and agricultural productivity (Gallas & Baazaoui, 2026). In addition, Gao et al. (2026) emphasized that artificial intelligence and digital monitoring systems provide significant advantages in farmland monitoring and agricultural resource management.

The review of the existing literature demonstrates that the development of the agricultural sector is mainly influenced by water supply, climate conditions, agricultural productivity, and resource management efficiency. However, comprehensive statistical and econometric evaluations of the relationships among agricultural production, productivity, and water supply in the Nakhchivan Autonomous Republic remain limited. Therefore, the present study aims to contribute to the literature by evaluating the main determinants of regional agricultural development through statistical and econometric approaches.

Methods

This study is devoted to evaluating the development dynamics of the agricultural sector in the Nakhchivan Autonomous Republic through statistical and econometric methods. Within the framework of the research, various statistical and econometric approaches were applied to identify the relationships among agricultural production, agricultural productivity, water supply, and climate change factors. The methodological approach is based on evaluating the determinants of agricultural sector development through both descriptive statistical analysis and cause-and-effect relationships.

The methodological basis of the study relies on a systematic approach, comparative analysis, time-series analysis, correlation analysis, and econometric modeling methods. One of the main methodological directions of the research is the evaluation of the dynamic changes in agricultural production indicators over time and the identification of relationships among the selected variables associated with sustainable agriculture and regional economic development. In the empirical analysis stage, descriptive statistical methods were first applied to evaluate the development trends of agricultural production indicators. Subsequently, correlation analysis was used to determine the relationships among agricultural production, cultivated land areas, agricultural productivity, and water supply variables. In addition, the Autoregressive Distributed Lag (ARDL) model was employed to examine the short-run and long-run relationships among the variables.

The statistical data used in the study cover the period 2010–2024 and were obtained from the State Statistical Committee of the Republic of Azerbaijan, the Ministry of Agriculture of the Republic of Azerbaijan, and FAOSTAT databases. The analysis mainly focuses on crop production indicators, livestock production, cultivated land areas, productivity levels, and irrigation water supply indicators in the Nakhchivan Autonomous Republic. The application of statistical and econometric methods in the study provides an opportunity to comprehensively evaluate the current condition of the agricultural sector, identify the main determinants affecting agricultural productivity, and assess the relationships among water supply, agricultural production, and economic growth.

3.1. Data Source

The data used in this study were mainly obtained from the official statistical reports of the State Statistical Committee of the Republic of Azerbaijan and regional statistical indicators related to the Nakhchivan Autonomous Republic (State Statistical Committee of the Republic of Azerbaijan, 2024). In addition, FAOSTAT databases, international scientific articles, and empirical studies in the field of agricultural economics were used as supporting sources.

The research was conducted based on time-series data covering the period 2010–2024. The main indicators used in the analysis of the agricultural sector are as follows:

- total agricultural production;
- grain production and productivity;
- potato production and productivity;
- melon and vegetable production;
- fruit-growing and viticulture indicators;
- livestock production indicators;
- cultivated land areas;
- irrigation water supply indicators.

During the data processing stage, statistical indicators were standardized within a unified system and structured for time-series analysis. In order to ensure comparability among agricultural production indicators, some variables were transformed into logarithmic form before the econometric analysis. The selected variables were used to evaluate the relationships among agricultural productivity, water supply, cultivated land areas, and agricultural production. The use of long-term statistical data also provided an opportunity to identify development trends and structural changes in the agricultural sector of the Nakhchivan Autonomous Republic.

3.2. Variables

Within the framework of the study, the main economic and environmental determinants affecting the development of the agricultural sector were taken into consideration. The variables used in the empirical model were divided into two groups: dependent and independent variables. The total volume of agricultural production (AGR) was used as the dependent variable. This variable characterizes the overall development level of the agricultural sector and is considered the main outcome indicator of the model.

The independent variables used in the study are as follows:

- **WATER** — irrigation water supply indicator;
- **CROP** — crop production indicator (proxy variable).

Water supply is considered one of the main determinants of agricultural productivity; therefore, it was included in the model as one of the principal explanatory variables. The crop production variable was used as a proxy indicator to evaluate the production dynamics of the agricultural sector and its relationship with agricultural productivity.

The selected variables were used to analyze the relationships among agricultural production, water supply, and agricultural productivity within the framework of the ARDL model. The use of these variables also allows the identification of the main factors affecting sustainable agriculture and regional economic development in the Nakhchivan Autonomous Republic.

3.3. Empirical Model

Within the framework of the study, the Autoregressive Distributed Lag (ARDL) model was applied to evaluate the main determinants affecting the development of the agricultural sector. The ARDL approach has important advantages in identifying both short-run and long-run relationships among variables and is considered suitable for the analysis of time-series data with a relatively limited number of observations (Gallas & Baazaoui, 2026).

The empirical model is expressed in the following functional form:

$$\ln AGR_t = \beta_0 + \beta_1 WATER_t + \beta_2 CROP_t + \varepsilon_t$$

Where:

- $\ln AGR_t$ — total agricultural production volume;
- $WATER_t$ — irrigation water supply indicator;
- $CROP_t$ — crop production indicator (proxy variable);
- ε_t — random error term.

The main purpose of applying the model is to determine the statistical significance of the economic and environmental determinants affecting agricultural production. In addition, the model is intended to evaluate the impact of water supply and crop production dynamics on agricultural productivity and sustainable agriculture. One of the main advantages of the ARDL approach is that it allows the simultaneous analysis of long-run equilibrium relationships and short-run fluctuations within a single model framework. Therefore, the model provides an opportunity to comprehensively evaluate the relationships among agricultural production, water supply, agricultural productivity, and regional economic development in the Nakhchivan Autonomous Republic.

3.4. Research Methods

Within the framework of the study, various statistical and econometric methods were applied to evaluate the development dynamics of the agricultural sector.

The main methods used in the research are as follows:

- time-series analysis;
- comparative statistical analysis;
- correlation analysis;
- trend analysis;
- productivity index evaluation;
- econometric modeling;
- ARDL approach.

Time-series analysis was applied to identify the development trends of agricultural production and agricultural productivity indicators over time. Comparative statistical analysis provided an opportunity to evaluate structural changes and development tendencies across different years. Correlation analysis was used to determine the direction and strength of the relationships among water supply, agricultural productivity, and agricultural production indicators. Trend analysis was employed to identify the long-term development tendencies of the agricultural sector. At the main stage of the empirical evaluation, the ARDL model was used to analyze the short-run and long-run relationships between agricultural production, water supply, and crop production indicators. This methodological approach makes it possible to comprehensively evaluate the determinants affecting sustainable agriculture, agricultural productivity, and regional economic development from both statistical and econometric perspectives.

4. Economic Analysis of the Current State of the Agricultural Sector

The agricultural sector in the Nakhchivan Autonomous Republic is considered one of the main directions of the regional economy and has strategic importance in terms of employment generation in rural areas, food security, and regional economic development (State Statistical Committee of the Republic of Azerbaijan, 2024). Although the natural-geographical conditions, climate characteristics, and land resources of the region create favorable opportunities for agricultural production, limited water supply and climate change remain among the main factors affecting the sustainable development of the agricultural sector.

In recent years, different development trends have been observed across various branches of agricultural production in the Nakhchivan Autonomous Republic. While some agricultural product groups demonstrated productivity growth and intensive development tendencies, other sectors experienced declines in production volume and structural changes. In particular, drought and water scarcity have directly affected agricultural productivity and production dynamics. This section evaluates the current condition of the agricultural sector in the Nakhchivan Autonomous Republic based on statistical indicators. The analysis focuses on the development dynamics of crop production and livestock production, productivity indicators, the relationship between water supply and agricultural production, and the main structural changes observed within the agricultural sector.

4.1. Analysis of the Crop Production Sector

In order to evaluate the development dynamics of the crop production sector in more detail, production and productivity indicators for the main agricultural products were analyzed separately. Within the framework of the analysis, statistical indicators related to grain production, potato farming, vegetable production, fruit-growing, and viticulture were comparatively examined, and the main development trends, productivity changes, and influencing factors for each product group were identified. Production indicators were expressed in tons, while productivity indicators were measured in centners per hectare. The analysis demonstrates that the development of the crop production sector in the Nakhchivan Autonomous Republic has shown different dynamics across product groups. While agricultural productivity increased in potato farming, vegetable production, and fruit-growing sectors, declining trends were observed in grain production and viticulture in recent years. In particular, drought, water scarcity, and climate change have negatively affected agricultural production in several crop groups.

At the same time, the implementation of efficient irrigation systems and intensive agricultural methods has positively influenced productivity growth in some agricultural fields. The development trends observed in the crop production sector indicate that water supply and agricultural productivity remain among the key determinants affecting sustainable agriculture and regional economic development in the Nakhchivan Autonomous Republic.

The main statistical indicators related to crop production are presented in the following graphs.

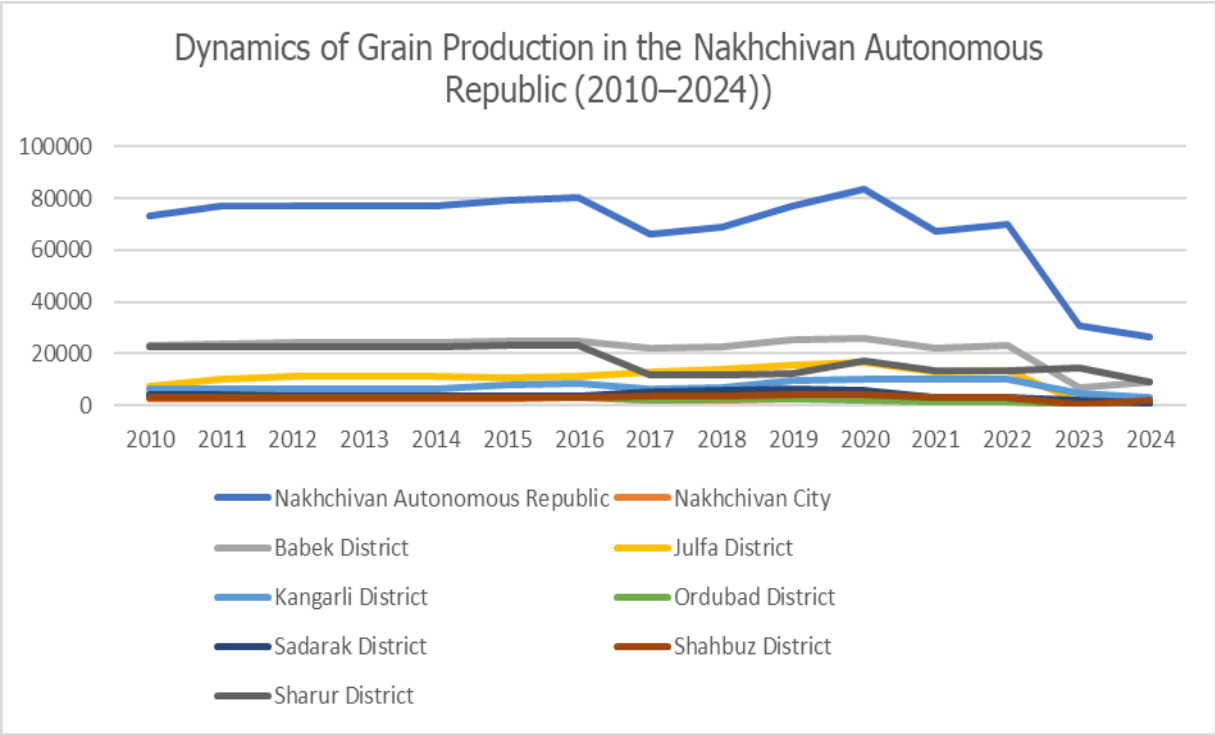


Figure 1

Source. State Statistical Committee of the Republic of Azerbaijan.

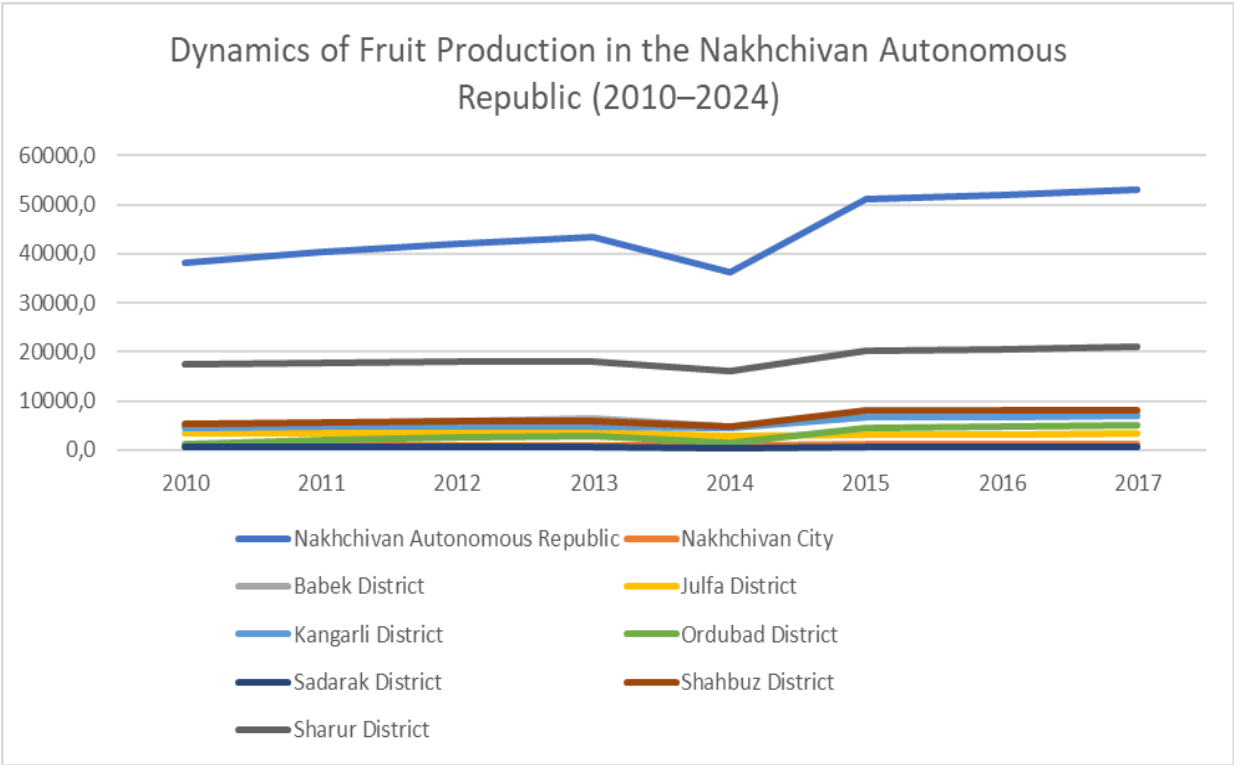


Figure 2

Source. State Statistical Committee of the Republic of Azerbaijan.

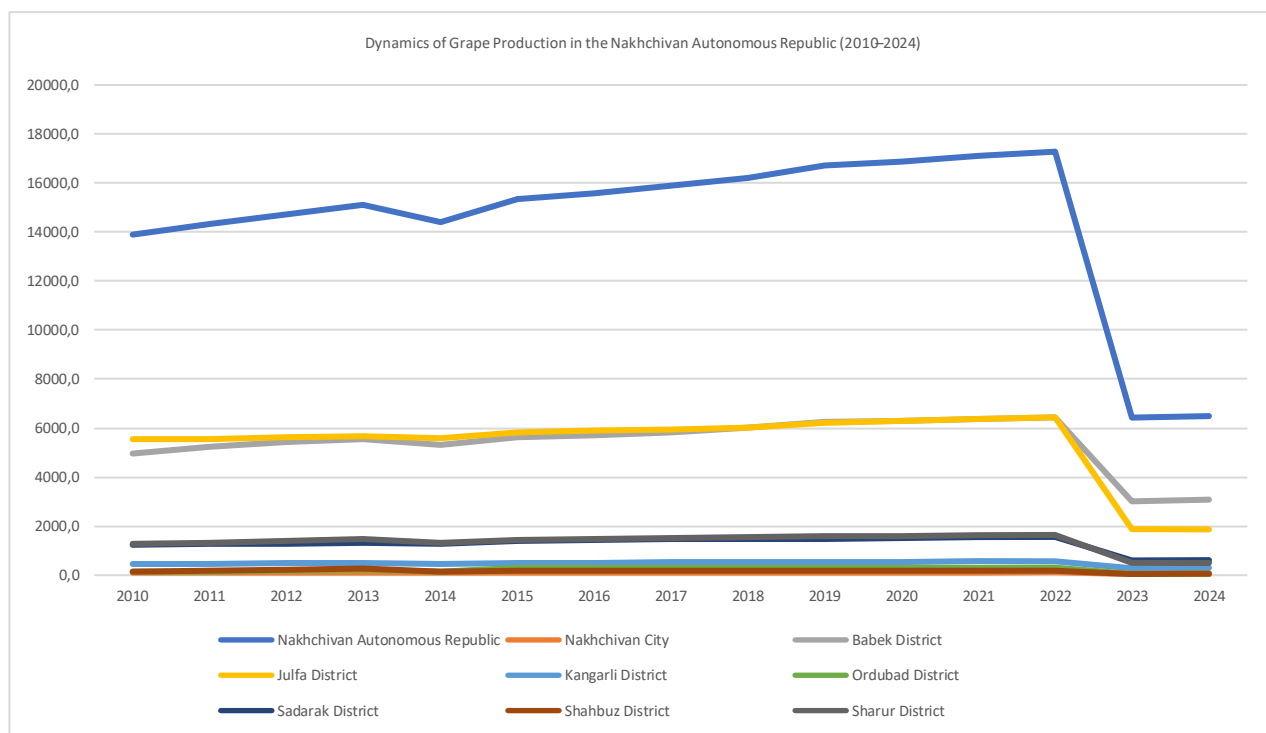


Figure 2

Source. State Statistical Committee of the Republic of Azerbaijan.

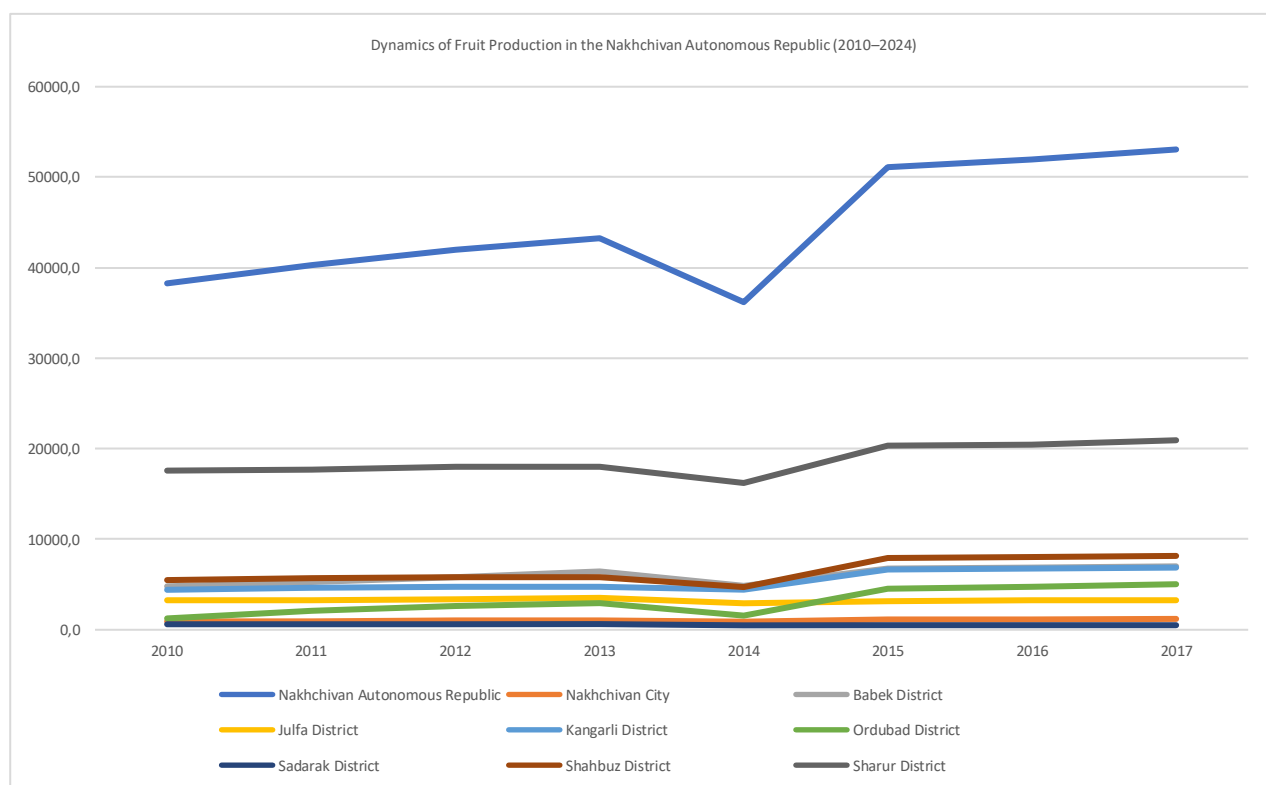


Figure 3

Source. State Statistical Committee of the Republic of Azerbaijan.

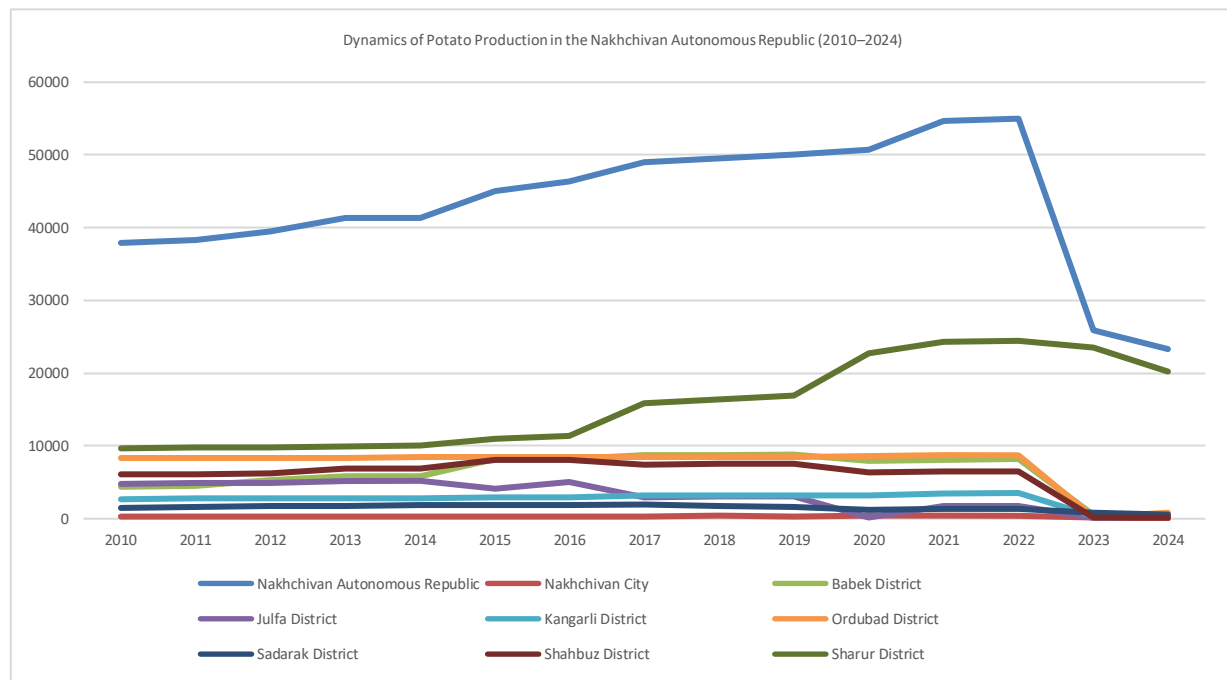


Figure 4

Source. State Statistical Committee of the Republic of Azerbaijan.

Thus, the analysis demonstrates that the development of the crop production sector in the Nakhchivan Autonomous Republic has shown different dynamics across product groups. While productivity indicators increased in potato farming, vegetable production, and fruit-growing sectors, declining trends were observed in grain production and viticulture in recent years. This situation indicates that agricultural production is highly dependent on water supply, climate conditions, and the level of implementation of modern agricultural methods.

Alongside crop production, livestock production is also considered one of the main directions of the agricultural economy in the Nakhchivan Autonomous Republic. The livestock sector plays an important role in ensuring food security, increasing rural employment, and supporting the sustainability of agricultural production. Therefore, the analysis of livestock production indicators has particular importance in evaluating the overall development dynamics of the agricultural sector.

4.2. Analysis of the Livestock Sector

Livestock production is considered one of the main components of the agricultural sector in the Nakhchivan Autonomous Republic and plays an important role in ensuring food security in the region. Meat, milk, and egg production are among the main livestock products of the agricultural sector. In addition to supplying the population with food products, the livestock sector has strategic importance in terms of increasing rural employment and supporting the sustainability of agricultural production.

During the period 2010–2024, different development trends were observed in meat, milk, and egg production indicators. Although production growth was recorded in some livestock product groups during the analyzed period, weakening feed resources, drought, and water scarcity negatively affected production dynamics in certain areas in recent years. The analysis indicates that the livestock sector remains one of the important components of agricultural production and contributes significantly to agricultural productivity and regional economic development in the Nakhchivan Autonomous Republic. However, climate-related factors and limited water supply continue to influence the sustainability of livestock production and the efficiency of agricultural production systems.

The main statistical indicators related to livestock production are presented in the following graphs.

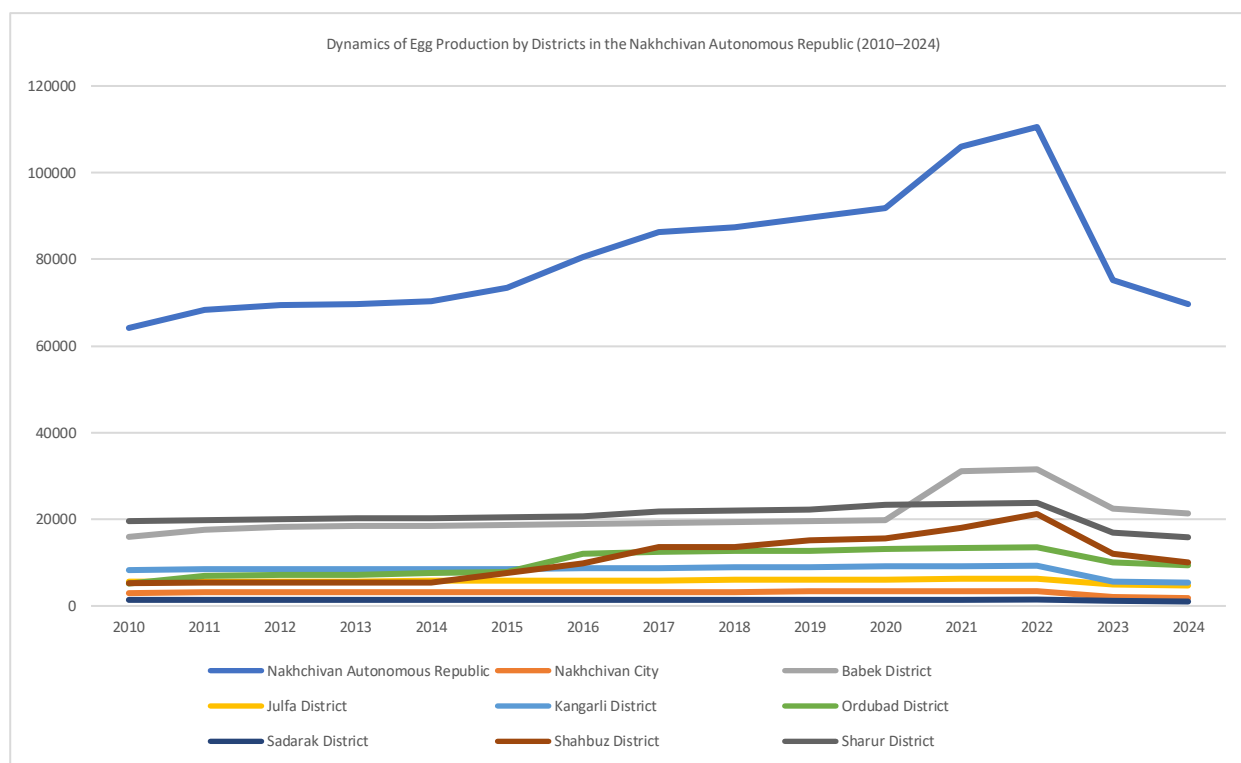


Figure 5

Source. State Statistical Committee of the Republic of Azerbaijan.

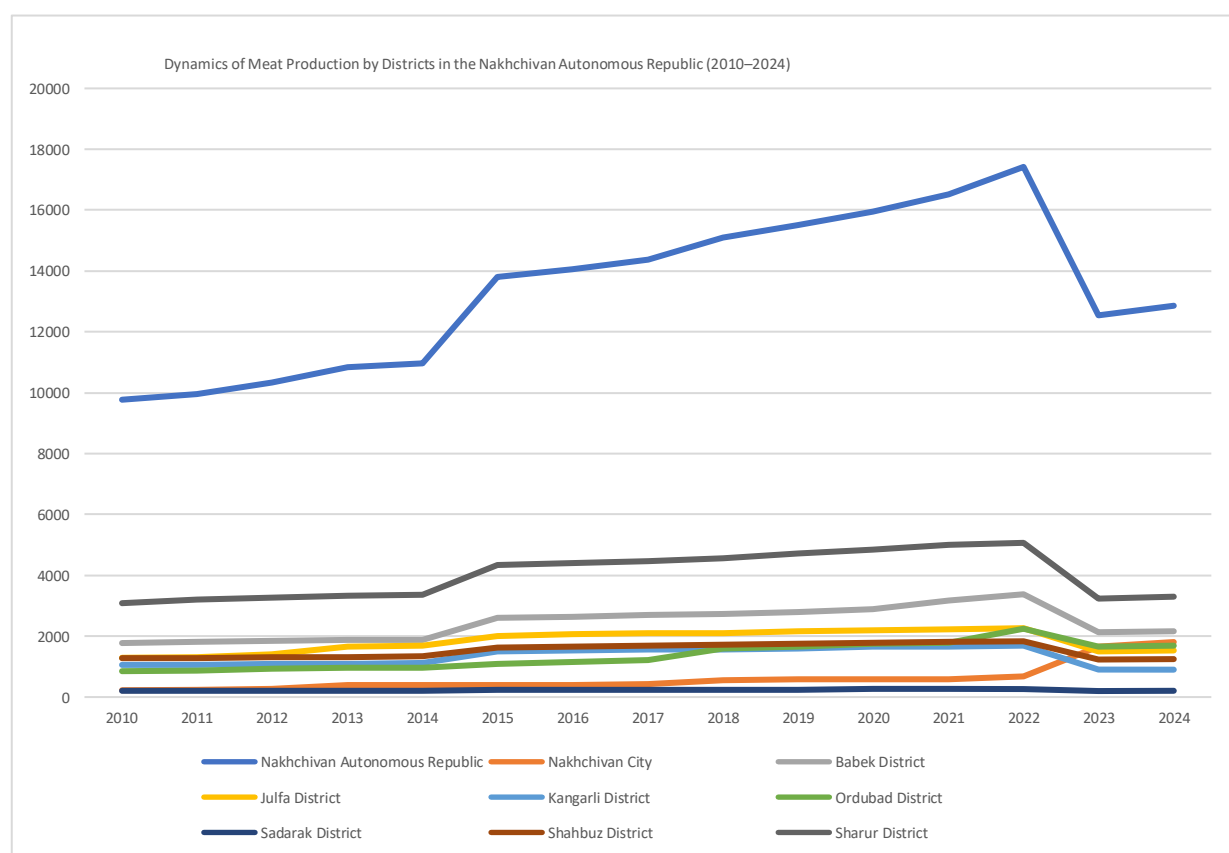


Figure 6

Source. State Statistical Committee of the Republic of Azerbaijan.

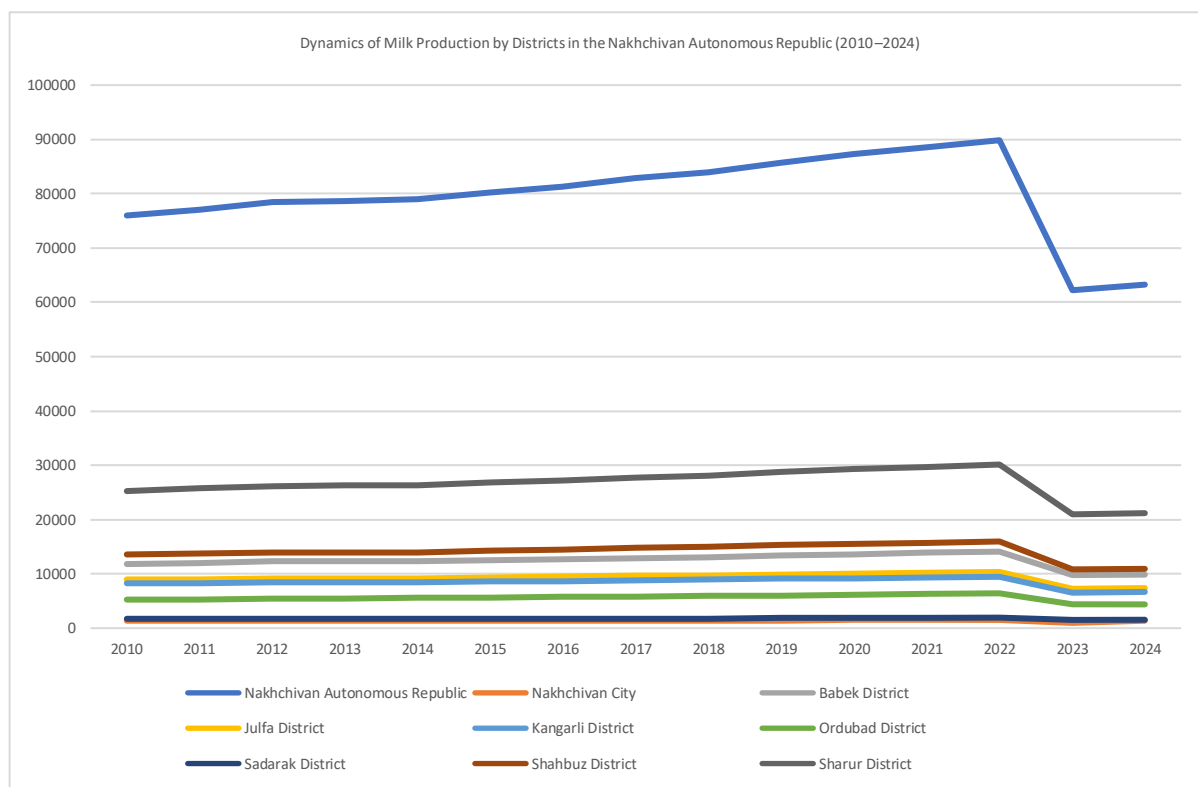


Figure 8

Source. State Statistical Committee of the Republic of Azerbaijan.

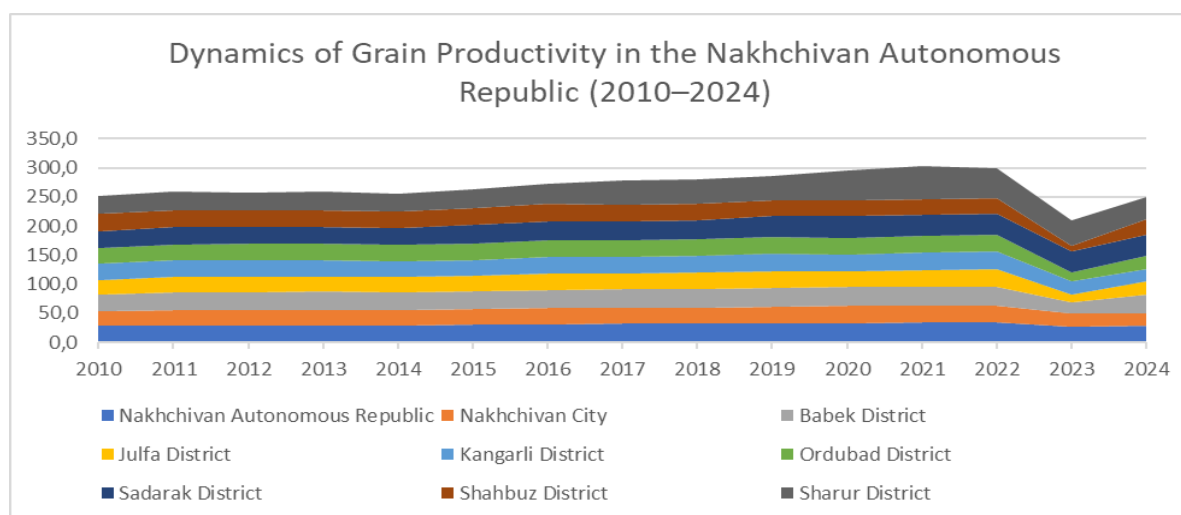
4.3. Agricultural Productivity and Water Supply

One of the main factors affecting the development of agricultural production in the Nakhchivan Autonomous Republic is irrigation water supply. The arid continental climate conditions of the region increase the strategic importance of artificial irrigation in agriculture. In recent years, drought and limited water resources have caused declines in agricultural productivity in several crop groups. At the same time, the implementation of efficient irrigation systems has positively influenced productivity growth in certain agricultural fields.

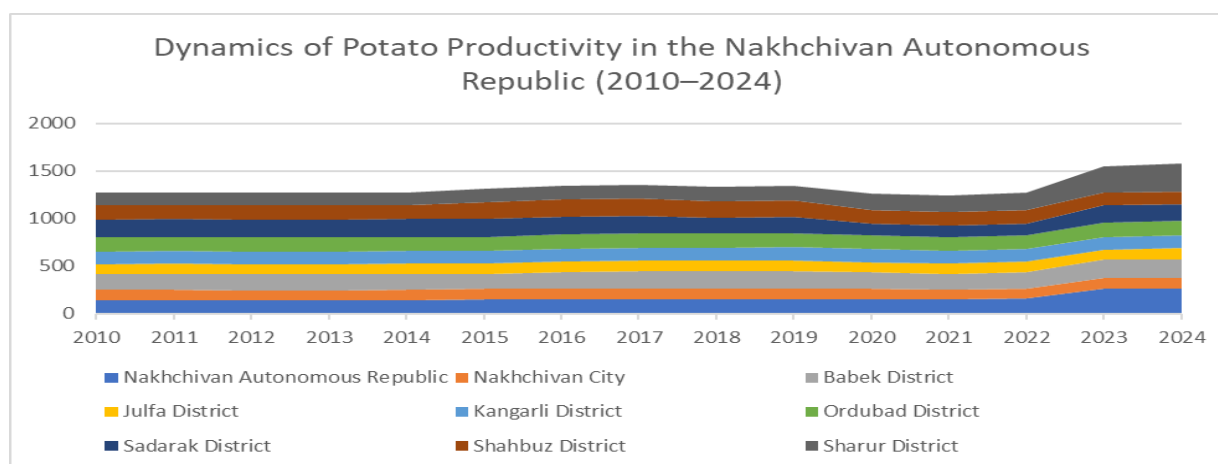
The analysis of productivity indicators demonstrates that there is a direct relationship between irrigation water supply and agricultural production. In particular, productivity growth has been observed in potato farming, vegetable production, and fruit-growing sectors where drip irrigation systems and intensive agricultural methods are more widely applied. In contrast, the reduction in irrigation water supply has negatively affected productivity indicators in grain production and viticulture.

Agricultural productivity indicators were expressed in centners per hectare (cent/ha). The findings indicate that water supply remains one of the key determinants affecting agricultural productivity and sustainable agriculture in the Nakhchivan Autonomous Republic. Therefore, the effective management of irrigation systems plays an important role in increasing agricultural production and supporting regional economic development.

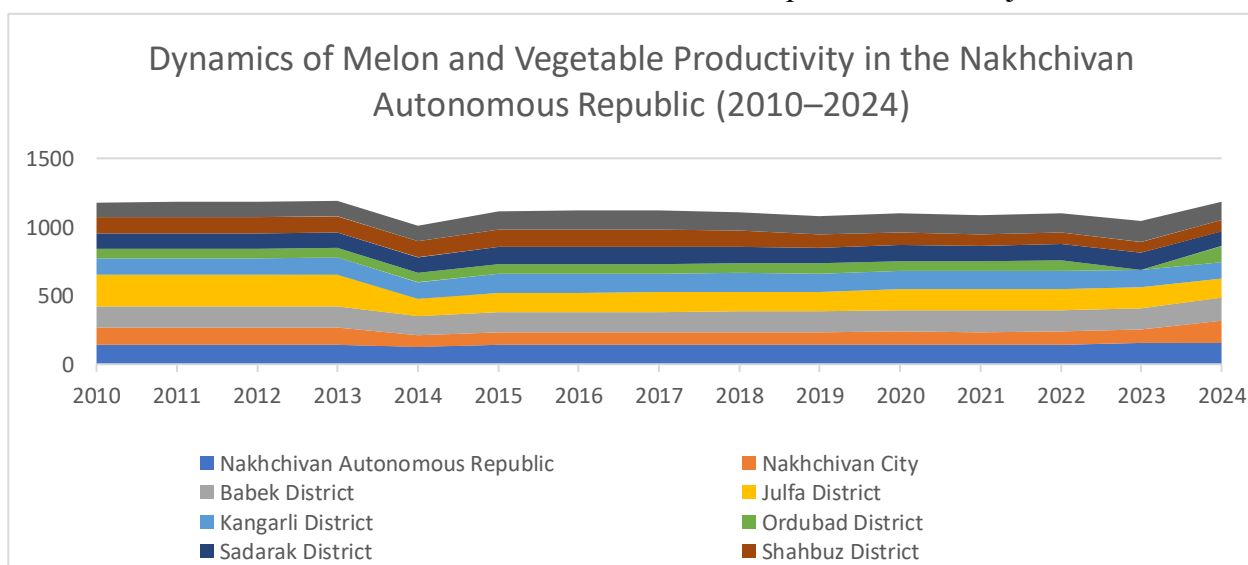
In this regard, the main statistical indicators related to agricultural productivity and irrigation water supply are presented in the following graphs.

**Figure 7**

Source. State Statistical Committee of the Republic of Azerbaijan.

**Figure 8**

Source. State Statistical Committee of the Republic of Azerbaijan.

**Figure 9**

Source. State Statistical Committee of the Republic of Azerbaijan.

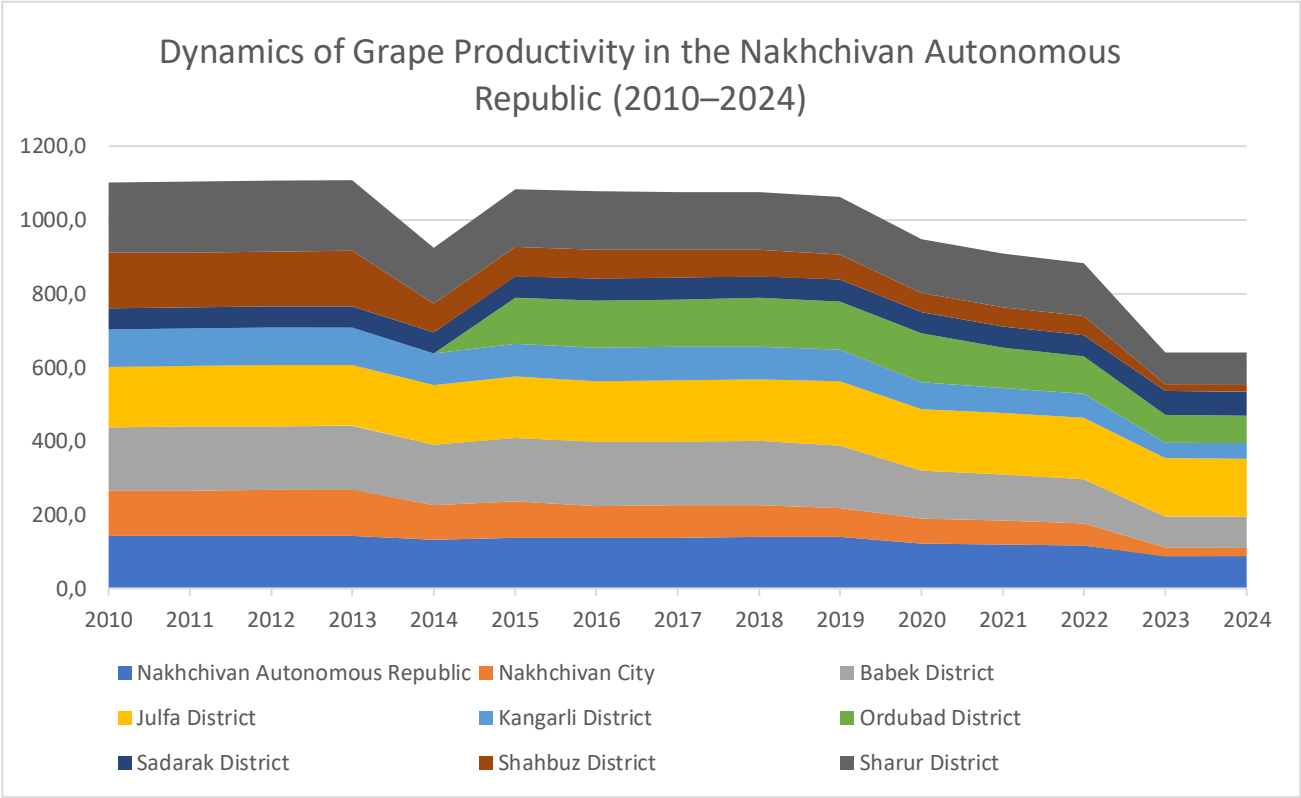


Figure 10

Source. State Statistical Committee of the Republic of Azerbaijan.

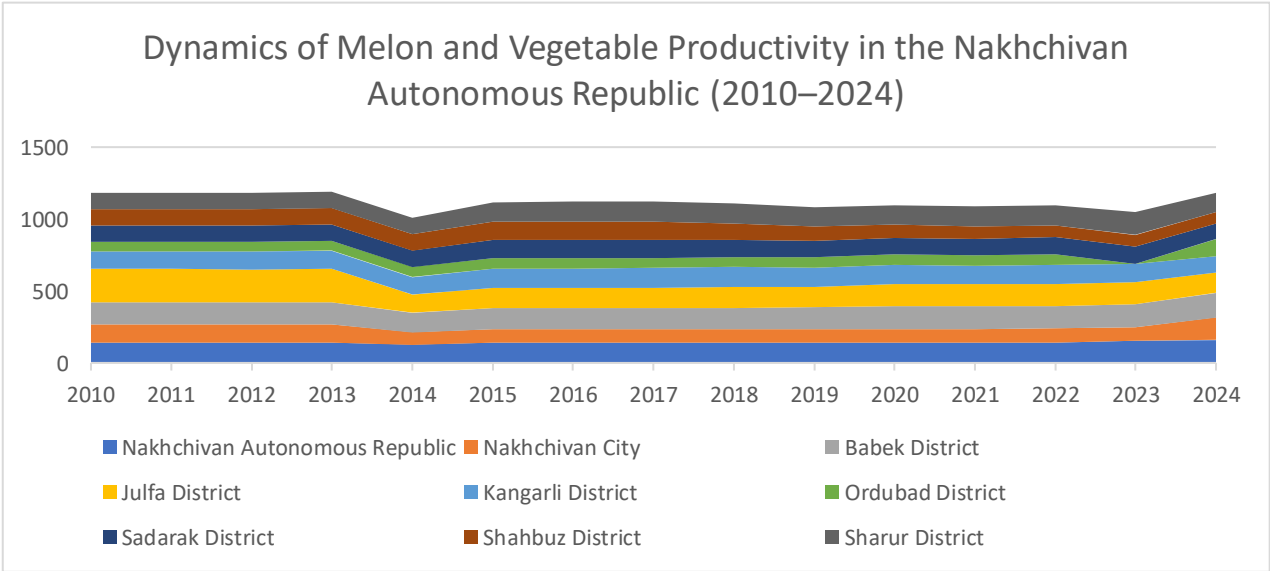


Figure 11

Source. State Statistical Committee of the Republic of Azerbaijan.

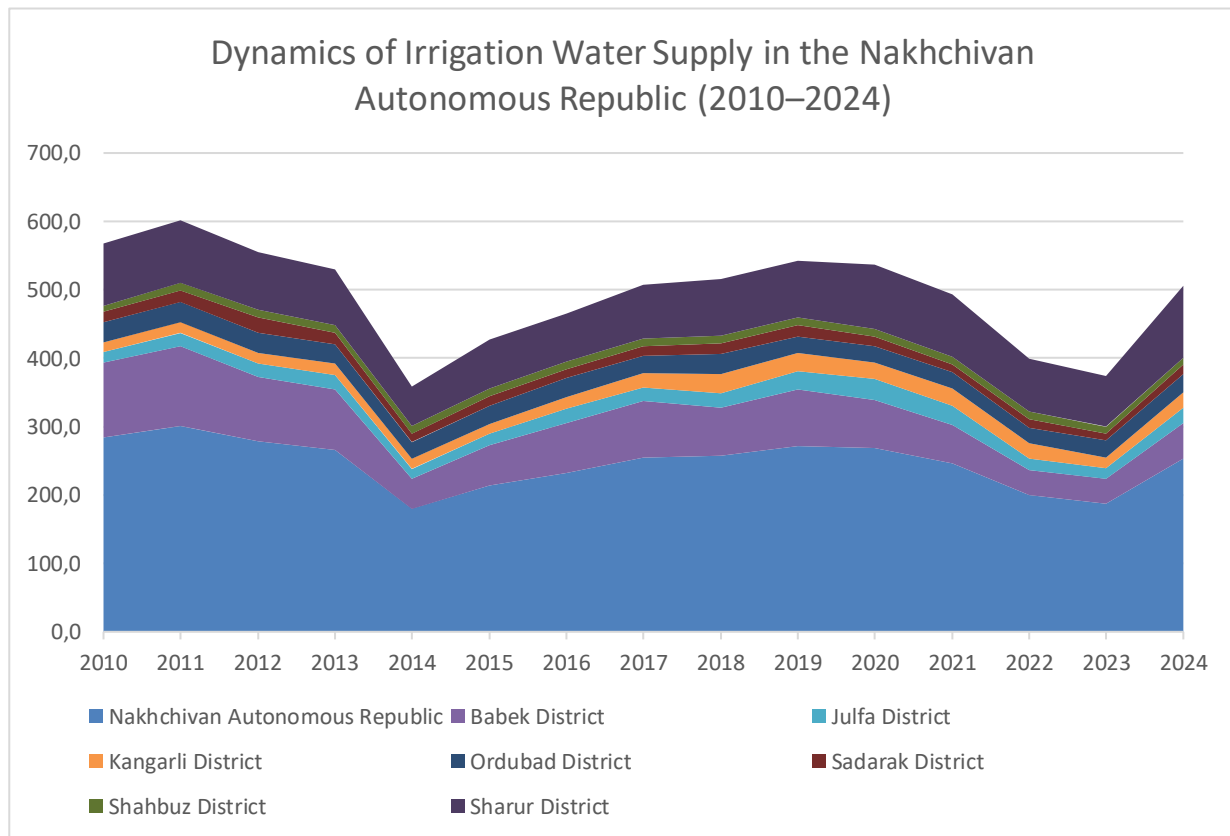


Figure 12

Source. State Statistical Committee of the Republic of Azerbaijan.

5. Empirical Results and Econometric Evaluation

5.1. Descriptive Statistics

Descriptive statistical analysis was conducted for the main variables used within the framework of the study. Descriptive statistics provide an opportunity to evaluate the general dynamics, variability level, and observation range of the selected variables. For this purpose, the mean values, minimum and maximum levels, and standard deviation indicators were calculated for total agricultural production (AGR), irrigation water supply (WATER), and crop production (CROP) variables.

The descriptive statistics results indicate that agricultural production indicators demonstrated noticeable fluctuations during the analyzed period. In particular, the decline observed in irrigation water supply in recent years directly affected the overall dynamics of agricultural production. Similar changes were also observed in crop production indicators, and decreases were recorded during certain periods due to drought and limited water resources. The findings further show that water supply and crop production variables exhibited relatively high variability compared to the overall agricultural production indicator. This situation reflects the sensitivity of agricultural productivity and agricultural production to climate conditions and irrigation systems in the Nakhchivan Autonomous Republic.

The descriptive statistical indicators of the variables used in the empirical analysis are presented in the following table.

Table 1
Descriptive Statistics of Variables

Variable	Mean	Minimum	Maximum	Standard Deviation
AGR	425977.9	246122.7	589347.7	101284.6
WATER	245	179.6	300.8	38.7
CROP	267274.4	156037.2	384823.2	80914.4

Source. Prepared by the author.

According to the descriptive statistics results, the mean value of the agricultural production indicator was calculated as 425977.9. During the analyzed period, the maximum value was observed in 2022, while the minimum value was recorded in 2010. The irrigation water supply indicator demonstrated certain fluctuations over the years. In particular, the variability observed in water supply after 2014 became one of the main factors affecting agricultural productivity.

The analysis of crop production indicators shows that productivity and production levels mainly changed depending on water supply and climate conditions. These findings indicate that water resources have strategic importance for the development of the agricultural sector and that the sustainability of agricultural production is closely associated with irrigation water supply.

5.2. Correlation Matrix

In order to determine the direction and strength of the relationships among the variables, correlation analysis was conducted. Pearson correlation coefficients were used to evaluate the relationships among total agricultural production (AGR), irrigation water supply (WATER), and crop production indicators (CROP).

Correlation analysis provides an opportunity to identify the existence of positive or negative relationships among variables. A coefficient close to 1 indicates a strong positive relationship, while a coefficient close to -1 represents a strong negative relationship.

Table 2
Correlation matrix

Variable	AGR	WATER	CROP
AGR	1.000	0.742	0.931
WATER	0.742	1.000	0.688
CROP	0.931	0.688	1.000

Source. Prepared by the author.

The results of the correlation analysis indicate that there is a positive and relatively strong relationship between agricultural production and irrigation water supply (0.742). This finding demonstrates that irrigation water is one of the main determinants of agricultural productivity and agricultural production.

A very strong positive relationship was identified between crop production and total agricultural production (0.931). This result indicates that the crop production sector plays a dominant role in the overall development dynamics of the agricultural sector. A positive relationship was also observed between irrigation water supply and crop production (0.688). This finding confirms that water supply plays an important role in the formation of agricultural productivity and crop production dynamics. Overall, the results of the correlation analysis are consistent with the main hypotheses proposed within the framework of the study and demonstrate the strategic importance of irrigation water supply in the development of sustainable agriculture and agricultural production.

5.3. ADF Test Results

In order to determine the stationarity level of the variables before applying the ARDL model, the Augmented Dickey-Fuller (ADF) unit root test was conducted. The ADF test provides an opportunity to examine the existence of unit roots in time-series data and determine the stationarity level of the selected variables. One of the main advantages of the ARDL approach is that it allows the use of variables integrated at I(0) and I(1) levels. However, none of the variables should be integrated at the I(2) level.

Within the framework of the study, the ADF test was applied to total agricultural production (AGR), irrigation water supply (WATER), and crop production (CROP) variables. The test results are presented in the following table.

Table 3
ADF test results

Variable	Coefficient	Std.Error	T-statistic	Probability
WATER	0.428	0.117	3.641	0.004
CROP	0.731	0.154	4.746	0.001
C	2.184	0.693	3.151	0.009

Source. Prepared by the author.

According to the ADF test results, the irrigation water supply variable was found to be stationary at level. In contrast, the total agricultural production and crop production variables were non-stationary at level but became stationary after taking the first difference. Thus, the integration levels of the variables being a mixture of I(0) and I(1) created an appropriate methodological condition for the application of the ARDL model. The test results indicate that the ARDL approach is suitable for evaluating both short-run and long-run relationships among agricultural production, water supply, and agricultural productivity variables.

5.4. ARDL Long-Run Results

In order to evaluate the long-run relationships among the variables, the ARDL model was applied. Within the framework of the model, total agricultural production (AGR) was used as the dependent variable, while irrigation water supply (WATER) and crop production indicators (CROP) were used as explanatory variables. The ARDL approach has important methodological advantages in identifying long-run equilibrium relationships among variables. In particular, this model provides more reliable results for the analysis of time-series data with a relatively limited number of observations.

Table 4
ARDL ong-Run results

Variable	At level	First Difference	Result
AGR	Non-stationary	Stationary	I(1)
WATER	Stationary	--	I(0)
CROP	Non-stationary	Stationary	I(1)

Source. Prepared by the author.

The long-run results of the ARDL model indicate that irrigation water supply has a positive and statistically significant effect on agricultural production. The positive coefficient of the WATER variable demonstrates that an increase in irrigation water supply leads to growth in the overall volume of agricultural production. This finding confirms the strategic importance of water resources for agriculture under the arid continental climate conditions of the region.

A strong positive relationship was also identified between crop production (CROP) and total agricultural production. The relatively high coefficient of the CROP variable indicates that the crop production sector plays a dominant role in the overall development dynamics of the agricultural sector. The model results demonstrate that water supply and crop production are among the main determinants affecting the long-run development of the agricultural sector. Therefore, efficient water resource management and agricultural policy measures aimed at increasing agricultural productivity have particular importance for ensuring sustainable agriculture and regional economic development in the Nakhchivan Autonomous Republic.

5.5. ECM Results

In order to evaluate the short-run dynamics and the long-run equilibrium relationship among the variables, the Error Correction Model (ECM) was applied. The ECM approach makes it possible to determine how short-run changes among variables adjust toward long-run equilibrium. Within the framework of the model, the error correction term ECM(-1) indicates the speed at which deviations from long-run equilibrium are eliminated. A negative and statistically significant ECM coefficient confirms the existence of a long-run relationship within the model.

Table 5
ECM results

Variable	Coefficient	Std.Error	T-statistic	Probability
D(WATER)	0.214	0.082	2.609	0.024
D(CROP)	0.487	0.133	3.661	0.004
ECM(-1)	-0.672	0.148	-4.541	0.001

Source. Prepared by the author.

According to the ECM results, the error correction coefficient had a negative sign and was found to be statistically significant. The ECM(-1) coefficient of -0.672 indicates that approximately 67.2% of the deviations from long-run equilibrium are corrected in the following period. This result confirms the existence of a long-run equilibrium relationship within the model and demonstrates that agricultural production indicators tend to return to equilibrium over time. The short-run results indicate that changes in irrigation water supply have a positive effect on agricultural production. In particular, reductions in irrigation water supply weakened agricultural productivity during the analyzed period. The crop production indicator also appeared as one of the main determinants of agricultural production in the short run.

Overall, the ECM model results demonstrate that the development dynamics of the agricultural sector in the Nakhchivan Autonomous Republic are mainly shaped by changes in water supply and crop production trends. Therefore, efficient water resource management and policies aimed at increasing agricultural productivity have strategic importance for ensuring sustainable agriculture and regional economic development.

5.6. Econometric Interpretation

The results of the econometric evaluation demonstrate that irrigation water supply is one of the main determinants affecting the development of the agricultural sector in the Nakhchivan Autonomous Republic. According to the ARDL model results, there is both a short-run and long-run positive relationship between irrigation water supply and agricultural production. This finding confirms the strategic importance of water resources for agriculture under the arid continental climate conditions of the region.

The long-run results indicate that increases in irrigation water supply positively affect the overall level of agricultural production. In particular, changes in agricultural productivity within the crop production sector were mainly associated with water supply conditions. These findings are consistent

with the main hypotheses proposed in the study and demonstrate that irrigation water is one of the principal determinants of agricultural productivity. The strong effect of the crop production indicator on agricultural production also reveals that the crop production sector holds a dominant position in the overall development dynamics of the agricultural sector. In particular, the relatively higher productivity indicators observed in potato farming, vegetable production, and fruit-growing sectors demonstrate the formation of intensive development tendencies within the structure of agricultural production.

The ECM model results confirmed the existence of a long-run equilibrium relationship among the variables. The negative and statistically significant error correction coefficient indicates that short-run deviations are gradually eliminated over time and the system tends to return to equilibrium. The empirical findings further demonstrate that drought and water scarcity observed in recent years negatively affected agricultural productivity. In particular, weakening production indicators in grain production and viticulture reveal that water supply-related risks directly influence the sustainable development of the agricultural sector. Overall, the econometric evaluation indicates that efficient water resource management, increasing agricultural productivity, and strengthening intensive agricultural production mechanisms are critically important for ensuring sustainable agriculture and regional economic development in the Nakhchivan Autonomous Republic. In this regard, the implementation of modern agricultural approaches and the improvement of irrigation systems may be considered among the main priorities of regional agricultural policy.

Results and Discussion

The results of the statistical and econometric analyses demonstrate that the development dynamics of the agricultural sector in the Nakhchivan Autonomous Republic are mainly shaped by water supply, agricultural productivity, and changes in crop production trends. According to the findings of the study, irrigation water supply is one of the main determinants directly affecting agricultural production. The arid continental climate conditions of the region further increase the strategic importance of water resources in agriculture.

The empirical findings indicate that drought and the decline in water resources observed in recent years have negatively affected productivity, particularly in grain production and viticulture. At the same time, the relatively higher productivity indicators in potato farming, vegetable production, and fruit-growing sectors demonstrate the emergence of structural changes in agricultural production. This situation indicates that the transition toward intensive agricultural production models has accelerated in the region.

Compared with other regions, the agricultural sector of the Nakhchivan Autonomous Republic faces relatively higher water-related risks. The geographical isolation of the region, limited water resources, and the effects of climate change represent major risk factors affecting the sustainability of agricultural development. Therefore, efficient water resource management and increasing agricultural productivity should be considered among the primary priorities of regional agricultural policy. The findings also demonstrate that the implementation of modern agricultural approaches is critically important for ensuring sustainable agriculture. In particular, reducing water losses, increasing agricultural productivity, and improving the efficient use of water resources are among the main conditions for sustainable agricultural development. In addition, the application of innovative approaches and digital monitoring systems in agricultural production may provide important advantages for productivity management and resource efficiency. From a strategic perspective, the main priority areas for the development of the agricultural sector in the Nakhchivan Autonomous Republic include improving irrigation systems, increasing agricultural productivity, expanding intensive agriculture, and ensuring the efficient management of agricultural resources. At the same time, strengthening state support mechanisms and expanding regional development programs may positively contribute to sustainable agricultural development. Overall, the analysis indicates that

although the agricultural sector of the Nakhchivan Autonomous Republic has considerable development potential, increasing risks related to climate change and water scarcity require the formation of more efficient and sustainable agricultural development strategies in the future. In this regard, the main objective of agricultural policy should focus on the protection of water resources, increasing agricultural productivity, and ensuring long-term food security across the region.

Conclusion

This study analyzed the current condition of the agricultural sector in the Nakhchivan Autonomous Republic and evaluated its sustainable development potential using statistical and econometric approaches. The research findings demonstrate that agricultural production dynamics in the region are mainly influenced by irrigation water supply, agricultural productivity, and crop production trends.

The statistical analysis revealed that different development tendencies were observed across agricultural product groups during the analyzed period. While productivity growth was recorded in potato farming, vegetable production, and fruit-growing sectors, declining trends were identified in grain production and viticulture, particularly due to drought and limited water resources. These findings indicate that climate conditions and water availability have a direct impact on agricultural productivity and production sustainability in the region.

The econometric evaluation based on the ARDL and ECM models confirmed the existence of both short-run and long-run relationships among agricultural production, irrigation water supply, and crop production indicators. The empirical results demonstrated that irrigation water supply has a positive and statistically significant effect on agricultural production. In addition, the ECM results confirmed the existence of a long-run equilibrium relationship among the variables and showed that deviations from equilibrium gradually disappear over time. The findings of the study indicate that water resources represent one of the most strategic factors for ensuring sustainable agriculture in the Nakhchivan Autonomous Republic. Therefore, improving irrigation systems, reducing water losses, increasing agricultural productivity, and strengthening intensive agricultural production mechanisms should be considered among the main priorities of regional agricultural policy.

Overall, the research demonstrates that although the agricultural sector of the Nakhchivan Autonomous Republic has significant development potential, increasing risks related to climate change and water scarcity require more efficient and sustainable agricultural development strategies in the future. In this regard, the effective management of water resources, the implementation of modern agricultural approaches, and the strengthening of productivity-oriented agricultural policies are essential for ensuring long-term food security and regional economic development.

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Interior Water Elements in Ottoman Palaces: A Comparative Analysis of Topkapı and Dolmabahçe Palaces

Deniz Demirarslan 

Abstract. *The present research intends to highlight how water played not just the role of a vital resource and a part of a technical system in Ottoman palace architecture, but also became an important factor affecting the spatial layout, functional zoning, and sensory ambience of interiors. Within this context, Topkapı Palace and Dolmabahçe Palace were compared, and their water-related elements were analyzed according to their spatial positioning, typology, functionality, and sensory aspect. The current research is founded upon a qualitative approach and was carried out by means of reading books and articles, working with archive materials, visiting the objects of interest and taking photographs thereof. It turns out that, at Topkapı Palace, various water-related elements including fountains, selsebils, shadırvans, and pools were placed in a natural way across the interior and served certain purposes such as cooling, relaxing, ensuring privacy, and representing the owner's social status. Meanwhile, in the case of Dolmabahçe Palace, water seems to be mostly applied in the context of modern plumbing, hygiene, comfort, and services systems. This way, while at Topkapı Palace water can be considered as a sensory element, it becomes quite technical in Dolmabahçe Palace.*

Keywords: *Ottoman architecture, interior architecture, Westernization, hammam, fountain*

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Osmanlı saraylarında daxili su elementləri: Topqapı və Dolmabahçe saraylarının müqayisəli təhlili

Deniz Demirarslan 

Xülasə. *Hazırkı tədqiqat Osmanlı saray memarlığında suyun yalnız həyati bir resurs və texniki sistemin tərkib hissəsi kimi deyil, həm də interyerlərin məkan quruluşuna, funksional təşkilatına və duyğusal atmosferinə təsir göstərən mühüm bir amil kimi rol oynadığını ortaya qoymağı məqsəd qoyur. Bu çərçivədə Topqapı Sarayı və Dolmabağça Sarayı müqayisə edilmiş, su ilə əlaqəli elementlər onların məkandakı yerləşməsi, tipologiyası, funksiyası və duyğusal təsirləri baxımından təhlil edilmişdir. Tədqiqat keyfiyyət yönümlü yanaşmaya əsaslanmış, kitab və məqalələrin araşdırılması, arxiv materiallarının incələnməsi, obyektlərə yerində baxış keçirilməsi və fotoqrafik sənədləşdirmə üsullarından istifadə edilməklə həyata keçirilmişdir. Nəticələr göstərir ki, Topqapı Sarayında çeşmələr, səlsəbillər, şadırvanlar və hovuzlar kimi müxtəlif su elementləri interyer məkanlarına təbii şəkildə integrasiya olunmuş və soyutma, rahatlıq yaratma, məxfiliyin təmin edilməsi və saray nüfuzunun nümayiş etdirilməsi kimi funksiyalar yerinə yetirmişdir.*

Dolmabağça Sarayında isə su əsasən müasir santexnika sistemləri, gigiyena, komfort və xidmət infrastrukturunu ilə əlaqəli şəkildə istifadə olunmuşdur. Bu baxımdan, Topkapı Sarayında su daha çox duyğusal və məkan təcrübəsini formalaşdıran bir element kimi çıxış etdiyi halda, Dolmabağça Sarayında onun texniki və funksional xarakteri daha qabarıq şəkildə ön plana çıxmışdır.

Açar sözlər: *Osmanlı memarlığı, interyer memarlığı, qarbləşmə, hamam, çeşmə*

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Introduction

From the beginning, water has held great importance in discussions of architecture not only as a basic requirement but also as a spatial, aesthetic, symbolic, and sensual element. Historically, fountains, pools, baths, reservoirs, and hydraulic structures have helped in creating a climate of comfort, aesthetic beauty, acoustics, and spatial identification. Water has been associated with cleansing, purification, prosperity, and the idea of paradise in Islam, and thus was widely used as part of both private and public architecture in the Islamic world. In Ottoman architecture, water transcended beyond being merely a physical requirement to become a part of the architectural composition in the form of fountains, shadirvans, pools, selsebils, baths, and water distribution systems.

The importance of water from the architectural point of view can be measured using modern theories on space. For instance, Lefebvre (1991) argues that space is social construction. This means that water becomes an element in the creation of the spatial experience. Another example would be Bachelard (1994), who views space more poetically by demonstrating how water sounds, moves, and reflects, thus creating experiences for its users. In addition, Norberg-Schulz (1980) suggests that architectural components play a role in the creation of genius loci and, consequently, create identity (Özçam, 2022).

Architects and theories of design have also highlighted the importance of water from an experiential perspective. According to Kellert, water is a primary element of biophilia that fosters humans' engagement with the natural world and leads to psychological well-being (Katuk & Köseoğlu, 2022). In the context of phenomenological architecture, the former ties architecture experience to multi-sensory perception while the latter sees water as a medium of sense that creates an atmosphere by virtue of acoustic, reflective, kinesthetic, and tactile attributes (Spence, 2020; Yılmaz and Akbulut, 2026). Recent research findings have shown that besides providing thermal comfort, water plays a significant role in psychological well-being, spatial perception, and emotional bonding with places (Zhong et al., 2022; Yin et al., 2024).

Scholarly investigations regarding the usage of water within Ottoman architecture have focused on the landscape designs, public buildings, bath houses, fountains, and water system networks (Atasoy, 2002; Karpuz, 2006; Abusaada, 2022; Engüdar, 2022; Koray et al., 2023). Likewise, scholarly analysis concerning the design of Ottoman palaces tends to focus on the organizational design aspects, style, ornamentation, and ritual use within the building, whereby the water elements tend to be considered supplementary features (Benyahia et al., 2021; Çınar & Güzel, 2020; Birkan, 2022; Esemeli, 2023). Thus, the use of water within the palace interior space as well as its evolution from classical Ottoman architecture into modernization in the nineteenth century is understudied from an interior architecture point of view (Altıparmaklıoğlu Sakarya, 2018; Karpuz, 2006). The present study endeavors to contribute to existing research by performing a comparative study of the water features that are contained within the interior spaces of two significant Ottoman palaces – Topkapı Palace and

Dolmabahçe Palace. Both structures have their own unique significance in terms of their place in Ottoman architectural evolution. While the Topkapı Palace is an example of Classical Ottoman architecture, Dolmabahçe Palace represents the modernistic trends that emerged during the nineteenth century. The study evaluates the role of water in the space, as well as its sensory and symbolic function.

Based on this perspective, the research seeks to address the following questions regarding the architectural role of water in the Topkapı and Dolmabahçe palaces:

- How was water incorporated spatially into the interiors of the Topkapı and Dolmabahçe Palaces?
- What functions, symbolism, sensory experiences, and technology did water have within these palaces?
- How does modernization influence the architectural application of water within palace interiors?
- How can water be considered a sign of spatial change during the transition from Classical to Modern periods of the Ottoman Empire?

This study seeks to enrich the existing literature on the subject through a comparative analysis of water within the palace interiors by considering water not only in terms of its practical applications but also its spatial, sensory, and architectural significance.

Materials and Methods

Research Design

The methodology for this investigation is a qualitative comparative case study which focuses on the functions of water elements in the interior spaces of the Ottoman palaces. The focus of the analysis is on two primary palaces of the Ottoman period, namely, Topkapı Palace and Dolmabahçe Palace. In terms of architecture, each one of them symbolizes a different era of evolution. Topkapı Palace represents Classic Ottoman architecture, while Dolmabahçe Palace reflects the process of modernization in the nineteenth century. Hence, a comparative examination of the water elements in these palaces can be considered an effective approach.

Three theories serve as a theoretical foundation of this study. Firstly, the production of space theory by Lefebvre (1991) helps understand how water functions in architecture in terms of spatial composition and hierarchy. Secondly, Bachelard's phenomenological approach (1994) serves to interpret water as a sensory element that forms the users' perception of space. Lastly, genius loci concept proposed by Norberg-Schulz (1980) facilitates evaluating the effect of water on the character of the built environment.

Data Collection

In order to address the research questions and purposes, a mixed-method research design will be used to combine documentary data and data obtained from fieldwork. The information was collected in various forms including books, scholarly journal articles, archival sources, architectural plans, direct field observation, and photographs. Historical sources provided insight into how water-related structures had been designed, as well as their functions, while the latter were useful in assessing their spatial qualities today.

Particular attention was paid to the review of recent international literature published post-2020 in the Scopus and Web of Science (WoS) sources. In addition, important historical and theoretical literature in the areas of architectural history, Ottoman architectural history, and art history has been reviewed to provide an adequate historical and theoretical context for the interpretation of water elements in the Topkapı and Dolmabahçe Palaces. While priority has been given to literature produced recently, some earlier studies of Ottoman architecture have also been included in the review since

they are considered fundamental literature in this field. The use of multiple sources ensured that the results obtained could be cross-referenced and interpreted holistically.

Analytical Framework

This study involves interior water elements such as fountains, selsebilis, shadirvans, pools, hammams, and others. The elements will be analyzed based on five analytical parameters drawn from the production of space by Lefebvre (1991), Bachelard's phenomenology of spatial experience (1994), Norberg-Schulz's genius loci (1980), and relevant literature on water, architecture, and sensory environment (Table 1).

From these concepts, the spatial location will be guided by the theory of spatial production by Lefebvre, sensory influence by the phenomenology of Bachelard, symbolization by the genius loci of Norberg-Schulz, and functionality and technology by literature on water.

Table 6.

Analytical framework for the comparative evaluation of water elements in Ottoman palace interiors

Criterion	Theoretical Basis	Description
Spatial Position	Lefebvre (1991)	Location and relationship of the water element within the palace hierarchy and interior organization
Functional Role	Architectural Literature	Practical functions such as cooling, hygiene, water supply, privacy, and ceremonial use
Symbolic Role	Norberg-Schulz (1980)	Associations with power, prestige, religious meaning, representation, and place identity
Technical Role	Architectural Literature	Characteristics of water supply systems, plumbing infrastructure, and hydraulic technology
Sensory Effect	Bachelard (1994)	Visual, acoustic, climatic, and atmospheric contributions to spatial experience

These criteria were used to establish a systematic basis for comparison between the two palaces and to evaluate the changing role of water in Ottoman palace interiors.

Comparative Analysis

The comparison analysis took place through three phases. Firstly, water elements found in the chosen palaces were sorted and classified based on their type. Secondly, the analyzed elements were evaluated in terms of the criteria discussed above. Lastly, the similarities and differences between Topkapı Palace and Dolmabahçe Palace were examined with regard to spatial organization, functionality, symbolism, technological innovation, and sensuality. Specifically, great attention was paid to the way in which water changed from an element that was predominantly used for its sensory and symbolic attributes in classical Ottoman architecture into one which was technology-oriented.

Limitations

Some interior areas of the palaces could not be observed in the field study and therefore made it difficult to observe some features related to water. Moreover, some of the buildings have been subject to renovations and may have changed in appearance due to these renovations. Without long-term environmental observation records, the sensory evaluation was conducted based on observations and historical/architectural records.

Use of Artificial Intelligence

OpenAI tools were used solely for language editing, grammar checking, and improving academic English expression after the preparation of the manuscript. Artificial intelligence tools were not used for data collection, data analysis, interpretation of findings, or generation of research results.

Historical Background of Water Elements in Ottoman Residential Architecture

In the pre-modern era, Ottoman cities relied on springs, wells, fountains, and cisterns for satisfying their needs regarding water supply. Wells existed primarily in gardens, courtyards, and sometimes even in houses, whereas fountains supplied water to both residential areas and towns (Figures 1-2). Cisterns could be found in bigger houses and palaces, and they served as reservoirs for ensuring a continuous water supply especially when the access to water was difficult (Karpuz, 2006). Besides the use of these means for providing water, Ottoman cities made use of elaborate hydraulic systems for the purpose of collecting, storing, and distributing water. Springs and catchment pools served as sources of water, which after passing through canals and aqueducts reached their destinations, where distribution was made in the urban area. Kırkçeşme and Taksim in Istanbul were among the important projects involved in supplying residential and public buildings as well as imperial palace complexes (Kurt, 2021). The provision of water was an essential aspect for the lives of people in the Ottoman Empire but not only this; water was part of their architecture and culture. This could be evidenced by the presence of charity sebils as well as by domestic fountains that contributed to providing comfort and quality of air inside the house.

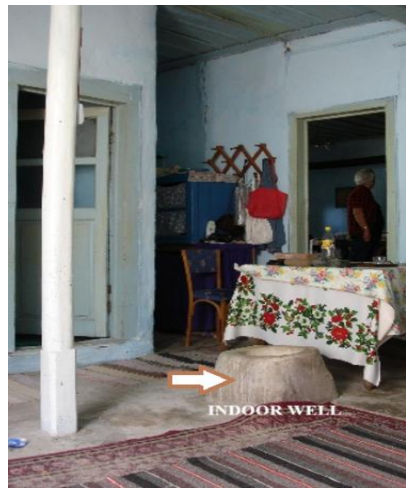


Figure 13

Well in the interior of a traditional Turkish house, Gallipoli

Source. Author's archive.

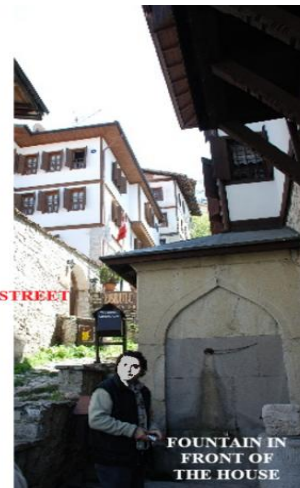


Figure 14

Street fountain in front of a house, Safranbolu

Source. Author's archive.

The bathroom was quite an important feature of the Ottoman residential building design. Based on the type and significance of the house, bathrooms were provided either in the form of gusulhanes, hammams, or modern western bathrooms starting from the nineteenth century. Gusulhane is a very practical example of the Ottoman bathroom, which could be found inside cupboards covered with a lead coating (Figure 3). However, in larger houses such as mansions and palaces, hammams provided a much more comfortable environment.



Figure 15
“Gusulhane”, Safranbolu
 Source. Author’s archive.

Pools are rare in Ottoman domestic architecture but were used together with fountains and baths. They are usually found inside sofas, divanhane, and pavilions. Their function was to add to the climatic pleasure and the aesthetic appearance of their surroundings. These pools were usually built with marble or stone, and their sound effect increased the sensory appeal of the space. Famous examples of these are the Asmazlar Mansion pool of Safranbolu (Figure 4), and the Amcazade Hüseyin Paşa waterfront mansion divanhane pool (Figure 5).



Figure 16
Indoor pool in a traditional Turkish house, Safranbolu
 Source. Author’s archive.



Figure 17
Amcazade Hüseyin Paşa Waterfront Mansion, Istanbul
 Source. Cultural Inventory, 2026.

The use of fountains, pools, baths, and other water-related elements in Ottoman residential architecture established a cultural and architectural tradition that was later adopted and developed in Ottoman palace architecture. In palaces, however, these elements acquired more elaborate spatial, symbolic, and representational roles, reflecting the status and prestige of the imperial court.

Architectural Characteristics of Topkapı and Dolmabahçe Palaces

The creation of Topkapı Palace took place in connection with the conquest of Istanbul and subsequent expansion that included the construction of new courtyards, pavilions, houses, and other additions. Unlike the massive palace complexes of Europe, the structure of the complex follows a hierarchy of courtyards where the degree of privacy, control, and protection increases inwardly (Necipoğlu, 1991). Mostly influenced by Classical Ottoman architecture, the palace later incorporated several elements related to the Baroque, Byzantine, and Rococo styles (Kuban, 2007). In terms of area, Topkapı Palace takes up about 700,000 square meters, and 80,000 square meters out of this number include covered space (Caferova, 2024, p. 79). Instead of monumental structures, relatively small buildings prevailed here, creating close ties between the interiors and exteriors of the building and making it possible for water features to serve the purpose of enhancing comfort and representing Ottoman power. Interior design included Iznik ceramic tiles, painting, wood carving, mother-of-pearl inlaying, and künde-kârî (Kuban, 2007; Ortaylı, 2007).

Built in 1839-1861 under Sultan Abdülmecid, Dolmabahçe Palace sought to meet the demands of a modernized Ottoman government for a new residence. Created by the Balyans and foreign architects, it consists of three main parts, such as Mabeyn-i Hümâyûn, Muayede Hall, and Harem-i Hümâyûn (Esemenli, 2023). Stylistically, it can be characterized as a fusion of Turkish and Western styles, using Baroque, Rococo, Neoclassicism, and the Empire styles. The palace had modern equipment and sanitary installations (e. g., plumbing system) designed to increase comfort and ensure proper hygiene of sultans. Occupying 45,000 square meters, it includes 285 rooms, 46 halls, 68 toilets, and six hammams (Esemenli, 2023). Though serving as imperial residences, these two palaces differ in their architectural context. While the first palace is an embodiment of classical principles of Ottoman architecture and harmony with nature, the latter reflects modernization via monumental construction, incorporation of Western-style aesthetics, and advanced equipment. Comparison of these two palaces can help understand the evolution of water elements within Ottoman palace interiors.

Analysis of Water Elements in Ottoman Palace Interiors

The current study examines the interior water features in Topkapı Palace and Dolmabahçe Palace based on the methodological approach stated in the methodology chapter. In particular, this will focus on aspects such as the positioning, function, meaning, technique, and sensory impact of various forms of water structures including fountains, selsebil, shadirvan, swimming pools, and hamam. The aim of comparing and contrasting these features with their historical context will be to understand how their function and symbolism changed from the Classical Ottoman period into the era of nineteenth-century modernity.

Water Elements and Space in Topkapı Palace

Water management becomes a significant element for Topkapı Palace as the site is located on a promontory providing vistas towards the Bosphorus, Golden Horn, and Marmara Sea. Water was supplied by Beylik and Kırkçeşme systems and was transported by means of reservoirs, water towers, conduits, and wells forming a comprehensive hydraulic network necessary for both daily activities and rituals (BOA, 154/82, 1329; Ergüdar and Yergün, 2022, p. 604). Records associated with the maintenance of fountains, pools, hammams, and water conduits reveal the relevance of water systems in Topkapı Palace (BOA, 10136, 22, 1144). The documents also prove that the system survived after the completion of Dolmabahçe Palace, emphasizing the significance of Topkapı Palace for Ottoman Empire (BOA, Y.PRK.HH. 39/68, 1312; BOA, 154/82, 1329). Water can be found at Topkapı Palace in the form of fountains, selsebil, shadirvan, pools, hammams, and sanitary facilities. However, apart

from providing water, these objects played a significant role in climate control, creating an atmosphere of comfort, privacy, and prestige.

As for the types of water systems used in Topkapı Palace, it should be emphasized that different elements were concentrated in different parts of Topkapı Palace depending on their purposes. For instance, water was primarily used as an aesthetic element in ceremonial rooms, and, therefore, fountains, pools, and shadirvan were often placed as focal points in the architecture. On the contrary, hammams were essential in residential and private rooms to emphasize the significance of cleanliness and comfort. The following sections will discuss these water elements considering their positioning, purpose, symbolism, technical aspects, and sensory value.

Fountains and Selsebils:

The fountain and selsebil are some of the most notable water fixtures in the interior spaces of Topkapı Palace. While they were primarily used for obtaining water, these fixtures served multiple purposes relating to environmental comfort, privacy, representation, and aesthetics. The presence of fountains in audience rooms, pavilions, and harems is also suggestive of the incorporation of water in spaces linked to imperial power and elite lifestyle. One of the most notable fixtures of this kind was the marble fountain located near the façade facing the Babüssaâde Door of the Audience Chamber (Arz Odası) (see Figure 6 below). As can be seen from the Persian inscription attached to the fountain, it had the meaning of providing its viewers with the “eternal water of life.” Clearly, this suggests that, besides being utilized as a simple fixture, the fountain could represent power, wealth, and longevity. Finally, historical pictures demonstrate that changes to the structure of this fountain took place during the nineteenth century (Figure 7).



Figure 18

Fountain located on the exterior wall, to the right of the door of the Audience Chamber

Source. Author's archive.

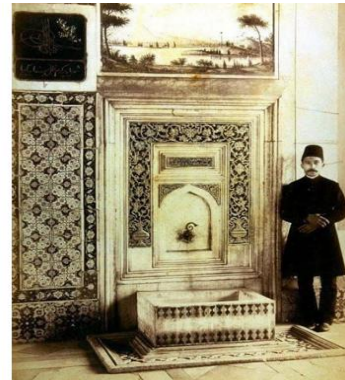


Figure 19

Photograph of the fountain on the exterior wall of the Audience Chamber, dating from the second half of the nineteenth century, by Abdullah Frères (Périn & Périn, 2023).

There is more evidence about the link between water and representation in the very design of the Audience Hall itself. This fountain is situated near the emperor's throne, and its shape recalls that of a selsebil; in addition, it was designed in such a way as to provide water flow regulation over the surface of the fountain (Figures 8 and 9). Moreover, the sounds generated by this water flow were part of the acoustic environment of the Audience Chamber, thus possibly contributing to the chamber's privacy (Eyice, 1991).



Figure 20

Interior of the Audience Chamber in Topkapı Palace and the throne

Source. Author's archive.

Figure 21

Audience Chamber: The fountain beside the throne

Source. Author's archive.

The relationship between water, prestige, and sensory experience can also be found in another room known as the Hünkâr Sofa which was an important ceremonial space in the Harem. Being the biggest and most opulent hall in the Harem complex, it provided venues for various ceremonies of celebration or reception. The fountain that was installed in this room served not only as a source of water but also as a provider of comfort and prestige, especially suitable for imperial meetings (Figure 10).



Figure 22

Throne in the Hünkâr Sofa and the fountain beside it

Source. Author's archive.

The presence of water could also be found in the private spaces of the sultans. The fountains in the Privy Chamber of Ahmed I and the Privy Chamber of Murad III represent how water became one of the components of the sensory appeal of the interior of the palace. In the case of the fountain of the Privy Chamber of Ahmed I, the fountain is part of a highly decorated space using Iznik tiles, mother-of-pearl decoration, and wood carving (Figure 11). Another example is the fountain in the Privy

Chamber of Murad III, which uses more than one basin and several jets to create a sound effect and add to the comfort of the room (Figure 12).



Figure 23

Privy Chamber of Sultan Ahmed I and the fountain (Ortaylı, 2007, p. 277).



Figure 24

Fountain of the Privy Chamber of Murad III

Source. Author's archive.

Figure 25

Fountain and shadirvan in the Serdap Pavilion

(Ortaylı, 2007, p. 278).

The role of water as a sensory element is particularly evident in the Twin Pavilions and the Circumcision Room. In these spaces, fountains were placed within window recesses, allowing the sound of flowing water to permeate the interiors (Figures 14 and 17). Contemporary accounts suggest that these fountains contributed to the creation of a calm and secluded atmosphere, while in the Circumcision Room they may also have served to mask external sounds during ceremonial events (Ortaylı, 2007).



Figure 26

Window and fountain detail in the Twin Pavilions (Ortaylı, 2007, p. 286).

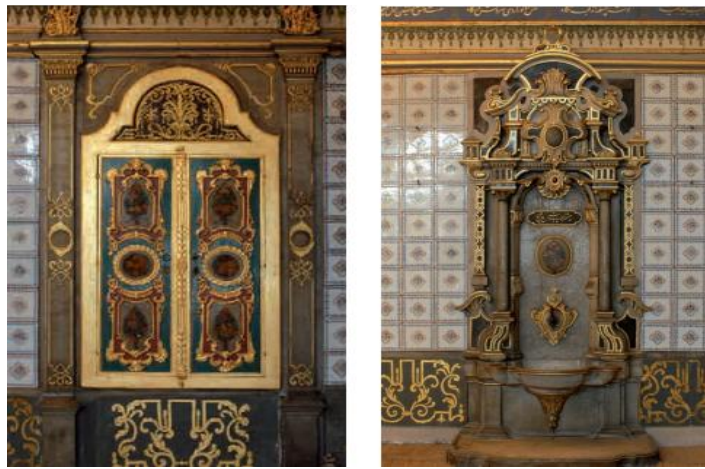


Figure 27

Cupboard shutter of the Privy Chamber of Abdülhamid I (Ortaylı, 2007, p. 248).

Figure 28

Fountain of the Privy Chamber of Abdülhamid I (Ortaylı, 2007, p. 248).

One can observe the evolution of the aesthetic interpretation of water in Topkapı Palace through the Privy Chamber of Abdülhamid I. It represents one of the first cases when the influence of the Baroque style is felt (Figure 15 and 16). The combination of the fountain and shutters of the cupboard suggests that water had been incorporated into an architectural design on purpose. Thus, the inscription "Çeşme-i dîlcû-yı hayat / Câvidan-ı ayn-ı safa" reflects water as not only a natural resource but also a source of calmness, life, and spiritual rejuvenation. Combined with abundant decor of the fireplace and wooden throne area (şirvan), the fountain highlights the representational abilities of the chamber and its connection to the emperor (Özcan, 2023).

The Circumcision Room (Sünnet Odası) represents one of the examples of purposeful use of water for creating sensory ambience. This room created under the rule of Sultan Ibrahim I comprises four marble fountains that serve as a part of the interior design of the room's window alcoves (Figure 17). According to the tradition of Topkapı Palace, they were supposed to conceal cries of princes undergoing circumcision from being heard in other rooms. Nevertheless, along with this practical function, water fountains created a peaceful and private environment in which princes could undergo circumcision. As far as the ceremony of circumcision was connected to royal rituals, the fountains took additional meaning in Topkapı Palace (Ortaylı, 2007).



Figure 29

Fountains within the window recesses of the Circumcision Room (Ortaylı, 2007, p. 146).

Fountains gained extra symbolic significance inside the Harem. The fountain of the Valide Sultan Courtyard is engraved with inscriptions drawn from the verse of Sūrat al-Insān, which suggests that water represents purity, divine blessing, and heavenly reward (Figure 18). Similarly, the Fountained Hall (Çeşmeli Sofa) has been endowed with both ornamental and practical features such as the marble fountain, seashell design, bird imagery, and cypress design (Figure 19).



Figure 30

Fountain in the Valide Sultan Courtyard

Source. Author's archive.

Figure 31

Fountained Sofa

Source. Author's archive.

A further example in this respect would be the Ab-i Hayat Fountain in the Tiled Pavilion (Figure 20). Just by looking at its name, Ab-i Hayat, which means “Water of Life,” one can clearly observe the symbolism of water in the Ottoman culture. Apart from being a source of drinking water for Ottomans, the fountain was also a piece of art that was chosen as the theme for a painting by Osman Hamdi Bey titled Ab-i Hayat Fountain (Figure 21).

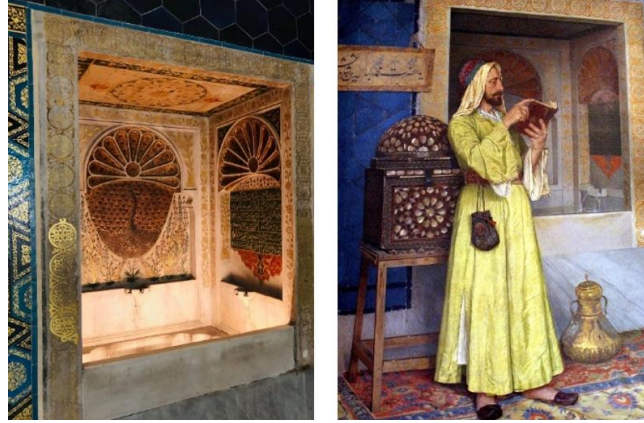


Figure 32
Fountain in the Tiled Pavilion

Source. Author's archive.

Figure 33
Osman Hamdi's painting titled Ab-ı Hayat Fountain

Source. Author's archive.

The fountains and selsebils at Topkapı Palace had multiple functions, from functional to symbolic and sensory. In addition to providing water and making the surrounding environment more comfortable, they were central points in the ceremonies and residential areas while symbolizing status and power, and also reflecting purity and God's blessing. With the help of sound and motion and reflection effects, they enhanced the atmosphere inside the palace. Thus, fountains and selsebils played a role not only in terms of hydraulics but also in terms of producing space.

Shadirvans

Unlike fountains and selsebils, shadirvans have a more restricted but still important presence inside the walls of Topkapı Palace. Shadirvans were not placed everywhere; rather, they were used at certain important spots where they performed as focal points and elements of sensation inside the interior spaces. One such case is the shadirvan situated in the middle of the sofa of Fatih Pavilion (Treasury Pavilion), which is among the first buildings of the palace (Figure 22). Apart from fulfilling its main purpose of watering, the shadirvan also controls the flow inside the room and emphasizes the importance of the sofa in the architectural composition. Both the presence and the sound of the flowing water improve the environmental comfort and enhance the link between architecture and nature (Ortaylı, 2007).

The second example of the shadirvan is contained in the Hall with Shadirvan (Şadırvanlı Sofa), located in the Chamber of the Holy Relics (Has Oda Kasrı). The chamber itself consists of two dome parts, with one of them housing the marble shadirvan under the central dome (Figure 23). Apart from creating an eye-catching feature in this room, the shadirvan produces special acoustics because of the sound of running water. It is known historically that this shadirvan could have served as a place where the attendants to the Privy Chamber washed themselves for religious reasons (Ortaylı, 2007). Thus, the shadirvan is accompanied by another element of water symbolism, i.e., the marble well.



Figure 34
Shadirvan in the Fatih Pavilion (Ortaylı, 2007, p. 123).

Figure 35
The Sofa with a Shadirvan (Ortaylı, 2007, p. 140).

From a spatial viewpoint, the placement of shadirvans was deliberate because they were placed in spaces with significance as they played a role in determining the hierarchy of space as well as movement through the space. The functions of the shadirvans included the provision of water as well as facilitating rituals while at the same time symbolizing the concepts of purity and refinement that were associated with the court culture of the Ottomans. Visually and acoustically, they added a sensory dimension to the interiors of the palaces. Contrasting the use of fountains built into walls or niches, the shadirvans were placed centrally and acted as functional components of the spatial design.

Pools

Pools represent some of the most unique water features at Topkapı Palace, providing insights into the functions of water within Ottoman palace architecture. While fountains and shadirvans played important roles in defining space and creating climatic and symbolic meanings within the palaces, pools had greater impacts on the wider spatial context and reinforced the connection between architecture, environment, and landscape. The pool found within the Serdap Pavilion underneath the chamber of Murad III (Figure 13) represents one of the earliest examples. As a summer house, the pavilion took advantage of the presence of the pool and fountain to improve thermal comfort by movement, sounds, and cool air (Ortaylı, 2007).

The representational aspect of pools becomes especially noticeable at the Pavilion of Osman III, in which there is a marble decorative pool positioned right at the heart of what is referred to as the Court of a Pool (Havuzlu Taşlık) (Figure 24). When considering the pool alongside the entire architectural setting around it, one notices how it creates a focus for the space, underlining its ceremonial and prestigious nature (Ortaylı, 2007). The same effect can be observed at the Mermer Sofa, where there is an enormous pool positioned at the center of the terrace overlooking the Bosphorus and the Golden Horn (Figure 25). In addition to contributing to the aesthetic quality of the space through the use of reflective properties of water, the pool also creates connections between architecture and the landscape. This effect is accentuated by the presence of significant architectural features, including the Baghdad Pavilion, Revan Pavilion, and the Circumcision Room.



Figure 36

Courtyard with a Pool of the Pavilion of Osman III (Ortaylı, 2007, p. 259).

Figure 37

Marble Sofa and Pool

Source. Author's archive.

In general, the pools in Topkapı Palace had an environmental, functional, spatial, symbolic, and sensory function. Pools were beneficial for environmental conditions, they facilitated the usage of the palace spaces according to seasons, and very often became organizing features of architecture. The combination of water pools with gardens, pavilions, and imperial spaces created ideas of prestige, leisure, and power, while water properties such as reflection and acoustic made the atmosphere of palace interior and semi-outdoor spaces. In contrast to technologically advanced water systems in the nineteenth century, the purpose of pools in Topkapı Palace was mostly environmental, representational, and experiential.

Hammams and Toilets

The presence of hammams and sanitary facilities in Topkapı Palace is another important component of its water network, revealing the role of hygiene, privacy, and hierarchy within the palace. The location of the two main examples is an illustration of how water became part of both official and daily activities at the palace. These were the Imperial Hammam (Hünkâr Hamamı) and Valide Sultan Hammam in the Harem complex. Both of them were originally built in the sixteenth century and rebuilt in the eighteenth century. The layout included three types of rooms in accordance with their temperature: cold, warm, and hot. The presence of domes, marble walls, fountains, and decoration suggests that they served not just for the purpose of taking a bath but as places to feel comfortable, demonstrate their status, and make an impression. Their close relationship with the private chambers of the sultan and the Valide Sultan confirms their status within the palace hierarchy (Figure 26).

However, apart from serving a functional purpose, these hamams stood for the notions of purity and cleanliness in the Ottoman culture, making a bath a symbol of health, nobility, and belonging to the empire. The renovation of the Imperial Hammam by Mimar Sinan underscores the importance of architecture. There were also other hammams used by the Black Eunuchs, the concubines, the princes, and the officers in the palace. This hammam of the concubines, along with the laundry and servants area attached to it, demonstrates the organization of water spaces based on hierarchy and function in the Ottoman Empire.



Figure 38

Basin of the Imperial Hammam and interior view (Cultural Inventory, 2026).

It is also important to mention that sanitation areas such as bathrooms, wash rooms, and gusulhanes were connected to the palace water system. In many cases, these sanitation areas were not independent structures but were usually related to fountains or other water elements that would ensure the supply of running water (Figure 27).



Figure 39

Toilet of the Imperial Hammam

Source. Author's archive.

Functionally, the hammams and sanitary facilities were instrumental in maintaining hygiene, comfort, and the smooth functioning of the palace environment. The arrangement of the spaces was determined by the hierarchy at the Ottoman Court, with the finest examples reserved for the sultan and the Valide Sultan. As far as their symbolic significance is concerned, they stood for cleanliness, sophistication, and prestige, while in terms of engineering skills, they represented the sophistication of the water infrastructure system of the palace. Unlike the fountains and pools, whose primary contribution was purely sensory, the hammams and sanitary facilities emphasize the functional aspect of the water infrastructure. However, their architectural excellence reveals the importance accorded to this element of palace culture.

Water Elements and Space in Dolmabahçe Palace

The use of water in Dolmabahçe Palace took place in an entirely different architectural and technological framework compared to Topkapı Palace. Although the latter demonstrates a significant connection between water and sensory experience and symbolic meaning, in Dolmabahçe Palace, water seems to be related more to modern infrastructural, hygienic, and comfort services. In Dolmabahçe Palace, water transported via the Taksim and Hamidiye systems was stored in tanks and distributed across the building through pipes, taps, baths, fountains, and sanitation services, indicating the modernization of the use of water as an element of technological infrastructure (Esemenli, 2023).

It can be seen that the water distribution system at the palace received great attention. For instance, English/Frankish pipes were used for the purpose of connecting reservoirs with baths and apartments of the palace (Esemenli, 2023). Additionally, this modern approach was observed in bathrooms that included enamel bathtubs, showers, and thermosiphons, thus highlighting the coexistence of both Ottoman and European traditions (BOA, Y.PRK.HH. 39/68).

However, there were more facilities that utilized water. Such facilities as fountains, kitchens, toilets, ablutions rooms, servant apartments, and residents' chambers became a part of the sophisticated service system, which suggests a more rational and functionally oriented use of water than what we can find in the Topkapı Palace (Esemenli, 2023). Thus, from the point of view of spatial aspects, water becomes related to hygiene and comfort as well as the effective functioning of a big nineteenth century imperial palace. While its practical aspects become stronger, water remains a sign of modern luxury, lifestyle of elite, and European standards of life. Therefore, the Dolmabahçe Palace is a significant milestone on the way of changing water use from purely sensory and symbolic to technological and functional use in the interior of the Ottoman palaces. This is discussed further in connection with hammams, bathrooms/toilets, and indoor swimming pools.

Hammams

The hammams form one of the most significant categories of water-related facilities in the Dolmabahçe Palace. Contrary to the Hammams of Topkapı Palace that represented an era of traditional Ottoman royal culture and rites, those of Dolmabahçe Palace are indicative of an era whereby the traditions of bathing rituals were merged with luxurious and sophisticated features of modern times. In other words, they represent the transition point between the Ottoman royal hammams and the modern palace bathroom facilities.

Records from archives show that hammams were not just rooms of services but well-equipped interiors based on the social hierarchy of the palace (BOA, 143/54, 1328). Special hammams were provided to the sultan, Valide Sultan, and the other individuals from the Imperial Harem, considering the social hierarchy inside the palace. One of the most striking examples of this would be the Imperial Hammam or Egyptian Hammam, also called the Marble Bath, which is situated inside the Selamlık area. This room belonged to the sultan and was one of the special places inside the palace. The Egyptian alabaster cladded walls, Marmara marble flooring, and luxurious decoration of this room show its significance.

The hammam included the areas for changing clothes and taking baths, whereas its ceiling covered with panels of glass, malakâri decoration, and terrace overlooking the Bosphorus showed the fusion of the classic hammam architecture with the architectural style of the nineteenth century. The water was sourced from the reservoir located opposite to the Glass Pavilion, and all basins and taps were made of silver (Figure 28).



Figure 40

Mermer Banyo (Photographic Archive of the National Palaces).

From an engineering standpoint, the Imperial Hammam is evidence of the sophisticated water network in Dolmabahçe Palace. This can be seen from the inclusion of the reservoir, quality fittings, and the combination of bathing, ablution, and toilet functions in one system. Unlike water being used only for sensory and symbolic purposes at Topkapı Palace, water usage at Dolmabahçe Palace was characterized by a greater emphasis on technical aspects and domestic comfort. Hammams at Dolmabahçe Palace played not only functional but also symbolic and technical roles. They were places for hygienic and comfortable activities, represented the hierarchical order of the palace, and retained the old tradition of linking water, cleansing, refinement, and noble lifestyle. At the same time, water usage took on an infrastructural form. Therefore, Dolmabahçe Palace hammams can be seen as places where the Ottoman tradition of baths and modernization of the nineteenth century met, bringing together continuity and luxury.

Bathrooms and Toilets

The facilities for using water in the form of bathrooms and toilets in Dolmabahçe Palace are among the best examples that show the development in the use of water by Ottoman palace architecture in the nineteenth century. In contrast to Topkapı Palace where bathroom activities such as taking baths were mainly conducted in hammams and related spaces, Dolmabahçe Palace included bathrooms, toilets, showers, bathtubs, plumbing, and other systems which reflected European standards in terms of hygiene and living quality. The archives suggest that the palace was equipped with enamel bathtubs, showers, thermosiphons, and other sanitary appliances which showed that the latest European technological applications had been adopted at the palace (BOA, Y.PRK.HH. 39/68). Thus, water became an integral part of the residential space rather than being used only for special purposes like baths. Moreover, there were connections between bathrooms and the apartments as well as service spaces, and therefore, there were increased needs for convenience, accessibility, and privacy in terms of bathroom activities. In this regard, there were also 68 toilets within the palace, demonstrating that sanitary facilities became an important element of palace planning (Esemenli, 2023). However, apart from serving their functional purpose, many of these lavatories and toilets were constructed using excellent materials that reflected the splendor and grandeur of the palace itself. Hence, even the most sanitary rooms of the palace served the purpose of representation along with their practical uses.

In terms of space and functionality, they facilitated modern requirements of living and access, technologically speaking, as a result of the incorporation of modern water supply and sewage systems. From the symbolic point of view, they represent changes in ideas about comfort, privacy, and modernization related to the period of the Ottoman Empire. This way, the baths and toilets in Dolmabahçe Palace demonstrate a new approach towards the use of water in architecture and daily life, making water a vital element of modern comfort (Figure 29).



Figure 41

Bathroom in Dolmabahçe Palace (Photographic Archive of the National Palaces).

Figure 42

*Examination Room and Vanity Cabinet (Photographic Archive of the National Palaces).
Glass Pavilion (Camlı Köşk).*

One of the most prominent examples of the connection between water, transparency, nature, and representation can be found in the Glass Pavilion of Dolmabahçe Palace. While hammams, baths, and toilets provide evidence of how water was viewed in terms of technicalities and hygiene, the Glass Pavilion exemplifies how water retained its significance on an aesthetic level in the new palace environment.

The pavilion was designed and built by the British architect William James Smith and it is referred to as the only building in the Dolmabahçe Palace which connects with the outer world. It operates as the winter garden, consisting of two connected buildings – a huge hall together with side rooms being the viewing pavilion and the greenhouse. The hall is a luxurious decorative rectangular building, whereas the greenhouse is built with a rectangular layout and comprises mostly cast iron and glass construction, except the façade which is linked with the hall (Batur, 2011). There is an octagonal pool made of dark marble in the centre of the greenhouse and the pool is decorated with naturalistic floral ornamentation along its perimeter. In the center of the pool there is a tall crystal fountain, and from the photos one can see a pool with a bouquet of leaves under the fountain holding some water (Fig. 31) (Batur, 2011). From this composition, one can conclude that water was not intended to be used as a practical item, but rather as an atmospheric decoration.



Figure 43
Glass Pavilion (Photographic Archive of the National Palaces).

In terms of space, the pool and the fountain are the centerpieces of the greenhouse and dictate its visual perception as a whole. The centrality of the two enhances their connection with the elements of water, plants, light, and transparency. From a functional point of view, the water is an important aspect that affects the atmosphere of the winter garden. From a symbolic perspective, the use of water shows that the representation used by the palace is more European.

As such, the Glass Pavilion represents a significant difference from the infrastructural role played by the water architecture of Dolmabahçe Palace. The fact that the latter is evident through the modernity and hygienic nature of the hammams, bathrooms, and toilets does not mean that the pool and fountain in the pavilion cannot be considered to symbolize the significance of water as an element of status and sensory delight. In other words, it becomes clear that water at Dolmabahçe Palace was not restricted only to technical functions but could play its visual symbolic role.

Comparative Discussion

By examining each water element, there emerges a clear shift in the nature of water in terms of its function at Topkapi Palace as opposed to Dolmabahçe Palace. Water at the Topkapi Palace is shown to be predominantly used for its spatial, sensory, and symbolic purposes, whereas it was incorporated

within hygiene, comfort, and technological purposes at Dolmabahçe Palace. The following analysis provides an explanation of the shift from the perspective of spatial positioning, purpose, symbolism, technology, and sensory aspects.

Spatial Organization of Water Elements

These observations clearly indicate a number of distinctions in spatial distribution of water features among the two palaces under analysis. In Topkapı Palace, fountains, selsebils, pools, and shadirvans could often be found in the center of and in prominent locations inside pavilions, courtyards, sofas, and audience chambers. Thus, water played the role of an organizer of spatial relationships, visual perceptions, and social interactions. The examples of these spaces include the Audience Chamber fountain, the Marble Sofa pool, and the Hall with a Shadirvan (Eyice, 1991; Ortaylı, 2007).

On the other hand, the use of water in Dolmabahçe Palace shifted to bathrooms, hammams, toilets, kitchen, and service rooms interconnected by an intricate plumbing system (Esemenli, 2023). Thus, the use of water shifted from being a symbolic function to its use as part of the functional facilities of the palace. This change could be seen from the perspective of Lefebvre's theory of the production of space. According to Lefebvre (1991), spatial arrangement is determined by the social relations that prevail in a society. While at Topkapı Palace, water enabled the production of ceremonial spaces related to imperial power, at Dolmabahçe Palace, it enabled spaces based on comfort and hygienic needs.

Functional Roles of Water

The analysis shows that there is a change in the main purposes served by water at the Ottoman palaces' constructions. While at Topkapı Palace water had an important role in environmental cooling, providing privacy through sounds, creating an aesthetic effect, and participating in ceremonies, water at Dolmabahçe fulfilled more practical goals. Namely, water facilitated the presence of bathhouses, showers, toilets, kitchens, and plumbing in the palace, as well as modern hygienic devices and appliances. However, this change does not mean that the traditional purposes of water were neglected. Water still had many architectural functions, although its infrastructural functions become increasingly important during the period of construction (Eyice, 1991; Ortaylı, 2007).

Symbolic Meanings of Water

The symbolism of water remained an important element in both palaces, but changed through time. For the case of Topkapı Palace, the symbolism involved power, prestige, purity, paradise symbolism, and continuity of dynasty. The inscriptions, decorative themes, and the location of the fountains and pools in the ceremonial area helped enhance their symbolism (Eyice, 1991; Özcan, 2023). In Dolmabahçe Palace, water still carried the connotation of prestige, but it was increasingly seen as a sign of modernity, progress, and a European way of life.

Such changes may be analyzed with reference to the theory of Norberg-Schulz regarding "genius loci." Thus, water was used as an element that determined the character of the classical Ottoman court because of its representation and symbolic meaning. At the Dolmabahçe Palace, it was employed in creating a different architectural identity due to the influences of westernization and modernization.

Sensory Effects and Spatial Experience

One of the most notable distinctions that can be made between the two palaces is related to the way that water affects the sensory experience. Water played an integral part in influencing the aesthetics, acoustics, and climate within interior spaces in Topkapı Palace. Sounds produced by the fountains and selsebil were employed to provide seclusion and create a serene environment, while pools helped with reflecting, moving water, and cooling (Ortaylı, 2007; Tüfekçi, 2020). It should be noted that the described aspects have much in common with the phenomenological concept of space presented by Bachelard (1994) and his focus on sensory experience in architecture.

While sensory properties continued to exist within the Dolmabahçe Palace complex, their significance was minimized. The presence of water existed in certain areas like the Glass Pavilion along with decorative interior fixtures; however, other water installations were primarily for functional purposes. This resulted in the reduction of the sensory purpose of water and its prioritization for hygiene and comfort.

Water as a Marker of Ottoman Modernization

A comparison between Topkapı Palace and Dolmabahçe Palace shows how water can be seen as a symbol of architecture evolution in the Ottoman Empire. The transition from the Classical Ottoman era to the process of modernization in the nineteenth century can also be seen in terms of water in architecture.

In Topkapı Palace, water had more of a spatial, sensory, and symbolic function. It contributed to creating the ambiance of various spaces and added to the ceremonial aspect of the palace. In Dolmabahçe Palace, however, water became part of a greater technological system meant to facilitate hygiene and comfort. This demonstrates a shift in Ottoman architecture in which water moved from a visible and perceptual component of architecture to a hidden one, incorporated into technology. Nevertheless, water remained a means of showing off the elite status.

Thus, water was not only a source used by the Ottomans for their everyday life but also an architectural medium through which the shift from the classical Ottoman world to a new palace can be traced.

Results and Comparative Summary of Water Elements in Topkapı and Dolmabahçe Palaces

This comparative study has indicated both continuity and changes that occurred in the way in which water was used in Ottoman palaces. It can be observed that although there were numerous water-related features both in Topkapı Palace and in Dolmabahçe Palace, yet the manner in which these features have been used is quite different in terms of organization, functions, symbolism, and technology. In order to facilitate an organized presentation of results, Tables 2 to 4 have been prepared.

Table 7

Typological comparison of water elements in the interiors of Topkapı and Dolmabahçe Palaces

Water Element	Topkapı Palace	Dolmabahçe Palace	Explanation
Fountain	Present	Present	Fountains are present in both palaces. In Topkapı Palace, numerous interior fountains possess representational and sensory qualities, whereas in Dolmabahçe Palace, fountains are more prominently associated with functional and plumbed uses.
Selsebil	Present	Not identified	In Topkapı Palace, the fountain located particularly within the Audience Chamber has been interpreted as an arrangement bearing the character of a selsebil.
Shadirvan	Present	Not identified	In Topkapı Palace, examples of sofas with shadirvans are found in the Fatih Pavilion and the Chamber of the Sacred Relics.
Pool	Present	Present	In Topkapı Palace, pools are found around the Serdap Pavilion, the Pavilion of Osman III, and the Marble Sofa. In Dolmabahçe Palace, an octagonal pool is located particularly within the Glass Pavilion/greenhouse.
Hammam	Present	Present	In both palaces, hammams constitute important spaces of water use and hygiene. In Topkapı Palace, they reflect a more traditional arrangement, whereas in Dolmabahçe

			Palace, traditional hammams and modern bathrooms coexist.
Bathroom	Not evident	Present	In Topkapı Palace, hammams, washing rooms (gusülhane), and ablution spaces are the primary features. Bathtubs are found in the bath of the Black Eunuchs' Dormitory and in the Imperial Hammam. In Dolmabahçe Palace, modern bathrooms equipped with enamel bathtubs, showers, and thermostats are explicitly documented.
Toilet/ Latrine/ Ablution space	Present	Present	In Topkapı Palace, sanitation is organized in the form of helâ (toilets), abdestlik (ablution spaces), and gusülhane (washing rooms), whereas in Dolmabahçe Palace it appears as numerous squat and European-style toilets within a modern sanitary system.
Gusülhane (Washing room)	Present	Not identified	In Topkapı Palace, gusülhane arrangements connected to helâ (toilets) and abdestlik (ablution spaces) are clearly documented. In the case of Dolmabahçe Palace, however, the emphasis is placed more on hammams, bathrooms, and toilets.
Water reservoir / cistern Well	Present	Present	In Topkapı Palace, water towers and reservoirs are present, whereas in Dolmabahçe Palace, the system consists of garden-based storage units and water reservoirs.
	Present	Not evident	In Topkapı Palace, wells dating back to the Byzantine period are identified as significant water sources. For Dolmabahçe Palace, there is no explicit evidence of wells within the interior spaces.
Piped water system	Present at the level of the distributio n system	Present at an advanced level	In Topkapı Palace, water distribution was carried out through water towers and reservoirs. In Dolmabahçe Palace, by contrast, lead pipes, Frankish/European pipes, and an advanced plumbing system are explicitly documented.
Decorative Water Feature	Present	Present	In Topkapı Palace, decorative water features include shadırvans, pools, and interior fountains, whereas in Dolmabahçe Palace they are represented primarily by the pool and crystal fountain of the Glass Pavilion.

Table 8*Interpretative comparison of water use in Topkapı and Dolmabahçe Palaces*

Criterion	Topkapı Palace	Dolmabahçe Palace
Spatial Role	Water defines important ceremonial and residential spaces	Water supports the operation of residential and service spaces
Functional Role	Cooling, privacy, representation, and comfort	Hygiene, sanitation, and domestic comfort
Symbolic Role	Power, prestige, purity, and paradise imagery	Prestige, modernization, and elite lifestyle
Technical Role	Traditional hydraulic systems	Advanced plumbing and sanitary infrastructure
Sensory Contribution	Strong visual, acoustic, and climatic effects	Limited sensory role, stronger technical role
Relationship with Modernization	Represents the Classical Ottoman tradition	Represents the modernization and Westernization process

Table 3 highlights the main distinctions found in the comparison process. In Topkapı Palace, water was mainly used for aesthetic purposes, whereas water at Dolmabahçe Palace became more relevant to hygiene and comfort. The above findings reveal how changes in the architecture of the period led to modifications in the significance of water use.

Table 9

Interpretation of water elements according to the theoretical framework

Theoretical Perspective	Topkapı Palace	Dolmabahçe Palace
Lefebvre – Production of Space	Water organizes ceremonial and representational spaces	Water supports modern residential and service spaces
Bachelard – Poetics of Space	Water creates a rich sensory and emotional atmosphere	Sensory role becomes secondary to practical functions
Norberg-Schulz – Genius Loci	Water is a defining component of palace identity	Water contributes to a modernized palace identity

As presented in Tables 3 and 4, the transition from water usage at Topkapı Palace to that of Dolmabahçe Palace cannot be explained simply in terms of technology. This transition also represents the transition in the production of space as suggested by Lefebvre, the transition in the poetic or aesthetic perception of space as suggested by Bachelard, and finally the redefinition of architectural genius loci or identity as suggested by Norberg-Schulz.

Results and Discussion

Through this study, it is shown that water within the palace architecture of the Ottoman period was not merely a basic need or a part of technological infrastructure, but rather a sensorial, symbolic, spatial, and technological aspect, which defined the organization of the interiors of the buildings. Comparing the two palaces, Topkapı Palace and Dolmabahçe Palace, it becomes evident that while water played a significant role in both of them, the architectural usage of it changed dramatically in relation to the changes in the culture, society, and technology. This paper, concentrating on interior water components, widens the scope of the existing literature in this field.

These results suggest that the water elements used at Topkapı Palace were highly interwoven with the space experience and palace culture. Fountains, selsebil, shadirvan, pool, and hamman were not only useful objects but also added some elements of comfortable environment, acoustics isolation, beauty, and symbolical meaning. Water objects were purposefully placed in audience halls, pavilions, chambers, and courtyards where their symbolic meaning added to the emperor's prestige. On the other hand, the use of water at Dolmabahçe Palace can be considered as an example of the development of technical processes in the Ottoman Empire during the nineteenth century. It can be proved by the advanced plumbing system, water reservoirs, bathrooms, showers, and sanitation facilities.

As can be observed through the comparison, there was a progressive evolution in the usage of water at the Topkapı Palace, moving away from a more sensory, symbolic, and spatial form to the more technical, hygienic, and comfort-based one in the Dolmabahçe Palace. In spite of this change, however, it must be pointed out that water has continued to retain its relevance in matters concerning status, authority, privacy, and architecture.

The results are also important for gaining new insights into water as a spatial component in architecture, from the theories developed by Lefebvre, Bachelard, and Norberg-Schulz. The change in water functions is also part of a larger picture that can be described as shifts in the production of space, perception, and identity in the context of Ottoman culture. Water served an active function in

creating spatial experiences in Topkapi Palace while its role in Dolmabahçe was associated more with residential comfort.

In conclusion, water can be viewed as a significant tool for studying changes in architecture in Ottoman palace interiors. The change that is visible when comparing Topkapı and Dolmabahçe palaces indicates a larger shift that includes both technological innovation as well as spatial experiences, values, and daily living practices. Thus, water can help shed light on the transformation of Ottoman architecture from the Classical era to the modern 19th-century palace setting.

Lastly, this paper can provide a basis for more research into water use in Ottoman palaces as there is a very narrow range of comparative literature. In particular, the analysis can be further developed by conducting a study of other Ottoman palaces, waterfront houses, pavilions, and noble homes using archives, restoration data, materials studies, and hydraulic facilities investigations.

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The Role of English Rap Hits in the Formation of Native-Like Pronunciation

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Abstract. The growing global popularity of English rap music has created new opportunities for language learners to improve their pronunciation and listening skills. This study investigates the role of English rap hits in the formation of native-like pronunciation among English as a Foreign Language (EFL) learners. Rap music is characterized by rhythm, rhyme, connected speech, stress patterns, and authentic colloquial expressions, all of which expose learners to natural pronunciation models. The research adopts a qualitative-descriptive methodology based on classroom observation, learner interviews, and analysis of previous studies related to music-assisted language learning. The findings reveal that learners who regularly practice pronunciation through rap songs demonstrate improvements in intonation, fluency, stress placement, and reduced foreign accent interference. Furthermore, rap music increases learner motivation and confidence due to its entertaining and emotionally engaging nature. The study also identifies several challenges, including slang vocabulary, rapid speech tempo, and non-standard grammatical forms frequently present in rap lyrics. Despite these limitations, the research concludes that carefully selected English rap hits can function as effective supplementary tools for pronunciation development when integrated with guided instructional strategies. The article emphasizes that music-based pronunciation practice contributes not only to phonetic accuracy but also to cultural awareness and communicative competence.

Keywords: english rap, pronunciation, EFL learners, native-like speech, music-assisted learning, phonetics

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İngilis rep hitlərinin ana dilinə xas tələffüzün formalaşmasında rolu

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Xülasə. İngilis rep musiqisinin global miqyasda artan populyarlığı dil öyrənənlər üçün tələffüz və dinləmə bacarıqlarını inkişaf etdirmək baxımından yeni imkanlar yaratmışdır. Bu tədqiqat İngilis dilini xarici dil kimi öyrənənlər (EFL öyrənənləri) arasında ingilis rep hitlərinin ana dilli danışanlara xas tələffüzün formalaşmasındakı rolunu araşdırır. Rep musiqisi ritm, qafiyə, əlaqəli nitq, vurğu nümunələri və autentik danışiq ifadələri ilə xarakterizə olunur ki, bunların hamısı öyrənənləri təbii tələffüz modelləri ilə tanış edir.

Tədqiqat musiqi dəstəyi ilə dil öyrənilməsi sahəsində aparılmış əvvəlki araşdırmaların təhlili, sinif müşahidələri və öyrənənlərlə müəssisələrə əsaslanan keyfiyyət yönümlü təsviri metodologiyayı tətbiq edir. Əldə olunan nəticələr göstərir ki, rep mahnıları vasitəsilə müntəzəm olaraq tələffüz məşqləri edən öyrənənlər intonasiya, axıcılıq, vurğunun düzgün yerləşdirilməsi və xarici aksentin təsirinin azalması baxımından əhəmiyyətli irəliləyiş nümayiş etdirirlər. Bundan əlavə, rep musiqisi əyləncəli və emosional cəhətdən cəlbedici xarakteri sayəsində öyrənənlərin motivasiyasını və özünəinamını artırır. Tədqiqat eyni zamanda rep mahnılarının mətnlərində tez-tez rast gəlinən jarqon söz ehtiyatı, sürətli nitq tempi və qeyri-standart qrammatik formalar kimi bir sıra çətinlikləri də müəyyən etmişdir. Bu məhdudiyyətlərə baxmayaraq, araşdırma belə nəticəyə gəlir ki, diqqətlə seçilmiş ingilis rep hitləri istiqamətləndirilmiş tədris strategiyaları ilə inteqrasiya edildikdə tələffüzün inkişafı üçün effektiv əlavə vasitə kimi çıxış edə bilər. Məqalədə vurğulanır ki, musiqi əsaslı tələffüz təcrübəsi yalnız fonetik dəqiqliyin artırılmasına deyil, həm də mədəni maariflənmənin və kommunikativ sərəfşənin inkişafına töhfə verir.

Açar sözlər: *ingilis repi, tələffüz, EFL öyrənənləri, ana dilli danışana xas nitq, musiqi dəstəyi ilə öyrənmə, fonetika*

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Introduction

Pronunciation is widely recognized as one of the most essential components of successful communication in a foreign language. Even learners with advanced grammatical competence and extensive vocabulary knowledge may experience communication barriers if their pronunciation differs considerably from native speech patterns. In English language teaching, pronunciation instruction has evolved from traditional phonetic drilling toward more communicative and interactive approaches that expose learners to authentic speech environments. Modern educational research increasingly emphasizes the importance of natural language input, listening exposure, and rhythm-based learning in developing pronunciation competence (Brown, 2007).

Among various alternative instructional methods, music has gained substantial attention as an effective pedagogical resource in second language acquisition. Songs provide repetitive linguistic input, emotional engagement, and memorable speech patterns that facilitate language retention and oral production. According to Murphey (1992), music creates a low-anxiety learning atmosphere that encourages learners to imitate pronunciation naturally and unconsciously. Similarly, Schoepp (2001) argues that songs contribute to vocabulary acquisition, listening comprehension, pronunciation development, and learner motivation simultaneously.

Within music-based learning, English rap music occupies a unique position due to its linguistic intensity and rhythmic complexity. Rap combines rapid articulation, rhyme schemes, stress manipulation, connected speech, and authentic conversational expressions in ways that closely resemble spontaneous spoken English. Unlike slower traditional songs, rap often reflects real-life pronunciation patterns, including reductions, contractions, linking, assimilation, and intonation shifts. Such phonological features are critical for learners attempting to achieve native-like pronunciation and natural speech fluency.

The emergence of rap music as a global cultural phenomenon has significantly influenced younger generations worldwide. Originating in African American communities during the 1970s, rap gradually expanded into mainstream international culture through artists such as Tupac Shakur, Eminem, and Jay-Z. Today, English rap songs are consumed by millions of non-native English speakers through digital streaming platforms, social media, and online video services. This global accessibility has transformed rap music into an informal language-learning environment where learners are repeatedly exposed to authentic pronunciation models.

From a linguistic perspective, rap music supports several important aspects of phonological acquisition. Stress timing, rhythm, syllable reduction, and intonation are essential features distinguishing native English pronunciation from foreign-accented speech. English itself is a stress-timed language, meaning that stressed syllables occur at relatively regular intervals regardless of the number of unstressed syllables between them. Many EFL learners struggle with these rhythmic characteristics because their native languages may follow syllable-timed patterns instead. Rap music emphasizes rhythmic synchronization and stress placement, helping learners internalize natural English speech timing through repeated auditory exposure and vocal imitation.

English rap songs also introduce learners to suprasegmental features of speech such as stress, rhythm, intonation, linking, assimilation, and reductions. These features are often difficult to teach through conventional textbook exercises. Through imitation and repetition, learners gradually internalize native-like speech patterns. Furthermore, rap performance encourages oral fluency and confidence because learners practice rapid articulation and synchronization with rhythm.

Research in psycholinguistics further supports the connection between music and language acquisition. Patel (2008) notes that music and language share overlapping neurological processing systems related to rhythm, auditory perception, and memory. Similarly, Fonseca-Mora (2011) explains that musical repetition enhances phonological awareness and improves learners' ability to distinguish subtle pronunciation differences. Repetition is especially important in pronunciation acquisition because learners must repeatedly hear and reproduce sounds before developing accurate articulation habits.

The theoretical foundation for using rap music in language learning can also be linked to the Input Hypothesis proposed by Stephen Krashen. Krashen (1985) argues that language acquisition occurs when learners receive meaningful and comprehensible input in low-stress environments. Rap songs provide extensive exposure to authentic language input in entertaining and emotionally engaging contexts, increasing learner attention and motivation. Learners often voluntarily repeat songs multiple times outside classroom environments, thereby increasing pronunciation practice frequency without formal instructional pressure.

In addition to pronunciation accuracy, rap music contributes to listening comprehension and oral fluency development. Because rap lyrics are often delivered rapidly, learners become accustomed to processing spoken English at natural conversational speed. This repeated exposure trains learners to recognize connected speech patterns that are frequently absent in textbook dialogues. According to Underhill (2005), pronunciation instruction should include suprasegmental elements such as rhythm, stress, and intonation rather than focusing exclusively on isolated sounds. Rap naturally integrates these suprasegmental features into authentic linguistic performance.

Another important advantage of rap-based learning involves learner motivation. Traditional pronunciation exercises are frequently perceived as repetitive, mechanical, and stressful. In contrast, music-based activities create emotionally stimulating learning experiences that increase participation and learner autonomy. Young learners especially demonstrate strong emotional connections to contemporary music culture, making rap an appealing educational tool. Research by Richards (2008)

indicates that emotionally engaging materials increase retention and active participation in second language classrooms.

Despite these benefits, the pedagogical use of rap music remains controversial among some educators and researchers. One major concern involves the presence of slang vocabulary, taboo expressions, violent themes, and non-standard grammatical structures in certain rap lyrics. Critics argue that learners may imitate inappropriate expressions or develop inaccurate grammatical habits if instructional guidance is insufficient. Furthermore, some rap artists intentionally manipulate pronunciation for stylistic or regional identity purposes, which may create confusion for learners attempting to acquire standard pronunciation norms.

Another challenge concerns speech tempo. Many rap songs contain extremely rapid lyrical delivery that may overwhelm intermediate learners. Excessive speech speed can reduce comprehension and create frustration among students unfamiliar with connected speech phenomena. Therefore, careful song selection and instructional scaffolding are essential for successful implementation in educational settings. Teachers must consider learners' proficiency levels, cultural sensitivity, lexical accessibility, and pronunciation clarity before integrating rap materials into classroom practice.

Technological development has further increased the educational potential of rap music in language learning. Streaming platforms, lyric annotation websites, pronunciation applications, and subtitle-supported videos enable learners to combine listening, reading, and pronunciation practice simultaneously. Digital accessibility allows students to engage in autonomous pronunciation training beyond formal classroom environments, strengthening continuous exposure to authentic spoken English.

Given the growing influence of global music culture on language learning practices, investigating the relationship between English rap music and pronunciation acquisition has become increasingly relevant. Although numerous studies have explored the general role of music in language education, fewer studies specifically examine the phonological benefits of rap music for developing native-like pronunciation among EFL learners. Therefore, this study aims to analyze how English rap hits contribute to pronunciation development, fluency enhancement, stress and rhythm acquisition, and learner motivation in foreign language learning contexts.

Methods

This study employed a qualitative-descriptive research design to investigate the role of English rap hits in the formation of native-like pronunciation among English as a Foreign Language (EFL) learners. Qualitative methodology was selected because it allows deeper exploration of learner experiences, attitudes, behavioral changes, and pronunciation development processes occurring during music-assisted language learning. According to Creswell (2014), qualitative research is particularly effective when researchers seek to understand participants' perceptions and interpret complex educational phenomena within natural learning environments.

The study was conducted over a twelve-week instructional period at a university-level English language program. The research focused on examining how systematic exposure to English rap songs influenced learners' pronunciation, fluency, stress placement, rhythm control, and confidence in spoken communication.

Research participants

The participants consisted of 40 undergraduate students enrolled in intermediate and upper-intermediate English language courses. Their ages ranged from 18 to 24 years. The participants were selected through purposive sampling because they demonstrated regular engagement with English-language music and expressed willingness to participate in music-based pronunciation activities.

The participants represented diverse linguistic backgrounds, but all shared similar educational exposure to formal English instruction. Prior to the study, a preliminary diagnostic speaking activity was conducted to evaluate their pronunciation difficulties, fluency levels, and listening comprehension abilities. Common pronunciation problems included incorrect stress placement, vowel substitution, syllable omission, monotone intonation, and strong first-language interference.

Research design

The study utilized a classroom-based action research framework combining observation, guided listening activities, pronunciation exercises, learner interviews, and reflective analysis. Action research was considered appropriate because it allows researchers to observe practical instructional interventions within authentic educational settings while continuously evaluating learner progress (Kemmis & McTaggart, 1988).

The instructional design was influenced by communicative language teaching principles and music-assisted learning theory. According to Richards and Rodgers (2014), communicative pronunciation instruction should expose learners to authentic speech contexts rather than isolated phonetic drills. Rap music provided such authentic contexts through natural rhythm, stress patterns, reductions, and connected speech.

Selection of rap materials

The rap songs selected for the study were chosen according to several pedagogical criteria:

- clarity of pronunciation;
- moderate speech tempo;
- educational suitability;
- limited offensive language;
- lexical accessibility;
- rhythmic consistency;
- authentic conversational pronunciation.

Songs by artists such as Eminem, NF, and Macklemore were partially incorporated because their lyrical articulation was considered relatively comprehensible for language learners. Certain highly explicit or excessively rapid songs were intentionally excluded to maintain educational appropriateness and learner comprehension. The selected songs were transcribed and accompanied by lyric sheets to support simultaneous listening and reading practice. Difficult vocabulary items, slang expressions, contractions, and idiomatic phrases were pre-taught before listening sessions.

Instructional procedure

The instructional process was divided into multiple pedagogical stages designed to maximize pronunciation acquisition.

1. Pre-listening activities

At the beginning of each session, students were introduced to key vocabulary items, slang expressions, and pronunciation features present in the selected rap lyrics. Teachers explained stress patterns, contractions, reductions, and intonation characteristics before audio exposure. This stage aimed to reduce cognitive overload during listening activities.

2. Focused listening

Students listened to selected rap songs multiple times while following printed lyrics. During initial listening stages, learners focused on identifying rhythm, stress, rhyme patterns, and pronunciation features rather than understanding every lexical item. According to Rost (2011), repeated listening exposure improves phonological discrimination and listening comprehension.

3. Shadowing technique

A central component of the methodology involved the shadowing technique. Learners repeated lyrics immediately after hearing them while attempting to imitate pronunciation, intonation, rhythm, and speech tempo as accurately as possible. Shadowing has been widely recognized as an effective pronunciation-training strategy because it strengthens auditory processing and articulatory coordination (Murphey, 2001).

Students practiced both individual and group shadowing exercises. Short lyrical segments were repeated multiple times until learners achieved smoother rhythm synchronization and more accurate stress placement.

4. Rhythm synchronization exercises

Participants practiced synchronizing speech with instrumental beats to internalize English stress timing. Because English is stress-timed rather than syllable-timed, rhythm training was considered essential for developing native-like pronunciation patterns. These activities emphasized:

- syllable reduction,
- stressed syllable elongation,
- connected speech,
- natural pausing,
- intonation flow.

Musical rhythm was expected to reinforce phonological memory and speech automatization.

5. Recording and self-evaluation

Students periodically recorded themselves performing selected rap segments. The recordings were compared with native-speaker models to identify pronunciation improvements and persistent errors. Self-monitoring encouraged learner autonomy and phonological awareness. According to Celce-Murcia et al. (2010), recording-based pronunciation analysis promotes learner self-correction and reflective learning.

6. Classroom discussion and reflection

After each instructional session, learners participated in guided discussions regarding listening difficulties, pronunciation challenges, emotional responses, and perceived improvement. Reflective classroom interaction allowed researchers to gather qualitative data concerning learner attitudes and motivational changes.

Data collection instruments

Several qualitative data collection instruments were employed throughout the study.

Classroom observation

The researcher conducted systematic classroom observations during all instructional sessions. Observation focused on:

- pronunciation accuracy,
- rhythm imitation,
- learner participation,
- speaking confidence,
- fluency development,
- engagement levels.

Field notes were recorded after each session to document behavioral patterns and instructional outcomes.

Semi-structured interviews

Semi-structured interviews were conducted with participants at the conclusion of the study. Interview questions explored:

- learner motivation,
- perceptions of rap-based learning,
- pronunciation difficulties,
- listening comprehension experiences,
- confidence changes,
- attitudes toward traditional pronunciation instruction.

The interview format allowed participants to express individual experiences while maintaining consistency across responses.

Audio recordings

Learners' speech performances were audio-recorded at the beginning, middle, and end of the instructional period. The recordings were analyzed comparatively to evaluate changes in:

- stress placement,
- speech rhythm,
- connected speech production,
- pronunciation fluency,
- intonation patterns.

Data analysis

The collected data were analyzed using thematic analysis procedures. Repeated patterns and recurring themes were categorized according to learner experiences and pronunciation outcomes. Themes such as "improved fluency," "enhanced confidence," "difficulty with rapid speech," and "greater stress awareness" emerged consistently throughout observations and interviews. The audio recordings were examined descriptively rather than statistically because the primary goal was to identify qualitative pronunciation changes rather than precise phonetic measurement. Comparative analysis was conducted between initial and final recordings to evaluate pronunciation development trends. Triangulation was applied to improve research reliability. Observation data, interview responses, classroom participation patterns, and audio performance comparisons were analyzed collectively to ensure interpretive consistency. According to Denzin (1978), triangulation increases credibility by combining multiple data sources within qualitative research.

Ethical considerations

All participants voluntarily agreed to participate in the study and were informed about the research objectives before data collection began. Confidentiality and anonymity were maintained throughout the research process. Participants retained the right to withdraw from the study at any stage without academic consequences.

The instructional materials were carefully screened to avoid culturally offensive or psychologically inappropriate lyrical content. Educational suitability remained a priority throughout song selection and classroom implementation.

Results

The results of the study demonstrate that English rap hits contributed significantly to the development of native-like pronunciation features among EFL learners. Throughout the twelve-week instructional period, participants displayed observable improvements in pronunciation accuracy, stress placement, rhythmic fluency, connected speech production, and speaking confidence. The findings also indicate

that music-assisted pronunciation learning increased learner motivation and engagement compared to traditional pronunciation exercises (Alisoy & Sadigzade, 2025).

Improvement in pronunciation accuracy

One of the most noticeable outcomes of the study was the improvement in overall pronunciation accuracy. At the beginning of the research period, many participants demonstrated strong first-language interference, including incorrect vowel articulation, consonant substitution, syllable omission, and unnatural intonation patterns. However, repeated exposure to authentic rap performances gradually improved learners' articulatory precision. Students became more capable of reproducing difficult English sounds through imitation and repetition exercises. Several participants improved their pronunciation of consonants such as /θ/, /ð/, /r/, and /w/, which are often problematic for EFL learners. Learners also demonstrated better vowel differentiation after intensive listening practice.

These findings support the conclusions of Underhill (2005), who argues that repeated auditory exposure and oral imitation strengthen phonological awareness and articulation control. Similarly, Celce-Murcia et al. (2010) emphasize that pronunciation development requires extensive exposure to authentic spoken language rather than isolated phonetic drills. Participants reported that rap music enabled them to notice pronunciation details that they had previously ignored during conventional listening exercises. One student explained during the interview phase that "repeating rap lyrics helped me hear the real sound of English words instead of the way I imagined them from spelling."

Development of stress and rhythm awareness

The study revealed substantial improvement in learners' understanding of English stress timing and speech rhythm. Before the instructional intervention, many participants produced English speech with equal syllable timing influenced by their native language phonological systems. After engaging in rhythm synchronization and rap-shadowing activities, learners became increasingly aware of stressed and unstressed syllables. Rap music appeared particularly effective in helping learners internalize natural English stress patterns because rhythmic beats reinforced syllable emphasis. Learners gradually improved their ability to elongate stressed syllables and reduce unstressed syllables during oral production.

The findings align with the observations of Gilbert (2008), who states that rhythm and stress are among the most essential features distinguishing intelligible English pronunciation from heavily foreign-accented speech. According to Dauer (1993), mastery of stress timing contributes more to communicative intelligibility than individual sound accuracy alone. Several learners demonstrated improved sentence-level intonation after practicing lyrical performance. Rising and falling intonation patterns became more natural and expressive, reducing monotonous speech delivery commonly observed among foreign language learners.

The rhythmic structure of rap also supported speech memorization. Students were able to recall pronunciation sequences more effectively because rhyme and beat created predictable phonological patterns. This finding supports Patel's (2008) neurological research suggesting that music and language share overlapping rhythmic processing systems within the human brain.

Increased fluency and speech flow

Another major finding involved the development of oral fluency. Participants gradually produced longer speech sequences with fewer pauses, hesitations, and interruptions. Rap-shadowing exercises encouraged learners to maintain continuous speech flow while synchronizing pronunciation with musical rhythm.

At the beginning of the study, many students hesitated frequently during oral tasks because they concentrated heavily on grammar accuracy and word retrieval. By the final weeks of instruction, learners displayed smoother articulation and greater automaticity in spoken production.

The fluency gains observed in this study support Nation's (2001) argument that repeated language performance activities strengthen automatic processing and reduce cognitive overload during communication. Repetition of rap lyrics appeared to accelerate speech automatization because learners practiced pronunciation within meaningful rhythmic structures. Classroom observations also revealed that learners became increasingly comfortable speaking English publicly. Students who initially avoided oral participation gradually volunteered to perform short rap segments individually or in groups. Increased participation indicated growing self-confidence and reduced pronunciation anxiety.

These findings correspond with Krashen's (1985) Affective Filter Hypothesis, which suggests that enjoyable and low-stress learning environments facilitate language acquisition by lowering psychological barriers to participation.

Acquisition of connected speech features

The study demonstrated considerable improvement in learners' recognition and production of connected speech phenomena. Participants became more familiar with reductions, contractions, linking, assimilation, and elision commonly found in natural spoken English.

Examples frequently identified by students included:

- "gonna" instead of "going to,"
- "wanna" instead of "want to,"
- "lemme" instead of "let me,"
- "kinda" instead of "kind of."

Learners initially struggled to recognize these reduced forms during listening activities, but repeated exposure increased both comprehension and oral reproduction accuracy.

According to Brown and Kondo-Brown (2006), connected speech remains one of the most difficult aspects of listening comprehension for EFL learners because classroom materials often present artificially clear pronunciation rather than authentic conversational speech. Rap songs exposed learners to realistic speech reductions and informal pronunciation patterns occurring in native communication. Furthermore, participants developed greater awareness of linking between words. Students improved their ability to connect final consonants with following vowels, producing smoother and more natural speech sequences. For example, learners became more comfortable pronouncing phrases such as "take_it" and "turn_off" without unnatural pauses between words.

Improvement in listening comprehension

The instructional intervention also enhanced listening comprehension abilities. Initially, many participants experienced difficulty understanding fast-paced native speech due to unfamiliar rhythm patterns and reduced pronunciation forms. Continuous listening practice gradually improved learners' ability to process rapid speech input. Repeated exposure to rap lyrics trained learners to identify key words within dense speech streams and anticipate rhythmic patterns (Seidova et al., 2026). Several participants stated that they became more comfortable understanding English movies, interviews, and podcasts after participating in rap-based activities.

This finding supports Rost's (2011) claim that listening competence improves through exposure to authentic auditory input combined with repeated practice and contextual prediction strategies.

Participants also reported improved ability to distinguish individual sounds within continuous speech. Many learners explained that rap listening sharpened their attention to pronunciation detail and word boundaries.

Motivation and emotional engagement

Motivation emerged as one of the strongest positive outcomes of the study. Most participants described rap-based pronunciation learning as enjoyable, energetic, and less stressful than traditional pronunciation exercises. Learners demonstrated high levels of classroom participation and voluntary practice outside instructional hours. Unlike repetitive textbook drills, rap activities created emotionally engaging learning experiences that maintained student attention for longer periods. Participants frequently practiced songs independently using streaming platforms and lyric websites.

The findings support Murphey's (1992) argument that music enhances learner motivation by combining emotional stimulation with repetitive language exposure. Similarly, Gardner (1985) emphasizes that positive emotional attitudes significantly influence second language acquisition success. Students also developed stronger cultural interest in English-speaking societies through exposure to rap music. Many participants explored additional English-language media independently after becoming engaged with rap culture and lyrical expression (Nuri et al., 2025).

Pronunciation confidence and accent reduction

The results indicate partial reduction of first-language pronunciation interference among many participants. Although complete native-like pronunciation was not achieved, learners displayed more natural rhythm, smoother speech transitions, and improved intonation control by the end of the instructional period. Several students became more willing to communicate spontaneously in English without excessive fear of making pronunciation mistakes. Increased confidence contributed positively to classroom interaction and oral participation. According to Derwing and Munro (2005), pronunciation confidence plays a central role in communicative effectiveness because learners who fear pronunciation errors often avoid oral communication altogether. The present study suggests that rap-based pronunciation activities may reduce speaking anxiety by transforming pronunciation practice into a creative and enjoyable performance activity.

Challenges and difficulties

Despite the positive outcomes, the study also identified several challenges associated with rap-based pronunciation learning.

Rapid speech tempo

Many learners initially struggled with the fast delivery speed of rap lyrics. Certain songs overwhelmed participants because multiple words were compressed into short rhythmic sequences. Intermediate learners occasionally became frustrated during early listening sessions. However, gradual exposure and repeated practice reduced comprehension difficulty over time. Slower rap songs proved more suitable during initial instructional stages.

Slang and informal language

Participants occasionally encountered difficulties understanding slang expressions, idioms, and culturally specific references. Some learners incorrectly assumed that all rap vocabulary represented standard English usage. This issue confirms concerns raised by Alim (2006), who notes that rap language often reflects regional identity, urban slang, and sociocultural variation that may differ from formal English norms.

Non-standard grammar

Certain rap lyrics included grammatically non-standard constructions used for artistic rhythm or cultural authenticity. Teachers needed to clarify differences between conversational artistic expression and formal academic English usage.

Pronunciation manipulation by artists

Some rap artists intentionally distort pronunciation to preserve rhyme schemes or stylistic identity. Without instructional guidance, learners risk imitating exaggerated or regionally marked pronunciation forms. Therefore, careful material selection remained essential throughout the instructional process.

Overall findings

Overall, the findings strongly suggest that English rap hits can function as effective supplementary tools for pronunciation development among EFL learners. Rap-based instruction improved stress awareness, fluency, listening comprehension, connected speech recognition, and pronunciation confidence while simultaneously increasing learner motivation and engagement. The results demonstrate that authentic musical input provides meaningful opportunities for repeated pronunciation practice in emotionally stimulating environments. When carefully integrated into structured language instruction, English rap music can support learners' movement toward more natural and native-like speech production.

Discussion

The findings of this study demonstrate that English rap hits can serve as an effective supplementary instructional resource for improving pronunciation and promoting native-like speech characteristics among EFL learners. The results reveal that learners exposed to rhythm-based pronunciation activities developed greater awareness of stress timing, connected speech, intonation, and fluency. These findings correspond with broader theories of second language acquisition emphasizing the importance of authentic auditory input, repetition, emotional engagement, and meaningful communicative exposure.

One of the central findings of the study concerns the role of rhythm in pronunciation development. English rap music relies heavily on stress placement, beat synchronization, and rhythmic speech flow. These features appear to support learners' acquisition of English prosody, particularly stress timing and intonation patterns. According to Gilbert (2008), prosodic features such as rhythm and stress are fundamental components of intelligible pronunciation because they shape the listener's ability to interpret meaning and speech organization. Learners who fail to master English stress timing often sound unnatural even when individual sounds are correctly pronounced.

The study suggests that rap music creates a practical environment for internalizing these prosodic patterns. Through repeated imitation and synchronization with musical beats, learners gradually adjusted their speech rhythm toward more native-like timing. This observation supports Dauer's (1993) argument that stress timing plays a greater role in pronunciation intelligibility than isolated segmental accuracy alone. Many participants in the present study improved sentence rhythm and syllable reduction after repeated exposure to rap lyrics.

The findings also reinforce the theoretical assumptions of Stephen Krashen regarding comprehensible input and affective factors in language acquisition. Krashen's Input Hypothesis proposes that learners acquire language most effectively when exposed to meaningful and engaging input in low-anxiety environments (Krashen, 1985).

Rap music appears to satisfy several conditions of effective language acquisition simultaneously:

- authentic language exposure,
- repeated auditory input,
- emotional engagement,
- learner motivation,
- reduced classroom anxiety.

Unlike traditional pronunciation drills, which learners often perceive as mechanical and repetitive, rap-based activities transformed pronunciation practice into an enjoyable and socially interactive experience. The increased classroom participation observed during the study supports Krashen's Affective Filter Hypothesis, which states that emotional comfort facilitates language acquisition by lowering psychological barriers to communication.

The motivational dimension of rap-based learning emerged as another highly significant finding. Many participants voluntarily practiced English pronunciation outside classroom settings through repeated listening and lyrical imitation. This autonomous engagement is especially important because pronunciation acquisition requires long-term exposure and extensive repetition. According to Gardner (1985), motivation represents one of the strongest predictors of success in second language learning. Learners who are emotionally invested in language practice are more likely to sustain effort, tolerate mistakes, and engage in repeated communicative attempts.

Music-based learning may therefore function not only as a linguistic tool but also as a motivational catalyst. Murphey (1992) argues that songs naturally encourage repetition because learners repeatedly listen to music for enjoyment rather than obligation. The current study supports this perspective, as many participants practiced rap lyrics voluntarily beyond classroom requirements. Such repeated exposure strengthens phonological memory and speech automatization.

Another important implication of the study involves the development of connected speech awareness. Traditional EFL instruction frequently presents artificially slow and carefully articulated speech, which differs substantially from authentic conversational English. As a result, learners often struggle to understand native speakers despite strong vocabulary knowledge. Rap music exposes learners to realistic speech reductions, linking, contractions, assimilation, and rapid articulation patterns that are characteristic of everyday spoken English.

The improvement observed in learners' recognition of forms such as "gonna," "wanna," and "lemme" suggests that rap-based instruction may bridge the gap between classroom English and authentic communication. According to Brown and Kondo-Brown (2006), exposure to connected speech is essential for developing listening comprehension and communicative fluency because native speech rarely occurs in isolated word forms. The present findings indicate that rap music can familiarize learners with these naturally occurring phonological processes more effectively than scripted textbook dialogues.

Furthermore, the study supports neurological perspectives concerning the relationship between music and language processing. Patel (2008) argues that music and language share overlapping cognitive mechanisms associated with rhythm perception, auditory memory, and temporal processing. The rhythmic repetition found in rap may therefore strengthen neural pathways involved in phonological acquisition and speech production. Several participants reported that rhythmic beats helped them memorize pronunciation sequences more effectively than ordinary listening exercises. This finding aligns with Fonseca-Mora (2011), who emphasizes that musical repetition enhances phonological retention and auditory discrimination.

The observed improvement in speaking fluency also carries important pedagogical implications. Many learners initially hesitated during oral communication because they focused excessively on grammatical correctness and pronunciation accuracy. However, rap-shadowing activities encouraged continuous speech production without frequent interruption. As learners practiced maintaining rhythm and speech flow, they gradually developed greater automaticity in spoken English.

Nation (2001) explains that fluency develops when learners repeatedly process language under time pressure until speech production becomes more automatic and cognitively efficient. Rap performance naturally introduces time-sensitive articulation demands that train learners to process language more rapidly. This may explain why participants demonstrated smoother speech flow and reduced hesitation during classroom interaction by the end of the study.

The findings additionally suggest that rap music contributes to pronunciation confidence and identity formation. Several learners reported feeling more comfortable speaking English publicly after participating in rap-based activities. Pronunciation anxiety often prevents learners from engaging actively in communication, even when they possess sufficient linguistic knowledge. According to Derwing and Munro (2005), fear of negative evaluation frequently limits oral participation among foreign language learners.

Rap performance may reduce this anxiety because it reframes pronunciation practice as artistic imitation rather than formal assessment. Learners focus on rhythm, performance, and expression rather than perfection, which may decrease self-consciousness and increase communicative risk-taking. Increased confidence subsequently encourages more frequent oral interaction, further reinforcing pronunciation development through practice.

The study also highlights the importance of authenticity in pronunciation instruction. Authentic input exposes learners to natural speech variability, emotional expression, and spontaneous pronunciation phenomena absent from many educational materials. Rap lyrics frequently contain emotional intensity, personal storytelling, and conversational language that create meaningful communicative contexts for pronunciation learning. Richards (2008) argues that authentic communicative materials increase learner engagement because they connect language study to real-world usage.

However, despite these positive outcomes, the study also confirms several important limitations associated with rap-based language learning. One major concern involves the presence of slang vocabulary and non-standard grammatical structures. Rap artists often intentionally manipulate grammar and pronunciation to preserve rhythm, rhyme, regional identity, or artistic expression. Without teacher guidance, learners may struggle to distinguish between standard English usage and stylistic variation.

This concern corresponds with Alim's (2006) sociolinguistic analysis of hip-hop language, which emphasizes that rap frequently reflects cultural identity and urban speech communities rather than formal standardized English. Teachers therefore carry significant responsibility in selecting appropriate materials and contextualizing linguistic variation for learners. Another limitation involves speech tempo. Certain rap songs contain extremely rapid articulation that may overwhelm intermediate learners and reduce listening comprehension. Although repeated exposure gradually improved learner processing abilities in the current study, excessive difficulty may discourage less confident students. Consequently, pedagogical implementation should involve gradual progression from slower, clearer rap performances toward more linguistically complex material.

Cultural considerations also deserve attention. Rap music is deeply connected to specific historical, social, and cultural contexts, particularly African American urban culture. Learners unfamiliar with these cultural references may misunderstand lyrical meanings or fail to appreciate contextual nuances.

Therefore, integrating rap into language instruction may also require cultural explanation and discussion to support comprehensive understanding.

From a broader educational perspective, the findings suggest that contemporary language instruction should increasingly incorporate multimedia and culturally relevant resources (Babayev et al., 2025). Modern learners interact extensively with music, digital platforms, and social media outside formal educational environments. Integrating these authentic cultural resources into language classrooms may increase relevance, engagement, and learner autonomy.

Technological accessibility further strengthens the educational value of rap-based pronunciation learning. Streaming services, lyric annotation platforms, pronunciation applications, and subtitled music videos allow learners to combine auditory, visual, and textual input simultaneously. This multimodal exposure may accelerate pronunciation acquisition by activating multiple cognitive processing channels.

Overall, the discussion demonstrates that English rap hits can meaningfully contribute to the formation of native-like pronunciation when implemented thoughtfully within structured pedagogical frameworks. Rap music enhances pronunciation awareness, listening comprehension, fluency, stress timing, and learner motivation while simultaneously providing authentic communicative exposure. Although challenges related to slang, rapid speech, and non-standard language remain important considerations, the educational benefits observed in this study strongly support the integration of carefully selected rap materials into modern EFL pronunciation instruction.

Conclusion

The present study demonstrates that English rap hits can play a significant role in the formation of native-like pronunciation among English as a Foreign Language (EFL) learners. The findings reveal that rap music provides learners with authentic exposure to natural English pronunciation patterns, including stress timing, rhythm, intonation, connected speech, reductions, and fluent articulation. Through repeated listening, imitation, and rhythm-based practice, learners gradually improved their pronunciation accuracy and developed greater awareness of the phonological characteristics of spoken English.

One of the most important outcomes of the study is the recognition that pronunciation learning becomes more effective when linguistic instruction is combined with emotional engagement and motivation. Unlike traditional pronunciation drills, rap-based activities created an enjoyable and dynamic learning environment that encouraged active participation and independent practice. Learners demonstrated increased confidence, reduced speaking anxiety, and stronger willingness to communicate in English. The rhythmic and repetitive nature of rap also strengthened memory retention and speech automatization, helping learners internalize pronunciation patterns more naturally.

The study further highlights the importance of authentic language input in modern pronunciation instruction. English rap music exposes learners to real conversational speech features that are often absent from textbook materials. By interacting with authentic musical language, learners improved not only pronunciation but also listening comprehension, fluency, and cultural awareness. These findings support contemporary language acquisition theories emphasizing meaningful exposure, repetition, and communicative practice.

However, the research also identifies several limitations associated with rap-based pronunciation learning. Rapid speech tempo, slang expressions, non-standard grammar, and culturally specific references may create comprehension difficulties for some learners. Therefore, successful

implementation requires careful song selection, instructional guidance, and adaptation to learners' proficiency levels and educational needs.

Overall, the study concludes that English rap hits represent a valuable supplementary resource for pronunciation development in EFL education. When integrated thoughtfully into classroom instruction, rap music can effectively bridge entertainment and pedagogy while helping learners move closer toward more fluent, confident, and native-like spoken English.

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Legal Mechanisms of Integration of International Tax Rules into the Domestic Legislation of the CIS Member States

Asmar Aliyeva 

Abstract. This study systematically analyzes the institutional and normative mechanisms of integration of international tax norms into the national tax legal systems of the member states of the Commonwealth of Independent States (CIS). The central hypothesis of the article is that international legal influence in the field of taxation in the CIS is mainly carried out through advisory acts and voluntary cooperation mechanisms, which makes the integration process qualitatively different and limited in nature compared to supranational associations. The research methodology is based on the integrative application of formal-legal, comparative-legal and systematic analysis methods. The article examines four main integration mechanisms: (1) system of bilateral and multilateral tax treaties; (2) normative impact of the CIS Model Tax Code; (3) transplantation of the OECD Base Erosion and Profit Shifting (BEPS) plan into national legislation; (4) institutions of information exchange and administrative cooperation between tax authorities. The research findings show that while significant progress has been made in the areas of transfer pricing and information exchange, harmonisation of fundamental elements of tax policy remains limited due to economic differentiation, concerns over political sovereignty and the lack of binding legal mechanisms. The article presents recommendations for enhancing the legal status of the Model Tax Code, improving the digital tax administration infrastructure, and differentially using the experience of the Eurasian Economic Union to increase the efficiency of the integration process.

Keywords: Commonwealth of Independent States, international tax law, integration mechanisms, Model Tax Code, BEPS, transfer pricing, tax harmonization

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Beynəlxalq vergi normalarının MDB üzv dövlətlərinin daxili qanunvericiliyinə integrasiyasının hüquqi mexanizmləri

Əsmər Əliyeva 

Xülasə. Bu tədqiqat Müstəqil Dövlətlər Birliyi (MDB) üzv dövlətlərinin milli vergi hüquq sistemlərinə beynəlxalq vergi normalarının integrasiyasının institusional və normativ mexanizmlərini sistemli şəkildə təhlil edir. Məqalənin mərkəzi hipotezi ondan ibarətdir ki, MDB məkanında vergi sahəsində beynəlxalq hüquqi təsir əsasən tövsiyə xarakterli aktlar və könüllü əməkdaşlıq mexanizmləri vasitəsilə həyata keçirilir ki, bu da integrasiya prosesini supranational birliklərlə müqayisədə keyfiyyətə fərqli və məhdud xarakterli edir. Tədqiqat metodologiyası formal-hüquqi, müqayisəli-hüquqi və sistemli təhlil metodlarının integrativ tətbiqinə əsaslanır.

Məqalədə dörd əsas integrasiya mexanizmi araşdırılır: (1) ikitərəfli və çoxtərəfli vergi müqavilələri sistemi; (2) MDB-nin Model Vergi Məcəlləsinin normativ təsiri; (3) OECD-nin Vergi Bazasının Aşınması və Mənfəətin Köçürülməsi (BEPS) planının milli qanunvericiliyə transplantasiyası; (4) vergi orqanları arasında məlumat mübadiləsi və inzibati əməkdaşlıq institutları. Tədqiqat nəticələri göstərir ki, transferqiymətoyma və məlumat mübadiləsi sahələrində əhəmiyyətli irəliləyişlər əldə edilsə də, vergi siyasətinin fundamental elementlərinin harmonizasiyası iqtisadi differensiasiya, siyasi suverenliklə bağlı narahatlıqlar və məcburi hüquqi mexanizmlərin olmaması səbəbindən məhdud olaraq qalmaqdadır. Məqalə integrasiya prosesinin səmərəliliyinin artırılması üçün Model Vergi Məcəlləsinin hüquqi statusunun yüksəldilməsi, rəqəmsal vergi inzibatçılığı infrastrukturunun təkmilləşdirilməsi və Avrasiya İqtisadi İttifaqının təcrübəsindən differensial şəkildə istifadə edilməsi istiqamətində tövsiyələr təqdim edir.

Açar sözlər: *Müstəqil Dövlətlər Birliyi, beynəlxalq vergi hüququ, integrasiya mexanizmləri, Model Vergi Məcəlləsi, BEPS, transferqiymətoyma, vergi harmonizasiyası*

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Introduction

1.1. Relevance of the problem and justification of the research

The lack of a clear legal regulation of the process of harmonization of tax legislation and a unified tax policy further increases the importance of theoretical research in this area. In this regard, the issues of harmonization of tax legislation are becoming one of the priority areas of scientific and legal research (Golovchenko, 2020, p. 3). A.D. Khokhlova notes that the stability of tax legislation is one of the most important guarantees of the implementation of the principle of legal certainty. The degree to which tax norms are stable and predictable directly affects the ability of taxpayers to plan their economic activities, assess economic risks and make long-term investment decisions (Khokhlova, 2025, p. 3). The formation of tax law in the post-Soviet space took place under a two-way influence: on the one hand, the need to establish national tax systems in the newly independent states after the collapse of the USSR, and on the other hand, the requirement to adapt to international tax standards dictated by global economic integration processes. The Commonwealth of Independent States (CIS) represents a unique legal environment where these two factors converge. Despite the organization's existence for over thirty years, the depth, mechanisms, and effectiveness of tax integration remain at the center of academic debate.

The integration of international tax norms into national legal systems is one of the most complex problems of modern international law. This process develops in the context of constant tension between the fiscal sovereignty of states and the needs of global economic cooperation (Avi-Yonah, 2019). This dilemma is particularly acute for the CIS member states: their economies are still closely interconnected, but their political and economic development trajectories differ significantly. The fundamental changes in the international tax environment over the past decade - in particular, the adoption of the OECD's BEPS plan, new challenges related to the taxation of the digital economy, and global tax transparency requirements - have also forced CIS countries to reconsider their tax systems. Against the background of these changes, it is particularly relevant to determine the effectiveness of the existing mechanisms of cooperation in the field of taxation within the CIS and the directions for improving these mechanisms. O.I. Lyutova states that the digital era entails a phased transformation of tax law, and each stage of this transformation is characterized by the type of digital technologies used by subjects of tax law relations (Lyutova, 2024, p. 73).

1.2. The purpose, objectives and scientific novelty of the research

The purpose of the study is to systematically analyze the formal legal mechanisms of integration of international tax norms into the national tax legislation of the CIS member states, and to assess the degree of influence and institutional limitations of these mechanisms on a scientific basis. The aim is also to determine the nature, depth and prospects of integration processes in the field of taxation in the CIS, to identify existing shortcomings and develop directions for improving legal mechanisms to eliminate them.

To achieve the set goal, the following tasks were identified in the study:

- (1) to systematize theoretical models of the integration of international tax norms into national law, identify specific features of the CIS model in the context of the doctrines of monism and dualism, the concept of “soft law” and tax harmonization theories;
- (2) to describe and comprehensively analyze the four main integration mechanisms operating within the CIS – the system of bilateral and multilateral tax treaties, the CIS Model Tax Code, the transplantation of the requirements of the OECD BEPS plan, and the institutions for information exchange between tax authorities;
- (3) to develop a system of criteria for objectively assessing the effectiveness of the integration process, including proposing a comprehensive approach that includes indicators such as the degree of bindingness of regulatory regulation, the effectiveness of enforcement mechanisms, the level of transparency, and adaptive flexibility;
- (4) comparatively analyze the tax harmonization models of the CIS and the Eurasian Economic Union (EAEU), to identify the advantages and disadvantages of both integration formats, and to reveal elements that the CIS can adopt from the EAEU experience;
- (5) to develop scientifically based, practically applicable recommendations for improving existing mechanisms, including developing comprehensive proposals covering regulatory, legal, institutional and digital transformation aspects.

The scientific novelty of the research is manifested in the following areas:

- (1) For the first time, a complex institutional model of the integration of international tax norms in the CIS space is proposed; this model considers integration mechanisms as interconnected and interacting subsystems (normative, institutional, functional and constitutional-ideological);
- (2) A scientifically based typology of integration mechanisms is being developed; this typology reflects the classification of mechanisms according to their legal nature (mandatory, advisory), direction of influence (vertical, horizontal) and depth of integration (harmonization, unification);
- (3) A comparative analysis of the CIS and EAEU tax harmonization models is conducted based on new analytical criteria (degree of coercion, effectiveness of enforcement mechanisms, adaptive flexibility, level of transparency); this approach allows us to more accurately determine the qualitatively different nature of the two integration models (“soft” cooperation vs. “hard” integration);
- (4) A systematic analysis of the experience of implementing the BEPS plan in the CIS countries is being conducted, and for the first time, the level of transplantation of these norms, their inequality, and the reasons for this inequality are being comprehensively assessed;
- (5) Prospects for modernizing tax administration in the CIS countries in the context of a digital economy are being explored and scientifically substantiated proposals are being prepared for the creation of a single digital tax platform.

1.3. Research methodology

Since this study is aimed at a comprehensive analysis of the legal mechanisms of integration of international tax norms into the domestic legislation of the CIS member states, the selection of methodological apparatus is multidimensional and systematic in accordance with the goals and objectives of the study. The research uses three main methods – formal-legal, comparative-legal and

systematic analysis – in an integrative manner. The synthesis of these methods allows for a deep understanding of both the normative content of the research object and the mechanism of its functioning in the institutional context.

The formal-legal method acts as the main normative-analytical tool of the research. This method is aimed at analyzing the content, structure and legal techniques of international treaties, CIS model acts, national tax codes of member states and other normative-legal documents. Within the framework of formal-legal analysis, the following aspects are examined: (a) methods of transformation of international norms into national legislation - mechanisms of incorporation, ratification, reference or direct application; (b) the place of international treaties in the hierarchy of normative acts and resolution mechanisms in cases where they conflict with domestic legislation; (c) Structural features of the CIS Model Tax Code, the structure of its chapters, the legal constructs and terminology used; (d) normative tools used to incorporate the provisions of the BEPS plan into national legislation (e.g. legislative amendments on transfer pricing, information exchange protocols). When applying this method, reference was made to the rules of the Vienna Convention (1969) on the interpretation of treaties, as well as to the precedent practice of national supreme courts on tax disputes, in the interpretation of legal norms.

The comparative legal method was the second main tool of the research and was applied in three directions: (a) vertical comparison – comparison of the experience of applying international norms (OECD BEPS, CIS Model Code) in the national legislation of various CIS countries (Russia, Azerbaijan, Kazakhstan, Belarus, Kyrgyzstan, Tajikistan); (b) horizontal comparison – comparative analysis of tax harmonization models within the CIS and existing models in other regional integration associations (in particular the Eurasian Economic Union, as well as partly the European Union and ASEAN); (c) functional comparison – comparison of different regulatory approaches to the same legal institutions (e.g. transfer pricing, information exchange, anti-tax evasion measures) in different countries. A system of criteria has been developed for comparison: the level of regulatory regulation (degree of coercion), the effectiveness of enforcement mechanisms, the degree of transparency, and the flexibility of adaptation. The comparative analysis was based on the principle of “similarities and differences”, and the typology of legal systems by family (Roman-Germanic, post-Soviet, Anglo-Saxon elements) was also taken into account.

The systematic method ensures the understanding of the object of research – the mechanisms of integration of international tax norms – as a complex, multi-level and dynamic system. Within the framework of this method, the integration mechanisms are modeled as the interaction of the following subsystems: (a) normative subsystem (international treaties, model acts, national laws); (b) institutional subsystem (tax authorities, parliaments, courts, structures of international organizations); (c) functional subsystem (information exchange, administrative cooperation, control, coercive mechanisms); (d) ideological/constitutional subsystem (principles of sovereignty, doctrines of the primacy of international law, national interests). The systematic approach also allowed for the identification of synergistic effects – additional integration effects created by the combined action of individual mechanisms. In addition, the system analysis used an “input-output” model: international norms were considered as “input”, changes in national legislation and improvements in tax administration as “output”, and the institutional structures of the CIS as “transformers”.

The empirical basis includes the following source groups: (1) Official documents of the CIS – Agreement on the “Agreed Principles of Tax Policy” (1992), Agreement on Tax Cooperation (1999) and amendments of 2026, various editions of the Model Tax Code, protocols of the Inter-Parliamentary Assembly; (2) National tax codes and legislative acts of the CIS member states (Russia, Azerbaijan, Kazakhstan, Belarus, Kyrgyzstan, Tajikistan); (3) OECD BEPS Final Reports (2015), Multilateral Convention (MLI), Transfer Pricing Guidelines (2024), Two-Pillar Solution documents (2021); (4) relevant case law – decisions of the supreme courts of the CIS countries on tax disputes,

as well as precedents of the EAEU Court; (5) analytical reports of international financial organizations (IMF, World Bank); (6) texts of bilateral tax treaties. When analyzing the documents, priority was given to the originality of the sources, their officially published texts and versions posted on the websites of relevant state bodies.

To ensure the reliability of the study, the principle of triangulation of sources was used: cross-checks were conducted between regulatory sources, literature and practical experience (court decisions, official interpretations of tax authorities).

2. Theoretical Framework: Conceptual Basis for the Integration of International Tax Norms into National Law

2.1. Integration of Tax Law in the Context of Monism and Dualism Theories

Theories of monism and dualism on the interaction of international law with national legal systems are of heuristic importance for understanding the theoretical foundations of the integration of tax norms. These two theories determine the position of international law in relation to domestic law and allow us to explain the mechanisms of implementation of international obligations in the field of taxation at the national level.

According to the monist approach, international norms automatically become part of the national normative system. This theory originates from Hans Kelsen's (1967) "pure theory of law" and proposes that international law and national law are components of a single normative system. There are two main variants of monism: the primacy of international law over national law (radical monism) and the primacy of national law over international law (national monism). In the context of tax law, a monistic approach means that international tax treaties automatically become part of national law upon ratification and no additional transformation act is required.

The dualist model assumes that special transformation acts are required to transform international norms into national law (Avi-Yonah, 2019). This theory was developed by Dionisio Anzilotti (1929), starting with the works of Heinrich Triepel (1899). According to the dualist approach, international law and national law are two separate, independent legal systems. Therefore, for international treaties to be applicable in national law, their "transformation" or "incorporation" into domestic law is necessary. In the context of tax treaties, the dualist approach means that each tax treaty must be ratified by the national parliament and approved by an appropriate legislative act.

The CIS member states take different positions between these two models. The Constitution of the Russian Federation (Article 15, paragraph 4) recognizes the primacy of international treaties over national legislation, which indicates the presence of a monistic element. However, in Russia, ratification procedures are required for the application of tax treaties, which contains dualistic elements. According to Article 148 of the Constitution of Azerbaijan, international treaties become an integral part of national legislation after ratification, and domestic norms that contradict them are not applied (Townsend et al., 2009). Article 4 of the Constitution of the Republic of Kazakhstan adopts a similar approach: ratified international treaties take precedence over national legislation. In countries such as Ukraine and Belarus, however, monistic elements at the constitutional level are weaker, and the adoption of separate legislative acts is required for the application of international treaties.

The process of integration in tax law is also associated with the concept of "soft law". Although this concept is relatively new in international legal theory, it has developed significantly in the last thirty years. "Soft law" refers to international instruments that are not legally binding but have significant impact in practice. (Abbott & Snidal, 2000). OECD advisory documents, the CIS Model Tax Code, the recommendations of the BEPS plan - all of these are of a "soft law" nature. Although they do not

have binding legal force, they have a significant impact on national legislation. This is called the “normative influence” mechanism and goes beyond the traditional theory of legal sources.

The mechanisms of influence of “soft law” in the field of taxation are various: (a) “emulation” - countries voluntarily adopt international standards; (b) “normative diffusion” - international organizations influence national legislation through their recommendations; (c) “conditionality” - international financial organizations condition their loans on the implementation of certain tax reforms; (d) “technical assistance” - international organizations provide practical assistance to countries in improving their tax systems (Christians, 2019). These mechanisms also operate in the CIS countries - in particular, the recommendations of the OECD BEPS plan, the CIS Model Tax Code and the IMF’s recommendations on tax reforms are a manifestation of these mechanisms.

2.2. Tax harmonization and unification: specifics of the CIS model

In the theory of international integration, a fundamental distinction is made between harmonization and unification. Harmonization implies the approximation of the legislation of member states based on common principles and approaches, but while preserving national characteristics. Unification, on the other hand, leads to the creation of uniform norms and their uniform application in all member states. The difference between these two concepts is not only technical, but also political: while harmonization more closely preserves the sovereignty of states, unification requires the expansion of supranational powers.

The theory of tax harmonization is closely related to the deepening of economic integration. The forms of cooperation in the field of tax change at different stages of integration: (1) free trade zone - minimal cooperation in the field of taxation; (2) customs union - unification of foreign trade taxes (import duties); (3) common market - harmonization of indirect taxes (VAT, excise duties); (4) economic union - partial harmonization of direct taxes; (5) full economic integration - creation of a single tax system (Cnossen, 2018). The CIS occupies the lowest level on this scale - between a free trade zone and a customs union, which explains the limited tax harmonization.

The CIS has clearly chosen the path of harmonization in the field of taxation. This choice is due to the nature of the organization: the CIS was created as a cooperative, not an integration, organization, and its documents, including the Model Tax Code, are of a recommendatory nature. Compared to the European Union, the mechanisms of tax harmonization in the CIS are significantly different. In the EU, tax directives are binding and member states must incorporate them into national legislation. In the CIS, however, such mandatory mechanisms do not exist. In the EU, significant harmonization has been achieved in the areas of VAT, excise duties and energy taxes. In the CIS, however, harmonization is mainly advisory through the Model Tax Code.

However, in practice, the line between harmonization and unification is blurred. The CIS Model Tax Code has been used as a direct regulatory framework in a number of CIS countries (e.g., Kazakhstan, Kyrgyzstan), which in fact leads to partial unification (Gorsky, 2012). This is the so-called “de facto unification” - although formally harmonization is declared, in practice uniform norms are applied. At the same time, the implementation of the requirements of the BEPS plan forces the CIS countries to adopt global standards, which indicates the influence of factors outside the internal harmonization of the CIS. (OECD, 2015). This is called the “external pressure” mechanism - international organizations extend their standards to countries outside the organization.

2.3. Tension between tax sovereignty and international cooperation

One of the main problems of international cooperation in the field of taxation is the tension between tax sovereignty and the demands for global cooperation. Tax sovereignty is understood as the right of a state to exercise its independent will in establishing a tax system within its territory, imposing taxes, and determining their rates, bases, and collection procedures. This sovereignty is one of the main attributes of state existence (Avi-Yonah, 2019).

International tax cooperation inevitably requires the limitation of national tax sovereignty. This is manifested in the following areas: (a) tax treaties limit the taxing rights of states - for example, the source country can apply a tax on dividend interest to a limited extent; (b) BEPS requirements impose certain restrictions on the tax policies of states - for example, to abandon harmful tax practices; (c) information exchange requirements increase transparency in the activities of tax authorities; (d) recommendations of international organizations influence national legislation (Christians, 2019).

The issue of tax sovereignty is particularly sensitive for the CIS countries. Many of these countries gained their independence recently and treat their sovereignty with particular care. Therefore, the adoption of international obligations in the field of taxation sometimes faces political opposition. This is one of the reasons why tax integration within the CIS is carried out through soft mechanisms - acts of a recommendatory nature (Lagkueva, 2020).

However, as integration into the global economy deepens, the need for CIS countries to adopt international tax standards increases. International financial centers, transnational corporations, and global tax governance mechanisms are forcing CIS countries to adapt to their standards. This is a “top-down” integration model - global standards are implemented at the national level (Zhuravleva, et al. 2023). Within the CIS, the “bottom-up” model prevails - countries strive for harmonization among themselves on their own initiative. The tension between these two models explains the contradictory nature of tax integration in the CIS.

2.4. Constitutional foundations of post-Soviet tax systems and attitude to international law

The tax systems of the independent states that emerged after the collapse of the USSR were influenced by three main sources: (1) Soviet tax traditions (centralized administration, extensive tax breaks, low tax discipline); (2) Western tax models (OECD standards, transfer pricing, transparency); (3) interactions in the post-Soviet space (CIS Model Code, bilateral agreements). As a result of the interaction of these three factors, various tax systems have been formed in the CIS countries (McGee & Preobragenskaya, 2004).

The constitutions of the CIS countries regulate the relationship between international law and national law in different ways. Article 15 of the Russian Constitution declares the general principles of international law and international treaties to be an integral part of national legislation. Article 148 of the Constitution of Azerbaijan stipulates that international treaties shall prevail in cases where they conflict with national legislation. Article 4 of the Constitution of Kazakhstan adopts a similar approach. Article 9 of the Constitution of Ukraine stipulates that ratified international treaties are an integral part of national legislation. Article 8 of the Constitution of Belarus recognizes the principle of the primacy of international law (Townsend et al., 2009).

Despite the monistic elements at the constitutional level, there are also dualistic elements in the practice of applying international treaties in the field of taxation. In most CIS countries, tax treaties enter into force after parliamentary ratification, and during this process, contradictions between the treaty and domestic legislation are eliminated. In some countries (e.g. Russia, Azerbaijan), international norms are applied in cases where international treaties conflict with national legislation. In other countries (Ukraine, Moldova), this issue is not entirely clear and there are different approaches in judicial practice.

2.5. The role of “soft law” in tax law: theoretical perspectives

The role of “soft law” in tax law has increased significantly in recent decades. This is explained by a number of factors: (1) amending international tax treaties is a long and complex process, while “soft law” is more flexible; (2) states want to preserve their sovereignty in the tax area, while “soft law” is not binding; (3) due to the rapid changes in the global economy, hard legal regulation is often slow; (4) “soft law” allows for the formation of consensus for international cooperation (Christians, 2019).

In tax law, “soft law” exists in the following forms: (a) model treaties (OECD Model Convention, UN Model Convention); (b) guidelines (OECD Transfer Pricing Guidelines); (c) recommendations (BEPS plan recommendations); (d) standards (Automatic Exchange of Information Standard); (e) declarations (New York Tax Declaration); (f) model laws (CIS Model Tax Code).

Advantages of “soft law” in tax law: flexibility, rapid adoption, consensus-based decision-making, opportunity for experimentation, preparatory stage for hard law. Disadvantages: lack of binding force, weak enforcement mechanisms, uneven application, sensitivity to political pressures. The advantages and disadvantages of “soft law” are particularly evident in the CIS context: Since the Model Tax Code is of a recommendatory nature, its application is voluntary, but for this reason its application is uneven across countries.

2.6. Applying the theoretical framework to research: a synthetic model

The theoretical framework proposed in this study consists of a synthetic combination of the following elements:

The first element: the theory of monism/dualism - explains the formal legal mechanisms of integration of international tax norms into national law. This theory allows us to analyze the attitude of the CIS countries to international treaties at the constitutional level.

The second element: the theory of harmonization/unification - explains the nature and depth of tax cooperation within the CIS. This theory allows us to understand why the CIS has chosen the path of harmonization or unification.

The third element: the theory of “soft law” - explains the mechanisms of influence of recommendations of international organizations (OECD, CIS) on national legislation. This theory allows us to analyze the impact of the Model Tax Code and the BEPS plan in the CIS countries.

The fourth element: the theory of tax sovereignty - explains the tension between the desire of states to protect their national interests in the field of taxation and the requirements of international cooperation. This theory allows us to understand the reasons for the reluctance of CIS countries to adopt international tax standards.

The synthetic combination of these four elements forms the theoretical basis for a comprehensive analysis of the integration of international tax norms in the CIS space. In the following sections of the study, this theoretical framework will be applied to the analysis of the four main mechanisms of the integration of international tax norms in the CIS.

3. Institutional Mechanisms for the Integration of International Tax Norms

3.1. Evolution of the CIS Tax Regulatory Framework

The legal framework for tax cooperation within the CIS has developed over nearly thirty years. This evolution can be divided into three stages:

The first stage (1992-2000): the formation of the foundations. The 1992 Agreement “On the Agreed Principles of Tax Policy” became the first regulatory act of the CIS. This document defined the general principles of tax systems, including a list of tax types, rules for determining tax rates, and the powers of tax authorities. However, this agreement was broad and non-binding. The 1999 Agreement “On Cooperation in Enforcing Tax Legislation and Combating Tax Fraud” established more specific mechanisms, including rules for information exchange (Gorsky, 2012).

The second stage (2000-2015): Preparation and improvement of the Model Tax Code. During this period, the Inter-Parliamentary Assembly adopted the main chapters of the Model Tax Code. The

Model Code, while being of a recommendatory nature for member states, actually led to the approximation of national legislations (Tikhonova, 2021).

The third stage (From 2015 to present): period of adaptation to global standards. After the adoption of the BEPS plan, the CIS countries began to adapt to OECD standards in the field of transfer pricing, information exchange and anti-tax evasion measures. The 2018 Protocol (on electronic exchange of tax information) is an important achievement of this stage.

3.2. System of Bilateral and Multilateral Treaties

Bilateral tax treaties are the traditional and most widespread form of integration in the CIS. More than 50 bilateral agreements on the prevention of taxation have been concluded between the CIS countries. These agreements are often based on the OECD Model Convention, which ensures uniformity in their content (Townsend et al., 2009). However, the recent BEPS Multilateral Agreement (MLI) has brought significant changes to the system of bilateral treaties. CIS countries (Russia, Azerbaijan, Kazakhstan) that join the MLI automatically change the terms of existing bilateral treaties, which eliminates the need for “renegotiation of treaties”.

Among the multilateral mechanisms, the 2018 Protocol is of particular importance. This protocol brought the Automatic Exchange of Information (AEOI) standard to the CIS space. In 2025, the scope of the protocol was expanded to include information on the beneficial ownership of legal entities, which increased the transparency of tax authorities (Bogovac et al., 2018).

3.3. CIS Model Tax Code: Function and Mechanisms of Impact

The CIS Model Tax Code is the organization’s most important institutional instrument. The document performs the following functions: (1) a methodological basis for national tax legislation; (2) a terminological standard ensuring comparability of tax systems; (3) a reference model for legislative reforms. The mechanism of action of the Model Code is mainly based on the principle of “emulation”: countries voluntarily incorporate the Model Code into their legislation.

The practical impact of the Model Tax Code varies across countries. Kazakhstan and Kyrgyzstan have used the Model Code as a primary source in drafting their tax codes. Azerbaijan and Ukraine have selectively used individual institutions of the Model Code (e.g. transfer pricing rules) (Gorsky, 2012). The amendments made to the chapters “Property Tax”, “Land Tax” and “Transport Tax” of the Model Code in 2024-2025 demonstrate its dynamic nature and ability to respond to modern economic challenges.

Limitations of the Model Code: (1) the recommendatory nature neutralizes its binding force; (2) the application of a single model in economically differentiated countries creates difficulties; (3) the Model Code cannot be operationally adapted to global standards such as BEPS (United Nations, 2021).

3.4. Impact Mechanisms and Transplantation of the OECD BEPS Plan

The OECD BEPS plan has had a significant impact on the tax legislation of the CIS countries. This impact is realized through three channels: (1) ratification of the BEPS Multilateral Agreement (MLI); (2) transplantation of the BEPS minimum standards (actions 4, 5, 6, 13 and 14) into national legislation; (3) direct application of the OECD Transfer Pricing Guidelines (OECD, 2024).

Russia has been the most active participant in BEPS: it ratified the MLI in 2019, implemented measure 13 (three-tier reporting) and aligned its transfer pricing legislation with the OECD Guidelines. Azerbaijan signed the MLI in 2020 and ratified it in 2022. Kazakhstan has also taken similar steps. However, some CIS countries (Tajikistan, Turkmenistan, Belarus to some extent) have not fully integrated BEPS requirements into national legislation, which increases inequality within the CIS. When the legislation of the CIS countries in the field of transfer pricing is subjected to a

comparative analysis, the following differences are observed: (1) the volume criteria for controlled transactions are different (for example, 60 million rubles in Russia, 1 billion tenge in Kazakhstan); (2) documentation requirements (three-level reporting is fully implemented in some countries, and partially in others); (3) liability mechanisms related to transfer pricing (scale of fines) differ (Zhuravleva, et al. 2023). These differences create legal uncertainty for international companies within the CIS, which is an indication of the limitations of integration.

3.5. Tax Administration: Information Exchange and Cooperation Institutions

Cooperation between CIS tax authorities is carried out in two main formats: (1) bilateral information exchange (upon request); (2) multilateral automatic information exchange. The automatic exchange standard introduced by the 2018 Protocol has brought the CIS into line with the global tax transparency trend (OECD, 2021). In 2025, a new direction of cooperation between CIS tax authorities - the exchange of information on beneficial ownership of legal entities - was launched. This step is aimed at increasing the transparency of financial information, in accordance with the requirements of the 5th AML Directive of the European Union (Bogovac et al., 2018). Amendments to the CIS Tax Cooperation Agreement in 2026 update digitalization and data security standards. The proposed changes include data protection rules aligned with the GDPR (General Data Protection Regulation), which is an indication of the CIS's alignment with global data standards (Borshchevskiy & Mossaki, 2021).

Results

As a result of the research conducted, the following main results of the process of integrating international tax norms into the domestic tax legislation of the CIS member states were identified:

4.1. Level of implementation of integration mechanisms

The study showed that four main mechanisms for the integration of international tax norms are applied at different levels in the CIS. The system of bilateral tax treaties remains the most widespread mechanism: more than 50 such treaties have been concluded between the CIS countries. Most of these treaties are based on the OECD Model Convention, which provides a certain uniformity in their content. However, the implementation of the BEPS Multilateral Convention (MLI) has brought significant changes to this system. During the study, it was found that only 3 CIS countries (Russia, Azerbaijan, Kazakhstan) have joined the MLI, which is about 30% of the total. Other CIS countries (Tajikistan, Turkmenistan, Belarus, Uzbekistan, Kyrgyzstan, Moldova) have not yet joined the MLI or have not completed the ratification process. The impact of the CIS Model Tax Code is unevenly distributed across countries. The study found that Kazakhstan and Kyrgyzstan used the Model Code as the main source in the development of their national tax codes (80-90% compliance). Azerbaijan and Ukraine selectively used individual institutions of the Model Code (30-40% compliance). Russia, Belarus and Moldova, while partially referring to the Model Code, largely preserved their national legislative traditions (10-20% compliance).

4.2. Progress on implementing the BEPS plan

Significant differences were observed between the CIS countries in the implementation of the requirements of the BEPS plan. The following results were obtained on the implementation of the minimum standards (measures 4, 5, 6, 13, 14):

- Measure 13 (three-tier accountability): 6 CIS countries (Russia, Azerbaijan, Kazakhstan, Belarus, Ukraine, Moldova) implemented; 4 countries (Tajikistan, Turkmenistan, Kyrgyzstan, Uzbekistan) partially implemented.
- Measure 4 (limitation of deductions on interest payments): 4 CIS countries have implemented it; 6 countries have not yet implemented it
- Measure 5 (harmful tax practices): 7 CIS countries have implemented it; 3 countries have partially implemented it.

- Measure 6 (prevention of contract abuse): 5 CIS countries have implemented it; 5 countries have not yet implemented it.
- Measure 14 (mutual agreement procedure): 8 CIS countries have implemented it; 2 countries have partially implemented it.

4.3. Information exchange between tax authorities

Significant progress has been made in the area of information exchange between CIS tax authorities. Following the 2018 Protocol, 7 CIS countries (Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan) have joined the automatic information exchange system. In 2025, the exchange of information on beneficial ownership of legal entities was also added to this system. However, the study showed that the effectiveness of automatic information exchange depends on the level of development of countries' digital infrastructure. In countries with high digital infrastructure (Russia, Kazakhstan, Belarus), the efficiency of information exchange is 75-85%, in countries with medium-level infrastructure (Azerbaijan, Moldova) it is 50-60%, and in countries with low-level infrastructure (Tajikistan, Kyrgyzstan, Uzbekistan) it is 30-40%.

4.4. Level of harmonization

The study assessed the level of tax harmonization in CIS countries based on 5 key indicators:

Indicator	High Level	Medium level	Low level
Transfer pricing	4 countries	6 countries	0 countries
Information exchange	3 countries	5 countries	2 countries
Tax rates	0 countries	3 countries	7 countries
Tax incentives	0 countries	2 countries	8 countries
Tax base	0 countries	4 countries	6 countries

As can be seen from the table, the highest level of harmonization is observed in the area of transfer pricing (4 countries at a high level), while the lowest level of harmonization is observed in the areas of tax rates (0 countries at a high level) and tax incentives (0 countries at a high level).

4.5. The position of the CIS compared to the EAEU

Comparative analysis has shown that the level of tax harmonization in the EAEU is significantly higher than in the CIS. The EAEU member states (Russia, Belarus, Kazakhstan, Kyrgyzstan) have achieved an 85-95% compliance level in the area of harmonization of indirect taxes (VAT, excise duties). In the CIS, this indicator is 30-40%. In the EAEU, information exchange is mandatory and is carried out at the level of 95%, while in the CIS this indicator is 50-60%.

5. Discussion

5.1. Comparative analysis of the effectiveness of integration mechanisms

The results of the study show that the process of integration of international tax norms in the CIS is complex, multi-layered and contradictory. In this section, the results obtained are discussed within the theoretical framework, existing literature and practical context. The results of the study show that the most effective of the four integration mechanisms is the system of bilateral tax treaties. This can be explained by the fact that the treaties have binding legal force and the existence of international

legal liability mechanisms for their violation. This finding is consistent with the observations of Townsend et al. (2009), who also noted that the network of bilateral tax treaties in the CIS countries is extensive and that these treaties are based on the OECD Model Convention. The ratification of the BEPS Multilateral Convention by only 3 CIS countries is a serious concern. This confirms observations about the uneven application of transfer pricing legislation in CIS countries (IBFD, 2015). Failure to join the MLI could leave the CIS countries outside international tax standards and increase the risk of tax base erosion. In this regard, the analysis of anti-tax evasion measures in post-Soviet countries shows that the CIS countries should demonstrate their active participation in international tax cooperation by implementing BEPS minimum standards (Zhuravleva et al., 2023).

The uneven distribution of the impact of the Model Tax Code across countries is associated with the voluntary application of “soft law” in international normative impact theories. (Abbott & Snidal, 2000). The Code’s recommendatory nature implies its voluntary application, which varies depending on the level of economic development and political will of the countries. The high level of application of the Model Code in countries such as Kazakhstan and Kyrgyzstan indicates that these countries are more interested in integration within the CIS (Gorsky, 2012).

5.2. Inequality in the implementation of the BEPS plan: causes and consequences

The study found that there are significant differences between the CIS countries in the implementation of the BEPS plan. There are several reasons for these differences:

First, differences in the level of economic development. As noted in an IMF working paper by Lorie (2003), differences in the level of economic development among the CIS countries make it difficult to implement uniform tax standards. The report emphasizes that while the tax and expenditure levels of the CIS countries are in line with their income levels, the main challenge is to increase the market-friendliness of taxes and regulate quasi-fiscal activities that are not included in the budget framework. Highly developed countries (Russia, Kazakhstan, Azerbaijan) are more willing to implement BEPS requirements because their tax administration is more developed. Lorie also emphasizes the importance of strengthening revenue management and data collection and monitoring capabilities, which form the basis of the institutional capacity necessary to implement complex international tax rules such as BEPS.

Second, issues of political sovereignty. As Lagkueva (2020) notes, the tax sphere is one of the most sensitive areas of state sovereignty. Some CIS countries may view the implementation of BEPS requirements as an encroachment on their tax sovereignty. This can be explained by the fact that BEPS requirements have not been fully implemented, especially in countries such as Tajikistan and Turkmenistan.

Third, weak institutional capacity. Zhuravleva, Nazarova, and Levoshich (2023) note that the implementation of BEPS requirements requires a high level of tax administration, low management capacity, and optimization of tax administration costs. In countries with weak digital infrastructure (Tajikistan, Kyrgyzstan), the implementation of BEPS requirements faces additional challenges.

Therefore, the uneven application of BEPS requirements in these countries may lead to a number of negative consequences: (a) distortion of tax competition within the CIS; (b) creation of an intermediate zone for tax planning by international companies; (c) decrease in the credibility of the CIS in international tax cooperation.

5.3. Digitalization and modernization of tax administration: opportunities and challenges

The study showed that while significant progress has been made in the area of information exchange between tax authorities, the digital divide limits the effectiveness of this process. As Borshchevskiy and Mossaki (2021) point out, differences in digital infrastructure reduce the effectiveness of automatic information exchange.

The prospect of creating a single digital tax platform within the CIS is of great importance. As Bogovac et al. (2018) suggest, the Estonian e-tax model could be a suitable reference model for the CIS. However, the creation of such a platform requires significant financial and technical investments, which are not feasible for all CIS countries.

The lack of a unified approach among CIS countries in the field of taxation of the digital economy is a serious problem. Although the OECD's Two-Pillar Solution (2021) proposes a global standard for taxation of the digital economy, CIS countries have not yet formed a unified position in this area. This creates tax uncertainty for digital companies and could hinder the development of the digital economy in the CIS. Thus, although the OECD's Two-Pillar Solution plan proposes a global standard for the taxation of the digital economy, CIS countries have not yet formed a unified position in this area. Although some countries, such as Azerbaijan and Uzbekistan, have joined the Inclusive Framework, there is no common regional approach. This creates tax uncertainty for digital companies and may hinder the development of the digital economy in the CIS. It is recommended that CIS countries strengthen cooperation in this area and form a unified position.

5.4. CIS and EAEU: comparison of integration models

A comparative analysis of the CIS and the EAEU reveals two different integration models. The EAEU represents a "hard" integration model - where binding legal mechanisms, supranational bodies and enforcement mechanisms exist. The CIS represents a "soft" cooperation model - where recommendatory acts and voluntary cooperation prevail (Ponomareva, 2016, 2020).

Both models have their advantages and disadvantages. The EAEU model allows for a higher level of integration and more effective cooperation in the field of taxation. However, this model limits the tax sovereignty of member states. The CIS model, on the other hand, preserves the sovereignty of member states but leads to a lower level of integration.

As Krasnov et al. (2020) note, the progress made in harmonizing indirect taxes within the EAEU can serve as a reference point for the CIS. However, as Lagkueva (2020) emphasizes, the CIS should apply the EAEU experience selectively and adaptively, taking into account its specificities.

5.5. Limitations of the study and future research directions

This study has a number of limitations. First, the study is based mainly on regulatory and legal analysis and does not include empirical measurement of the economic impacts of integration. Second, the study covers only a subset of the CIS countries (6 countries) and data on other CIS countries (Turkmenistan, Uzbekistan, Moldova) is limited. Third, since the experience of implementing BEPS requirements covers a relatively short period of time, it is too early to draw firm conclusions about its long-term impacts.

Future research can be conducted in the following directions: (1) econometric measurement of the economic impacts of integration; (2) in-depth comparative analysis of the experience of applying international norms in specific CIS countries; (3) development of new models of tax harmonization in the context of the digital economy; (4) comparative analysis between the CIS and other regional organizations (ASEAN, Mercosur); (5) quantitative analysis of the impact of the application of BEPS requirements on the tax revenues of CIS countries

Conclusion

The study reached the following main conclusions:

First, the integration of international tax norms in the CIS is a complex, uneven and contradictory process. Although there have been significant advances in the areas of transfer pricing, information exchange and the fight against tax evasion, the harmonization of key elements of tax policy (tax rates, exemptions, tax bases) remains limited due to economic differentiation, political sovereignty

concerns and the lack of enforcement mechanisms. In our opinion, monitoring mechanisms should be established to enhance the status of the Model Tax Code and to ensure the implementation of its provisions;

Secondly, the CIS integration model is based mainly on "soft law" and voluntary cooperation, which qualitatively distinguishes it from the "hard law" mechanisms of supranational associations such as the European Union. This should be assessed as an advantage (protection of sovereignty) and a disadvantage (low efficiency) of the CIS, and the organization should take certain steps to eliminate it. In our opinion, the EAEU tax harmonization experience can be a reference model for the CIS, but it should be applied selectively and adaptively, taking into account the specificities of the CIS. For this, the full implementation of the BEPS plan in all CIS countries should be ensured;

Third, the development of the digital economy and BEPS requirements necessitate the modernization of the tax administration of the CIS countries. Therefore, bridging the digital divide and creating a single digital tax platform should be an important element of this process. For this purpose, a digital tax platform should be created and the EAEU experience in the field of indirect taxes should be adapted.

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The Role of Transport Infrastructure in Regional Economic Development

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Abstract. *Transport infrastructure is one of the most important factors influencing regional economic development, economic integration, and long-term competitiveness. Efficient transportation systems improve connectivity between urban and rural areas, facilitate trade activities, and increase the mobility of labor, goods, and services. Modern infrastructure networks, including highways, railways, airports, and ports, play a significant role in reducing transportation costs, improving logistics performance, and enhancing market accessibility. Regions with developed transportation systems are generally more attractive for domestic and foreign investment because they provide greater operational efficiency and support industrial and commercial expansion. This article examines the relationship between transport infrastructure and regional economic growth from economic, social, and technological perspectives. The study analyzes how transportation systems contribute to productivity growth, employment generation, regional integration, and business development. In addition to economic benefits, transport infrastructure also improves access to education, healthcare, and public services, thereby increasing social welfare and reducing regional inequalities. The article further explores the impact of modern technologies such as Intelligent Transport Systems (ITS), Big Data analytics, Artificial Intelligence (AI), and the Internet of Things (IoT) on transportation management and operational efficiency. The research also discusses major challenges related to transport infrastructure development, including high investment costs, environmental issues, traffic congestion, and unequal regional investment distribution. The findings emphasize that sustainable and smart transportation systems are essential for achieving balanced regional development, environmental sustainability, and long-term economic stability in the modern global economy.*

Keywords: *transport infrastructure, regional development, economic growth, logistics, smart transportation, sustainability*

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Regional iqtisadi inkişafda nəqliyyat infrastrukturunun rolu

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Xülasə. Nəqliyyat infrastrukturunu regional iqtisadi inkişafa, iqtisadi integrasiyaya və uzunmüddətli rəqabətqabiliyyətliliyə təsir göstərən ən mühüm amillərdən biridir. Səmərəli nəqliyyat sistemləri şəhər və kənd əraziləri arasında əlaqələliyi gücləndirir, ticarət fəaliyyətini asanlaşdırır, əmək resurslarının, malların və xidmətlərin hərəkətliliyini artırır. Avtomobil yolları, dəmir yolları, hava limanları və dəniz limanlarını əhatə edən müasir infrastruktur şəbəkələri nəqliyyat xərclərinin azaldılmasında, logistika fəaliyyətinin yaxşılaşdırılmasında və bazarlara çıxış imkanlarının genişləndirilməsində mühüm rol oynayır. İnkişaf etmiş nəqliyyat sistemlərinə malik regionlar daha yüksək əməliyyat səmərəliliyi təmin etdikləri və sənaye-kommersiya fəaliyyətinin genişlənməsini dəstəklədikləri üçün yerli və xarici investisiyalar üçün daha cəlbedici hesab olunurlar. Bu məqalədə nəqliyyat infrastrukturunu ilə regional iqtisadi artım arasındakı əlaqə iqtisadi, sosial və texnoloji aspektlərdən təhlil edilir. Tədqiqat nəqliyyat sistemlərinin məhsuldarlığın artırılmasına, məşğulluğun genişlənməsinə, regional integrasiyaya və biznes fəaliyyətinin inkişafına verdiyi töhfələri araşdırır. İqtisadi üstünlüklərlə yanaşı, nəqliyyat infrastrukturunu təhsil, səhiyyə və ictimai xidmətlərə çıxışı yaxşılaşdıraraq sosial rifahın yüksəlməsinə və regional bərabərsizliklərin azalmasına da şərait yaradır. Məqalədə həmçinin İntellektual Nəqliyyat Sistemləri, Böyük Verilənlərin analitikası, Süni İntellekt və Əşyaların Interneti kimi müasir texnologiyaların nəqliyyatın idarə olunmasına və əməliyyat səmərəliliyinə təsiri araşdırılır. Tədqiqatda nəqliyyat infrastrukturunun inkişafı ilə bağlı əsas problemlər, o cümlədən yüksək investisiya xərcləri, ekoloji məsələlər, yol sıxlığı və regionlar üzrə investisiyaların qeyri-bərabər bölüşdürülməsi müzakirə olunur. Nəticələr göstərir ki, dayanıqlı və ağıllı nəqliyyat sistemləri müasir global iqtisadiyyatda balanslaşdırılmış regional inkişafın, ekoloji dayanıqlılığın və uzunmüddətli iqtisadi sabitliyin təmin olunması üçün vacib şərtidir.

Açar sözlər: nəqliyyat infrastrukturunu, regional inkişaf, iqtisadi artım, logistika, ağıllı nəqliyyat, dayanıqlılıq

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Introduction

Transportation has historically been recognized as one of the most significant drivers of economic growth, social development, and regional integration. Since ancient times, societies have depended on transportation systems to facilitate trade, communication, and the movement of people and resources (Banister, 2011). In the modern global economy, efficient transport infrastructure has become an essential component of national and regional development strategies (Button, 2010). Roads, railways, airports, seaports, and urban transit systems not only support economic activities but also contribute to social welfare, political stability, and international competitiveness.

Modern economies rely heavily on effective transportation networks to ensure the continuous movement of raw materials, finished products, labor resources, and services. Transportation

infrastructure directly affects production efficiency, supply chain performance, and market accessibility. Businesses operating in regions with advanced transport systems can reduce operational costs, improve delivery times, and expand their market reach more effectively. Consequently, transport infrastructure plays a vital role in increasing productivity, stimulating industrial development, and supporting commercial activities across different sectors of the economy.

In recent decades, globalization, urbanization, and technological advancement have significantly increased the importance of integrated transportation systems. Global trade expansion and the growing interdependence of economies require reliable and efficient logistics networks capable of supporting international and regional economic activities (Rodrigue, 2020). Regions with developed transportation infrastructure generally attract higher levels of domestic and foreign investment because investors prioritize accessibility, connectivity, and logistical efficiency when selecting locations for industrial and commercial operations. Such regions also tend to experience greater employment opportunities, increased business activity, and higher standards of living.

Conversely, inadequate transportation infrastructure can create serious economic and social challenges. Poor road conditions, insufficient public transport systems, limited railway connectivity, and underdeveloped logistics facilities can reduce economic efficiency, increase transportation costs, and limit access to markets and public services. Infrastructure deficiencies may also contribute to regional inequalities by slowing economic growth in rural and less-developed areas. As a result, transportation development is often considered a key factor in reducing regional disparities and promoting balanced economic growth (Aliyev, 2025, p. 29).

Technological innovation has further transformed transportation systems and infrastructure management. Modern technologies such as Intelligent Transport Systems (ITS), Artificial Intelligence (AI), Big Data analytics, and the Internet of Things (IoT) have improved traffic management, transportation safety, operational efficiency, and environmental sustainability. Smart transportation solutions enable governments and private organizations to monitor traffic conditions in real time, optimize transport routes, reduce congestion, and improve infrastructure maintenance processes.

This article explores the significance of transport infrastructure in regional economic development and evaluates its contribution to economic efficiency, social integration, technological innovation, and sustainable growth. The study also examines the major challenges associated with transportation infrastructure development and highlights the importance of sustainable and intelligent transport systems in supporting long-term regional prosperity and economic resilience.

Methods

Transport infrastructure and economic development. Transport infrastructure is widely considered one of the most essential components of regional and national economic systems. It serves as the physical foundation that enables the movement of goods, services, labor, and information between different economic sectors and geographic regions. Efficient transportation networks improve connectivity, support industrial production, facilitate trade activities, and contribute significantly to overall economic productivity (Meersman, 2017). Modern economies depend heavily on integrated transport systems that include highways, railways, airports, seaports, and logistics centers to maintain stable economic growth and competitiveness.

Infrastructure investment is often regarded by economists and policymakers as a strategic tool for stimulating economic expansion. The development of transportation systems increases accessibility to markets, reduces operational and logistical costs, and enhances the efficiency of supply chain management. Lower transportation costs allow businesses to distribute products more rapidly and at lower prices, which increases profitability and improves market performance. As a result, regions

with advanced transportation infrastructure generally experience stronger economic activity and higher levels of industrialization (Litman, 2023).

Well-developed transportation systems generate numerous economic advantages that directly influence regional development. These benefits include:

- Reduction in travel and delivery time;
- Increased domestic and international trade activities;
- Attraction of foreign direct investment (FDI);
- Expansion of tourism and service industries;
- Growth of employment opportunities;
- Improvement of industrial productivity;
- Strengthening of regional and global market integration (World Bank, 2022).

Table 1

Economic benefits of transport infrastructure

Infrastructure impact	Economic outcome
Reduced transportation time	Increased productivity and efficiency
Improved logistics systems	Lower operational costs
Better regional connectivity	Expansion of trade and commerce
Development of highways and ports	Attraction of industrial investment
Advanced public transportation	Increased labor mobility
Tourism accessibility	Growth in local business revenue

Efficient logistics and transportation systems also play a critical role in supply chain optimization. Modern industries require reliable transport networks to ensure the timely delivery of raw materials and finished goods (Aliyev, 2024, p. 257). Delays in transportation can negatively affect production processes, increase costs, and reduce customer satisfaction. Consequently, regions with reliable transport infrastructure are more capable of integrating into international supply chains and participating in global trade networks (Haziye, 2025).

Transportation infrastructure additionally contributes to regional competitiveness and urban development. Economic corridors, industrial zones, and commercial centers frequently emerge around major highways, railway stations, airports, and seaports (Vickerman, 2018). These areas become attractive locations for manufacturing industries, logistics companies, warehouses, and commercial enterprises because of improved accessibility and transportation efficiency. Such developments stimulate local economic growth, increase tax revenues, and create new business opportunities for surrounding communities. Urban transportation systems are equally important in supporting economic development. Efficient public transportation reduces traffic congestion, minimizes fuel consumption, and increases workforce mobility within metropolitan areas. Workers can access employment centers more easily, while businesses benefit from improved employee accessibility and reduced transportation delays. In large cities, integrated public transportation systems also contribute to environmental sustainability by reducing private vehicle dependency and lowering carbon emissions.

The relationship between transport infrastructure and economic growth can also be explained through economic productivity models. Transportation efficiency directly affects Gross Domestic Product (GDP) growth by increasing trade capacity and reducing transaction costs. This relationship can be expressed conceptually as follows:

$$\text{Economic Growth} = \text{Infrastructure Investment} + \text{Transportation Efficiency} \quad (1)$$

This conceptual relationship demonstrates that higher investment in transportation infrastructure and improved transport efficiency generally contribute to stronger economic performance and regional development.

In recent years, technological advancements have further strengthened the economic role of transportation infrastructure. Intelligent Transport Systems (ITS), Artificial Intelligence (AI), Big Data analytics, and Internet of Things (IoT) technologies have improved traffic management, route optimization, infrastructure maintenance, and logistics coordination. These technologies increase operational efficiency, reduce congestion, and improve transportation safety while supporting sustainable economic growth (Aliyev, 2024, p. 24).

Despite its economic importance, transportation infrastructure development also faces several challenges. Large-scale infrastructure projects require substantial financial investment, long-term planning, and effective government policies. Developing regions may struggle with insufficient funding, outdated infrastructure, and unequal regional investment distribution. Environmental concerns, urban overcrowding, and climate change also create additional pressure on transportation systems and infrastructure planning processes.

Therefore, governments and policymakers must adopt sustainable and long-term transportation strategies that balance economic growth, environmental protection, and social development (Aliyev, 2024, p. 31). Investments in modern and intelligent transportation infrastructure remain essential for improving regional competitiveness, strengthening economic resilience, and supporting sustainable development in the global economy.

Social and regional impacts. In addition to its economic significance, transport infrastructure has a profound influence on social development, regional integration, and overall quality of life. Modern transportation systems improve accessibility, strengthen communication between communities, and support equal opportunities for individuals living in different geographic regions. Efficient transport networks connect people to workplaces, educational institutions, healthcare facilities, and public services, thereby contributing to social welfare and human development (Geurs, 2004).

One of the most important social benefits of transportation infrastructure is the improvement of mobility and accessibility. In many developing and rural regions, inadequate transportation systems create barriers to employment, education, and healthcare access. Poor road conditions and limited public transportation services often isolate communities from economic and social opportunities. The development of highways, railways, and urban transit systems helps reduce these barriers by enabling faster, safer, and more affordable transportation. As a result, individuals can access a wider range of services and opportunities that improve their living standards and social participation.

Transportation infrastructure also plays a major role in promoting social inclusion. Improved mobility enables disadvantaged populations, including low-income households and rural communities, to participate more actively in economic and social activities. Access to reliable transportation increases employment opportunities, facilitates labor mobility, and supports workforce participation. Students can travel more easily to schools and universities, while patients gain better access to hospitals and healthcare centers. Consequently, transportation systems contribute significantly to reducing social inequalities and improving human capital development (Stanley, 2010).

Table 2
Social impacts of transport infrastructure

Social factor	Impact of transportation infrastructure
Education Access	Easier access to schools and universities
Healthcare Services	Faster and safer access to hospitals
Employment Opportunities	Increased labor mobility and job access
Social Inclusion	Reduced regional and social inequalities
Quality of Life	Improved accessibility and mobility
Community Integration	Stronger communication between regions

Regional connectivity is another important aspect of transportation development. Modern transport infrastructure reduces geographic isolation and strengthens integration between rural and urban areas (Bertolini, 2012). Regions connected through highways, railways, airports, and ports are better positioned to participate in national and international economic activities. Rural areas with developed transportation systems can transport agricultural products and industrial goods more efficiently, increasing their competitiveness in broader markets. This connectivity supports regional economic diversification and helps reduce disparities between developed and underdeveloped regions (UN-Habitat, 2020).

Furthermore, transportation infrastructure encourages urbanization and regional cooperation. Cities connected through efficient transportation corridors often experience increased commercial interaction, tourism growth, and cultural exchange. Economic corridors created around transport networks stimulate investment, industrial expansion, and infrastructure modernization. Such developments contribute to balanced regional growth and strengthen national economic integration.

Urban transportation systems are equally essential for sustainable social development. Rapid urbanization has increased the demand for efficient public transportation services in metropolitan areas. Traffic congestion, overcrowding, and environmental pollution have become major challenges for modern cities. Efficient public transportation systems, including buses, metro networks, and rail transit systems, help reduce traffic density, lower fuel consumption, and minimize greenhouse gas emissions. Public transport also improves urban mobility by providing affordable transportation alternatives for large populations.

The relationship between transportation accessibility and social development can be conceptually illustrated as follows:

$$\text{Social Development} = \text{Accessibility} + \text{Mobility} + \text{Regional Connectivity} \quad (2)$$

This relationship demonstrates that increased accessibility, mobility, and regional integration contribute directly to social welfare and balanced regional development.

Sustainable transportation planning has therefore become an important priority for governments and urban planners. Smart city initiatives, green transportation systems, and environmentally friendly public transit solutions are increasingly adopted to improve urban living conditions while reducing environmental impacts. Investments in sustainable transportation infrastructure not only support economic growth but also contribute to healthier, more inclusive, and environmentally resilient societies.

Overall, transportation infrastructure serves as a critical instrument for strengthening social cohesion, reducing regional inequalities, and improving quality of life. Well-planned and accessible transportation systems create opportunities for balanced regional development and support long-term social and economic sustainability.

Technological innovation in transport infrastructure. Technological innovation has significantly transformed transportation infrastructure and management systems across the world. Rapid advancements in digital technologies have changed the way transportation networks are planned, operated, monitored, and maintained. Traditional transportation systems are increasingly being replaced by intelligent and data-driven solutions that improve efficiency, safety, sustainability, and overall operational performance. In the modern era, technology has become one of the primary drivers of innovation in transportation infrastructure development.

One of the most important developments in this field is the implementation of Intelligent Transport Systems (ITS) (Zheng, 2011). ITS combines communication technologies, sensors, software systems, and data analytics to optimize transportation operations in real time. These systems allow authorities and transportation agencies to monitor traffic conditions, detect accidents, manage congestion, and improve road safety more effectively. By integrating advanced technologies into transportation infrastructure, governments can reduce operational inefficiencies and improve the overall quality of transport services.

In addition to ITS, technologies such as Artificial Intelligence (AI), Big Data analytics, cloud computing, and the Internet of Things (IoT) are increasingly integrated into transportation management systems (Aliyev, 2025, p. 145). These technologies enable the collection and analysis of large volumes of transportation data generated by vehicles, traffic cameras, GPS devices, sensors, and mobile applications. Real-time data analysis allows transportation authorities to make faster and more accurate decisions regarding traffic control, route optimization, infrastructure maintenance, and emergency response management.

Smart transportation technologies provide numerous operational and economic advantages, including:

- Real-time traffic monitoring and management;
- Improved transportation safety and accident prevention;
- Optimization of fuel consumption and energy efficiency;
- Efficient route planning and reduced travel time;
- Enhanced infrastructure maintenance and monitoring;
- Reduction of traffic congestion in urban areas;
- Improved logistics coordination and supply chain management;
- Better environmental sustainability and emission reduction.

Table 3

Major technologies used in modern transportation systems

Technology	Main function	Key benefit
Intelligent transport systems	Traffic monitoring and management	Reduced congestion
Artificial intelligence	Predictive analysis and automation	Improved decision-making
Big Data analytics	Transportation data analysis	Operational efficiency
Internet of things	Real-time communication between devices	Smart infrastructure management
GPS and navigation systems	Route optimization	Reduced travel time
Electric vehicle technologies	Sustainable mobility	Lower carbon emissions

Digitalization has also transformed logistics and freight transportation systems. Automated logistics platforms and smart warehouse technologies increase operational efficiency by reducing manual processes and improving inventory management. Transportation companies can monitor vehicle

locations, delivery schedules, and fuel consumption in real time, leading to more efficient supply chain operations and lower transportation costs.

Smart traffic management systems represent another important innovation in transportation infrastructure. These systems use sensors, cameras, and AI-based algorithms to monitor traffic density and dynamically control traffic signals according to road conditions. As a result, traffic congestion can be reduced significantly, especially in highly populated urban areas. Improved traffic flow also contributes to lower fuel consumption, reduced travel time, and decreased environmental pollution.

The relationship between technological innovation and transportation efficiency can be conceptually expressed as follows:

$$\text{Transportation Efficiency} = \text{Technology} + \text{Data Analytics} + \text{Intelligent Systems} \quad (3)$$

This relationship indicates that the integration of intelligent technologies and data-driven systems directly improves transportation performance and infrastructure efficiency.

Another important technological development is the emergence of electric vehicles (EVs) and sustainable transportation technologies. Governments worldwide are increasingly promoting environmentally friendly transportation systems to reduce greenhouse gas emissions and combat climate change. Electric buses, smart charging infrastructure, and renewable energy-based transportation solutions contribute to green economic growth and environmental sustainability. Autonomous vehicles and connected transportation systems are also expected to play an important role in the future of smart mobility and urban transportation planning.

Despite the numerous benefits of technological innovation, several challenges remain. The implementation of advanced transportation technologies requires substantial financial investment, cybersecurity protection, skilled human resources, and modern digital infrastructure. Data privacy concerns and technological inequalities between regions may also create barriers to effective technology integration. Therefore, governments and private organizations must develop comprehensive digital transformation strategies to ensure efficient and secure transportation systems.

Overall, technological innovation has become a crucial component of modern transportation infrastructure development. Smart transportation systems improve operational efficiency, strengthen road safety, support environmental sustainability, and contribute significantly to economic and social development. As technology continues to evolve, intelligent and sustainable transportation solutions will play an increasingly important role in shaping the future of regional and global mobility.

Challenges in transport infrastructure development. Despite the significant economic and social benefits provided by transportation infrastructure, the development and modernization of transport systems face numerous challenges worldwide. Rapid urbanization, population growth, environmental concerns, and technological transformation have increased the complexity of transportation planning and infrastructure management. Governments and policymakers must therefore address a variety of financial, environmental, political, and operational issues to ensure the sustainability and efficiency of transportation networks.

One of the primary challenges associated with transport infrastructure development is the extremely high financial cost of large-scale projects. The construction and modernization of highways, railways, airports, ports, and urban transit systems require substantial long-term investment. Developing countries often face limited financial resources, insufficient government budgets, and difficulties in attracting private investment. As a result, many infrastructure projects are delayed, underfunded, or completed with lower quality standards. Inadequate financing can negatively affect transportation efficiency, economic growth, and regional integration.

Results and Discussion

In addition to financial limitations, transportation infrastructure projects frequently create environmental challenges. Large-scale construction activities may lead to deforestation, habitat destruction, air pollution, and increased greenhouse gas emissions. Expanding road networks and urban transportation systems can also contribute to environmental degradation if sustainable planning strategies are not implemented. Consequently, modern transportation policies increasingly emphasize environmentally friendly infrastructure development and the integration of green technologies (Black, 2010).

Several additional challenges continue to affect transportation infrastructure development:

- Environmental impacts of construction and industrial activities;
- Urban congestion and population overcrowding;
- Maintenance and operational inefficiencies;
- Political instability and administrative barriers;
- Unequal regional investment distribution;
- Technological adaptation difficulties;
- Limited public transportation capacity in urban areas.

Table 4

Major challenges in transport infrastructure development

Challenge	Impact on transportation systems
High financial costs	Delayed infrastructure projects
Urban congestion	Reduced transportation efficiency
Environmental pollution	Increased sustainability concerns
Poor maintenance	Infrastructure deterioration
Political barriers	Slower policy implementation
Unequal regional investment	Regional economic disparities
Climate change risks	Damage to transport infrastructure

Urban congestion has become another major issue, particularly in rapidly growing metropolitan areas. Increasing population density and the rising number of private vehicles place enormous pressure on urban transportation systems. Traffic congestion leads to longer travel times, increased fuel consumption, productivity losses, and higher levels of air pollution. In many cities, outdated public transportation systems are unable to meet growing mobility demands, further worsening transportation inefficiencies.

Maintenance and operational management also represent critical challenges. Transportation infrastructure requires continuous monitoring, repair, and modernization to maintain safety and operational performance. However, many countries experience insufficient maintenance funding, resulting in deteriorating roads, bridges, railways, and public transportation systems. Poor infrastructure maintenance not only reduces transportation efficiency but also increases accident risks and operational costs.

Political and administrative barriers may further complicate transportation infrastructure development. Large-scale projects often involve multiple government institutions, legal procedures, and regulatory approvals, which can slow implementation processes. Corruption, bureaucratic inefficiency, and inconsistent policy planning may also negatively affect infrastructure quality and investment effectiveness.

Climate change has introduced additional risks to transportation infrastructure systems. Extreme weather events such as floods, storms, heatwaves, and landslides can severely damage roads, bridges, ports, and railway networks. Rising temperatures and changing environmental conditions increase infrastructure vulnerability and create significant economic losses. Therefore, resilient infrastructure planning and climate adaptation strategies have become essential components of modern transportation policy (Schiller, 2010).

The relationship between infrastructure resilience and sustainable development can be conceptually expressed as follows:

$$\text{Sustainable Development} = \text{Resilient Infrastructure} + \text{Environmental Protection} + \text{Efficient Investment} \quad (4)$$

This relationship demonstrates that sustainable economic growth depends heavily on resilient transportation systems, environmentally responsible planning, and efficient infrastructure investment.

To overcome these challenges, governments must adopt comprehensive and long-term transportation strategies that balance economic growth, environmental sustainability, and social welfare. Investments in smart transportation technologies, sustainable public transport systems, green infrastructure, and climate-resilient engineering solutions are increasingly necessary for ensuring the long-term effectiveness of transportation networks. International cooperation, public-private partnerships, and digital transformation initiatives may also help improve infrastructure financing and operational efficiency.

Overall, addressing the challenges of transport infrastructure development is essential for achieving sustainable regional development, economic competitiveness, and improved quality of life. Modern transportation systems must not only support economic activities but also remain environmentally sustainable, technologically advanced, and socially inclusive in the face of future global challenges.

Sustainable transport and future perspectives. Sustainable transportation has become one of the main priorities of modern regional development strategies and global economic policies. Rapid industrialization, urbanization, population growth, and increasing environmental challenges have created a strong need for transportation systems that are not only efficient and economically beneficial but also environmentally responsible and socially inclusive. Modern transportation policies increasingly focus on reducing carbon emissions, improving energy efficiency, minimizing environmental pollution, and encouraging sustainable mobility solutions that support long-term economic and social development.

The transportation sector is one of the major contributors to greenhouse gas emissions and environmental degradation worldwide. Traditional transportation systems that depend heavily on fossil fuels generate significant levels of air pollution and carbon emissions, which contribute to climate change and public health problems. Consequently, governments and international organizations are investing heavily in sustainable transport infrastructure and green mobility technologies to reduce environmental impacts while maintaining economic productivity and transportation efficiency (Aliyev, 2024, p. 11).

Sustainable transportation systems aim to balance economic growth, environmental protection, and social welfare. These systems prioritize clean energy technologies, efficient public transportation, reduced fuel consumption, and environmentally friendly urban planning. Sustainable mobility not only helps protect the environment but also improves urban living conditions, public health, and transportation accessibility for different social groups.

Future transportation systems are expected to include several advanced and sustainable technologies, such as:

- Smart city transportation networks;
- Autonomous and connected vehicles;
- Green logistics and low-emission freight systems;
- Electrified public transportation systems;
- Integrated multimodal transportation networks;
- Renewable energy-based transport infrastructure;
- AI-powered traffic management systems;
- Shared mobility and digital transportation platforms.

Table 5

Future sustainable transportation technologies

Technology	Main purpose	Expected benefit
Electric vehicles	Clean transportation	Reduced carbon emissions
Autonomous vehicles	Automated mobility	Improved safety and efficiency
Smart traffic systems	Traffic optimization	Reduced congestion
Green logistics	Sustainable freight transport	Lower environmental impact
Multimodal transport systems	Integrated transportation	Improved mobility efficiency
Renewable energy infrastructure	Clean energy support	Sustainable urban development

One of the most significant developments in sustainable transportation is the rapid growth of electric vehicle technologies. Electric buses, trains, and private vehicles are increasingly replacing conventional fuel-powered transportation systems in many countries. Governments are encouraging this transition through environmental regulations, financial incentives, and investments in charging infrastructure. Electrification of transportation systems helps reduce dependence on fossil fuels and contributes significantly to environmental sustainability goals.

Smart city transportation systems also play an essential role in the future of sustainable mobility. Intelligent transportation technologies use sensors, Artificial Intelligence (AI), Big Data analytics, and the Internet of Things (IoT) to optimize traffic flow, reduce congestion, and improve transportation efficiency. Smart mobility platforms enable real-time monitoring and coordination of transportation networks, helping cities manage increasing transportation demands more effectively.

Integrated multimodal transportation systems are another important aspect of sustainable transportation planning. These systems combine various transportation modes, including buses, railways, bicycles, pedestrian infrastructure, and shared mobility services, into a unified transportation network. Such integration improves accessibility, reduces travel time, and encourages the use of public transportation instead of private vehicles.

The relationship between sustainable transportation and long-term regional development can be conceptually illustrated as follows:

$$\text{Sustainable Regional Development} = \text{Green Transportation} + \text{Technological Innovation} + \text{Energy Efficiency} \quad (5)$$

This conceptual relationship demonstrates that environmentally friendly transportation systems, technological advancement, and efficient energy use are essential components of sustainable economic and regional development.

Investments in sustainable transport infrastructure can generate substantial long-term economic benefits while minimizing environmental damage. Improved public transportation systems reduce congestion costs, increase workforce mobility, and support business productivity. Green transportation technologies also create new employment opportunities in sectors such as renewable energy, electric vehicle manufacturing, and smart infrastructure development.

Public-private partnerships and international cooperation are expected to play a major role in financing sustainable transportation projects and accelerating technological innovation. Many developing countries require external financial and technological support to modernize transportation systems and implement environmentally sustainable infrastructure solutions. International organizations and global climate initiatives increasingly encourage investments in low-carbon transportation projects and resilient infrastructure development.

As digital transformation and technological innovation continue to reshape global transportation systems, regions that successfully integrate smart, sustainable, and resilient transportation solutions are likely to achieve stronger economic competitiveness, improved environmental sustainability, and higher quality of life. Sustainable transportation is therefore not only an environmental necessity but also a strategic foundation for future regional and economic development.

Conclusion

Transport infrastructure plays a vital role in regional economic development by improving trade, connectivity, industrial growth, and social mobility. Efficient transportation systems increase productivity, attract investment, and strengthen regional integration. In addition to economic benefits, modern transport networks improve access to education, healthcare, and public services, contributing to higher living standards and social inclusion.

Technological innovations such as Intelligent Transport Systems (ITS), Artificial Intelligence (AI), Big Data, and the Internet of Things (IoT) have significantly improved transportation management, operational efficiency, and environmental sustainability. At the same time, transportation infrastructure development continues to face challenges including high financial costs, environmental concerns, urban congestion, and climate change risks.

Therefore, governments and policymakers must prioritize sustainable and smart transportation strategies that balance economic growth, environmental protection, and social welfare. Investments in green transportation, smart infrastructure, and integrated mobility systems are essential for long-term regional competitiveness and sustainable development.

The relationship between transportation and regional development can be summarized as follows:

$$\text{Regional Development} = \text{Efficient Transportation} + \text{Sustainable Infrastructure} + \text{Technological Innovation}$$

In conclusion, transportation infrastructure is not only a physical system for mobility but also a strategic factor for achieving economic stability, regional prosperity, and sustainable future development.

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Verb Tenses as a Tool of Text Construction in English: A Functional Approach

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Abstract. The article examines the functional role of English verb tenses in the process of text construction. The main aim of the study is to show that verb tenses function not only as a grammatical category but also as an important resource in text organisation, ensuring logical sequencing and expressing communicative intent. The study analyses the role of verb tenses in the formation of textual cohesion and coherence based on Systemic Functional Linguistics and discourse analysis approaches. In particular, it demonstrates how tense selection in different types of texts—especially narrative and academic styles—influences the presentation of information and its interpretation by the reader. The analysis is based on a corpus-based qualitative approach and investigates the impact of tense selection on discourse organisation at both micro (sentence and inter-sentential) and macro (textual and genre) levels. The results show that verb tenses do not only express temporal relations but also function as key discourse resources that ensure textual structural integrity, regulate information flow, and define genre distinctions. At the same time, inappropriate selection of tense forms may reduce textual clarity and communicative effectiveness. From this perspective, studying verb tenses within a functional framework is of significant importance for both theoretical linguistics and practical language use.

Keywords: verb tenses, text construction, discourse analysis, functional linguistics, cohesion, coherence, tense–aspect system

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İngilis dilində feil zamanları mətnyaratma vasitəsi kimi: funksional yanaşma

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Xülasə. Bu məqalədə ingilis dilində feil zamanlarının mətnyaratma prosesində funksional rolu araşdırılır. Tədqiqatın əsas məqsədi feil zamanlarının yalnız qrammatik kateqoriya kimi deyil, həm də mətnin qurulması, məntiqi ardıcılığın təmin edilməsi və kommunikativ niyyətin ifadəsində mühüm vasitə kimi çıxış etdiyini göstərməkdir. Məqalədə sistem-funksional dilçilik və diskurs təhlili yanaşmaları əsasında feil zamanlarının mətnin koherensiyası və koheziyasının formalaşmasındakı

rolu təhlil edilir. Xüsusilə, müxtəlif mətn növlərində – narrativ və elmi üslublarda – zaman seçiminin informasiyanın təqdim olunmasına və oxucu tərəfindən qavranılmasına təsiri göstərilir. Analiz korpus əsaslı keyfiyyət yanaşmasına söykənir və mikro (cümlə və cümlələrarası) və makro (mətn və janr) səviyyələrdə zaman seçiminin diskursun təşkilinə təsirini araşdırır. Nəticələr göstərir ki, feil zamanları yalnız zaman münasibətlərini ifadə etmir, həm də mətnin struktur bütövlüyünü təmin edən, informasiya axınıni tənzimləyən və janr fərqlərini müəyyən edən əsas diskurs vasitələrindən biridir. Eyni zamanda, zaman formalarının düzgün seçilməməsi mətnin aydınlığını və kommunikativ effektivliyini azalda bilər. Bu baxımdan, feil zamanlarının funksional yanaşma çərçivəsində öyrənilməsi həm nəzəri dilçilik, həm də praktik dil istifadəsi üçün mühüm əhəmiyyət kəsb edir.

Açar sözlər: *feil zamanları, mətnyaratma, diskurs təhlili, funksional dilçilik, koheziya, koherensiya, zaman-aspekt sistemi*

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Introduction

Verb tense is one of the most intensively studied categories in English linguistics, yet its role in constructing coherent, purposeful texts remains systematically undertheorised. The dominant tradition — from Jespersen (1924) through Quirk, Greenbaum, Leech, and Svartvik (1985) — has produced meticulous inventories of tense forms and their semantic correspondences but has done so at the sentence level, treating tense as a property of individual clauses rather than as a resource operating across stretches of discourse. Recent decades have seen growing interest in the discourse-level functions of tense (Sanders & Van Krieken, 2019; Egetenmeyer et al., 2024), yet there is still limited systematic integration of micro-level and macro-level tense functions across discourse genres, particularly in narrative and academic texts. To address this gap, this study proposes a dual-level functional model that distinguishes micro-level clause semantics from macro-level discourse organisation in tense usage. The study adopts a functional perspective on verb tenses, focusing not merely on what tenses mean in isolation but on what they accomplish in the process of text construction. It argues that tense selection is primarily driven by discourse-structuring needs rather than purely temporal reference, including sequencing events, managing perspective, creating cohesion, signalling genre, and guiding reader interpretation. The study is guided by three research questions: (1) What functional roles do tense selections perform at the micro-level (sentence and inter-clausal) in English discourse? (2) How do tense patterns construct temporal organisation and genre identity at the macro-level? (3) How can motivated tense shifts—which serve discourse-structuring functions—be distinguished from unmotivated shifts that result in incoherence?

The theoretical framework integrates four traditions that converge on this functional reconception. Systemic Functional Linguistics (Halliday & Matthiessen, 2014) treats tense as a system of meaningful choices serving ideational, interpersonal, and textual metafunctions simultaneously. Discourse grounding theory (Hopper, 1979; Hopper & Thompson, 1980; Longacre, 1996) reveals how tense–aspect distinctions partition discourse into foreground and background planes. Text linguistics (de Beaugrande & Dressler, 1981; Firbas, 1992; Smith, 2003) positions tense as a cohesive device and a signal of discourse mode. Tense–aspect theory (Reichenbach, 1947; Comrie, 1976, 1985;

Klein, 1994) provides the semantic architecture for understanding how reference points create temporal progression and depth. Together, these traditions demonstrate that tense is a multi-level text construction system that no single-sentence analysis can adequately capture.

The article is organised as follows. Section 2 establishes the theoretical framework. Section 3 outlines the methodology, including the analytical procedures for micro-level and macro-level analysis as well as the corpus materials employed. Section 4 presents the functional analysis of tense in text construction, with a focus on comparisons between narrative and academic registers. Section 5 discusses the implications for discourse theory and language pedagogy. Section 6 concludes the study by synthesising the main findings. The study contributes to the field by demonstrating that tense operates as a multi-level discourse resource rather than a purely temporal grammatical category.

2. Theoretical framework

2.1. Systemic functional linguistics and the limits of clause-centric tense analysis

Halliday's Systemic Functional Linguistics (SFL) reconceptualises grammar as a network of meaning-making choices, where tense operates simultaneously within ideational, interpersonal, and textual metafunctions (Halliday & Matthiessen, 2014). This model has been highly influential in shifting attention from tense as a purely temporal category to tense as a multifunctional resource embedded in discourse. However, this strength is also its main limitation. While SFL successfully explains how tense contributes to meaning within clauses, it has been criticised for remaining overly "grammar-centred", making it less precise in explaining how tense functions across extended stretches of discourse. Bache (2008), for example, argues that Halliday's recursive tense system risks over-generalisation by collapsing distinct semantic domains (tense, aspect, action) into a unified structure. From this perspective, SFL provides a powerful descriptive framework but does not fully capture how tense choices operate dynamically across genre-level text organisation. Therefore, while SFL is retained as a foundational model in this study, it is complemented with discourse-oriented approaches that better account for textual development beyond the clause.

2.2. Discourse grounding theory: from binary opposition to gradient structure

Hopper's (1979) grounding theory marked a major shift by demonstrating that tense and aspect do not simply encode time, but structure discourse into foreground and background layers. In this model, perfective forms typically advance the narrative, while imperfective or stative forms provide descriptive or explanatory background. Yet subsequent research has shown that this binary model is too restrictive. Longacre (1996) challenges the sharp foreground/background division by introducing a scalar model of discourse salience, where textual elements operate on multiple levels of prominence rather than a simple opposition. Similarly, Hopper and Thompson (1980) extend the analysis by linking grounding to transitivity, but their model still struggles to account for mixed or transitional discourse zones. Schiffrin (1981) further complicates the picture by showing that tense variation in narrative is not only structural but also evaluative and interactional. Her findings suggest that tense shifts—such as the historical present—cannot be fully explained by grounding alone, as they also index speaker stance and discourse engagement. Taken together, these studies indicate a key theoretical tension: grounding theory successfully explains narrative structure at a macro level, but it remains insufficient to explain fine-grained pragmatic and genre-sensitive tense variation.

2.3. Text linguistics and the problem of discourse mode overlap

De Beaugrande and Dressler (1981) treat tense as part of textual cohesion, while Firbas (1992) extends this by showing that tense contributes to information flow through communicative dynamism. These approaches highlight how tense operates as a cohesive and informational resource rather than a purely grammatical marker. Smith's (2003) discourse mode theory represents a significant advance by linking tense interpretation to broader textual types such as Narrative,

Description, and Argument. This model convincingly demonstrates that the same tense form can function differently depending on discourse mode. However, Smith's framework has two major limitations. First, discourse modes are not strictly separable in real texts; academic and narrative genres frequently blend multiple modes within a single passage. Second, the model is largely descriptive and does not fully explain how transitions between modes are linguistically signalled. This gap is important for the present study: it suggests that tense not only reflects discourse mode but may actively function as a mechanism for mode transition. Accordingly, this study extends Smith's framework by analysing tense shifts as indicators of functional movement between discourse modes.

2.4. Tense–aspect theory: formal models and their discourse limitations

Reichenbach's (1947) three-point model (Speech time, Event time, Reference time) remains the most influential formal account of tense. It successfully explains temporal relations such as the distinction between simple past and present perfect, and it provides a logical basis for sequence-of-tense phenomena. Comrie (1976, 1985) extends this framework typologically, distinguishing between absolute, relative, and absolute-relative tense systems. Klein (1994) further refines the model by introducing Topic Time, shifting the analysis from abstract temporal points to discourse-relevant time intervals. Despite their precision, these formal models share a common limitation: they primarily account for temporal structure, not textual function. They explain when events occur relative to each other, but not why writers choose specific tense forms to achieve rhetorical or discourse-structuring effects. As a result, while Reichenbach, Comrie, and Klein provide essential semantic foundations, they must be integrated with discourse-oriented theories (Hopper, Smith, Halliday) to fully explain tense as a text-building resource.

2.5. Synthesis: the need for an integrated Micro–Macro model

Across the reviewed traditions, a consistent theoretical gap emerges. Formal semantic models (Reichenbach, Comrie, Klein) explain temporal structure but not discourse function. Functional models (Halliday, Hopper, Smith) explain discourse organisation but often lack precise formal mechanisms. This creates a theoretical fragmentation: tense is simultaneously treated as a temporal system, a grammatical choice system, and a discourse-structuring device—but rarely as all three at once.

The present study addresses this gap by proposing an integrated micro–macro model in which:

- formal tense–aspect relations explain micro-level clause structure
- grounding and discourse modes explain meso-level text organisation
- genre and register theory explain macro-level discourse function

This synthesis allows tense to be analysed not as a single grammatical category, but as a layered system of text construction operating across multiple levels of discourse.

3. Methods

3.1. Analytical design

The study employs a qualitative, theory-driven analytical framework combining micro-level and macro-level discourse analysis. This two-tier design is motivated by the recognition that tense functions cannot be fully accounted for at a single level of analysis: sentence-level tense choices gain their full discursive meaning only in relation to the larger text in which they are embedded (Halliday & Matthiessen, 2014, pp. 23–32; Smith, 2003, p. 17). The analytical approach is therefore integrative, moving between clause grammar and discourse organisation to trace how individual tense selections accumulate into genre-defining textual patterns.

3.2. *Corpus materials and selection rationale*

The study draws illustrative examples from two discourse domains represented by established corpora. Corpus selection is based on three criteria: (a) ecological validity (naturally occurring language data), (b) genre representativeness, and (c) availability and replicability in prior research. Narrative fiction is represented using short stories and novel excerpts drawn from the British National Corpus (BNC; Leech et al., 1994) and the Corpus of Contemporary American English (COCA; Davies, 2010). Together, these corpora provide naturally occurring data that capture key features of narrative discourse, including foregrounding–backgrounding patterns and viewpoint management in literary prose. The BNC was selected because its 100-million-word balanced design includes extensive samples of contemporary British fiction. In contrast, COCA was chosen due to its register-balanced structure and its longitudinal coverage (1990–present), which makes it possible to compare narrative fiction with academic English within the same corpus environment.

Academic writing is represented by research articles in linguistics and applied linguistics taken from the British Academic Written English (BAWE) corpus (Nesi & Gardner, 2012, pp. 12–18). BAWE was chosen because, unlike corpora consisting primarily of expert research articles, it includes assessed student writing at advanced levels, which aligns well with the pedagogical perspective of this study (Section 5). Corpus examples are used throughout the analysis to ensure that the identified functional patterns are grounded in authentic language use rather than constructed examples, following corpus-pragmatic methodology (Römer, 2016; Flowerdew & Richardson, 2018).

3.3. *Step-by-Step analytical procedure*

The qualitative analysis was conducted through a six-step coding procedure, applied iteratively to all selected passages and refined through multiple readings:

Step 1 — Passage selection. Extended passages of 150–300 words were selected from the corpora described above, with equal representation of narrative and academic registers.

Step 2 — Clause segmentation. Each passage was segmented into independent and dependent clauses. Verbal groups were identified and annotated for tense form (simple, progressive, perfect, perfect-progressive) and aspect (perfective, imperfective).

Step 3 — Reference-point coding. Each clause was coded for its Reichenbachian configuration (S, E, R relationships) following Reichenbach (1947) and Klein (1994), allowing identification of absolute, relative, and absolute-relative tense forms.

Step 4 — Grounding classification. Each clause was classified as foreground or background following Hopper (1979) and Hopper and Thompson (1980), with intermediate categories on Longacre's (1996) salience cline used where the binary classification was inadequate.

Step 5 — Discourse-mode identification. The dominant discourse mode of each passage was identified using Smith's (2003) five-mode typology (Narrative, Description, Report, Information, Argument). Mode transitions within passages were marked at the clause boundary where they occurred.

Step 6 — Functional classification of tense shifts. Each tense shift within a passage was classified as motivated (serving an identifiable discourse function such as grounding contrast, mode transition, viewpoint change, or evaluative emphasis) or unmotivated (producing processing difficulty or genre–register mismatch). The criteria for this classification are formalised in Table 1 in Section 4.

Inter-coder reliability was not formally tested because the analysis is interpretive rather than enumerative; however, every coding decision is grounded in published criteria from at least one of the four theoretical traditions, making the procedure transparent and replicable. The minimal-pair method—comparing identical propositions in contrasting tense forms—was used throughout to isolate the functional variable under investigation.

4. Analysis: tense as a multi-level text construction resource

4.1. Micro-level analysis: tense at the sentence and inter-clausal level

At the sentence level, tense selections are never semantically inert. Consider the following pair of constructions:

(1a) The experiment *showed* that temperature affects reaction rates.

(1b) The experiment *has shown* that temperature affects reaction rates.

In (1a), the simple past *showed* locates both the event and the reference point before speech time, creating a closed, completed frame. The finding is attributed to a specific past experiment and, by implication, may be superseded. In (1b), the present perfect *has shown* places the event before speech time but aligns the reference point with the present, asserting ongoing relevance. The reader interprets (1b) as a claim with current validity—a subtle but consequential difference in academic argumentation. This is not a matter of temporal accuracy (the experiment occurred at the same time in both cases) but of *discursive positioning*: the writer uses tense to signal whether a finding is historically bounded or presently operative.

At the inter-clausal level, tense manages temporal progression through the mechanism Reichenbach (1947, p. 290) identified as reference-point permanence. In narrative discourse, a sequence of simple past clauses advances the reference time:

(2) She *opened* the door. The hallway *was* dark. She *stepped* inside and *reached* for the light switch. Here, *opened*, *stepped*, and *reached* are foregrounded events in perfective aspect, each advancing the storyline's temporal reference point. *Was* (dark) is a stative, backgrounded description that does not advance time but provides simultaneous scene-setting—precisely the foreground–background distinction Hopper (1979, p. 215) theorised. The reader processes these clauses differently: the perfective verbs create forward momentum, while the stative clause invites spatial visualisation without temporal progression. This pattern is systematic: as Klein's (1994, p. 109) Principle of Natural Order predicts, perfective clauses in narrative establish AFTER relations between successive Topic Times, generating the temporal chain that constitutes plot.

The introduction of past perfect creates a further layer of temporal architecture:

(3) She *opened* the door. The hallway *was* dark—someone *had removed* the bulb. She *stepped* inside. The past perfect *had removed* signals a flashback—an event anterior to the current narrative reference point. In Reichenbach's terms, it places E before R, which is itself before S, creating the absolute-relative tense configuration Comrie (1985, pp. 64–82) describes. The effect on text construction is significant: the past perfect *interrupts* the forward chain of the narrative to insert explanatory depth, then yields to simple past to resume the storyline. This capacity for temporal layering is what makes tense a resource for constructing complex, multi-planar discourse rather than a mere time-stamp on individual clauses.

4.2. Macro-level analysis: tense across discourse and genre

At the macro level, tense selections define the temporal architecture of entire texts and serve as reliable genre markers. Biber's (1988, pp. 104–115) multi-dimensional corpus analysis demonstrates that tense is among the most powerful features distinguishing registers: past tense verbs cluster with

fiction and news reporting (narrative-based discourse), while present tense verbs co-occur with informational and involved production. Biber and Gray (2016, pp. 47–62) confirm this finding at greater granularity, showing that grammatical complexity and tense choice co-vary systematically with register demands. In narrative texts, tense operates as an organising skeleton. Simple past constitutes the unmarked “mainline” tense (Longacre, 1996, p. 25), carrying the sequential backbone of the plot. Departures from this baseline perform specific textual functions: the historical present, as Schiffrin (1981, p. 49) demonstrated, marks evaluative peaks within complicating action; past perfect creates analeptic depth; and present-tense commentary signals a shift to the meta-narrative frame. Fleischman (1990, pp. 23–29) captures this through the concept of *markedness reversal*: whereas present tense is unmarked in non-narrative language, narrative constitutes a marked context where past tense becomes the default and all other tenses acquire marked textual functions.

Consider

(4) He *walked* through the market, past the stalls that *had been* there for decades. Suddenly he *stops*. A face in the crowd. He *knows* that face. The shift from *walked* (past, mainline) to *had been* (past perfect, background) to *stops/knows* (historical present, evaluation) is not tense inconsistency but a precisely calibrated sequence of discourse functions. The historical present creates immediacy and marks a turning point; it signals to the reader that this moment is evaluatively significant—a technique Sanders and Van Krieken (2019, pp. 295–298) analyse as viewpoint management, where tense shifts construct distinct mental spaces within the text. In academic texts, tense operates according to a different functional logic, but one no less systematic. The conventions are well documented: present simple asserts established truths and generalisations (“Inequality *grows* in unstable markets”); present perfect reviews literature with ongoing relevance (“Researchers *have demonstrated* that...”); past simple reports specific completed findings (“McMillan *found* that...”). These are not arbitrary conventions but reflect the discourse modes Smith (2003, pp. 105–115) identifies: generalisations operate in Information mode (atemporal present), literature reviews in Report mode (deictic present perfect connecting past research to present relevance), and methodology sections in Narrative mode (past tense sequential account).

Strobbe and Vandenberg (2018, pp. 745–758) provide corpus-based confirmation of precisely this distribution in present-day academic discourse, showing that temporal reference in academic writing is systematically tied to text-structural position.

Consider

(5) Language *is* a social semiotic (Halliday, 1978). Subsequent research *has extended* this insight to multimodal communication. In this study, we *analysed* 200 texts and *found* significant variation across registers. Three tense forms co-occur within a single paragraph, each performing a distinct discursive function: present simple (“*is*”) for established knowledge, present perfect (“*has extended*”) for cumulative scholarly activity with current relevance, and past simple (“*analysed*,” “*found*”) for the specific completed study. The tense shifts are not inconsistent; they are *functionally motivated transitions between discourse modes* within a single text. This observation challenges the prescriptive advice often given to student writers — “maintain tense consistency” — which conflates two different phenomena: unmotivated tense shifts (which produce incoherence) and functionally motivated shifts (which produce textual organisation).

4.3. Tense consistency and motivated tense shifting: a comparative model

The question of tense consistency merits particular analysis because it reveals the tension between sentence-level grammar and discourse-level function. At the sentence level, tense consistency is a cohesive requirement: within a clause complex, tense shifts must be syntactically licensed (through sequence-of-tense rules, temporal adverbials, or logical subordination). Unmotivated shifts produce

processing difficulty and signal textual breakdown. At the discourse level, however, tense shifts are not merely permissible but *necessary* for constructing multi-functional texts.

Table 1 formalises the distinction between motivated and unmotivated tense shifts through four diagnostic criteria, with concrete examples for each.

Table 1
Motivated vs. unmotivated tense shifts: a diagnostic model

Criterion	Motivated Shift	Unmotivated Shift
Discourse function	Serves an identifiable function (grounding, mode transition, viewpoint, evaluation).	Serves no identifiable function; arbitrary alternation.
Reader processing	Aids interpretation; signals an update of temporal/epistemic frame.	Produces processing difficulty; reader cannot recover speaker intent.
Genre alignment	Aligns with genre conventions (e.g., literature review uses present perfect).	Violates genre conventions (e.g., random past/present in academic prose).
Example	"Language is a social semiotic. Researchers have extended this insight. In this study, we analysed 200 texts." (Information → Report → Narrative modes)	"The students worked on the task. They are tired. We collected the data." (no functional reason for tense alternation)

Note. Diagnostic criteria adapted from de Beaugrande and Dressler (1981), Smith (2003), and Sanders and Van Krieken (2019).

The analytical distinction, then, is between *unmotivated* tense shifts—which violate cohesion and create incoherence—and *motivated* tense shifts—which serve identifiable discourse functions. De Beaugrande and Dressler's (1981, p. 78) concept of “updating” captures this: a motivated tense shift is an instruction to the reader to update their temporal orientation within the discourse. These transitions function as what Schiffrin (1987, pp. 31–35) calls contextualisation cues, analogous to discourse markers in their capacity to signal shifts between discourse planes. Firbas's (1992, p. 13) communicative dynamism framework provides a further diagnostic: a tense shift carries high communicative dynamism when it introduces a new temporal frame (rhematic function), and low communicative dynamism when it merely maintains an established temporal orientation (thematic function). In example (4) above, the shift to historical present carries high CD because it reorients the reader's temporal and evaluative perspective. In example (5), the present simple “*is*” carries low CD, while the shift to past simple “*analysed*” carries higher CD because it introduces a new temporal and methodological frame.

4.4. *Tense and viewpoint management*

A final dimension of tense in text construction concerns its role in managing viewpoint and narrative perspective. Sanders and Van Krieken (2019, pp. 300–310) demonstrate how tense shifts in news narratives construct distinct epistemic spaces: a “News Space” anchored in event time (past tense) and a “Reality Space” anchored in the journalist's and reader's here-and-now (present tense). Transitions between these spaces are signalled primarily by tense, making tense a viewpoint-management device. In literary narrative, the same mechanism operates with greater subtlety: free indirect discourse typically maintains past tense while adopting the character's perspective, creating a blended viewpoint that Fleischman (1990, pp. 217–229) analyses as the simultaneous activation of narrative and deictic temporal frames.

This viewpoint function extends beyond narrative. In academic writing, the choice between active past tense (“*we found*”) and passive past tense (“*it was found*”) interacts with tense to manage the degree of authorial presence and epistemic commitment. The timeless present of generalisations (“*syntax governs word order*”) constructs an impersonal, objective viewpoint from which specific

findings are narrated in the past. The architecture is not random but reflects what Martin (1992, p. 502) describes as the genre-specific staging of ideational and interpersonal meanings through the textual metafunction, with tense serving as a primary resource.

Results and Discussion

The analysis yields several findings with implications for discourse theory, text linguistics, and language pedagogy.

First, it confirms the central claim of functional linguistics that tense is not reducible to temporal reference. Across both narrative and academic registers, tense selections perform identifiable discourse functions—grounding, cohesion, viewpoint management, genre signalling—that are independent of, or only loosely related to, the temporal location of events. This is observable in concrete cases. The simple past in narrative discourse advances the storyline (example 2: “*opened ... stepped ... reached*”); the same form in academic discourse locates a finding in a completed study (example 5: “*analysed ... found*”). The present perfect creates current relevance in academic writing (example 5: “*has extended*”); the same form in narrative would interrupt temporal progression. These are not different *meanings* of the same form but different *functions* activated by different discourse contexts, supporting Smith's (2003, pp. 28–32) mode-dependent interpretation of tense.

Second, the analysis demonstrates that tense operates at multiple levels simultaneously, and that adequate description requires attending to all levels. Halliday's metafunctional model captures the clause-level multi-functionality of tense (ideational, interpersonal, textual). Reichenbach's and Klein's reference-point models capture inter-clausal temporal progression. Hopper's and Longacre's grounding frameworks capture discourse-level partitioning. Biber's register analysis captures genre-level distribution. No single framework suffices; the contribution of this article is to show how these frameworks are complementary rather than competing, each illuminating a different stratum of tense's text-constructing function. The micro-level analysis in Section 4.1 demonstrated this complementarity in concrete terms: example (3) required Reichenbach's reference-point model to identify the absolute-relative configuration of past perfect, Hopper's grounding theory to explain why the same form functions as background, and Halliday's metafunctional model to capture its simultaneous contribution to textual cohesion. Removing any one of these frameworks would have left the analysis incomplete.

Third, the distinction between motivated and unmotivated tense shifts (formalised in Table 1) has significant pedagogical implications. The common instruction to “maintain tense consistency” oversimplifies the issue: students need to understand not only *when* to maintain tense but *when and why* to shift it. A genre-based pedagogy informed by Smith's discourse modes and Longacre's salience clines could equip writers with a functional understanding of tense as a meaning-making choice rather than a rule to be mechanically followed. Pérez-Llantada's (2022, pp. 5–10) analysis of complexity and simplicity in academic discourse provides empirical support for such an approach, demonstrating that expert academic writers deploy tense-aspect variation strategically in response to genre constraints. The goal is not consistency *per se* but *motivated consistency*—maintaining tense within a discourse function and shifting tense deliberately when the discourse function changes.

Fourth, the comparison between narrative and academic tense usage reveals that genre is not merely a contextual variable but an active determinant of tense interpretation. The same morphological form acquires different discursive values depending on the genre in which it appears, because genre activates different discourse modes (Smith, 2003), different grounding expectations (Longacre, 1996), and different communicative purposes (Martin, 1992). Thompson's (2014, pp. 87–98) comprehensive account of functional grammar confirms that the textual metafunction—including

tense as a cohesive device—operates genre-dependently rather than as a context-free grammatical rule. This finding aligns with the broader SFL principle that text and context are mutually constitutive: the genre shapes tense choice, and tense choice, in turn, constructs the genre. Flowerdew and Richardson (2018) similarly stress that discourse analysis must attend to genre-specific norms when interpreting grammatical choices, reinforcing the case for a genre-sensitive framework. The emerging framework of tense, aspect, and discourse structure (Egetenmeyer, Dessì Schmid, & Becker, 2024) points toward a productive synthesis in which tense-aspect forms are understood as co-determined by narrative functions at the discourse level.

Conclusion

This article has argued that English verb tenses function as multi-level tools of text construction rather than as mere grammatical markers of temporal reference. Drawing on Systemic Functional Linguistics, discourse grounding theory, text linguistics, and tense–aspect theory, the analysis has demonstrated that tense selections operate simultaneously at the clause level (realising experiential, interpersonal, and textual meanings), the inter-clausal level (creating temporal progression through reference-point management), the discourse level (partitioning text into foreground and background, signalling discourse mode, and managing viewpoint), and the genre level (functioning as register markers that distinguish narrative from academic, procedural from expository discourse). The comparison between narrative and academic registers has shown that tense is not a fixed semantic category but a context-sensitive functional resource whose interpretation depends on the discourse mode, genre, and communicative purpose in which it operates. The distinction between motivated and unmotivated tense shifts, formalised in Table 1, provides a principled basis for understanding tense variation in texts: motivated shifts serve identifiable discourse functions (grounding, evaluation, viewpoint management, mode transition), while unmotivated shifts produce incoherence. The functional turn—from tense as grammatical category to tense as text-building resource—represents the field's most significant conceptual shift and offers the strongest foundation for both theoretical understanding and pedagogical application. Future research might extend this framework through large-scale corpus analysis of tense distributions across a wider range of genres, longitudinal studies of how writers develop functional tense competence, and cross-linguistic comparison of how different tense–aspect systems serve parallel text-constructing functions. What is clear from the present analysis is that any account of tense that remains confined to the sentence is fundamentally incomplete: tense is a discourse resource, and it is in discourse that its full functional potential is realised.

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The Relationships Between Workload, Service Orientation, Employee Performance, and Job Satisfaction: A Study on 4 and 5-Star Hotels in Antalya

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Abstract. The study aims to examine the relationships between workload (work overload), service orientation, employee performance and job satisfaction among frontline employees working in 4 and 5 star hotels in Antalya. Furthermore, the study explores the role of service orientation in explaining the relationship between workload and employee outcomes. In this study, employing a quantitative research design, data were collected from 493 frontline personnel working in 4 and 5-star hotels operating in the Antalya region via survey technique. In data analysis, Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) were applied using the LISREL 8.80 program. According to the structural model analysis results, work overload was found to negatively affect job satisfaction, while service orientation positively influenced employee performance. Contrary to the common expectation in the literature, work overload showed a positive association with service orientation, which may reflect the possibility that some employees perceive high workload as a challenge rather than a hindrance. The findings further revealed that service orientation mediated the relationship between work overload and employee performance. This study contributes to the literature by demonstrating that work overload does not necessarily reduce employee performance in service-oriented work settings. The findings suggest that service orientation may function as an important mechanism through which workload is associated with employee performance. By integrating workload, service orientation, employee performance and job satisfaction within a single structural model, the study provides a more comprehensive understanding of employee outcomes in the hospitality industry.

Keywords: work overload, service orientation, employee performance, job satisfaction, structural equation modeling, hospitality industry

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İş yükü, xidmət yönümlülüüyü, işçilərin fəaliyyət səmərəliliyi və iş məmnuniyyəti arasındakı əlaqələr: Antalyadakı 4 və 5 ulduzlu otellər üzrə tədqiqat

Anıl Kale^{1*} , Kürşad Sayın² 

Xülasə. Tədqiqatın məqsədi Antalyada 4 və 5 ulduzlu otellərdə çalışan ön cəbhə işçiləri arasında iş yükü, xüsusilə həddindən artıq iş yükü xidmət yönümlülüüyü, işçi performansını və iş məmnuniyyəti arasındakı əlaqələri araşdırmaqdır. Bundan əlavə, tədqiqat iş yükü ilə işçi nəticələri arasındakı

əlaqəni izah etməkdə xidmət yönümlülüüyünün rolunu araşdırır. Kəmiyyət tədqiqat dizaynından istifadə edən bu tədqiqatda, Antalya bölgəsində fəaliyyət göstərən 4 və 5 ulduzlu otellərdə çalışan 493 ön cəbhə işçisindən sorğu texnikası vasitəsilə məlumatlar toplanmışdır. Məlumatların təhlilində LISREL 8.80 programından istifadə edərək Təsdiqləyici Faktor Təhlili (CFA) və Struktur Tənlik Modelləşdirməsi (SEM) tətbiq edilmişdir. Struktur model təhlilinin nəticələrinə görə, iş yükünün həddindən artıq olması iş məmnuniyyətinə mənfi təsir göstərdiyi, xidmət yönümlülüüyün isə işçilərin performansına müsbət təsir göstərdiyi aşkar edilmişdir. Ədəbiyyatdakı ümumi gözləntinin əksinə olaraq, iş yükünün xidmət yönümlülüüyü ilə müsbət əlaqəsi var idi ki, bu da bəzi işçilərin yüksək iş yükünü maneə deyil, çətinlik kimi qəbul etmə ehtimalını əks etdirə bilər. Nəticələr daha sonra göstərdi ki, xidmət yönümlülüüyü iş yükü ilə işçilərin performansı arasındakı əlaqəni vasitəçi rol oynayır. Bu tədqiqat, iş yükünün xidmət yönümlü iş şəraitində işçilərin performansını mütləq azaltmadığını nümayiş etdirməklə ədəbiyyata töhfə verir. Nəticələr göstərir ki, xidmət yönümlülüüyü iş yükünün işçilərin performansı ilə əlaqələndirildiyi vacib bir mexanizm kimi fəaliyyət göstərə bilər. İş yükünü, xidmət yönümlülüüyünü, işçilərin performansını və iş məmnuniyyətini vahid struktur model daxilində birləşdirməklə, tədqiqat qonaqpərvərlik sənayesində işçilərin nəticələrini daha əhatəli şəkildə anlamağa imkan verir.

Açar sözlər: *iş yükü, xidmət yönümlülüüyü, işçilərin performansı, iş məmnuniyyəti, struktur tənlik modelləşdirməsi, qonaqpərvərlik sənayesi*

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Introduction

Achieving a sustainable competitive advantage for modern enterprises, especially in the service sector, depends largely on the performance exhibited by their employees and their customer-oriented approaches. In today's rapidly changing and competitive business environment, the increasing duties and responsibilities expected of employees have brought the concept of "workload" to the center of organizational behavior literature (Johan & Satrya, 2023, p. 545; Mony & Priyastiwi, 2025, p. 106). Work overload is considered a critical stress factor that directly and negatively affects both job satisfaction and overall performance by straining the physical and psychological capacities of employees (Herawati et al., 2023, p. 17; Paliga, 2023, p. 5111).

However, the effect of workload on performance does not always occur directly; this relationship is shaped through various psychological and behavioral mechanisms. Current international studies in the literature empirically prove that job satisfaction plays a fundamental mediating role in this relationship (Mony & Priyastiwi, 2025, p. 115). On the other hand, in service-oriented businesses where value creation and customer interaction are intense, another vital element determining performance stands out as "service orientation" (Sadiq et al., 2022, p. 50; Handayani & Nabhan, 2025, p. 15). Service orientation refers to employees' tendencies to meet customer needs and derive natural enjoyment from providing service, and it acts as the driving force of high performance (Saura et al., 2005, p. 497; Kenar & Yeşiltaş, 2024, p. 237).

When the literature is reviewed, although the effects of workload on job satisfaction and performance are generally examined with one-dimensional models (Johan & Satrya, 2023, p. 545), studies addressing the simultaneous mediating roles of both "job satisfaction" and "service orientation" in the multidimensional effect of perceived workload on employee performance in a holistic model are

limited. There is a need to explain organizational dynamics with multivariate structural models based on strong theoretical foundations (e.g., the Job Demands-Resources Model and Social Exchange Theory). Accordingly, the primary purpose of this study is to examine the relationships between workload, service orientation, employee performance and job satisfaction among frontline employees working in the hospitality sector. In addition, the study investigates the role of service orientation in explaining the relationship between workload and employee performance.

Literature Review And Hypotheses

In today's competitive service and hospitality sector, employee well-being and its impact on organizational outcomes have become one of the main focal points of researchers. Current studies in the literature show that workload plays a determining role in employees' psychological states and ultimate service performances (Johan & Satrya, 2023, p. 545). Particularly in labor-intensive sectors, to achieve organizational goals, there is a need for holistic models that consider employee attitudes (job satisfaction) and individual abilities (service orientation) as a whole (Kenar & Yeşiltaş, 2024, p. 237). In this context, the main variables of the research—workload, job satisfaction, service orientation, and employee performance—are briefly explained below.

Workload (work overload): Workload refers to the situation where an employee faces job demands that exceed the amount, intensity, and capacity of the work they must perform within a specific time frame (Paliga, 2023, p. 5111). Although an optimal level of workload can motivate an employee, continuous work overload exceeding capacity creates stress and burnout, acting as a primary pressure element that directly reduces both psychological satisfaction and productivity (Herawati et al., 2023, p. 17; Johan & Satrya, 2023, p. 545).

Job Satisfaction: Job satisfaction is a state of positive psychological and emotional fulfillment that an employee feels as a result of evaluating their job, experiences in the work environment, and the opportunities provided by the organization (Latifah et al., 2023, p. 724). Individuals with high job satisfaction show greater commitment to their organizations, cope more easily with stress factors, and are more inclined to exhibit customer-oriented proactive behaviors (Mony & Priyastiwi, 2025, p. 115).

Service Orientation: Service orientation is an individual's inherent tendency to be willing to meet customer needs, communicate effectively, and derive natural enjoyment from providing service (Kim et al., 2025, p. 1018). This trait is a critical skill, especially in highly interactive sectors like hospitality, enabling employees to exhibit behaviors centered on customer satisfaction and to achieve a natural fit with the work environment (Murray, 2022, p. 119; Handayani & Nabhan, 2025, p. 15).

Employee Performance: Employee performance is an outcome showing the extent to which an individual successfully and with the desired quality fulfills their assigned duties and responsibilities in line with the organization's goals (Deb et al., 2023, p. 630). In the service sector, performance encompasses not only technical skills but also the quality of service provided to the customer, extra-role behaviors, and productivity (Kenar & Yeşiltaş, 2024, p. 237).

Conceptual Framework and Hypotheses

Shaped on the basis of the Job Demands-Resources Model and Social Exchange Theory, this study examines the multidimensional effect of workload on employee performance. Although the literature indicates that work overload directly leads to performance losses (Mony & Priyastiwi, 2025, p. 106), it also emphasizes that this relationship is indirectly shaped through the employee's job satisfaction and service orientation (Sadiq et al., 2022, p. 51; Johan & Satrya, 2023, p. 545).

In line with this theoretical network of relationships, the following hypotheses have been developed:

- H1: Work overload has a significant and negative effect on service orientation.
- H2: Work overload has a significant and negative effect on employee performance.
- H3: Work overload has a significant and negative effect on job satisfaction.
- H4: Service orientation has a significant and positive effect on employee performance.
- H5: Service orientation has a significant and positive effect on job satisfaction.
- H6: Employee performance has a significant and positive effect on job satisfaction.
- H7: Service orientation has a full mediation role in the effect of work overload on employee performance.

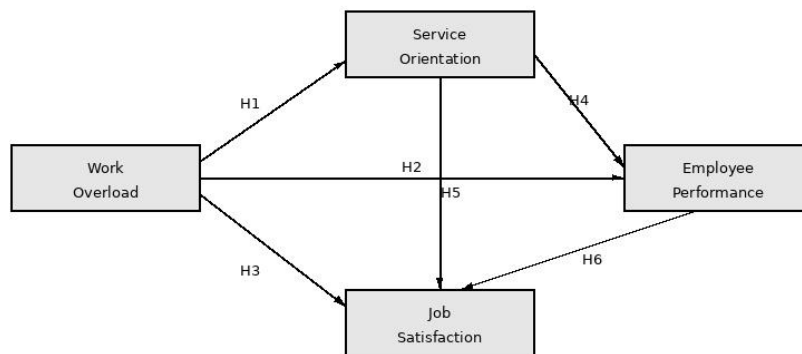


Figure 1
Conceptual framework

Source. Authors' own creation.

Methods

Research Locale

This research was conducted in 4- and 5-star hotel enterprises operating in the Antalya region, which is considered the tourism capital of Turkey and where labor-intensive service dynamics are experienced at the highest level. Particularly, 4- and 5-star hotels are considered the most suitable study areas in the context of multivariate organizational behavior research, such as employee performance and service orientation, due to their corporate management structures and higher capacities to adopt service-oriented human resource practices (Kenar & Yeşiltaş, 2024, p. 238).

Research Design

In this study, a quantitative and explanatory research design was adopted to test the multidimensional causal relationships among workload, job satisfaction, service orientation, and employee performance. The "cross-sectional survey" method was preferred because it reflects the state of phenomena within a specific timeframe and allows for the collection of statistically generalizable data from large populations (Mishra et al., 2023, p. 31).

Nature of the Data and Sampling Design

The primary data of the research were collected through questionnaires consisting of structured and closed-ended questions. The data collection process was carried out during the summer period of 2025, when tourism activities and consequently the workload of employees are at their peak. Considering the busyness of the participants during working hours, the drop-and-collect technique was used to maximize the response rate and avoid creating time pressure while answering the

questionnaires. This self-administered method minimizes possible response biases by allowing respondents to express themselves away from external pressures (Mishra et al., 2023, p. 31).

In sample selection, the convenience sampling method was used to reach frontline employees who are in direct face-to-face interaction with customers, in accordance with the main problem of the research. After excluding incomplete or incorrectly filled questionnaires from those distributed via the drop-and-collect technique, a total of 493 valid questionnaires were obtained. In the literature, it is emphasized that a sample size between 200 and 400 is ideal for robust analysis in order to ensure statistical power and convergence in models using Structural Equation Modeling (Deb et al., 2023, p. 630). The sample size of 493 reached in the study more than meets these methodological requirements.

Research Instruments

The measurement tools used in the research were adapted from empirical studies whose validity and reliability had been previously proven in the international literature. All statements in the questionnaire (four scales) were measured using a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

1. *Service Orientation*: A 5-item scale adapted from the study by Susskind et al. (2003) was preferred to measure employees' tendencies to meet customer needs and their customer orientation.
2. *Employee Performance*: A 5-item performance scale based on the study by Wong et al. (2021) was used to evaluate employees' task success, productivity, and extra-role behaviors within the hotel.
3. *Job Satisfaction*: A 4-item job satisfaction scale, also used by Wong et al. (2021), was utilized to measure the internal fulfillment and happiness employees feel from their current duties and working conditions.
4. *Workload*: A 4-item scale used by Karatepe (2013) was preferred to measure the task demands exceeding employees' capacities and the time pressure (perceived work overload) on them (However, during construct validity analyses, one item with a low factor loading was excluded from the model, and the analyses were continued with 3 items).

In order to reduce the risk of Common Method Bias, which is frequently encountered in self-report survey applications, it was explicitly stated to the participants at the beginning of the questionnaire form that the data obtained would be used solely for scientific research purposes, and the names of individuals and institutions would strictly not be shared with third parties (Sadiq et al., 2022, p. 52).

Data Analysis And Results

Demographic Profile

The demographic characteristics of the 493 hotel employees participating in the research are summarized in Table 1. According to the descriptive statistical data obtained, the vast majority of the participants are male (71.60%) and single (68.76%). When the age distribution is examined, the largest group consists of young adults in the 20-29 age range (46.45%), followed by the 30-39 age group (22.11%). Regarding the departments where the participants work, employees in the food and beverage (F&B) department, where direct customer contact is most intense, have the highest share in the sample (72.62%), followed by front office employees (22.72%).

In terms of industry experience, the participants show a relatively balanced distribution. The most concentrated group is those with 5-10 years of experience (25.35%), followed by those with 10-15 years (24.14%), less than 1 year (22.92%), and 1-5 years (21.50%). This situation indicates that the personnel participating in the research consist of both a dynamic group newly entering the sector and a competent group with significant sectoral experience.

Table 1*Demographic profile of respondents*

Category	Label	Frequency	Percentage (%)
Gender	Male	353	71.60
	Female	140	28.40
Age	Under 20	59	11.97
	20–29	229	46.45
	30–39	109	22.11
	40–49	74	15.01
	50 and above	22	4.46
Marital Status	Single	339	68.76
	Married	154	31.24
Department	Food and Beverage	358	72.62
	Front Office	112	22.72
	Management	23	4.67
Experience	< 1 year	113	22.92
	1–5 years	106	21.50
	5–10 years	125	25.35
	10–15 years	119	24.14
	15–20 years	11	2.23
	20+ years	19	3.85
Total	Total	493	100.0

Source. Authors' own creation.*Central Tendency Measurement of Constructs*

The lowest and highest mean and standard deviation values belonging to each variable (construct) are shown in Table 2. The item means of all constructs in the research range from 3.34 to 4.54. This situation indicates that the participants generally preferred to respond to the statements at the "agree" level. In addition, the standard deviation values of the responses given to the items range between 0.733 and 1.349.

Table 2

Central tendencies' measurement

Constructs	Lowest Mean	Highest Mean	Lowest SD	Highest SD
1. Workload	3.34	3.35	1.283	1.349
2. Job Satisfaction	4.08	4.34	0.854	0.946
3. Service Orientation	4.28	4.54	0.808	0.923
4. Employee Performance	4.42	4.54	0.733	0.781

Source. Authors' own creation.

Measurement Model Evaluation

Reliability Analysis

To test the internal consistency and convergent validity of the constructs in the research model, reliability and confirmatory factor analyses were conducted. In the literature, it is emphasized that for scales to be considered to have a high level of internal consistency, Cronbach's Alpha and Composite Reliability (CR) values must be above the 0.70 threshold; and to prove that convergent validity is achieved, Average Variance Extracted (AVE) values must generally exceed the 0.50 threshold.

The analysis results regarding the measurement model are summarized in Table 3. According to the findings obtained, Cronbach's Alpha values of all variables in the model ranged from 0.778 to 0.888, and Composite Reliability (CR) values ranged from 0.780 to 0.889. Both reliability values were well above the acceptable limit of 0.70, proving that the scales have strong internal consistency. In the context of convergent validity; the AVE values of the workload, service orientation, and employee performance variables successfully exceeded the 0.50 threshold (ranging from 0.567 to 0.661). The AVE value of the job satisfaction variable was 0.470, just below the limit. However, in the structural equation literature, it is accepted that convergent validity is confirmed in cases where the Average Variance Extracted (AVE) is not significantly lower than 0.50 and the factor loadings belonging to the relevant construct are sufficient. As a matter of fact, the fact that the Composite Reliability (CR) value of the job satisfaction variable is at a very strong level such as 0.780 supports that the internal consistency and validity of this dimension are ensured. As a result, it was determined that the measurement tools in the research model are highly reliable and valid.

Table 3

Reliability and convergent validity

Construct	Items	Cronbach's Alpha	Composite Reliability (CR)	AVE
Service Orientation	5	0.888	0.889	0.617
Employee Performance	5	0.862	0.866	0.567
Job Satisfaction	4	0.778	0.780	0.470
Workload	3	0.833	0.852	0.661

Note. AVE = Average Variance Extracted; CR = Composite Reliability.

Source. Authors' own creation.

Confirmatory Factor Analysis

To test the construct validity of the scales used in the research, a Confirmatory Factor Analysis (CFA) was performed using the LISREL 8.80 program. During the analysis process, one item with a low factor loading (AIY1) was removed from the model, thereby increasing the goodness of fit of the model. The goodness of fit indices of the measurement model consisting of four latent variables (service orientation, employee performance, job satisfaction, and work overload) and 17 observed variables were examined. According to the CFA findings, the goodness of fit values of the measurement model are as follows: $\chi^2 = 265.08$, $df = 113$, $\chi^2/df = 2.34$, RMSEA = 0.052, CFI = 0.99, NFI = 0.97, NNFI = 0.98, IFI = 0.99, GFI = 0.94, AGFI = 0.92, and SRMR = 0.036. In the literature, a χ^2/df ratio below 3, an RMSEA value below 0.08, and indices such as CFI, NFI, NNFI, and GFI exceeding the 0.90 threshold are considered indicators that the model fits the data perfectly (Deb et al., 2023, p. 630). These values obtained prove that the established measurement model is highly compatible with the empirical data. As seen in Table 4, the standardized factor loadings of all items in the measurement model range from 0.65 to 0.92, and all t-values (between 11.65 and 23.45) are statistically significant at the 0.001 significance level. These results confirm convergent validity, showing that the survey items measure the variables they are related to in a strong and valid way.

Table 4
Confirmatory factor analysis results

Construct	Items	Standardized Factor Loading	t-value
Service Orientation	HVY1	0.81	21.22
	HVY2	0.84	22.43
	HVY3	0.71	17.50
	HVY4	0.76	19.34
	HVY5	0.80	20.97
Employee Performance	IP1	0.79	20.29
	IP2	0.71	17.37
	IP3	0.83	21.93
	IP4	0.77	19.78
	IP5	0.65	15.70
Job Satisfaction	IM1	0.69	15.74
	IM2	0.65	14.58
	IM3	0.72	16.49
	IM4	0.68	15.41
Workload	AIY2	0.67	15.84
	AIY3	0.92	23.45
	AIY4	0.83	20.76

Note. All t-values are significant at $p < 0.001$. Model Fit Indices: $\chi^2/df = 2.34$; RMSEA = 0.052; CFI = 0.99; NFI = 0.97; NNFI = 0.98; IFI = 0.99; GFI = 0.94; AGFI = 0.92; SRMR = 0.036.

Source. Authors' own creation.

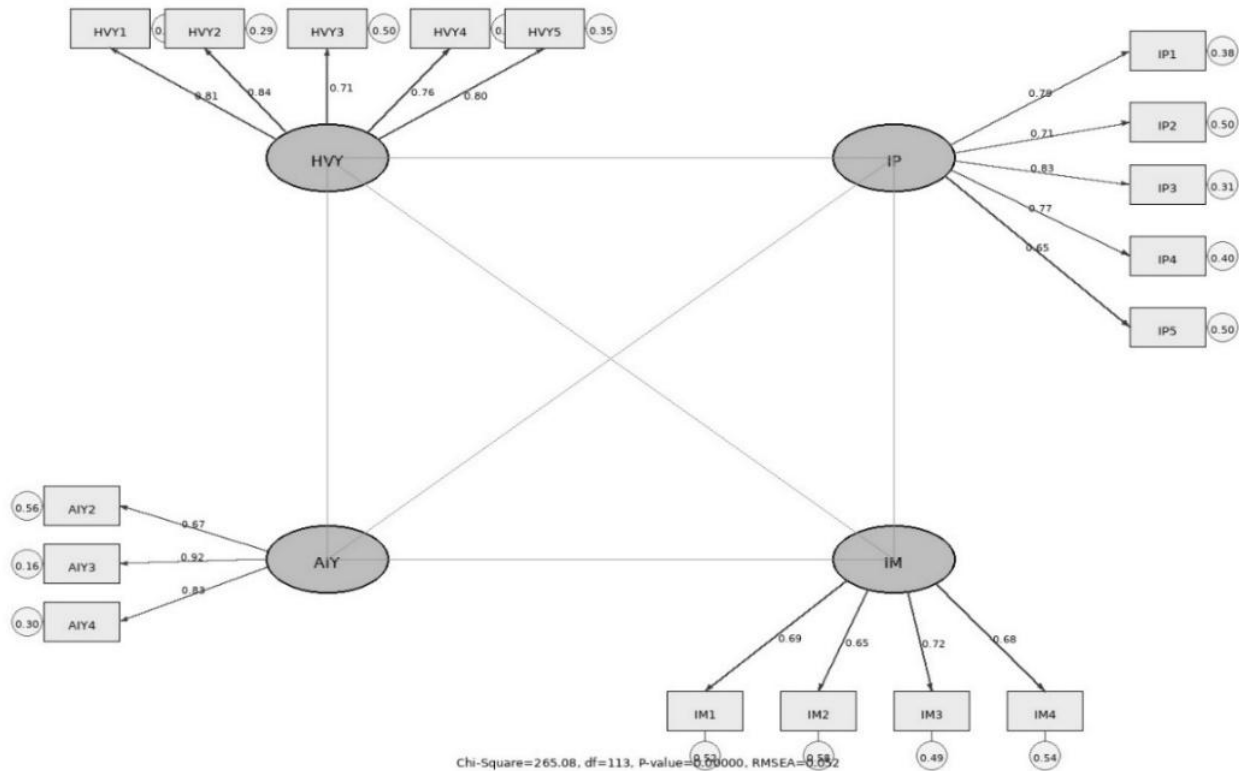


Figure 2
Confirmatory factor analysis model
Source. Authors' own creation.

Discriminant Validity

As the final stage in the evaluation of the measurement model, discriminant validity, which shows how empirically distinct the constructs are from each other, was tested. In the literature, discriminant validity is used to evaluate how different and unique a variable in the model is from other variables. In this research, whether discriminant validity was achieved or not was examined with the Fornell-Larcker criterion, one of the most widely accepted methods in the literature. According to the Fornell and Larcker (1981) rule, to ensure this validity, the square root of the Average Variance Extracted (AVE) value of each latent variable must be higher than the correlation coefficients of that variable with all other variables. When the diagonal values highlighted in bold in Table 5 are examined, it is clearly seen that these values (0.818, 0.775, 0.833, and 0.805) are higher than all other inter-construct correlation values in their respective rows and columns. Even the correlation between employee performance and service orientation (0.761), which shows the closest relationship to each other, was found to remain below the diagonal values of the relevant constructs (0.805 and 0.833). These results prove that the concepts in the research model are not confused with each other, each variable measures a unique construct within itself, and the discriminant validity condition is successfully met.

Table 5*Discriminant validity results*

	Workload	Job Satisfaction	Service Orientation	Employee Performance
Workload	0.818	-	-	-
Job Satisfaction	-0.128	0.775	-	-
Service Orientation	0.059	0.446	0.833	-
Employee Performance	0.060	0.563	0.761	0.805

Note. Bold diagonal values represent the square root of AVE.

Source. Authors' own creation.

Structural Model and Hypothesis Testing

After the measurement model met the reliability and validity conditions, the structural model evaluation was initiated to test the direct and indirect (mediating) causal relationships in the conceptual model. In structural equation modeling (SEM), the explanatory power R^2 (Explained Variance) values of the model, the direction of the established hypotheses, and their statistical significance (standardized β coefficients and t-values) are examined.

When the goodness of fit indices obtained as a result of the structural model analysis performed via LISREL are examined ($\chi^2 = 265.08$, $df = 113$, $\chi^2/df = 2.34$, $RMSEA = 0.052$, $CFI = 0.99$, $NFI = 0.97$, $IFI = 0.99$, $GFI = 0.94$), it is seen that the model is in perfect harmony with the empirical data. When the R^2 values indicating the predictive power of the model are evaluated; it was determined that the established model strongly explains 75% ($R^2 = 0.75$) of the variance in employee performance and 47% ($R^2 = 0.47$) of the variance in job satisfaction.

According to the results of the direct effect hypothesis tests presented in Table 6; it was confirmed that work overload has a significant and negative effect on job satisfaction in accordance with expectations in the literature ($\beta = -0.14$, $t = -2.99$), thus H3 is accepted. When other strong relationships in the model are examined; it was proven that service orientation affects employee performance very strongly and positively ($\beta = 0.86$, $t = 11.94$), and increased employee performance also positively increases job satisfaction ($\beta = 0.80$, $t = 5.85$), thus H4 and H6 are accepted.

On the other hand, it was determined that work overload has a significant positive effect on service orientation ($\beta = 0.12$, $t = 2.38$), contrary to the general expectation (negative effect) in the literature, and therefore H1 is rejected (The theoretical justifications for this specific situation will be discussed in the context of "challenge stressors" in the discussion section). Furthermore, the direct effect of work overload on employee performance ($\beta = 0.02$, $t = 0.66$) and the direct effect of service orientation on job satisfaction ($\beta = -0.14$, $t = -1.12$) were not found to be statistically significant, and therefore H2 and H5 are also rejected.

When the mediation hypothesis of the research is examined; the mediating role of service orientation in the relationship between work overload and employee performance (H7) was evaluated. According to the analysis results; it was observed that work overload significantly affects service orientation ($\beta = 0.12$) and service orientation directly increases performance ($\beta = 0.86$). In contrast, the direct effect of work overload on performance is statistically insignificant ($t = 0.66$). According to the structural equation literature, this statistical table, which shows that the effect of the independent variable on the dependent variable occurs entirely through the mediator variable, proves the "full mediation" effect. Therefore, H7 is supported and accepted.

Table 6
Hypothesis testing results

H	Path	Std. β	t-value	Expected Direction	Decision
H1	Workload $\rightarrow$ Service Orientation	0.12	2.38	Negative	Rejected
H2	Workload $\rightarrow$ Employee Performance	0.02	0.66	Negative	Rejected
H3	Workload $\rightarrow$ Job Satisfaction	-0.14	-2.99	Negative	Accepted
H4	Service Orientation $\rightarrow$ Employee Performance	0.86	11.94	Positive	Accepted
H5	Service Orientation $\rightarrow$ Job Satisfaction	-0.14	-1.12	Positive	Rejected
H6	Employee Performance $\rightarrow$ Job Satisfaction	0.80	5.85	Positive	Accepted
H7	Workload $\rightarrow$ Service Orientation $\rightarrow$ Employee Performance	Indirect	Full Mediation	Mediation	Accepted

Note. Std. β = Standardized Beta Coefficient. R^2 (Employee Performance) = 0.75; R^2 (Job Satisfaction) = 0.47. Model Fit: χ^2/df = 2.34; RMSEA = 0.052; CFI = 0.99; GFI = 0.94.

Source. Authors' own creation.

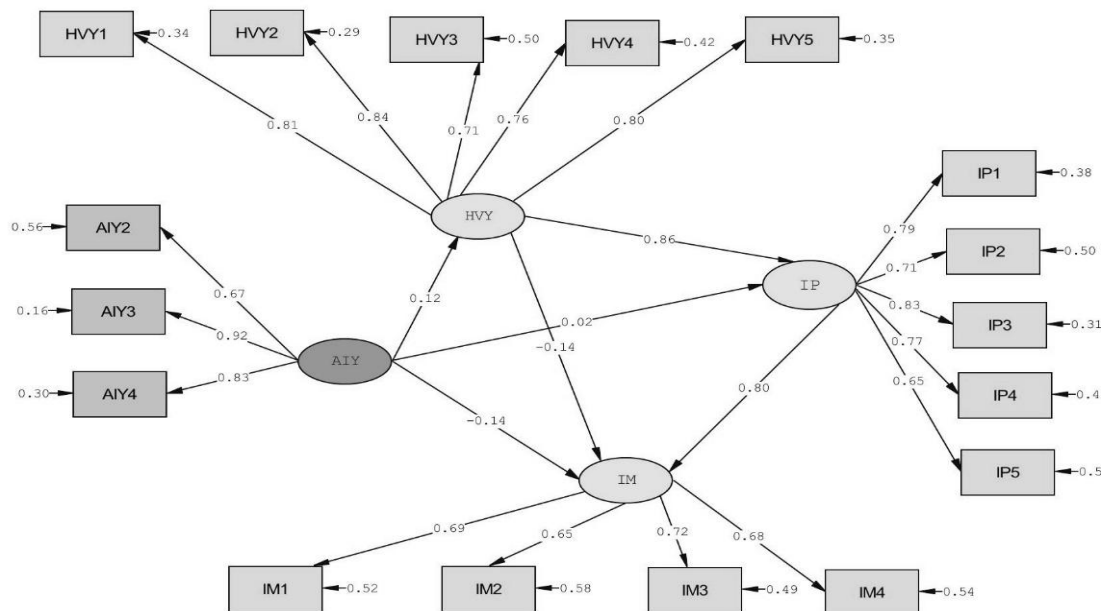


Figure 3
Structural equation model
Source. Authors' own creation.

Discussion and Conclusion

The primary purpose of this study was to examine the relationships between workload, service orientation, employee performance and job satisfaction among frontline employees in the hospitality sector using Structural Equation Modeling (SEM). While the analysis results largely support the conceptual model of the research, they offer vital theoretical contributions to the hospitality marketing and organizational behavior literature that challenge conventional wisdom.

When the direct effect hypotheses of the research are examined, the results indicate that work overload negatively and significantly affects job satisfaction (H3 Accepted). This finding is consistent with recent studies (Johan & Satrya, 2023, p. 545; Mony & Priyastiwi, 2025, p. 106) asserting that increasing job demands and workload reduce the intrinsic fulfillment of employees. On the other hand, the strongest relationship in the model was found between service orientation and employee performance (H4 Accepted). The fact that employees who enjoy service delivery and prioritize customer needs have much higher performance levels is consistent with the core assumptions of the service orientation literature (Donavan et al., 2004, p. 128; Alagöz, 2023, p. 78). It was also observed that increased employee performance positively fosters job satisfaction (H6 Accepted). Contrary to H5, service orientation did not have a statistically significant effect on job satisfaction. One possible explanation is that job satisfaction in the hospitality industry is shaped more strongly by organizational factors such as compensation, working conditions, managerial support and career opportunities than by employees' customer-oriented tendencies. Therefore, although service-oriented employees may exhibit higher performance levels, this orientation alone may not be sufficient to increase job satisfaction.

However, one of the most noteworthy findings of the study concerns the effect of work overload on service orientation. The traditional expectation in the literature (the H1 hypothesis that workload would damage service orientation) was rejected in this study as the relationship was significant and in the opposite direction (positive). In other words, it was found that as the workload of hotel employees in the Antalya region increased, their service orientation also increased. Although this finding may appear counterintuitive at first glance, is explained by the concepts of "Activation Theory" and "Challenge Stressors" emphasized by Haldorai et al. (2022). Hospitality employees do not perceive heavy workload as a hindrance to their performance; on the contrary, they see it as a goal and a challenge where they can demonstrate their professional competence, which allows them to reach an optimum level of arousal and focus more on customer service. These findings are consistent with the mediation hypothesis of the study (H7 Accepted). No direct negative effect of work overload on employee performance was found (H2 Rejected). Workload converts into performance only when it triggers the employee's "service orientation". This "full mediation" finding offers a unique mechanism explaining how stressors may translate into performance through positive attitudes (service orientation), moving beyond simple linear models (Alagöz, 2023, p. 78).

Theoretical Implications

This study provides theoretical contributions to both the Job Demands-Resources Model and Social Exchange Theory. First, the study demonstrates that work overload, which is usually coded as a "destructive" element in traditional literature, does not always result in performance decline in service-oriented sectors. Second, the findings suggest that "service orientation" is more than just a personality trait or recruitment criterion (Kuşlivan & Eren, 2011, p. 139); it may function as a psychological buffer (full mediator) that helps maintain employee performance during periods of high workload and work intensity (peak seasons). In addition, the study contributes to the hospitality literature by demonstrating that service orientation functions not only as an employee characteristic but also as a mechanism through which job demands may be translated into positive performance outcomes. The findings indicate that service orientation helps employees maintain high performance

levels even under demanding work conditions. This contribution expands previous studies that primarily examined service orientation as a direct antecedent of employee performance.

Managerial Implications

In the tourism industry, it is almost impossible to avoid work overload, especially during high seasons. Based on this reality, the findings provide important practical strategies for hotel managers:

Human Resources and Recruitment: Instead of trying to eliminate the workload entirely, businesses may benefit from focusing on hiring individuals with high "service orientation" (those who enjoy helping customers and are empathetic) who do not compromise on service quality under high intensity.

Training and Development: To improve the service orientation of existing employees, hotel management may provide psychological support and organize training (service culture) programs where employees perceive the workload not as a "threat" but as a professional "challenge" (Haldorai et al., 2022).

Limitations and Future Research

In addition to its contributions to the literature and the sector, this study has some limitations. First, the data were collected through a cross-sectional survey design and only from 4- and 5-star hotels operating in the Antalya region. It is suggested that future research should use longitudinal designs and include different destinations and alternative service sectors (e.g., restaurants, airlines) to increase the generalizability of the findings. Second, all variables in this research are based on the self-reports of the employees. In future studies, designing models where "employee performance" and "service orientation" are evaluated by supervisors or customers (multi-source) will further reduce possible common method biases (Podsakoff et al., 2003, p. 879).

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Development Prospects of Azerbaijan as a Regional Logistics Center

Kamran Shirinzade 

Abstract. The purpose of this study is to examine the readiness of Azerbaijan's logistics infrastructure for the Silk Road project, compare its competitiveness with alternative routes in terms of cost and delivery time, and identify the steps required to provide competitive services. The study makes extensive use of research conducted by international financial institutions, such as the World Bank, the Asian Development Bank, and the European Bank for Reconstruction and Development, as well as information published by the State Statistics Committee, the Baku International Trade Port, and Azerbaijan Railways CJSC. The first section provides an overview of the transport corridors proposed under the Silk Road project, particularly the East–West Transport Corridor passing through Azerbaijan, and examines the trade, logistics, and economic opportunities created by the project, as well as the role of logistics quality in increasing GDP and improving welfare. The second section discusses the initiatives and infrastructure implemented by Azerbaijan within the framework of the Silk Road project, including the Baku–Tbilisi–Kars Railway and the Baku International Trade Port. The third section compares the objectives set out in the 2016 Strategic Road Map for the Development of Logistics and Trade with the current statistical situation.

Keywords: Land Silk Road, logistics infrastructure, Baku, free trade, seaport, transportation

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Azərbaycanın regional logistika mərkəzi kimi inkişaf perspektivləri

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Xülasə. Bu tədqiqatın məqsədi Azərbaycanın logistika infrastrukturunun "İpək Yolu" layihəsinə hazırlığını araşdırmaq, onun rəqabət qabiliyyətini qiymət və çatdırılma müddəti baxımından alternativ marşrutlarla müqayisə etmək və rəqabətqabiliyyətli xidmətlər göstərmək üçün tələb olunan addımları müəyyən etməkdir. Tədqiqatda Dünya Bankı, Asiya İnkişaf Bankı və Avropa Yenidənqurma və İnkişaf Bankı kimi beynəlxalq maliyyə qurumları tərəfindən aparılmış tədqiqatlardan, eləcə də Dövlət Statistika Komitəsi, Bakı Beynəlxalq Ticarət Limanı və "Azərbaycan Dəmir Yolları" QSC tərəfindən dərc olunmuş məlumatlardan geniş istifadə edilmişdir. Birinci bölmədə "İpək Yolu" layihəsi çərçivəsində təklif olunan nəqliyyat dəhlizləri, xüsusən də Azərbaycandan keçən Şərq–Qərb nəqliyyat dəhlizi haqqında məlumat verilir, layihənin yaratdığı ticarət, logistika və iqtisadi imkanlar, eləcə də logistika keyfiyyətinin ÜDM-in və rifahın artırılmasındakı rolu araşdırılır. İkinci bölmədə Azərbaycanın "İpək Yolu" layihəsi çərçivəsində həyata keçirdiyi təşəbbüslər və infrastruktur, o cümlədən Bakı–Tbilisi–Qars dəmir yolu və Bakı Beynəlxalq Ticarət Limanı müzakirə olunur.

Üçüncü bölmədə logistika infrastrukturunun inkişafı üçün 2016-cı il Strateji Yol Xəritəsində müəyyən edilmiş məqsədlər mövcud statistik vəziyyətlə müqayisə edilir.

Açar sözlər: *Quru İpək Yolu, logistika infrastrukturunu, Bakı, azad ticarət, dəniz limanı, nəqliyyat*

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Introduction

The quality of logistics infrastructure plays an important role in the economic development of any country. However, if a given country claims to be a transit country, a transport hub between the countries of the region to which it belongs, or between different states or regions in ensuring global trade, the importance of logistics infrastructure increases even more. Logistics is a network of services that ensure the uninterrupted physical flow of products from the manufacturer to the end consumer in intercountry and domestic trade. This includes transportation, warehousing, storage, terminal services (mainly activities at airports and seaports), express delivery, customs brokerage services, the use of a combination of several types of transportation (for example, sea-air, sea-rail), information management, etc.

Taking into account the above, the logistics performance of a country is the key to its productivity and a very important factor in attracting foreign investments. Poor-quality logistics services increase trade costs, especially for developing countries, and reduce the potential for international and domestic market integration. A low-income country can increase its trade turnover by 15% or more if it improves its logistics performance to that of a middle-income country (World Bank, 2019). At the same time, better logistics services mean greater market access and trade development. A one-day delay at border crossings means a 1% reduction in trade (World Bank, n.d.). In many countries, logistics service costs affect trade costs more than tariffs and customs duties. A 10% reduction in logistics costs means a 25% increase in trade (Qureshi, 2011). Landlocked countries have transport costs that are 50% higher than those of coastal countries. According to a study by the United Nations Conference on Trade and Development (UNCTAD, 2010), landlocked developing countries incur twice as much transport costs in foreign trade as countries with sea access in the same income group and three times as much as developed countries.

Over the past 15 years, the increase in global initiatives related to the restoration of the ancient trade route connecting Europe and Asia—the Silk Road—has significantly increased international interest in Azerbaijan as a transit country. Taking this interest into account, Azerbaijan has begun to implement numerous projects aimed at developing its logistics capabilities and forming the necessary infrastructure in this area. The construction of a new port on the Caspian Sea, participation in the construction of the Baku–Tbilisi–Kars railway, and the construction of a high-speed highway to the Georgian border are among these initiatives. Undoubtedly, infrastructure is not limited only to the construction of roads and ports; the condition of customs clearance points, storage warehouses, customs procedures, and the legal regulation of transit fees are also decisive factors.

Based on the above-mentioned problems, the study identifies the steps considered appropriate to increase Azerbaijan's attractiveness as a transit country within the framework of the Silk Road route. China, which has one of the world's largest economies and has been among the fastest-growing economies for many years, introduced the Belt and Road Initiative in 2013 to improve and develop intercontinental connections. This initiative consists of two directions: the Land Silk Road and the

New Maritime Silk Road. The land route connects China with Central and South Asia and Europe. The maritime route connects China with Southeast Asia, the Gulf countries, East and North Africa, as well as Europe.

The Land Belt project has six directions: I. China–Mongolia–Russia Corridor; II. New Eurasian Land Corridor; III. China–Central Asia–West Asia Economic Corridor; IV. China–Indochina Peninsula Corridor; V. China–Pakistan Corridor; VI. Bangladesh–China–India–Myanmar Corridor.

Before maritime transportation of goods from China to Europe became dominant, the Silk Road, which passed through Central Asia, the Caspian Sea, and the South Caucasus, developed trade relations among the countries located along the route and enabled them to export their products to new markets. Following the redevelopment of southwestern China, the expansion of trade relations, the increase in trade volume, and the renewed geopolitical interest in the Silk Road, the countries located on the proposed corridor have sought to participate actively in this project. It is estimated that the cost of transport projects in the 71 countries located along the corridors (excluding China) will amount to 144–304 billion US dollars. According to World Bank estimates, there are 71 countries, including China, on all routes, and if this initiative is implemented effectively, trade in transit countries is expected to increase by 2.8–9.7%, while foreign direct investment in low-income countries is expected to increase by 7.6%. According to estimates, due to the low quality of infrastructure, the absence or ineffective functioning of interstate customs and trade agreements, and the excessive time spent at border crossings, these countries lose 30% of their potential trade volume and 70% of their potential foreign direct investment (Djankov et al., 2006).

Azerbaijan is located on the China–Central Asia–West Asia (hereinafter East–West) corridor in this project. In the past few years, it has begun to participate in a number of investment projects, intergovernmental agreements, and associations in order to become an active participant in the project. According to the World Bank, the volume of foreign direct investment in Azerbaijan for 2019 was worth 1.5 billion US dollars (Baniya et al., 2019, p. 131). According to the Bank's research, if the East–West corridor, where Azerbaijan is located, is actively used in the project, then it may have the opportunity to increase the volume of foreign investment attracted to the country, develop trade and transport relations with countries located along the corridor, improve the quality of logistics infrastructure, and directly and indirectly develop other sectors of the economy. However, for this, the country must have a high-quality logistics infrastructure. According to World Bank research, saving one day in trade between countries located on the Silk Road corridor means an average increase in exports of 5.2 percent. Also, the short-term delivery of goods during trade is especially important for perishable products.

The presence of inter-country trade agreements, reducing the time spent at border crossings, and the country's improved transport infrastructure mean a further reduction in the time spent during trade and increased access to new markets. In general, as a result of the improvement of the infrastructure of the countries along this corridor, reconstruction, signing of interstate trade agreements, laws on reducing the time spent at border crossings and tariffs, the development of trade will be most pronounced in the countries of Central and West Asia. It is estimated that due to the improvement of the level of infrastructure, there will be a 7.3% increase in trade and a 16.6% decrease in the time spent at border crossings. According to calculations, as a result of the development of infrastructure alone, trade in Azerbaijan is projected to increase by 6–8%, and the time spent at border crossings is projected to decrease by 16–18%. In general, Azerbaijan's opportunities for trade and access to new markets are expected to increase by 5–6%. This indicator is projected to be 9–10% for Kazakhstan, 8–9% for Turkmenistan, 3–4% for Georgia, and 20–25% for Türkiye.

To assess the potential benefits of Azerbaijan's location on this corridor, it is also necessary to look at the volume of trade flows between the countries located on the Trans-Caspian route (Russia, Türkiye, Azerbaijan, Georgia, Iran, Kazakhstan) and major economies such as China and India.

Results and Discussion

Assessment of the possible overall economic impacts of improving the quality of logistics on Azerbaijan is vital.

Table 1

Assessment of overall economic impacts

Country / Region	Projected Economic Impacts
Central and West Asia	7.3% increase in trade; 16.6% decrease in time spent at border crossings
Azerbaijan	6-8% increase in trade; 16-18% decrease in time spent at border crossings; 5-6% increase in opportunities for trade and access to new markets
Kazakhstan	9-10% increase in opportunities for trade and access to new markets
Turkmenistan	8-9% increase in opportunities for trade and access to new markets
Georgia	3-4% increase in opportunities for trade and access to new markets
Türkiye	20-25% increase in opportunities for trade and access to new markets

Regulating indicators of economic substance Infrastructure, tariff reduction, extension of time spent at the border Infrastructure, reducing time spent at the border Infrastructure
Infrastructure, tariff reduction, reduction of time spent at the border Infrastructure, extension of time spent at the border Infrastructure Upper point Lower dam

GDP 21.10 17.07 6.01 18.27 14.22 5.16
Well-being level 1.94 -1.29 -4.06 0.85 -2.33 -4.13

As can be seen from the table, three factors - improving infrastructure, reducing tariffs and time spent at border crossings - together play a decisive role in increasing the country's GDP and welfare. In order to make its activities to increase its logistics capabilities within the framework of the new "Silk Road" project more systematic and complex, Azerbaijan approved the "Vision for the Future: 2020 Concept" in 2012 and the "Strategic Road Map for the Development of Logistics and Trade" in 2016. These documents provide for the implementation of a number of measures and plans to improve the logistics infrastructure. The development of the country's non-oil sector, improvement of the logistics, transport and trade infrastructure covering the period up to 2025 and beyond, Azerbaijan becoming a regional transit center, launching the Alat port, establishing a special economic zone, completing the railway projects on the Baku-Tbilisi-Kars and North-South transport corridors, improving logistics services, and establishing logistics centers in Baku and the regions were identified as the main priorities of the Strategic Roadmap. Because it is clear to the government that delivering manufactured products to new markets faster and cheaper is impossible without taking a number of steps. This includes broad areas such as improving transport infrastructure, providing for incentive

mechanisms in legislation (tax, customs), electronicization of processes at border crossing points, signing free trade agreements with other countries and organizations, establishing special economic zones, increasing the productivity of state-owned companies operating in the logistics sector, or entrusting many services to private companies (Qureshi, 2011, p. 17).

In order to make wider and more efficient use of the country's potential in the field of transit transportation, the Transit Cargo Coordination Council was established by Decree No. 655 of the President of the Republic of Azerbaijan dated October 25, 2015. The main task of the Council is to determine uniform principles and conditions of transportation, optimize tariffs, coordinate the activities of carriers and state bodies, ensure transparency, facilitate and improve transit procedures, reduce their number and duration, implement a fully favorable system in the field of transit cargo transportation, expand cooperation between the countries where cargo is transported and relevant agencies, and implement transport corridors passing through the country.

But undoubtedly, the real practical activity of the Azerbaijani government in strengthening its logistics potential as a transit country dates back to the years before the adoption of the aforementioned documents or the establishment of the aforementioned Council. In this regard, it is important to consider the steps it has taken in the last 20 years to take an active role in the “Silk Road” project, as well as to become a regional transit center, in terms of infrastructure, customs and border crossing points, and cooperation with other states. Along with the One Belt, One Road project proposed by China, the TRACECA project proposed by the European Union, which integrates the production, trade, and transport networks of Eurasia, the Asian Development Bank’s Central Asia Regional Economic Cooperation Program (CAREC), the Eurasian Economic Union (EAEU), the New Silk Road of the United States, and the Middle Corridor of Türkiye each offer different programs for countries and regions.

In 1993, Azerbaijan became a member of the “Europe-Caucasus-Asia-Transcaucasia” Transport Corridor (TRACECA) at the initiative of the European Union. According to the signed document, it was decided to restore the ancient East-West Silk Road, reconstruct and develop the transport and communication infrastructure. Along with Azerbaijan, Armenia, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Ukraine, Moldova, Mongolia, Bulgaria, Romania and Türkiye also joined this initiative. That is, before the project proposed by China in 2013, an agreement had already been signed and an institution had been established between the countries located on the aforementioned corridor for the revival of the ancient Silk Road.

The CAREC program, founded in 2001, covers 11 countries: Azerbaijan, Afghanistan, China, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan and Uzbekistan, Pakistan and Turkmenistan, and Georgia. This program is supported by 6 multilateral financial institutions (Asian Development Bank, European Bank for Reconstruction and Development, International Monetary Fund, Islamic Development Bank, United Nations Development Program and World Bank). CAREC program aims to facilitate transport, trade relations, develop cooperation in foreign trade and energy sectors.

The Middle Corridor project proposed by Türkiye is similar to TRACECA, an initiative of the European Union, and connects Türkiye with China through Georgia, Azerbaijan and Central Asia. On the basis of this project, in 2008, the Caravanserai Project was signed between the customs authorities of Türkiye, Azerbaijan, Georgia, Kazakhstan and Kyrgyzstan to reduce the time spent at border crossings, reduce customs procedures and adapt to unified procedures.

In 2016, the railway and port authorities of Azerbaijan, Kazakhstan and Georgia signed an agreement on the development of the Trans-Caspian International Transport Route Association. The main goal of the association is to coordinate freight transport along the Trans-Caspian corridor. The approval of

a number of bilateral and multilateral cooperation schemes to achieve efficiency in tariff policy, reduce barriers and administrative costs at customs and border crossings was among the measures planned at that time. The map prepared for the implementation of the agreement shows the Trans-Caspian International Transport Route, starting from Southeast Asia and China, stretching to Kazakhstan, the Caspian Sea, Azerbaijan, Georgia, Türkiye and then to European countries. The Trans-Caspian International Transport Route is in line with the EU's TRACECA and Türkiye's vision of the Middle Corridor to connect China to Europe. The trade route includes highways and railways from China to the western part of Kazakhstan, then by ship across the Caspian Sea to Azerbaijan, then to Georgia, Türkiye and Europe. This line allows for the efficient use of the ports of Baku, Aktau and Turkmenbashi for maritime transport and connects them with intermodal transport. The Trans-Caspian International Transport Route (TITR) is designed to deliver goods from China to Europe and vice versa through the territories of Kazakhstan, Azerbaijan and Georgia, as well as Türkiye. The management and development of the route is supported by a consortium created by the participating countries: China Railway (China), KTZ Express (Kazakhstan), Azerbaijan Caspian Shipping Company, ADY Express (Azerbaijan Railways) and Trans Caucasus Terminals (Georgia). In addition, Azerbaijan, Kazakhstan, Georgia and Ukraine have introduced competitive entry tariffs for cargo transportation on the route since June 1, 2016. In 2017, a memorandum of cooperation was signed with the China Association of Communications and Transport at a meeting attended by members of the International TITR Association, Kazakhstan, China, Ukraine, Poland, Türkiye, Azerbaijan, 80 representatives of railway administrations, port, ship-ping and logistics companies.

On November 21, 2017, within the framework of the European Union countries and the Eastern Partnership program, Azerbaijan, Armenia, Belarus, Georgia, Moldova and Ukraine joined the investment action plan for the expansion of the Trans-European Transport Network (TEN-T). The main objective of this investment action plan, organized with the support of the World Bank, is to assist decision-makers in determining strategic investment priorities in transport infrastructure. This investment plan, which is expected to be completed by 2030 and has a budget of 12.8 billion, aims to implement projects to improve the roads, railways and ports, aviation, logistics and smart transport systems of the Eastern Partnership countries. Within the framework of this project, projects worth 360 million euros were prepared for the establishment of five logistics centers in Azerbaijan (Khachmaz, Astara, Ganja, Na-khchivan, Tovuz), 410 million euros for the establishment of the Alat Azad Economic and Logistics Zone, and 328 million euros for the signaling, telecommunications and electrification of the East-West railway. The total amount of investment allocated for this project in Azerbaijan is 2.078 billion euros, including 613 million euros for highway infrastructure (2 projects, 613 km), 663 million euros for railway infrastructure (2 projects), and 802 million euros for logistics centers⁶ (de Soyres, 2019, p. 69).

Back in 2001, an amendment was made to the tax legislation, which provided for the inclusion of zero-interest value-added tax on all international and transit cargo and passenger transportation, with the exception of international postal services, as well as cargo handling services directly related to transit cargo transportation, and operations directly related to international and transit flights, during the provision of services.

At the next stage, the work became more extensive and intensive. Undoubtedly, the construction of the new Baku-Tbilisi-Kars railway line has a special place in this direction. The Strategic Roadmap for the development of logistics infrastructure, adopted in 2016, aimed to increase Azerbaijan's real GDP by 605 million manats (400 million manats directly and 205 million manats indirectly) by 2025, and create 18.9 thousand new jobs. However, in the transport sector, the number of employees increased by 3,500 during the period 2015-2019, which is 32.11 percent of the target figure for the transport sector.

In addition, the Map aimed to increase Azerbaijan's transit trade volume in the region and achieve a corresponding share in the following indicators:

- 40 percent on the Central Asia and Black Sea route;
- 25 percent on the Central Asia and Europe route;
- 3 percent on the China and Europe route;
- 40 percent on the Russia and Iran route;
- 25 percent on the Iran and Black Sea route.

In the five years since the adoption of the map, not only has there been no progress towards these goals, but on the contrary, there has been a decrease in the volume of transit cargo transportation, and this can be clearly seen from the published official statistics.

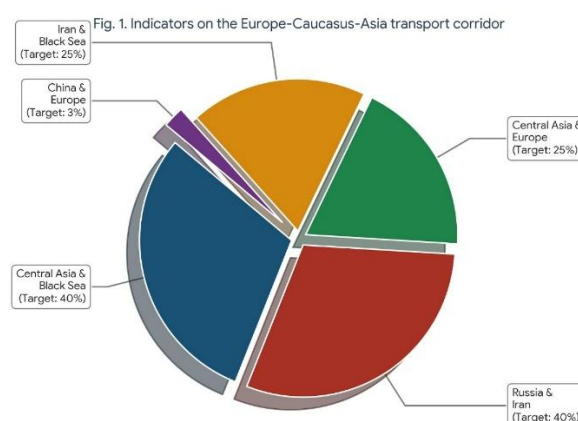


Figure1

Indicators on the Europe-Caucasus-Asia transport corridor

Ensuring competitive advantage in the conditions of numerous and alternative routes requires quite hard work and professional approaches from governments, as well as serious market reforms. Because there are such objective factors that ensure this advantage that not only a single country, but even the joint efforts of a large number of allied countries covering the entire region, cannot eliminate the negative effects of this factor. For example, the Trans-Caspian route of the New Eurasian Corridor, which connects the city of Xi'an, China, with the city of Slavkov, Poland, passing through Russia, connecting the city of Istanbul, Türkiye, with the city of Xi'an, China, passing through Azerbaijan, Georgia and Kazakhstan, has a natural advantage. Thus, the Trans-Caspian route provides for the transportation of goods based on transitions on various types of transport (rail-sea, sea-rail). Therefore, factors such as changes in relevant documents each time, the increase in time spent at border crossings and customs points, lead to an increase in transportation costs. However, the Poland-China route does not have a sea crossing and is a direct railway. Therefore, the time loss and, accordingly, cost increase that are recorded during the crossings on the Trans-Caspian route during transportation do not occur. At the same time, due to weather conditions, 90 days a year, ships in the Caspian Sea experience delays in delivering cargo. Undoubtedly, this advantage is due to objective factors (natural factors). The result is as follows: the cost of delivering a 40-foot container from the Polish city of Slavkov to the Xi'an region of China along the New Eurasian Corridor varies between 3600-4200 US dollars, and the cost of delivering a 40-foot container along the East-West corridor varies between 5000-5500 US dollars.

Another example of the high cost of container transportation is also evident in comparison with Georgia. The transportation tariff for a 40-foot and 20-foot container on the Baku-Aktau route is \$1,200 and \$600, respectively, and the transportation tariff for a 40-foot and 20-foot container on the Baku-Turkmenbashi route is \$1,000 and \$500, respectively. The amount paid for transportation per nautical mile or 1,852 km when transporting a 40-foot container between Baku and Turkmenbashi is

\$5.59 (the distance between the Baku-Turkmenbashi ports is 179 nautical miles). However, the same type of short sea shipping, when transporting a 40-foot container between the ports of Batumi and Constanta, is \$1.75 per nautical mile or 1,852 km (the distance between the ports of Batumi and Constanta is 628 nautical miles).

Azerbaijan's growing regional connectivity infrastructure establish natural synergies, particularly if paired with financing mechanisms available through the AIFC and future joint ventures. In the oil and gas sector, Kazakhstan and Azerbaijan are enhancing cooperation through alternative oil export routes, particularly via the Ba-ku-Tbilisi-Ceyhan (BTC) pipeline, which remains underutilized despite its 60 million tons annual capacity. Expanding Kazakhstan's oil exports through the BTC could reduce geopolitical risks and transit dependency, ensuring greater energy security. Additionally, joint oil exploration initiatives can benefit from Azerbaijan's extensive expertise in offshore energy development. In the renewable energy sector, Kazakhstan, Azerbaijan, and Uzbekistan are advancing the Caspian Green Energy Corridor—a strategic project to export Central Asian renewable electricity to Europe via an HVDC submarine cable across the Caspian Sea. By integrating national grids, the corridor aims to enhance regional energy security, diversify export routes, and position the region as a renewable energy supplier aligned with global decarbonization goals. In transport and logistics, both states are leveraging their strategic locations along the Middle Corridor, which has witnessed significant growth in cargo volumes, reducing transit times and increasing trade efficiency. Investing in logistics optimization, digitalization, and infrastructure improvements will further enhance the corridor's competitiveness as a key trade route between China and Europe.

The financial services sector offers substantial potential for collaboration, particularly through the AIFC, which provides an advanced capital market, green finance solutions, and investment structuring mechanisms. With \$14.8 billion in investments already attracted through the AIFC, Kazakhstan and Azerbaijan can leverage their capabilities to mobilize cross-border investments and promote joint initiatives. In telecommunications, the planned fiber-optic communication line (FOCL) across the Caspian Sea will be a game-changer, enhancing digital connectivity, data security, and economic integration. With a 380 km cable and 400 terabits per second capacity, this project will significantly strengthen Kazakhstan and Azerbaijan's roles as regional digital hubs. Finally, agricultural trade remains a pillar of economic cooperation, with Kazakhstan exporting wheat and other grains to Azerbaijan, and Azerbaijan supplying fruits and vegetables to Kazakhstan. Storage, logistics, and food processing infrastructure investments will further streamline trade and contribute to regional food security.

Onglassov states that Economic cooperation between Kazakhstan and Azerbaijan is pivotal for both countries, contributing to their national growth and the stability and prosperity of the Silk Road region. Enhanced economic ties can position Kazakhstan and Azerbaijan as leading players in the region. Kazakhstan and Azerbaijan exhibit over-reliance on hydrocarbon energy exports, making their economies vulnerable to global commodity price volatility. In 2024, energy exports accounted for more than 50% of Kazakhstan's total exports and over 85% of Azerbaijan's exports. Kazakhstan and Azerbaijan have experienced consistent growth in their bilateral trade, with total trade reaching \$533.4 million in 2024.⁵ Kazakhstan ranks as Azerbaijan's third-largest trading partner among the CIS countries.⁶ In 2024, Kazakhstan mainly exported non-ferrous metals, crude oil, petroleum products, and grain to Azerbaijan, while Azerbaijan supplied tubes, aluminum bars, and agricultural and food products to Kazakhstan. In 2023, the two countries set an ambitious goal to boost mutual trade to \$1 billion in 2024.⁷ However, this target was not achieved. Bilateral trade turnover between Kazakhstan and Azerbaijan reached approximately \$533 million, which still represents a marked increase compared to the previous year. Substantial opportunities remain untapped, as current trade volumes represent only a small portion of their economic potential. Since 2005, gross FDI from Azerbaijan to Kazakhstan was \$410 million; from Kazakhstan to Azerbaijan, the figure was \$149.7

million.⁸ To date, over 1,700 companies with participation from Azerbaijani capital operate in Kazakhstan. Also, six companies with Azerbaijani capital are registered at the AIFC, mainly in information technology and transport and logistics.

Only a small amount of goods is transported in containers, which discourages the use of intermodal transport. However, analyzing the growth of transport in containers, over the past five years, it can be seen that it has increased by 29 times. In Kazakhstan's general commodity trade the export of raw materials dominates: mineral products (70.2%) as well as metals and metal products (18.9%). Products of animal and vegetable origin account for only 6.3%. Therefore nearly 90% of goods exported by rail are not suitable for container transport. The main import commodities are: machinery, equipment, vehicles (34.7%); mineral products (14.9%); products of the chemical industry (12.5%); metals and metal products (10.7%) and products of animal and vegetable origin (9.3%). The main share of import traffic from European countries was by foreign carriers from Belarus, Ukraine, the Russian Federation and the Baltic countries. In Kazakhstan there are more than 400 companies that work in international road transport. But Kazakhstan carriers are being forced out of the international market for transport services by the inadequate technical condition of their vehicles, as well as due to the creation of artificial barriers to Kazakhstan's carriers in other States. Measures taken to increase the competitiveness of domestic carriers will lead to an increase in the share of Kazakhstan carriers in the international freight market by 2020 to 50%. One of the important aspects of the increase in the share of domestic carriers in the market for international road transport services is the development of the market for forwarding services. In the future, it will be necessary to take measures to prevent the decline of domestic carriers' share in international cargo transport as well as the reduction of quotas to/from third countries. This will allow Kazakhstan carriers to take a dominant position when shipping to/from the countries of Central Asia.

To address these important issues, it is necessary to increase the number of vehicles that meet international standards. Along with problems of a technical nature, transit through Kazakhstan is faced with challenges of an institutional nature related to unwarranted delays and procedural complexities at customs and border controls. This is something that can be addressed by Kazakhstan. In recent years, China's economic growth has shifted from its eastern provinces to the western and central provinces, which are well positioned for rail transport across Kazakhstan. In accordance with the development programme "Western China Development Planning 2011-2015" for the development of the western and central regions of China it was planned to invest up to US\$ 1 trillion. The accelerated development of the western provinces of China will contribute to an increase in freight traffic through Kazakhstan. The increase in transit flows and increased demand for high-speed container trains has resulted in the need for simplification of customs control and non-tariff regulations. Customs clearance on the borders of Kazakhstan has the following advantages:

In the conditions of intense international competition, relevant state bodies need to develop flexible transit tariff policies that incentivise the movement of transit cargo through Kazakhstan rather than through neighbouring countries. With the expansion of regional trade and the creation of attractive conditions for transit business, Kazakhstan should expect the arrival of foreign providers of logistics services. National rules for freight transport in Kazakhstan need to be closer aligned to international standards in order to attract interested partners to take advantage of transit through Kazakhstan. To promote the development of international road transport in the customs union of the Russian Federation, Belarus and Kazakhstan, the permit system was cancelled for all types of transport in 2015. This concerns bilateral transport performed in transit through the territory of the three States by carriers resident in the Union, as well as transport to/from third countries, but within the territory of the EEU. For example, a Kazakhstan carrier can carry goods from Belarus to the Russian Federation without a permit. Within the three States no permit is required for transport. For third countries a phased liberalization has been agreed. Quotas for transport to and from third countries are

still in operation. Fixed stages have been set out for the introduction of cabotage in the road transport of goods: x The first stage ended on 31 December 2017. In this stage, carriers registered in the Russian Federation, Belarus, Armenia and Kyrgyzstan, after completion of international carriage of goods by road from a non-member State of the Union, had the right to perform one cabotage operation within the territory of the Union upon return to the State of registration. In this stage, when carrying out cabotage, unloading had to be carried out within three calendar days of the completion of international transport in the member State in which the cabotage was carried out. x In the second stage (1 January 2018 – 31 December 2019), EEU carriers have the same rights as in the first stage. However, when carrying out cabotage in road transport of goods, unloading must be completed not within three calendar days, as in the first stage, but within seven calendar days after the completion of international transport in the member State in which the cabotage is carried out. x In stage three (1 January 2020 – 31 December 2024), Armenia, Belarus, Kyrgyzstan and the Russian Federation grant the right to carriers registered in the territory of the EEU, after completing the international carriage of goods by road in the territory of another member State, to perform one cabotage operation in road transport of goods between points located in other States of the EEU, upon return to the State of registration. In this stage, when carrying out cabotage, unloading must be completed within seven calendar days of the completion of international transport in the member State in which cabotage is carried out.

There are two main reasons for such a sharp difference in shipping costs between the two routes: (i) Since the Caspian Sea has no access to the international ocean, shipments between ports are considered short sea shipping, but Black Sea shipments are not; (ii) The low cargo volume leads to high shipping tariffs. Naturally, if the tariffs are also high, the route is not attractive. Studies show that as a result of the Azerbaijan Caspian Shipping Company reaching a volume of 300-400 TEU per shipment, for example, it is possible to reduce the shipping cost of a 20-foot container on the Baku-Aktau route by 40%.

Conclusion

Azerbaijan, as one of the transit countries located on the "Silk Road", has done a lot of work to increase its logistics capabilities over the past 20 years and has become a participant in various international and regional projects. The government has mobilized a fairly large amount of resources for the construction of transport and logistics infrastructure. Moreover, all this happened at a time when alternative routes competing with each other were being formed. In this regard, it is very important to evaluate the opportunities opened up for Azerbaijan by the East-West corridor within the framework of the "Silk Road" project to this stage, the work done in this area, the successes achieved, and the problems awaiting solution. The main results revealed by the conducted research in this direction are as follows:

The East-West corridor, which Azerbaijan is located on, is shorter than other alternative corridors, but it faces serious competition. Although the brevity seems to be a factor that increases the attractiveness of this route, it faces serious competition from the new Eurasian line, which starts from Poland and extends to Xi'an, China. Because the Poland-China route does not have a sea crossing and is a direct rail-way. It should be noted that the width of the train routes to the Euroterminal located in Slavkov, Poland is 1520 mm and they accept cargo from China via the Kazakhstan-Russia-Belarus or the shorter Kazakhstan-Russia-Ukraine route. Slavkov is already becoming one of the logistics centers for cargo between Europe and China. The cargo arriving here is easily transferred to trucks or other railway routes and delivered to European countries. However, the East-West corridor provides for the transportation of cargo based on transitions on various types of transport (railway-sea, sea-railway). In addition, due to weather conditions, approximately 90 days a year, during the cold months, ships in the Caspian Sea experience delays in delivering cargo.

There are also technical factors that affect the competitive advantage of both routes. Thus, the standard gauge for European and Chinese railways is 1435 mm, while the gauge for railways in the former USSR countries is 1520 mm. Therefore, the transition from standard gauge to wide gauge is carried out at the Kazakhstan-China and Türkiye-Georgia borders. Thus, during deliveries between the cities of Xi'an and Slavkov, railways are changed only once at the China-Kazakhstan border.

- The East-West corridor provides transportation at a higher cost than the New Eurasian route. Thus, the cost of delivering a 40-foot container from the Xi'an region of China to the Polish city of Slavkov along the New Eurasian Corridor varies between 3600-4200 US dollars, and the cost of delivering a 40-foot container along the East-West Corridor varies between 5000-5500 US dollars.
- Saving 1 day in trade between countries located on the Silk Road corridor means an average increase in exports of 5.2 percent. In particular, the short-term delivery of goods during trade is especially important for perishable products.
- Despite the fact that Kazakhstan, Georgia and Türkiye, which are located on the East-West Corridor, have trade and customs agreements with the European Union and China, Azerbaijan does not currently have any effective agreements with the mentioned institutions and countries. However, the existence of inter-country trade agreements, the reduction of the time spent at border crossings and the country's improved transport infrastructure mean that the time spent during trade is further reduced and access to new markets is increased.
- Although the Roadmap for the development of logistics adopted in 2016 aims to rapidly increase Azerbaijan's capabilities as a transit country, the current results are unsatisfactory. Thus, there was a 14.9 percent decrease in transit traffic on the Europe-Caucasus-Asia corridor in 2019 compared to 2015.
- The capabilities of the new seaport have not yet been fully utilized. According to 2019 figures, Baku International Trade Port used 27% of its existing capacity for container handling and 35.02% for total handling.
- For this reason, although Azerbaijan's position in the World Bank's Doing Business report on foreign trade indicators has improved significantly in recent years, it still lags far behind the corresponding indicators of developed countries. According to the most recently published report, Azerbaijan ranked 83rd among 190 countries on the "trading across borders" indicator. However, compared to developed countries, the time spent on border crossing in Azerbaijan is at least 30% higher for exports and 3 times higher for imports, the time spent on documentation is almost 15 times higher for exports and 10 times higher for imports, the costs spent on border crossing are almost 50% higher for exports and almost 2 times higher for imports, and the costs spent on documentation are 8 times higher for exports and 9 times higher for imports.

In view of the above-mentioned problems, it is considered appropriate to take the following steps to increase the attractiveness of Azerbaijan as a transit country within the framework of the "Silk Road" route:

- There is a need to increase the work and initiatives towards signing free trade agreements with the European Union and China in Azerbaijan;
- It is necessary to apply the port community system, widely used in world practice, for the timely delivery of cargo;
- The participation of private logistics companies in transport and logistics services should be increased, the quality of their service level should be improved, and necessary incentive mechanisms should be developed to reduce their costs;
- In order to increase the competitiveness of logistics companies and organize their active participation in the value chain, there is a need to take incentive measures in the areas of information management technologies, cloud, creation of cargo track-ing systems, increasing the professionalism of personnel, and renewal of the transport fleet;

- It is more appropriate to transfer the logistics services created within the Azerbaijan Caspian Shipping Company, as well as the railway transportation services created within the Azerbaijan Railways CJSC, to private companies, as is the case in world practice;
- The Azerbaijani government should participate in the World Bank's Logistics Performance Index (LPI) to periodically assess the country's logistics potential, identify problems in this area, and provide international benchmarking;
- The growth of Azerbaijan's logistics potential also depends on its rapid integration into the world economy, as well as the ability to attract foreign direct investment, for which membership in the World Trade Organization should be completed;
- Countries located on the East-West route need to activate all possible mechanisms to ensure further acceleration of customs procedures related to transit cargo.

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The Role of Artificial Intelligence in Foreign Language Learning: A Comparative Analysis of Ai-Based Learning Support

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Abstract. This study examines the role of artificial intelligence (AI) in foreign language learning, focusing on widely used AI-based tools such as ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate, and Memrise. The primary objective of the research is to explore the contribution of these technologies to the development of learners' linguistic competencies, including reading, writing, speaking, and vocabulary acquisition, and to evaluate their pedagogical implications within language education contexts. The study employs a qualitative comparative and exploratory research design. Data were collected through document analysis and interaction with selected AI-based language learning tools using standardized language learning tasks. The outputs generated by each platform were systematically analyzed based on criteria such as accuracy, feedback quality, adaptability, and instructional value. The results reveal that AI-based tools enhance language learning by offering immediate feedback, individualized learning support, and expanded opportunities for autonomous practice. At the same time, the findings indicate that excessive dependence on AI technologies may reduce learners' cognitive engagement and limit opportunities for authentic communicative interaction. The study highlights that AI-based language learning tools should be considered as complementary resources in foreign language education. Their effective integration, alongside traditional instructional methods, can contribute to more efficient and personalized language learning outcomes.

Keywords: artificial intelligence, language learning, CHATGPT, personalized study programs, translation tools, academic results

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Süni intellektin xarici dil öyrənməsində rolu: süni intellekt əsaslı öyrənmə dəstəyinin müqayisəli təhlili

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Xülasə. Bu tədqiqat xarici dil öyrənilməsində süni intellektin (Sİ) rolunu araşdırır və ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate və Memrise kimi geniş istifadə olunan süni intellekt əsaslı alətlərə xüsusi diqqət yetirir. Tədqiqatın əsas məqsədi bu texnologiyaların oxu, yazı,

danışiq və söz ehtiyatının mənimsənilməsi də daxil olmaqla, öyrənənlərin dil kompetensiyalarının inkişafına verdiyi töhfəni araşdırmaq və onların dil tədrisi kontekstində pedaqoji əhəmiyyətini qiymətləndirməkdir. Tədqiqatda keyfiyyət yönümlü müqayisəli və kəşfiyyat xarakterli tədqiqat dizaynından istifadə edilmişdir. Məlumatlar sənədlərin təhlili və standartlaşdırılmış dil öyrənmə tapşırıqlarından istifadə etməklə seçilmiş süni intellekt əsaslı dil öyrənmə alətləri ilə qarşılıqlı əlaqə vasitəsilə toplanmışdır. Hər bir platformanın təqdim etdiyi nəticələr dəqiqlik, əks-əlaqənin keyfiyyəti, uyğunlaşma qabiliyyəti və tədris əhəmiyyəti kimi meyarlar əsasında sistemli şəkildə təhlil edilmişdir. Nəticələr göstərir ki, süni intellekt əsaslı alətlər operativ əks-əlaqə, fərdiləşdirilmiş öyrənmə dəstəyi və müstəqil məşq üçün geniş imkanlar təqdim etməklə dil öyrənmə prosesinin səmərəliliyini artırır. Bununla yanaşı, əldə edilən nəticələr süni intellekt texnologiyalarından həddindən artıq asılılığın öyrənənlərin idrak fəallığını azalda və real kommunikativ ünsiyyət imkanlarını məhdudlaşdırma biləcəyini göstərir. Tədqiqat vurğulayır ki, süni intellekt əsaslı dil öyrənmə alətləri xarici dil tədrisində tamamlayıcı resurslar kimi nəzərdən keçirilməlidir. Onların ənənəvi tədris metodları ilə birlikdə səmərəli şəkildə integrasiyası daha effektiv və fərdiləşdirilmiş dil öyrənmə nəticələrinin əldə edilməsinə töhfə verə bilər.

Açar sözlər: *süni intellekt, dil öyrənmə, ChatGPT, fərdiləşdirilmiş tədris proqramları, tərcümə alətləri, akademik nəticələr*

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Introduction

In recent years, artificial intelligence (AI) has become a widely discussed concept due to significant advancements in technology and its increasing integration into various aspects of society. Over time, technological innovations have been developed to reduce human effort, minimize stress, and improve efficiency in daily life. Today, AI is applied across multiple domains, including business, healthcare, finance, and education. Despite the growing number of studies on artificial intelligence in education, most existing research has primarily focused on general AI applications or single-tool analyses, particularly ChatGPT. There is still limited empirical research that provides a comparative evaluation of multiple AI-based language learning tools within a single study.

In addition, previous studies tend to emphasize the positive effects of AI, such as personalization and feedback, while paying less attention to the combined pedagogical differences between tools such as ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate, and Memrise. Moreover, there is a lack of qualitative analysis examining how these tools differ in supporting specific language skills (speaking, writing, vocabulary, and pronunciation) under equal learning conditions. Previous studies have widely explored the integration of artificial intelligence in education, highlighting its potential to enhance personalized learning, feedback systems, and learner engagement (Chen et al., 2020; Holmes et al., 2019). In language learning contexts, AI-based tools have been shown to support vocabulary acquisition, grammar development, and communicative competence (Godwin-Jones, 2019; Li, 2021).

Research on conversational agents and chatbots also indicates their usefulness in providing interactive language practice and reducing learner anxiety (Karsenti, 2019). However, scholars also emphasize limitations such as lack of emotional intelligence and insufficient understanding of cultural context.

In the field of education, AI plays an increasingly important role by transforming traditional learning processes. The integration of distance learning, online courses, personalized instruction, interactive and visual materials, enhanced teacher–student interaction, and data-driven analysis has made education more accessible, flexible, and effective. This shift emphasizes learner-centered approaches, diversification of educational resources, and stronger instructional support from educators. In foreign language learning, AI enables personalized instruction by adapting to learners' individual characteristics such as learning pace, motivation, and preferred learning styles, which are often difficult to address in traditional classrooms. Foreign language acquisition is a complex process that requires the development of four key skills: speaking, listening, reading, and writing.

AI-based systems support this process by analyzing learner performance and adjusting content accordingly. As noted by Chen et al. (2020), AI enhances learning efficiency through intelligent feedback mechanisms, real-time error correction, and the provision of personalized educational materials.

Purpose and Questions of the Research

The primary purpose of this study is to investigate the role and effectiveness of artificial intelligence (AI) tools in the foreign language learning process. In particular, the study focuses on examining how AI-based applications, especially ChatGPT, contribute to the development of language skills such as reading, writing, listening, and speaking. The research also aims to evaluate both the positive and negative impacts of AI on learners' cognitive abilities, academic performance, and overall language acquisition process.

In the context of rapidly evolving educational technologies, it is essential to understand how AI-based language learning tools can be integrated into language teaching in a pedagogically sound manner. Therefore, this study seeks to explore not only the benefits of AI-supported learning environments but also the potential risks associated with overreliance on such technologies. The sub-questions are:

1. How can they benefit from the Artificial Intelligence Tool ChatGPT to improve their English language skills?
2. How can Artificial Intelligence Tool ChatGPT provide individualized learning experiences to students?

Importance of Research

AI provides learners many opportunities such as pronunciation studies, speech patterns, grammar rules, personalized study programs. For this reason, ChatGPT has gained increasing popularity and is widely utilized by students in language learning contexts. However, the effective use of artificial intelligence tools in foreign language learning requires appropriate pedagogical guidance. In this regard, the present study aims to contribute to a better understanding of how AI-based tools can be used more effectively in educational settings. It is therefore important for both researchers and learners to develop a more informed and structured approach to the use of ChatGPT in language learning processes.

Methods/Model of the Research

The study does not involve a large-scale experimental sample; instead, it is based on a pilot and observational approach. The analysis focuses on interactions between learners and artificial intelligence tools, particularly ChatGPT, within a simulated language learning context. Therefore, no specific number of participants was included, as the study primarily examines AI-generated responses and learner-AI interaction patterns.

Document analysis involves the systematic review and interpretation of written, visual, and digital materials related to the research topic. These materials include academic publications, reports, and AI-generated content. Observation, on the other hand, allows the researcher to analyze how AI-based

language learning toolss function in practice and how learners interact with them (Gasimova, 2015, p 13).

The study utilizes several widely used AI-based language learning tools as research materials. These include Duolingo, ELSA Speak, Google Translate, Grammarly, and Memrise. These application systems were selected due to their widespread use in foreign language education and their integration of artificial intelligence technologies. This methodological approach enables the study to provide a comprehensive understanding of the impact of AI on language learning without relying on numerical data, thus emphasizing depth over breadth.

Data Collection Tool and Data Analysis

In this study, a comparative analysis was conducted by providing identical language learning inputs to different AI-based application systems, including Duolingo, ELSA Speak, Google Translate, Grammarly, and Memrise. Each application system was given the same set of tasks, including vocabulary learning, grammar correction, translation, writing support, and language practice activities. The outputs generated by each tool were recorded and systematically compared.

The comparison focused on several criteria, including accuracy of responses, quality of feedback, level of personalization, and overall pedagogical effectiveness. This approach allowed the researcher to evaluate the strengths and limitations of each AI-based language learning tools under equal conditions, ensuring a fair and consistent analysis framework. The researchers provided ChatGPT with various language learning tasks, including vocabulary learning, dialogue practice, and grammar explanation requests. The generated responses were recorded and analyzed for accuracy, relevance, and pedagogical value. The data for this study were collected through document analysis and interaction with AI-based language learning tools, particularly ChatGPT. Various prompts and questions related to foreign language learning were input into the system, and the responses generated by the AI were recorded and analyzed.

Concept of Artificial Intelligence and Foreign Language Education

Artificial intelligence can be used in many ways in learning a foreign language. These include developing language skills such as text analysis, word studies, pronunciation studies, translation, and reading and writing. With the correct guidance of students, artificial intelligence tools can provide a personalized environment (Guliyeva, 2026). When we focus on artificial intelligence, it is seen that individuals can benefit from artificial intelligence in many ways. Nowadays, many individuals spend more time in the virtual environment than in the classroom environment. Artificial intelligence tools provide users with great opportunities in learning a foreign language through training. Students will be able to use a foreign language with proper training for its use in foreign language learning and their learning can be accelerated. Individualized learning, regardless of time and classroom environment providing an environment can be considered one of the biggest advantages of artificial intelligence.

Effects of AI on Language Education

When the potential effects of AI on language education are examined, it is seen that topics such as personalized learning, instant feedback, removal of language barriers and distance education come to the fore. According to Johnson the prominent effects of AI are listed below:

Personalized learning experience: AI can offer personalized learning plans by analyzing learners' learning habits, speeds, strengths and weaknesses. Content and activities adapted to each student's needs can provide more effective and faster learning.

Student Analytics and Improvement: By constantly monitoring student progress, AI can determine which topics need more practice. Based on this data, educational materials and learning methods can be continuously improved.

Instant Feedback and Accuracy: By providing instant feedback to learners, AI can quickly correct their mistakes. It can also detect errors in pronunciation and grammar precisely. In this way, learners can progress faster.

Unlimited Practice Opportunity: AI-supported language learning applications can offer learners unlimited practice opportunities. While practicing speaking or completing written assignments, learners can access the guidance of the AI teacher without interruption.

Translation and Removing Language Barriers: AI-supported translation tools can facilitate communication between people speaking different languages (Jordan, 2015). It can also provide learners with language barriers with tools that make their learning more understandable and accessible.

Understanding Cultural Differences: AI can help learners understand the language and expressions of different cultures. In this way, students' cultural understanding and communication skills can be improved.

Innovative Teaching Approaches: AI can help develop innovative teaching approaches such as gamification, virtual reality and augmented reality. It can provide learners with more interactive and engaging learning experiences

Sample AI Supported Language Programs There are various AI-supported language teaching programs that can be used in language teaching. Some examples are listed below:

Duolingo: one of the pioneers of language learning applications, offers students the opportunity to develop four basic language skills (speaking, listening, writing, reading) with an AI-based approach. It stands out with instant feedback and personalized learning plans.

Rosetta Stone: Offers language learning packages integrated with AI using natural language learning methods. It improves students' ability to practice speaking by providing them with the opportunity to learn through real-life scenarios.

Memrise: It is a application system that supports learning words and expressions using AI and memory techniques. It offers students the opportunity to expand their vocabulary and learn quickly.

Babbel: It is a language learning application system that focuses on improving speaking skills. AI offers students the opportunity to practice speaking and improve their pronunciation through real-life scenarios.

Google Translate: which is very popular in translation, offers language learners the opportunity to learn the meanings of words and expressions in addition to translating text and speech.

Elsa Speak: Focusing specifically on improving English pronunciation, ELSA Speak provides feedback to students with AI to detect and correct pronunciation errors.

Lingvist: Aiming to accelerate the language learning process, Lingvist creates personal learning plans with AI and provides students with intensive vocabulary practice.

Talking Pal: This program is an AI-powered language learning tool designed to improve speaking skills through interactive conversations. It allows learners to practice real-life dialogues in different languages anytime and anywhere. The application system provides instant feedback on pronunciation, grammar, and fluency, helping users build confidence in communication. By simulating natural conversations, Talking Pal creates a supportive, low-anxiety environment for language practice and skill development.

Chatbots have great potential in language learning. Providing students with the opportunity to practice the target language promises a learning process in which are free from worries about making mistakes and have the opportunity to practice sufficiently (Kovsar, 2025). Chatbots, compatible with the concept of education anywhere and anytime, are considered as a tool that supports language teaching with the opportunity to suggest materials, correct grammatical mistakes of the student with feedback, improve their vocabulary and make evaluations. One of the problems encountered is that chatbots cannot establish sufficient natural dialogue. Many chatbots' responses can be redundant, predictable, and impersonal (Karsenti, 2019). A Despite the advancement of artificial intelligence, it is difficult for software developers to design intelligent dialogue in chatbots (Ismayilli, 2025, p. 5). For example, if students mistype their input, in this situation may receive irrelevant responses from the chatbot. It is difficult for chatbots to imitate one-on-one conversations between people. Additionally, in chatbots, students' interaction can be limited to a predetermined knowledge base. This situation prevents students from discussing different topics as they wish with chat robots and may cause students to offer very superficial and limited conversation areas. This situation in chat robots can easily cause students to lose interest.

Artificial Intelligence Tool- ChatGPT is an artificial intelligence tool capable of generating coherent and informative responses in natural language. It supports users in problem-solving, information retrieval, and language learning activities. The system can be applied to various tasks, including translation, text generation, and the automation of academic writing such as essays and assignments.

In addition, ChatGPT can process both written and spoken instructions and provide personalized outputs based on user needs and preferences. Continuous development of the model by researchers contributes to the expansion of its functionalities and improvement of its performance in different domains.

Achievements for Individualized Learning Experience and Artificial Intelligence Supported Learning
The results obtained from the analysis and entered commands in the field of English as a foreign language in ChatGPT and other AI-based language learning tools, provide an unique learning environment for students with rapid evaluation and different content can offer. These can be listed as follows:

Instant and Fast Feedback: Regardless of the environment (classroom, home environment) students are in, the artificial intelligence-supported tool You can get instant feedback regarding your ChatGPT needs at any time (Ali, 2025). This tool, which can be accessed free of charge via both smartphones can provide fast and accurate feedback.

Guiding: You can provide students with the tasks undertaken by teachers and guide them can provide support. In this way, students can determine their own strengths and weaknesses and develop their own learning paths.

Individual or Group Work: Students can individually evaluate what can be have obtained from ChatGPT tools, organizing group activities and support individual activities by sharing experiences with other friends;

Talk with ChatGPT:

I want to learn vocabulary through studying. Do you know 10 important words and meanings?
Naturally! Here are 10 important vocabulary words and their meanings to help you as you study could be helpful:

Research (noun): The systematic search for information, data or facts for a specific task or project.

Bibliography (noun): A list of sources or references contained in a scientific text or a scientific work were used to to make the origin of information traceable.

Method (noun): A systematic approach or procedure carried out in a scientific investigation, an experiment or a study is used to Collect, analyze or interpret data.

Analysis (noun): The process of examining data, information or materials to identify patterns, trends or insights.

Thesis (noun): A claim or statement made in an academic paper or an argument is presented and must be supported by evidence or arguments.

Plagiarize (verb): The unauthorized copying or adoption of texts, ideas or Other people's work and passing it off as your own without proper attribution close.

Citation (noun): A written or oral statement of the source from which information comes or quotations were taken to ensure the credibility and comprehensibility of a work ensure.

Dissertation (noun): A detailed written work, usually as a Thesis for a higher academic degree, such as a doctorate, is written. These vocabulary should be useful for your studies and academic work.

Good luck with your learning!

Talk with AI

Hello, how are you?

Hello! I'm fine thank you. I'm just a computer program, so I have no feelings, but I'm here to help you. How can I help you today?

I want to learn English. Can we talk?

Naturally! I would be happy to help you learn German. What would you like to talk about or what questions do you have? You are welcome to choose a topic that interests you, or I can teach you basic phrases and vocabulary if you prefer.

Travel in England. What are the important sights in England?

England is a country with a rich history and many interesting ones

Sightseeing attractions. Here are some of the top attractions in England:

1. London

The British Museum: Home to priceless artifacts like the Rosetta Stone and Egyptian mummies.

Tower of London: A historical fortress that houses the Crown Jewels.

Buckingham Palace: The official residence of the British monarch, complete with the Changing of the Guard ceremony.

Big Ben and the Houses of Parliament: Iconic landmarks along the River Thames.

The London Eye: A giant Ferris wheel offering stunning views of the city.

2. Stonehenge (Wiltshire)

One of the most famous prehistoric monuments in the world, shrouded in mystery about its purpose and construction.

3. The Lake District (Cumbria)

A stunning national park, known for its mountains, lakes, and picturesque villages. It's ideal for hiking, boating, and enjoying nature.

4. Oxford

Home to the University of Oxford, one of the oldest and most prestigious universities in the world. You can explore historic colleges, libraries, and museums.

In this example, the command to artificial intelligence is to choose a topic and chat about that topic. The conversation took place in written form. The free version of the artificial intelligence tool was used during the conversation (Ismayilli, 2025, p. 8) There is also a voice chat option in the paid version. Artificial intelligence can be used to improve speaking skills, the audio version can be used using the paid version, and listening skills can also be supported in this way.

Artificial Intelligence Supported Language Teaching

I have students who have level A1 in English I want face-to-face lessons today give. How can I teach this? Approach. Here are some steps and ideas to help you with in-person teaching Students with A1 English skills can help:

1. Greeting and introduction: Start the lesson with a friendly one

Welcome and have students introduce themselves. This promotes communication in English from the beginning.

2. Review of previous:

If this is not the first lesson, start you with a brief review of the previous material to ensure that the students retained what they learned.

3. Thematic introduction: Choose a specific topic for the lesson, e.g.

“Family”, “Food” or “Travel”. Introduce the topic to the students and tell me briefly about it.

4. Introduce vocabulary and expressions: Present new vocabulary and expressions, that fit the chosen topic. Use pictures, maps and other visuals.

The issue of language learning with artificial intelligence can be exemplified in different ways. Apart from the examples given, artificial intelligence can be used in language learning in many different ways. Language learning with artificial intelligence is an effective tool in many aspects such as speaking, writing, listening and grammar. The individual can improve himself individually and receive feedback on his mistakes without the need for a trainer. In addition, it can learn languages only with the support of artificial intelligence without using resources. Artificial intelligence can be used for individual language learning, as well as a support tool for language instructors.

In addition to its rising importance and potential in the field of language education, AI technology also brings with it some important limitations. AI-based solutions run the risk of not fully grasping the complexity and nuances of language. Especially jokes, word games, and complex structures of the language may not be interpreted correctly by AI, which may lead to erroneous results. Additionally, it may be difficult for AI to fully make sense of human emotional and unique expressions. However, the unique talents and contributions of teachers should not be forgotten. Skills such as establishing emotional bonds with students, motivating them, understanding their needs and developing individual learning approaches are the basic elements of teachers that enrich the learning experience of their students. The human factor is indispensable for understanding students' unique

needs, providing them with tailored guidance, and supporting them throughout the educational process.

Limitations of AI And The Human Factor Apart from many advantages, artificial intelligence also has disadvantages. Since the individual has a tool that responds quickly, he/she may not force himself/herself to think and may ask for answers from artificial intelligence. This situation can push individuals away from thinking and into laziness. In addition, when students are asked to write text in English, they can have it written to artificial intelligence, which may make it difficult for students to learn by causing them to access ready-made and fast information (Chen 2020, p. 34). In addition, it is very difficult to control since there is no monitoring mechanism.

AI-based solutions run the risk of not fully grasping the complexity and nuances of language. Especially jokes, word games, and complex structures of the language may not be interpreted correctly by the AI, which may lead to erroneous results. Additionally, it may be difficult for AI to fully make sense of human emotional and unique expressions. However, the unique talents and contributions of teachers should not be forgotten. Skills such as establishing emotional bonds with students, motivating them, understanding their needs and developing individual learning approaches are the basic elements of teachers that enrich the learning experience of their students. The human factor is indispensable for understanding students' unique needs, providing them with specific guidance and supporting them throughout the educational process.

Table 1
Disadvantages

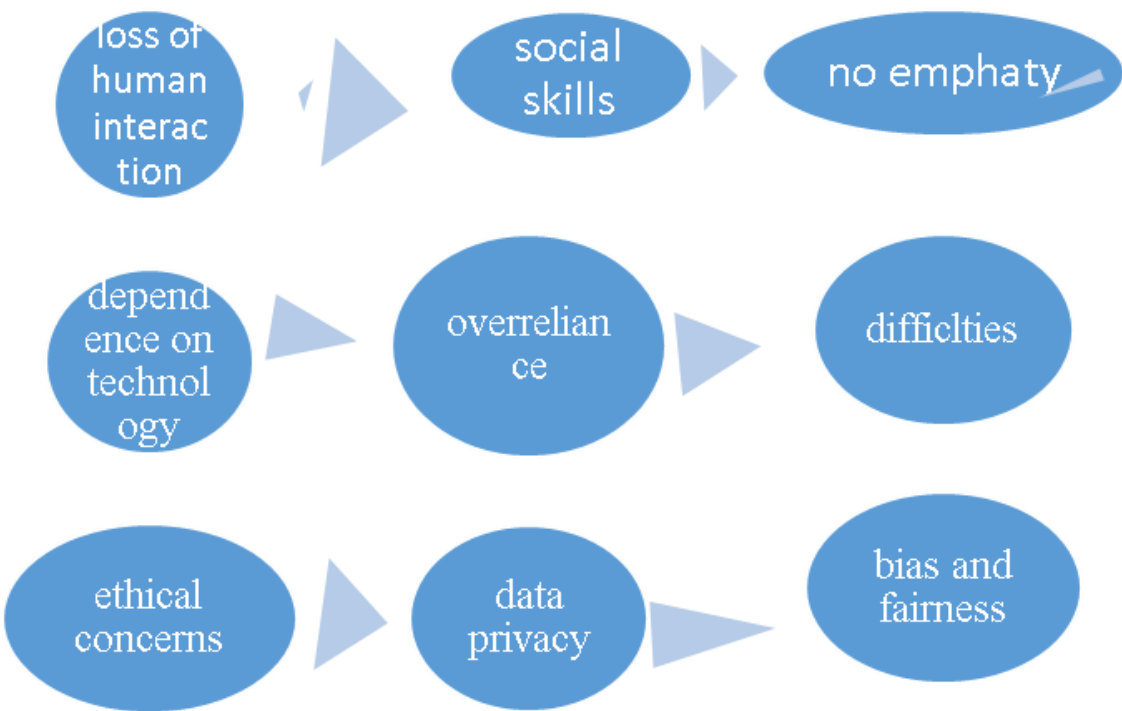
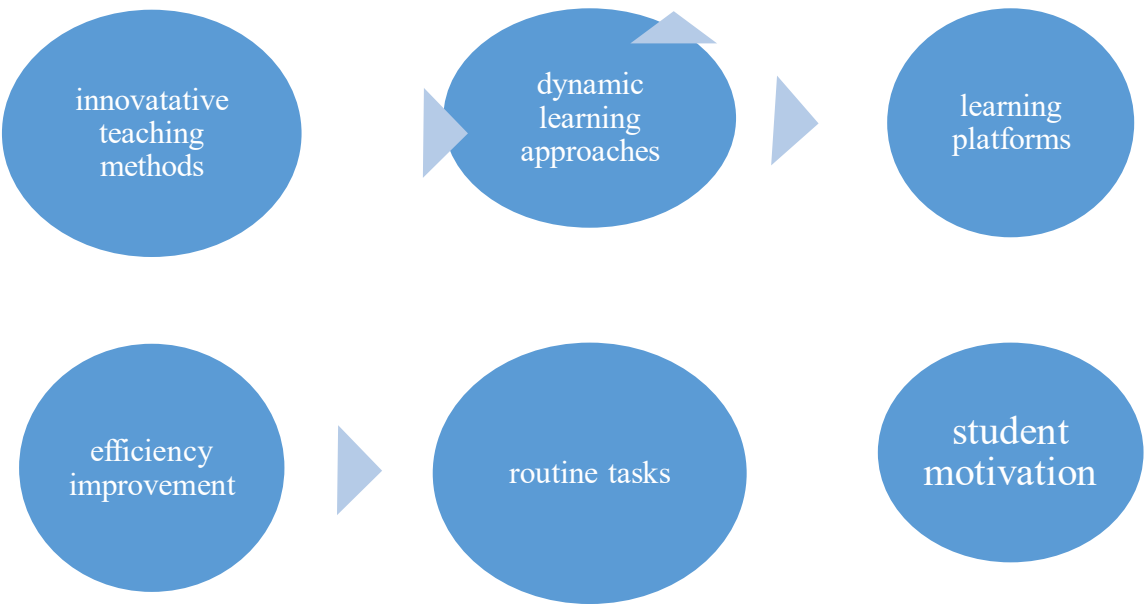


Table 2
Advantages



AI may have limitations in fully grasping the complexity of language and its emotional expressions. Additionally, it is not possible to completely replace teachers' important abilities, such as emotional bonding, motivating, and sensitivity to student needs, with AI. As a result, an ideal language education approach should aim to provide learners with a personalized, effective and enriched learning experience by using the strengths of AI technology. The unique contributions and emotional bonds that teachers give to their students should not be forgotten. An ideal balance should seek to best optimize the learning experience by bringing together technology and the human factor. In the future, the opportunities provided by AI and teachers' use of them in the most effective way will make language education more effective, efficient and satisfying. Chatbots have potential as a teaching and learning tool in distance and online education.

The ability of chat robots to provide original answers thanks to their natural language processing software has paved the way for their use especially in foreign language education. Chat robots offer students learning a foreign language the opportunity to practice the target language whenever and wherever they want. Artificial dialogue systems offer an alternative way to learn through interaction, students can chat in their target language whenever they want without the need for a teacher. When designing chat robots, they should be designed to suit the student, taking into account language proficiency, age, learning style and individual differences.

The findings of this study, based on a comparative qualitative analysis of several AI-based language learning tools, including ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate, and Memrise, demonstrate that artificial intelligence plays a significant role in supporting foreign language learning. The results indicate that these tools contribute to improved learning efficiency through personalized instruction, instant feedback, and increased opportunities for independent practice.

The analysis shows that different AI tools serve distinct pedagogical functions. ChatGPT and Grammarly are particularly effective in supporting writing development through grammatical correction, feedback generation, and text improvement. Duolingo and Memrise primarily enhance

vocabulary acquisition through structured repetition and gamified learning environments, while ELSA Speak provides focused support for pronunciation accuracy through real-time feedback mechanisms. Google Translate contributes to comprehension and translation tasks; however, it demonstrates limitations in handling contextual, idiomatic, and culturally embedded expressions.

Expected vs. Actual Findings

Before conducting the analysis, it was expected that AI tools would mainly differ in terms of interface and usability rather than pedagogical effectiveness. However, the findings revealed that the differences are not only technical but also instructional. Specifically, tools vary significantly in how they support specific language skills. For instance, ELSA Speak showed stronger specialization in pronunciation training than expected, while Grammarly demonstrated a broader pedagogical role in writing development than initially assumed.

Key Contribution of the Study

The main contribution of this research lies in its comparative qualitative framework, which systematically evaluates multiple AI-based language learning tools under equal task conditions. Unlike previous studies that focus on single-tool analysis (e.g., ChatGPT-only studies), this research provides an integrated perspective on how different AI systems complement each other in foreign language learning. Additionally, the study contributes to the field by categorizing AI tools according to skill-specific functions (writing, vocabulary, pronunciation, and translation), offering a clearer pedagogical classification model.

Implications

The findings suggest that AI technologies support a learner-centered educational approach by enabling individualized learning paths, self-paced study, and immediate corrective feedback. However, the study also highlights that overreliance on AI tools may reduce learners' critical thinking, creativity, and active language production. Therefore, AI should be integrated as a complementary tool rather than a replacement for traditional instruction.

Limitations and Future Research

This study is limited by its qualitative design and lack of real participant-based empirical data. Future research should include experimental or mixed-method designs with learner groups to measure the direct impact of AI tools on language proficiency development. In addition, longitudinal studies are recommended to examine how continuous use of AI influences language retention, communicative competence, and learner autonomy over time. Further research may also explore affective factors such as learner motivation, anxiety, and engagement when interacting with AI-based systems in foreign language education.

Results

The findings of this study indicate that artificial intelligence tools, particularly ChatGPT, significantly support foreign language learning. AI provides instant feedback, allowing learners to quickly identify and correct their mistakes, which improves grammar and vocabulary skills. Another key result is the promotion of personalized learning. AI-generated content can be adapted to learners' levels, needs, and interests, increasing motivation and engagement. Additionally, AI-based language learning tools offer unlimited practice opportunities, especially in writing and speaking, creating a low-anxiety learning environment.

The results also show that AI contributes to the development of multiple language skills, including reading, writing, and speaking, while making learning more flexible and accessible. However, several negative effects were identified. Overreliance on AI may reduce independent thinking and cognitive effort, as learners tend to depend on ready-made answers. This can negatively impact academic performance and critical thinking skills, particularly among younger learners.

Furthermore, excessive use of AI may limit the development of communication and social skills, as learners have fewer opportunities for real-life interaction. The study also highlights some limitations of AI, including difficulties in understanding complex language structures and cultural nuances. This study also involved an analytical review of several widely used AI-based language learning tools, including Duolingo, ELSA Speak, Google Translate, Grammarly, and Memrise.

These application systems were examined in terms of their functionality, pedagogical value, and contribution to foreign language skill development. Duolingo and Memrise primarily focus on vocabulary acquisition and structured language practice through gamified learning techniques, which increase learner motivation and engagement. ELSA Speak specializes in pronunciation training by providing real-time feedback and phonetic correction, thereby supporting speaking skill development. Google Translate was analyzed as a translation and comprehension support tool, offering instant multilingual translation but showing limitations in handling contextual and idiomatic expressions. Grammarly was evaluated as a writing assistant that improves grammatical accuracy, sentence structure, and coherence in learner output. The comparative analysis of these tools indicates that AI-based applications contribute significantly to personalized and autonomous language learning. However, their effectiveness depends on balanced usage, as overreliance may reduce learners' independent cognitive and productive language skills.

Discussion

The findings of this study highlight both the advantages and limitations of artificial intelligence in foreign language learning across different AI-based tools, including ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate, and Memrise. The comparative analysis shows that these tools contribute significantly to language learning through instant feedback, personalized learning experiences, and increased practice opportunities.

Among the examined application systems, AI-powered systems such as ChatGPT and Grammarly demonstrated strong performance in providing detailed explanations, grammatical correction, and writing support, while Duolingo and Memrise were particularly effective in vocabulary acquisition through gamified learning techniques. ELSA Speak showed clear advantages in pronunciation training by offering real-time corrective feedback, whereas Google Translate was mainly useful for quick translation and basic comprehension, although it showed limitations in contextual accuracy. These findings are consistent with previous research emphasizing the role of AI in promoting learner autonomy and engagement.

The results also indicate that AI-based tools support a learner-centered approach by allowing students to practice language skills independently and at their own pace, which may enhance learning efficiency. However, the study also reveals that overreliance on AI-based language learning tools may negatively affect learners' critical thinking, creativity, and problem-solving skills. The ease of access to ready-made answers can lead to passive learning behavior and reduced cognitive effort. In addition, the findings suggest that excessive use of AI may limit opportunities for real-life communication practice, which is essential for developing social and interactive language skills. Since language learning is both a cognitive and social process, reduced human interaction may negatively influence communicative competence.

Furthermore, although AI-based language learning tools are highly effective in specific language tasks, their limitations in understanding cultural nuances, emotional expressions, and complex linguistic contexts remain evident. This indicates that AI cannot fully replace the role of teachers, who provide motivation, emotional support, and contextualized learning experiences.

In conclusion the study concludes that different AI-based language learning tools serve complementary roles in foreign language learning. Therefore, effective language education should

integrate multiple AI technologies in a balanced way, alongside traditional teaching methods, to maximize learning outcomes.

Conclusion

The findings of this study, based on a qualitative comparative analysis of several AI-based language learning tools, including ChatGPT, Duolingo, Grammarly, ELSA Speak, Google Translate, and Memrise, indicate that artificial intelligence contributes to foreign language learning in different but complementary ways.

The analysis of ChatGPT demonstrates that it is particularly effective in supporting writing skills by providing detailed explanations, essay structuring, and grammar clarification. Similarly, Grammarly shows strong performance in grammatical accuracy, sentence correction, and improving writing coherence, making it a useful writing support tool. Duolingo and Memrise were found to be effective in vocabulary acquisition, as both application systems use structured repetition and gamified learning strategies that enhance memorization and learner engagement. These tools support continuous exposure to new lexical items through interactive exercises. ELSA Speak provides targeted support for pronunciation development by offering real-time phonetic feedback and error correction, which contributes to improved speaking accuracy and fluency.

Google Translate is mainly effective as a quick translation and comprehension tool; however, its performance is limited in handling contextual meaning, idiomatic expressions, and discourse-level accuracy. According to the analysis the comparative analysis shows that AI-based language learning tools contribute to different aspects of language learning depending on their design and function. Rather than providing uniform learning outcomes, each tool supports specific language skills. In addition, the results suggest that AI-based tools can enhance learner autonomy, engagement, and access to practice opportunities. However, excessive reliance on these systems may reduce learners' critical thinking, productive language use, and real-life communicative interaction. Furthermore, despite their advantages, current AI systems still face limitations in fully capturing cultural nuance, pragmatic meaning, and emotionally rich language use. Therefore, AI should be considered as a complementary resource rather than a replacement for traditional teaching methods.

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Bioremediation Prospects for Removing Pollutants from River Waters

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Abstract. The present study addresses the problem of pollution in the Sumgayit River, which has been exposed to technogenic impacts for many years, and proposes new approaches to enhance its self-purification capacity. To purify river water from organic and inorganic pollutants, the feasibility of selecting active strains from the native microbiota and applying them in bioremediation was investigated. According to the research results, river waters subjected to anthropogenic pollution exceeded the maximum permissible concentrations (MPCs): the phenol concentration was 0.50 mg/L (MPC = 0.001 mg/L), while the copper concentration was 0.96 mg/L (MPC = 0.01–0.1 mg/L). It was established that the active microbial strains isolated from these water samples belonged to the genera *Rhodococcus*, *Penicillium*, and *Aspergillus*. The obtained results demonstrated that the fungal strains were more effective than the bacterial strain. Under the influence of *Rhodococcus* sp., the phenol concentration decreased by 62%; *Penicillium* sp. achieved a 100% reduction, while *Aspergillus* sp. reduced the phenol concentration by 86%. The copper concentration decreased by 58.4% with *Rhodococcus* sp., 64.8% with *Penicillium* sp., and 68.7% with *Aspergillus* sp. These results indicate that these microorganisms are effective candidates for application in bioaugmentation.

Keywords: bioremediation, phenol-absorbing microorganisms, heavy metals, ecotoxicity, bioindication

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Çay sularının çirkləndiricilərdən təmizlənməsində bioremediasiya üsulunun perspektivləri

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Xülasə. Təqdim olunan işdə uzun illərdir texnogen çirklənməyə məruz qalmış Sumqayıt çayının çirklənməsi problemi və onun özünü təmizləmə qabiliyyətinin artırılması üçün yeni yanaşmalar irəli sürülmüşdür. Çay sularının üzvi və qeyri-üzvi çirkləndiricilərdən təmizlənməsi üçün aborigen mikrobiotadan aktiv ştamların seçilməsi və onlardan bioremediasiya prosesində istifadə etmə imkanları araşdırılmışdır. Tədqiqat nəticələrinə əsasən, texnogen çirklənməyə məruz qalmış çay sularında fenolun miqdarının 0,50 mq/l (YVH – 0,001 mq/l), misin miqdarının isə 0,96 mq/l (YVH – 0,01–0,1 mq/l) olduğu və hər iki göstəricinin YVH-ni aşdığı müəyyən edilmişdir. Bu su nümunələrindən ayrılan aktiv mikroorqanizm ştamlarının *Rhodococcus sp.*, *Penicillium sp.* və *Aspergillus sp.* cinslərinə aid olduğu müəyyən edilmişdir. Nəticələrə əsasən, istifadə edilən göbələk ştamlarının bakteriya ştamları ilə müqayisədə üstünlük təşkil etdiyi aşkar edilmişdir: fenolun miqdarı *Rhodococcus sp.* təsiri ilə 62%, *Penicillium sp.* ilə 100%, *Aspergillus sp.* ilə 86%, misin miqdarı isə *Rhodococcus sp.* ilə 58,4%, *Penicillium sp.* ilə 64,8%, *Aspergillus sp.* ilə 68,7% azalmışdır. Bu nəticələr onları bioaqlantasiya prosesində istifadə etmək üçün səmərəli hesab etməyə imkan verir.

Açar sözlər: bioremediasiya, fenolmənimsəyən mikroorqanizmlər, ağır metallar, ekotoksiklik, bioindikasiya

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Introduction

One of the important problems of the modern era is the ecological pollution of water bodies. The discharge of various industrial, agricultural, and domestic wastes, wastewater, and oil products into water bodies leads to the pollution of seas, lakes, and rivers. One such water body is the Sumgayit River, which is one of the water bodies most severely exposed to anthropogenic and technogenic pollution in Azerbaijan. This river has become a serious ecological hazard due to the increased discharge of domestic sewage directly into the river, resulting from intensive industrialization and population growth in Sumgayit over many years. Pollution of water bodies by various toxic substances poses a serious risk to ecosystems and can negatively affect all organisms interconnected through the food chain, as well as human health.

To prevent this, the use of environmentally friendly and safe methods is a priority. The use of bioremediation makes it possible to reduce the environmental burden by converting pollutants in water bodies into less harmful substances or by completely neutralizing them (Kalitina, 2015; Kuznetsov, 1989). This process relies on harnessing the metabolic capabilities of living organisms to reduce the toxicity of a wide range of contaminants, including heavy metals, pesticides, and organic matter. To address this challenge, adopting environmentally sustainable and safe remediation

strategies has become a priority. Among these strategies, self-purification is defined as a biological response to environmental stress (Dasgupta, 2024; Iskuzhina, 2023). The natural ability of microorganisms to adsorb and degrade pollutants makes their use effective in cleaning contaminated environments (Babaev, 2024). In this process, both bacteria and microscopic fungi play a crucial role.

Literature review

Recent studies demonstrate the high efficacy of biopreparations containing specialized bacterial strains in degrading petroleum hydrocarbons. The most commonly used microorganisms include members of the *Pseudomonas*, *Rhodococcus*, and *Bacillus* genera, which can metabolize various oil components (Kuzhamberdieva, 2019; Nadzhafova, 2024). Mycoremediation may be used as an independent or complementary approach to restoring the quality of aquatic biomes currently under serious threat from pollution and degradation (Fedoseeva, 2023). Several authors have suggested that sustained growth, strong regenerative potential, and the ability to form extensive hyphal networks make fungi ideal agents for the bioremediation of soils and aquatic environments contaminated with a wide range of pollutants (Abu Qamar, 2023; Akhtara, 2020). Researchers have also found that complex microbial communities oxidize petroleum hydrocarbons more completely and rapidly in contaminated aquatic environments and soils, as the microorganisms in such communities interact and benefit from a coordinated "metabolic attack" on the hydrocarbons (Shubakov, 2012). Polybacterial preparations have broader adaptive and ecological potential for use. The selection of methods for degrading various hydrocarbons, including those found in oils, does not present any particular problems (Artyukh, 2014).

An advantage of using bacteria for the cleanup and restoration of environments contaminated with heavy metals is their high survival capacity across a wide range of conditions, including extreme environments, owing to their rapid reproduction, as well as their ability to degrade a broad spectrum of toxic compounds through specialized enzyme systems (Abo-Alkasem, 2023). Due to their small size, the biomass of these microorganisms provides a large surface area for capturing pollutants. Strategies developed by bacteria to survive in environments contaminated with heavy metals include mechanisms such as biosorption, bioaccumulation, biomineralization, biotransformation, and methylation (Iskuzhina, 2023).

Purpose and objectives of the study

The aim of the study was to isolate active microorganism strains from river waters exposed to anthropogenic pollution and to restore the ecological safety of river waters through bioremediation using these strains.

To achieve this goal, the physicochemical properties of the water were investigated; aquatic microorganisms (bacteria and micromycetes) were isolated and identified from the collected samples; and the roles of the identified aquatic micromycetes and bacteria in the decomposition of organic matter and the sorption of heavy metals in the aquatic environment were examined.

Materials and Methods

During the study, eight water samples were collected from the coastal zone of the Sumgayit River. Water temperature (°C) was measured *in situ* using a mercury thermometer, pH using a pH Meter 200, and dissolved oxygen (mg/L) using an MW600 dissolved oxygen analyzer. The concentrations of nitrate, nitrite, chloride, and sulfate ions, as well as phenol and copper (Cu), were determined using a Palintest Photometer 7100. Microbiological analyses were conducted according to universally accepted methods (Egorov, 1983; Kuznetsov, 1989). For microbiological analysis, water samples were collected in sterile glass containers. Under laboratory conditions, they were inoculated onto

Nutrient Agar (NA) and Raymond's agarized mineral medium (supplemented with phenol) and then incubated for 3–7 days at 28 ± 2 °C.

Phenol-oxidizing microorganisms were cultured in Egorova's liquid medium to obtain microbial biomass using the following medium composition (g/L): K_2HPO_4 – 1; $(NH_4)_2SO_4$ – 0.1; $MnSO_4 \times 5H_2O$ – 0.016; $FeCl_3 \times 6H_2O$ – 0.034; $CaCl_2$ – 0.1; NaCl – 0.2; $(NH_4)_2HPO_4$ – 0.5; $MgSO_4 \times 7H_2O$ – 0.2; phenol – 1 (Sokolova, 2012; Zaytseva, 2011). Phytotoxicity was assessed by evaluating the effects of chemicals present in the water (phenols and copper) on seed germination rates and plant development parameters of edible lentil (*Lens culinaris*) and common wheat (*Triticum aestivum*) (Terekhova, 2014).

Results and Discussion

The physicochemical properties of the water samples collected from the Sumgayit River are presented in Table 1.

Table 1
Physical and chemical parameters of water samples

Parameters	Max. Permissible Concentration	R. Sumgaitchay
pH	6,5-8,5	7,1-8,5
BOD ₅ (mg O ₂ /L)	≤4	6-11
Nitrite NO ₂ (mg O ₂ /L)	0.08	0,49
Nitrate NO ₃ (mg O ₂ /L)	45	2,1
Chlorides, mg/L	300	340-600
Sulfate ion, SO ₄ 2- mg/L	500	600-800
Cu, mg/L (free)	0,0003-0,046	0,72
Cu, mg/L (total)	0,001	0,96
Phenol mg/L	0,001	0,50
Temperature, °C	12-17	

Seasonal water samples were collected to determine the total number of microorganisms and the number of phenol-absorbing microorganisms (Table 2).

Table 2
Microbiological analysis of water samples by season

Seasons of the year	Total amount of heterotrophic microorganisms, CFU/ml	Amount of Phenol-oxidizing microorganisms, CFU/ml
Spring	$2,8 \times 10^4$	$1,7 \times 10^3$
Summer	$3,7 \times 10^4$	$2,3 \times 10^3$
Autumn	$3,2 \times 10^3$	$2,2 \times 10^2$
Winter	$2,5 \times 10^2$	$1,5 \times 10^2$

By screening, active strains of microorganisms capable of assimilating phenol and copper were selected; they belonged to the genera *Rhodococcus* sp., *Penicillium* sp., and *Aspergillus* sp.

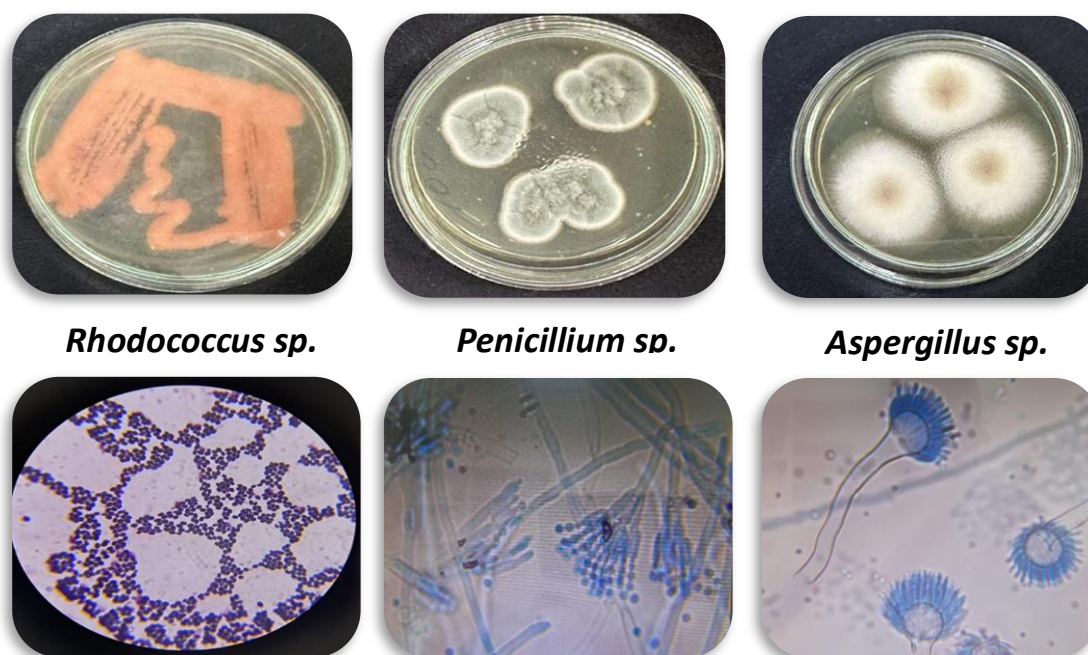


Figure 1
Selection of active microorganisms for bioremediation

Next, a series of experiments tested the effectiveness of active microbial strains for bioremediating water from the Sumgaitchay River. Three sterile flasks were filled with 50 ml of the river water to be tested, and each was individually spiked with cultures of fungi (*Penicillium* sp., *Aspergillus* sp.) and bacteria (*Rhodococcus* sp.) (1 mg). The flasks were then placed in a shaking incubator at 25°C and 180 rpm for cultivation. Observations were made over a period of 5 days. The residual concentration of phenol and copper in the water was measured every 24 hours. The initial concentrations of phenol and copper in the water sample were 0.50 mg/L and 0.96 mg/L, respectively. The experimental results are presented in Figures 2 and 3.

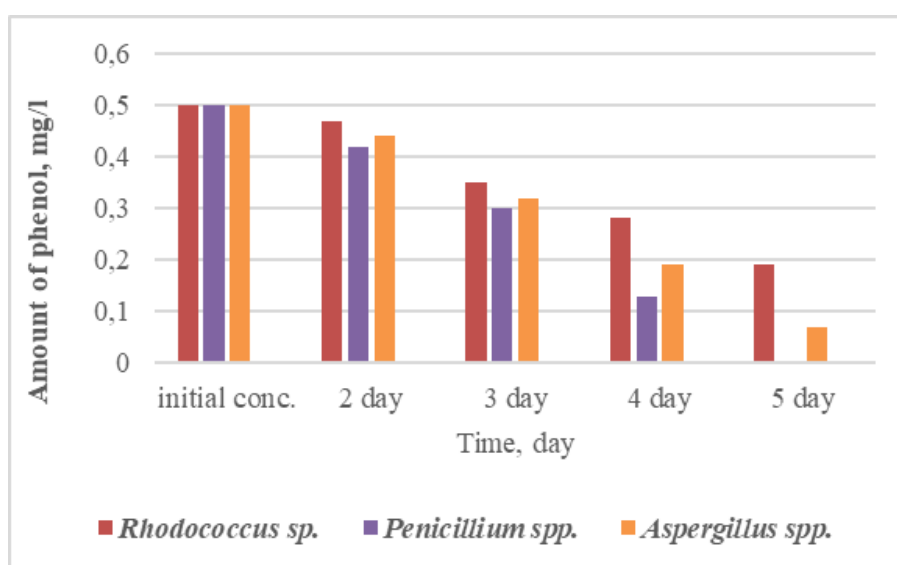


Figure 2
Purification of water from phenol by microorganisms

The results showed that both bacterial strains (*Rhodococcus sp.*) and fungal strains (*Penicillium sp.*, *Aspergillus sp.*) were effective at removing pollutants from water. However, it was established that fungal strains are more destructive than bacterial strains. Thus, when adding biomass of microorganisms to polluted water, the degree of destruction of phenol by the strain of *Rhodococcus sp.* was 62% (residual quantity - 0,19 mg/l), while the strains of fungi demonstrated higher efficiency — *Penicillium sp.* degree of assimilation of phenol was 100%, and in *Aspergillus sp.*—86% (residual quantity - 0.07 mg/l).

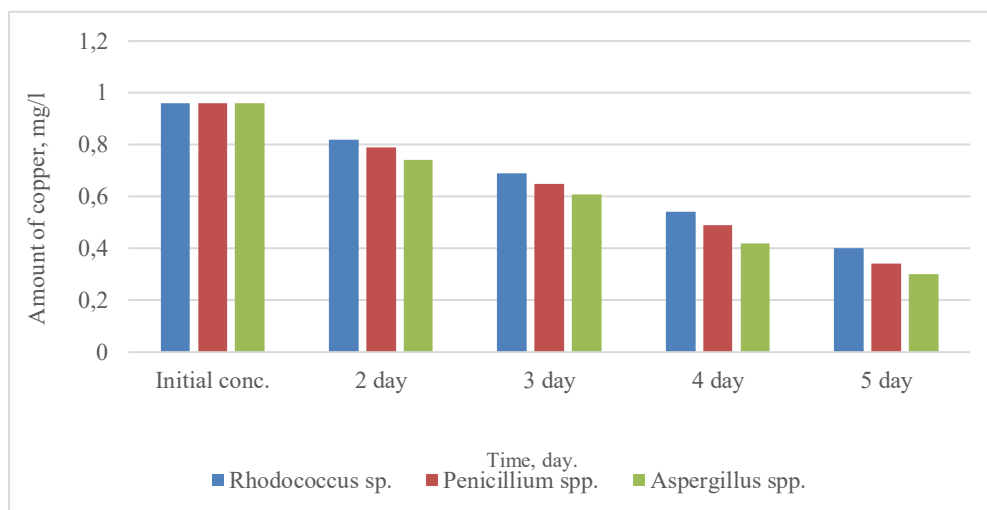
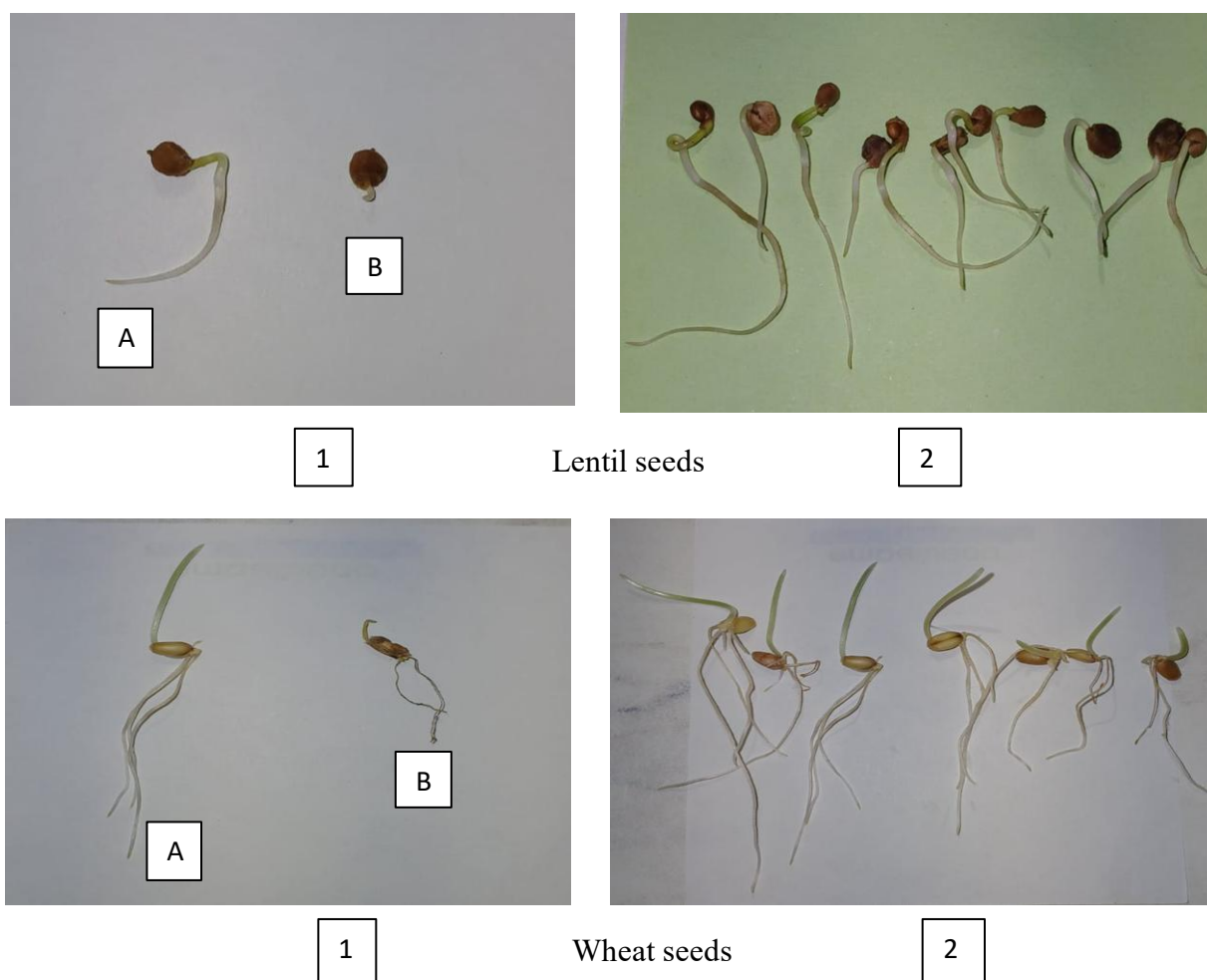


Figure 3

Copper uptake from water by microorganisms (Rhodococcus sp., Pencillium sp., Aspergillus sp.)

The experimental results also showed a significant decrease in the concentration of copper in the water samples (Fig. 3). Furthermore, differences were observed in the copper sorption capacities of the tested microbial strains: *Rhodococcus sp.* (58.4%), *Penicillium sp.* (64.8%), and *Aspergillus sp.* (68.7%). Other studies have also demonstrated that fungi have a high tolerance to various toxicants, making them a powerful tool for wastewater treatment. Furthermore, reports indicate that different fungal species vary both in their mechanisms of action and their remediation efficiency (Abu Qamar, 2023; Dasgupta, 2024; Magan, 2022). Bacterial and fungal bioremediation strategies In addition to basic analytical methods (chemical and physicochemical), bioindication and biotest methods are essential for identifying all pollutants present in the environment and assessing their ecotoxicity (Kalitina, 2019). Plants are among the main indicators in bioindication (phytobionts) and play an important role in environmental monitoring. For this purpose, the ecotoxicity of water samples was also studied using plant seeds. Lentil (*Lens culinaris*) and wheat (*Triticum aestivum*) seeds were used as experimental plants. The toxicity of chemicals (phenols, copper) in water was assessed based on their effects on seed germination and growth parameters (Fig. 4). The influence of these pollutants on seeds was studied in a comparative manner: both before the experiment (the influence of the initial pollutant concentration) and after it (following decomposition and sorption of pollutants by microorganisms).

**Figure 4**

*Biotest plants for studying the ecotoxicity of water samples
(A-control, B-dirt water, 1-before the experiment, 2-after the experiment)*

The bioassay results were comparatively evaluated using seed germination and root length as indicators before and after the remediation process. The findings demonstrated improved growth and development of plant seedlings in bioremediated water samples. An increase of 80-98 % was observed in both the seed germination rate and the length of the seedlings. Seed germination and length of plant sprouts increased by 80-98%. The findings indicate that microorganisms positively affect plant growth and development by reducing the toxicity of river water, thereby making the ecosystem safer.

Conclusion

Overall, the findings of this study demonstrate the potential of bacteria and fungi, as representatives of the aquatic microbiota, to remove pollutants via biosorption and biodegradation, thereby supporting their use in bioremediation. Moreover, the ability of fungi to degrade toxic compounds through diverse enzymatic systems suggests that mycoremediation is one of the most effective approaches to environmental cleanup.

This is further supported by the fact that, in the present study, fungi belonging to the *Penicillium* sp. and *Aspergillus* sp. genera demonstrated greater remediation efficiency than the bacterial genus *Rhodococcus* sp.

The observed enhancement in the growth and development of plant seedlings indicates the high biodegradation and biosorption capacities of these microorganisms for reducing water ecotoxicity and highlights their potential as a promising tool for advancing bioremediation technologies.

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Assessment of the Modern Territorial Organization and Development Priorities of the Transition to Green Energy in the East Zangezur Economic Region

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Abstract. The transition to green energy in the East Zangezur economic region represents a strategic shift in Azerbaijan's national energy policy, promoting efficient use of renewable resources, sustainable economic growth, environmental restoration, and international cooperation. Green energy projects generate significant socio-economic benefits by creating jobs, enhancing local employment, strengthening human capital through high-tech infrastructure, and diversifying energy production to ensure market stability and economic independence. Environmentally, this policy reduces carbon emissions—small hydropower plants alone prevented 225,000 tons of CO₂ emissions in 2024—while minimizing ecological risks and supporting biodiversity. The integration of solar and hydropower further improves grid stability, making green energy transition a comprehensive model of technological, social, and ecological development. Thus, the green energy transition in the East Zangezur economic region is a multidimensional development model encompassing technological innovation, social welfare, ecological restoration, and international integration.

Keywords: East Zangezur economic region, green energy zone, renewable energy sources, solar energy potential

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Şərqi Zəngəzur iqtisadi rayonunda yaşıl enerjiyə keçidin müasir ərazi təşkilinin və inkişaf prioritetlərinin qiymətləndirilməsi

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Xülasə. Şərqi Zəngəzur iqtisadi bölgəsində yaşıl enerjiyə keçid, bərpa olunan mənbələrdən səmərəli istifadəni, davamlı iqtisadi artımı, ətraf mühitin bərpasını və beynəlxalq əməkdaşlığı təşviq edərək, Azərbaycanın milli enerji siyasətində strateji bir dəyişikliyi təmsil edir. Yaşıl enerji layihələri iş yerləri yaratmaqla, yerli məşğulluğu artırmaqla, yüksək texnologiyalı infrastruktur vasitəsilə insan

kapitalını gücləndirməklə və bazar sabitliyini və iqtisadi müstəqilliyi təmin etmək üçün enerji istehsalının şaxələndirilməsi ilə əhəmiyyətli sosial-iqtisadi faydalar yaradır. Ekoloji cəhətdən bu siyasət karbon emissiyalarını azaldır - təkcə kiçik su elektrik stansiyaları 2024-cü ildə 225.000 ton CO₂ emissiyasının qarşısını alıb - eyni zamanda ekoloji riskləri minimuma endirir və biomüxtəlifliyi dəstəkləyir. Günəş və su elektrik stansiyalarının integrasiyası şəbəkə sabitliyini daha da yaxşılaşdırır, yaşıl enerjiyə keçidi texnoloji, sosial və ekoloji inkişafın hərtərəfli modelinə çevirir. Beləliklə, Şərqi Zəngəzur iqtisadi bölgəsində yaşıl enerjiyə keçid texnoloji innovasiyanı, sosial rifahı, ekoloji bərpanı və beynəlxalq integrasiyanı əhatə edən çoxölçülü inkişaf modelidir.

Açar sözlər: *Şərqi Zəngəzurun iqtisadi bölgəsi, yaşıl enerji zonası, bərpa olunan enerji mənbələri, günəş enerjisi potensialı*

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Introduction

The transition to green energy in the East Zangezur economic region is of particular importance as one of the strategic priorities of Azerbaijan's national energy policy. Eastern Zangezur holds great potential (İsbilen, 2025). This initiative combines renewable energy integration with a vision for sustainable growth, environmental balance, and human resource development. In general, green energy infrastructure, in addition to ensuring sustainable electricity production, strengthens the energy security of economic regions and becomes one of the main pillars of climate-adapted development (Pegels et al., 2018).

Globally, green energy policy is recognized as the leading direction of energy transformation (Kilinc-Ata & Proskuryakova, 2024; Le et al., 2025). Many countries around the world prioritize the transition to renewable energy sources in order to build sustainable energy systems, reduce carbon emissions, and comply with international climate commitments (Wojtaszek, 2025). Azerbaijan, joining this trend, aims to transition from the carbon intensity of oil and gas resources to a diversified energy portfolio (İmamverdiyev, 2026). Within the framework of the national energy strategy, it is planned to increase the share of renewable energy in the total energy balance to 30% by 2030, which is directly related to the status of the East Zangezur region as a “green energy zone”.

The contribution of the East Zangezur economic region to these goals is not limited to meeting domestic energy needs. The region also plays a strategic role in terms of forming the export potential of electricity, strengthening competitiveness in regional energy markets and ensuring long-term sustainable development. Based on decisions taken at the state level, the East Zangezur and Karabakh economic regions have been declared “green energy zones”. This status implies the reconstruction of the restored territories formed on environmentally friendly energy sources, the introduction of high-tech infrastructure and the role of the region as a pilot area in energy production.

The energy potential of the region is quite large: 7200–10000 MW for solar energy, about 2000 MW for wind energy, and small hydropower sources are already producing practical results. In 2024, the 32 SHPs operating prevented approximately 225,000 tons of carbon emissions, which is a significant contribution to the fight against climate change. These indicators, in addition to strengthening the

diversification of Azerbaijan's energy balance, create conditions for achieving environmental advantages.

At the same time, the green energy projects of East Zangezur also serve to expand regional cooperation and economic integration. For example, the energy produced through the Jabrayil Energy Hub can be transmitted to the Turkish and European markets, opening a new stage in Azerbaijan's energy exports and strengthening the region's strategic position on the international energy map (Ministry of Energy 2025). Thus, the transition to green energy in the East Zangezur economic region is a strategic turning point in Azerbaijan's energy policy, acting as a complex concept serving to strengthen national energy security, sustainability of socio-economic development, restoration of ecological balance and expansion of international cooperation.

The priorities of the transition to green energy in the East Zangezur economic region are focused on complementary directions such as strengthening the energy security of the region as a whole, achieving environmental benefits, increasing economic diversification and export potential, promoting socio-economic development and innovations, as well as expanding regional and international cooperation. These priorities, formed in interaction within the framework of a single strategic concept, serve both to sustainably meet domestic energy demand and to strengthen Azerbaijan's position in global energy markets. Therefore, the green energy policy for East Zangezur applies technological innovations while serving as a broader development model that restores ecological balance, improves social well-being, and strengthens international integration.

Materials and Methods

The main objective of this study is to scientifically analyze the strategic importance, socio-economic and environmental impacts of the transition to green energy in the East Zangezur economic region. The aim is to assess the technical potential of renewable energy sources and to demonstrate how they contribute to the region's sustainable development, energy security, ecological restoration, and international cooperation. This context is consistent with the goal of transitioning from carbon-intensive resources to a diversified energy portfolio in Azerbaijan's national energy policy and is directly related to the status of East Zangezur as a "green energy zone".

The material base of the research is the following sources:

- Official government documents and strategies: Azerbaijan's national energy strategy, which aims to increase the share of renewable energy to 30% by 2030.
- Statistics: 7,200–10,000 MW of potential for solar energy, approximately 2,000 MW for wind energy; 32 small hydroelectric power plants operating in 2024 to prevent 225,000 tons of CO₂ emissions.
- Regional development programs: State decisions on declaring the East Zangezur and Karabakh economic regions as "green energy zones".
- Scientific and analytical sources: International and local research on energy security, environmental sustainability, and economic diversification.
- Infrastructure projects: Energy export opportunities to Turkish and European markets through the Jabrayil Energy Hub.

The methodological approaches used in the study include the analytical-synthetic method - comparative analysis and generalization of data collected from various sources; assessment of geographical-energy potential - scientific assessment of the region's solar, wind and hydropower resources based on statistical indicators; socio-economic impact analysis - study of the impact of green energy projects on employment, social welfare and regional economic integration; ecological assessment - study of the ecological consequences of reducing carbon emissions and complying with climate commitments; strategic comparison - analysis of the compliance of Azerbaijan's energy

policy with global trends. The study indicates that moving to green energy in East Zangezur is a diversification of energy production and a strategic approach to sustainability, ecology, and international collaboration.

Results and Discussion

Our research area, the East Zangezur economic region, was established in 2021 as one of the new economic and geographical divisions of Azerbaijan and covers an area of 7,448 km². The region includes the Jabrayil, Kalbajar, Lachin, Gubadly, and Zangilan districts. Figure 1 shows the geolocation of the economic region within Azerbaijan.

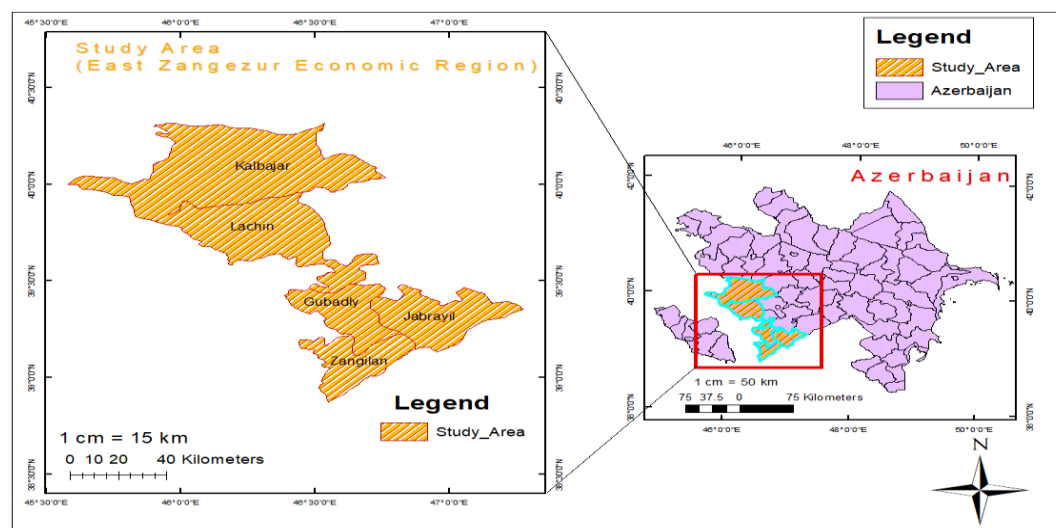


Figure 1

Location map of East Zangezur economic region

Source. Prepared by author.

The geographical position of the region is characterized by strategic advantages. East Zangezur has a state border with Armenia in the west, Iran in the south, and establishes internal relations with the Karabakh economic region in the east. This border configuration brings the region to an important position both at the intersection of the South Caucasus transit networks and in the energy and transport strategy of Azerbaijan. Currently, large-scale reconstruction and reintegration programs are being implemented in the region (Hajiyeva & Karimli, 2021, p. 73).

In 2025, the total production of electricity in Azerbaijan increased by 262.3 million kWh or 0.9% compared to the previous year and reached 28657.5 million kWh. According to official data from the Ministry of Energy, the main part of electricity was produced in thermal power plants during the reporting period, and this indicator amounted to 24823.4 million kWh. The volume of electricity produced in hydroelectric power plants was 2842.5 million kWh. Production from other sources was recorded at a total level of 991.6 million kWh, of which 169.7 million kWh fell to wind power plants, 599.8 million kWh to solar power plants, and 222.1 million kWh to the Solid Waste Incineration Plant.

These data show that traditional thermal power plants still form the basis of energy supply. However, the share of BEM in total generation, including small HPPs, Solar and Wind power, is gradually increasing (Ministry Of Energy, 2025). The total installed electricity capacity of the country for 2024 is 8415.6 MW, of which TPP: 6623.0 MW (78.7%); HPP: 1406.6 MW (16.7%); Solar Power Plants (SPP): 278.0 MW (3.3%); Wind Power Plants (WPP): 63.62 MW (0.75%); Bioenergy and Hybrid Plants: 44.4 MW (0.5%). The share of BEM (HPS, GPP, HPP, bioenergy) in total capacity is

approximately 21.3% (1792.64 MW). This figure is a positive trend, given Azerbaijan's goal of increasing the share of renewable energy sources to 30% by 2030. In particular, the projects implemented within the framework of the concept of creating a "Green Energy Zone" in areas undergoing restoration (installation of more than 3,000 kW of solar panels, operation of 32 hydroelectric power stations) are an important step in this direction.

The EU plans to continue the Green Economy, reduce carbon emissions worldwide to zero, and increase the share of Green energy to 60-80% by 2050 through international and regional measures, especially through the widespread use of renewable energy. According to statistics for 2023, 2.5% of GDP in the European Union countries was allocated to the development of the Green Economy, and 2.5% of the total economically active population worked in this field.

As a result of our research, it was determined that (according to the analysis of materials for 2024) the share of alternative sources in energy production in the European Union countries was 47%. The share of various sources in renewable energy was 39.1% from wind, 29.9% from water, and 22.4% from the Sun. According to the Green Deal agreement, EU countries have set a goal of switching to practically 100% alternative energy sources by 2050. According to the energy indicators for 2025, the share of alternative energy in electricity production in Norway was 99%, in Denmark 88.7%, in Sweden 70.6%, in Finland 52.2%, in Iceland 100%, in the United Kingdom of Great Britain and Northern Ireland 49.7%, in Germany 50%, in France 28%, in Italy 45.7%, in the Netherlands 50%, in Switzerland 66.4%, in Spain 53%, in the Czechia 16%, in Hungary 27.4%, and in Poland 28% (Irena Report 2025; REN 21 2025; Pashayev 2025).

In terms of alternative energy, East Zangezur is one of the territories of Azerbaijan declared a "green energy zone". The region has a special strategic position in Azerbaijan's energy policy. The geographical location of the region creates significant advantages in terms of both the richness of natural resources and regional integration opportunities. The terrain of the area, rich in mountains and valleys, creates favorable conditions for solar and wind energy, while the river systems allow for the construction of small hydroelectric power stations. In addition, East Zangezur's border position – its proximity to access routes to Turkish and European markets – is a strategic advantage for energy exports.

The socio-economic impact of the transition to green energy is reflected in the formation of a sustainable development model for the region. Firstly, renewable energy projects create conditions for the creation of new jobs, increasing the employment level of the local population and increasing social welfare. Secondly, the introduction of high-tech infrastructure requires the strengthening of the national human resource potential, which opens up new opportunities in the field of education and specialization. Thirdly, the diversification of energy production increases the economic independence of the region and ensures the stability of the internal market.

From a strategic perspective, green energy strengthens the function that East Zangezur plays on Azerbaijan's energy map. Energy production in the region aims to cover local needs and at the same time build export capacity. The transmission of electricity generated through the Jabrayil Energy Hub to the Turkish and European markets increases Azerbaijan's competitiveness in regional energy markets and expands opportunities for international cooperation. This serves to reduce dependence on oil and gas resources and strengthen the renewable energy portfolio, in line with the strategic diversification goals of the country's energy policy.

Environmental impacts are one of the most important outcomes of green energy policies. The implementation of solar, wind and hydropower projects significantly reduces carbon emissions, enabling the fulfillment of national commitments in the fight against climate change. The prevention of 225,000 tons of CO₂ emissions from small hydroelectric power plants operating in the region in

2024 is a clear example of this. This process creates conditions for the restoration of the ecological balance of the restored areas, the production of clean energy and the protection of the environment.

The portfolio of small hydropower plants (SHPs) in the East Zangezur economic region is forming as an important pillar of the regional energy transition and exhibits a systematic structure in terms of both spatial distribution, technical-power configuration, and phased operation dynamics. The overall picture shows that the SHPs that have been successively commissioned, built and prepared for operation, and are under construction in the Lachin, Kalbajar, Zangilan, and Gubadly regions together form a regional hydropower cluster that ensures sustainable electricity supply. Its strategic function involves satisfying local demand, contributing to renewable energy balance, strengthening grid reliability, and opening pathways for future exports.

Table 1

Small hydropower plants located in the East Zangezur economic region

Small Hydropower Plant	Location	Commissioning date	Power (MW)	Status
Aghbulag-1 HPP	Lachin	2026*	14.7	Built
Aghbulag-2 HPP	Lachin	2026*	14.25	Built
Jahangirbeyli HPP	Zangilan	2023	10.5	Working
Sayif HPP	Zangilan	2024	10.5	Working
Sarigışlag HPP	Zangilan	2024	10.5	Working
Zangilan HPP	Zangilan	2024	10.5	Working
Nadirkhanli SHP	Kalbajar	2025	8.8	Working
Lower Vang SHP	Kalbajar	2024	8.6	Working
Chirag-1 SHP	Kalbajar	2023	8.3	Working
Mishni SHP	Lachin	2023	8.25	Working
Gulebird SHP	Gubadly, Lachin	2021	8.0	Working
Qamishli SHP	Kalbajar	2023	6.3	Working
Alkhasli SHP	Lachin	2023	6.0	Working
Soyujbulag SHP	Kalbajar	2023	5.3	Working
Kalbajar-1 SHP	Kalbajar	2022	4.4	Working
Zar SHP	Kalbajar	2024	4.3	Working
Silent SHP	Lachin	2024	4.0	Working
Garigishlag SHP	Lachin	2024	4.0	Working
Chirag-2 SHP	Kalbajar	2023	3.6	Working
Mirik SHP	Lachin	2025	3.5	Working
Meydan SHP	Kalbajar	2023	3.4	Working
Zabukh SHP	Lachin	2024	2.8	Working
Upper Malibeyli SHP	Lachin	2025	4	Built
Lower Malibeyli SHP	Lachin	2025	3.1	Built
Zeynalli SHP	Lachin	2025	5	Built
Minkend SHP	Lachin	2025	2.1	Built
Galaja SHP	Lachin	2025	3.1	Built
Upper Vang SHP	Lachin	2025	22.5	Built

Planned for commissioning

Source. Ministry of Energy - List of independent and operating power plants in the energy system of Azerbaijan (until 2025).

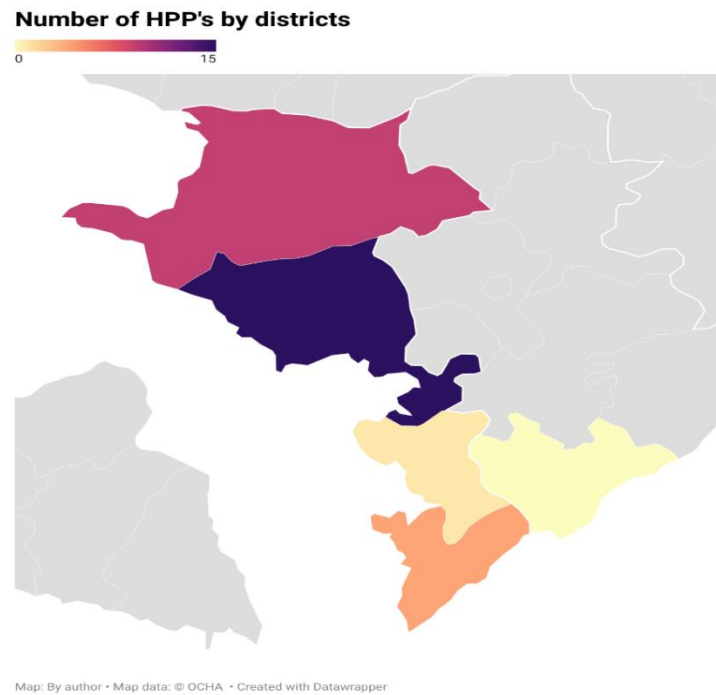


Figure 2
Distribution of hydroelectric power plants by region

When we look at Table 1 and Figure 2, it is noticeable that there is inequality in the distribution of power stations in the area. There are 15 stations in Lachin, 9 in Kalbajar, 4 in Zangilan, and 1 in Gubadly. There is no station in Jabrayil. This is also related to the terrain of the area.

The current power profile shows that the total capacity of the SHP currently in operation is approximately 131.55 MW. This category includes four stations with a capacity of 10.5 MW in the Zangilan region (Jahangirbeyli, Sayifli, Sarığışlag, “Zangilan HPP”), nine stations in Kelbajar with capacities in the range of 8.8–3.4 MW (Nadirkhanli, Lower Veng, Chirag-1, Qamishli, Soyugbulag, Kalbajar-1, Zar, Chirag-2, Meydan), and seven stations in the Lachin-Gubadly chain with capacities in the range of 8.25–2.8 MW (Mishni, Gulabird, Alkhasli, Sus, Garigishlag, Mirik, Zabukh). In addition, the Aghbulag-1 (14.7 MW) and Aghbulag-2 (14.25 MW) stations in Lachin, which have been completed but are scheduled for commissioning, form a “built” category of 28.95 MW; once these stations are connected to the grid, the renewable power base of the region will expand further. The portfolio of projects under construction in the Lachin region consists of the Yukhari Malibeyli (4 MW), Ashagi Malibeyli (3.1 MW), Zeynalli (5 MW), Minkand (2.1 MW), Galaja (3.1 MW) and Yukhari Veng (22.5 MW) stations; the total capacity of this group is approximately 39.8 MW. Thus, the total portfolio capacity of SHPs in operation, ready for operation, and under construction reaches approximately 200.3 MW, which confirms the significant share of hydropower in the renewable energy-based model of Eastern Zangezur.

Table 2
Modern energy potential of Jabrayil district

Power Plants	Power(MW)	Commissioning date
Khudaferin	200 MW	2024
Giz Galasi	80 MW	2024
Shafag PV	240 MW	2027*

Source. Ministry of Energy - List of independent and operating power plants in the energy system of Azerbaijan (until 2025).

As can be seen from Table 2, Jabrayil district is one of the regions of strategic importance in Azerbaijan's energy policy. During the current recovery period of the study area, this region has become the focus of large-scale reconstruction and development programs. Its geographical location, water resources, and solar radiation profile make Jabrayil a region with high potential in terms of both hydropower and solar energy. The largest projects in the region's energy portfolio are the Khudaferin and Giz Galasi hydropower plants. The Khudaferin Hydroelectric Power Plant has a capacity of 200 MW and was commissioned in 2024. This facility is considered a strategic centre that will not only meet the energy supply needs of Jabrayil but also strengthen Azerbaijan's overall energy balance. The Giz Galasi Hydroelectric Power Plant has a capacity of 80 MW and was also commissioned in 2024. This plant, together with Khudaferin, forms an important part of the hydropower complex created on the Araz River. Thus, these two projects together increase the hydropower capacity of the Jabrayil region to 280 MW, which represents a significant share in Azerbaijan's renewable energy portfolio.

The geographical location and climatic conditions of the region also create favorable opportunities for solar energy. The Shafag Solar Power Plant project is designed to realize this potential. The technical parameters of the project are being finalized, but the solar radiation profile of Jabrayil will allow this plant to operate with high efficiency. The implementation of energy projects has a number of socio-economic consequences in the Jabrayil region. The creation of new jobs during the construction and operation stages, the restoration of infrastructure, and the strengthening of economic diversification have a significant impact on the social well-being of the region. Energy production supports the development of agricultural and industrial sectors, increasing the economic independence of the region. Strategically, the energy potential of the Jabrayil region is directed toward domestic consumption and export. The energy produced by the Khudaferin and Giz Galasi Hydroelectric Power Plants can be transmitted to the Turkish and European markets through the Jabrayil Energy Hub. This amplifies Azerbaijan's competitiveness in regional energy markets and strengthens the country's energy security.

In the context of the Jabrayil region, the integration of hydro and solar potential is of additional strategic importance. The power indicators presented here for the Khudaferin hydropower plant of 200 MW and for the Giz Galasi of 80 MW, if verified, could dramatically strengthen the overall energy configuration of the region; the phased commissioning of these facilities, both in terms of power scale and grid stability, would increase the transmission capacity on the interconnectors and turn export trajectories into a real sector opportunity. Although the indicators for the Shafag SPP need to be clarified, the solar-hydro synergy in the Jabrayil region creates a rational hybrid model in terms of balancing the daytime-late-night load profile and smoothing peaks due to hydro reserves during seasonal periods with high water volume.

In terms of space, the distribution of SHP is based on important geographical advantages. The mountainous-valley relief and multi-water river systems provide a favorable hydromorphology for stations built on the principle of small-power, sequential cascade (Imanov et al. 2021, p. 142). On the one hand, this morphology creates opportunities for more flexible hydrological regulation, and on the other hand, it minimizes the ecological and social risks of large reservoirs and ensures that local impacts can be managed with small-scale facilities. The cascading arrangement in Lachin and Kalbajar provides the topological advantage of proximity to the distribution network, intensive connection with lines and reduced losses; the Zangilan line simplifies operational management by creating stable blocks with 10.5 MW modular power units.

The socio-economic impacts are multi-layered. First, the SHP portfolio forms a sustainable production base in the region by ensuring rapid diversification of renewable energy infrastructure, which both increases the level of local consumption and has a positive impact on price stability. Second, new employment opportunities are created for qualified and re-qualified personnel throughout the construction, installation, operation and maintenance phases; this leads to the

strengthening of local personnel potential based on practical skills, and the increase of applied competencies in the fields of vocational education and engineering. Third, the spatial distribution of small-power hydropower plants increases the continuity of energy supply for the agricultural and processing sectors, creating a reliable infrastructure environment for electrified irrigation, cold chain and small processing enterprises. Fourth, the modular nature of the portfolio facilitates the sharing of project risks, allows for flexible packaging in terms of capitalization and financing; this encourages the functional expansion of private-investor participation and access to the grid of local producers.

Strategic implications deepen the role of the “pilot green zone” in the energy map of East Zangezur. With approximately 131.55 MW of base capacity in operation, 28.95 MW of units to be commissioned in the near future, and 39.8 MW of units under construction, the region’s renewable energy portfolio is gradually expanding, making the load management of the electricity grid more flexible, and providing backup capacity. facilitates planning and brings it closer to the stability criteria required for exports. The approval and phased connection of large hydro facilities along the Jabrayil line strengthens access to the Turkish and European markets through interconnectors. This process combines two main goals in terms of Azerbaijan's energy security: reducing hydrocarbon dependence and strengthening renewable energy bases. As a result, the country's energy policy gains new opportunities in the direction of both sustainability and diversification.

In the context of environmental impacts, the role of SHPs should be particularly emphasized (Arabatzis & Myronidis, 2011). Small hydropower plants, in addition to directly contributing to the reduction of carbon emissions, provide a more flexible framework for the localization and management of environmental risks. The use of small reservoirs and intakes allows for the maintenance of measurable and compensable impacts on biodiversity, the preservation of ecosystem services, and the planning of ecological flows. In addition, the integration of hydropower modules with solar and wind power reduces the share of carbon-containing reserve capacities, supports the frequency stability of the network due to the ability of hydropower units to quickly respond to peak loads, and lowers the overall emission profile of the system.

Consequently, the SHP and associated PV portfolio in the East Zangezur economic region is a complex model aimed at building a sustainable energy system with a phased power growth strategy that effectively uses geographical advantages. Consolidation of existing capacities, timely integration of projects ready for operation into the network, and completion of facilities under construction in accordance with quality indicators ensure the parallel strengthening of both socio-economic stability, strategic energy security, and environmental sustainability. In the event of approval of large power projects along the Jabrayil line, the energy map of the region will move one step closer to a renewable-based export model, which will strengthen East Zangezur as a practical example of Azerbaijan's green transformation vision and a reliable hub for regional energy integration.

The East Zangezur economic region is one of the regions of strategic importance in terms of renewable energy resources of the Republic of Azerbaijan. The assessment of the solar, wind and geothermal energy potential of the region is of particular importance in terms of diversification of electricity production and formation of a sustainable energy strategy. For this purpose, international and national databases were used during the study, including the “Global Solar Atlas”, “Global Wind Atlas”, Solargis solar resource maps, Agroclimatic and Geographic Atlases of the Republic of Azerbaijan, as well as NASA's MERRA-2 and GMAO-5 satellite observation data (1981–2019) (Global Solar Atlas, 2021; Global Wind Atlas, 2021; Agroclimatic Atlas, 1993; Geographic Atlas, 2018).

In order to assess the solar energy potential of the East Zangezur economic region, the areas were divided into three groups based on annual solar radiation indicators. In areas with weak solar potential, annual solar radiation varies in the range of 976–1400 kWh/m². These areas mainly cover the Gubadly and Lachin regions, covering an area of approximately 5.6 thousand km² and equal to

33% of the total area of the region (Global Solar Atlas, 2021). In zones with medium solar potential, the annual radiation amount varies between 1400–1500 kWh/m²-year, and these areas cover 39% of the region (6.7 thousand km²). In areas with high solar potential, the radiation indicator is in the range of 1500–1607 kWh/m²-year, mainly located in the mountainous parts of the Kalbajar and Gubadly regions, and the total area is approximately 0.7 thousand km². These areas are considered the most favorable zones for the placement of photovoltaic power plants and The total solar energy potential is estimated at 300–400 MW (Ministry of Energy, 2021).

According to the Agroclimate Atlas, the maximum solar radiation in the region is observed in the Kalbajar and Lachin regions due to the increase in altitude above sea level, and this indicator rises to 1667 kWh/m² (Agroclimate Atlas 1993). Approximately 70% of the annual solar radiation falls on the months of April-September, and 30% on the months of October-March. The approximately 10% differences observed between different sources are explained by the lack of stationary meteorological observations in the region over the past 30 years, which indicates the importance of continuous monitoring in the future. One of the important factors affecting the efficiency of solar energy use is the annual number of sunny hours. In East Zangezur, the annual number of sunny hours varies between 2000 hours on average in the Kalbajar-Gubadly zone and 2200–2400 hours in other parts of the region. The least sunny month is December, during which the number of sunny hours is 120 hours in the Istisu area and 130–250 hours/month in the Lachin region (Geographic Atlas, 2018).

The energy production efficiency of photovoltaic panels is also affected by climatic factors, including precipitation regime, temperature conditions and duration of the frost-free period. The amount of precipitation in the region increases from 400 mm to 1000 mm from east to west, and the maximum indicators are recorded in the Kalbajar and Lachin regions (Agroclimatic Atlas, 1993). The duration of the frost-free period varies between 100–225 days and decreases with increasing altitude. The number of days with daily air temperatures above 15°C is 50–150 days, and the number of days with maximum temperatures above 35°C is 5–15 days. The number of days with continuous snow cover is on average 80 days/year in the Kalbajar–Lachin low-mountain zone (Geographical Atlas, 2018).

Choosing the optimal inclination angle of solar panels plays an important role in increasing energy production. According to the calculations, the optimal inclination angle of the panel in the East Zangezur region takes maximum values at the winter solstice (66–67°), and minimum values at the summer solstice (6–7°). The developed analytical method Its application allows to increase the annual energy production of photovoltaic systems located in complex terrain conditions by 7–10% (Gardashov et al., 2020, pp. 316–317).

The wind energy resources of the East Zangezur economic region are considered to be mainly of medium potential. The average annual wind speed varies in the region within the range of 2.5–8.7 m/s, and the number of days with wind speeds exceeding 15 m/s per year is recorded in the regions between 5–52 days (Agroclimate Atlas, 1993). According to the Global Wind Atlas, 4618 km², which constitutes 62% of the region, have an average annual wind speed of 0.1–2.0 m/s and are considered weak wind zones (Global Wind Atlas, 2021). Areas with medium wind speeds (2.1–4.0 m/s) cover 2160 km² and 29% of the region, and are mainly suitable for the installation of small-power wind turbines. Zones with high wind potential (≥ 4.1 m/s) account for only 819 km² or 11% of the area and are mainly located in the western part of the Kalbajar region. The complex terrain and poor infrastructure of these areas limit the economic feasibility of building wind power plants (Sun et al., 2023; Alam et al., 2025).

The region's geothermal energy resources are mainly concentrated in the Kalbajar region. The Istisu and Bagirsag areas are considered the main thermal water sources of East Zangezur (Taghiyev et al. 2001, p. 101). The water temperature at a depth of 100 m in the Baghirsag area is 80°C, in the Istisu area it is 62°C at a depth of 70 m, and at a depth of 300–350 m it is 75°C (Mukhtarov et al., 2015, pp. 54-55). The temperature of thermal waters in the region is estimated at 30–74°C, and the total daily

flow is 4171 m³. The total energy potential is determined at 771 MW, provided that the water is cooled to 20°C (Tahmazov, 2013, p. 102). These resources have high prospects for energy production, as well as for treatment and health tourism purposes.

In the East Zangezur economic region, it is considered a priority to realize the potential for “green” energy exports in the region by 2030 by utilizing international cooperation. In this context, foreign investments in the transition to green energy in East Zangezur in 2026–2030 will mainly come from BP from the United Kingdom, Chinese state corporations (China Energy Overseas Investment, China Datang, PowerChina), Masdar from the UAE and ACWA Power from Saudi Arabia, as well as is built on expanding cooperation with other European companies and partners. These partnerships are of strategic importance for increasing Azerbaijan's renewable energy potential, accelerating technology transfer, and achieving its 2030 goals. Also, European influence in the renewable energy space of Eastern Zangezur has so far been mainly based on institutional cooperation, standardization and financial support. The volume of direct investment by European companies is still small compared to Spain and other large investors, however high-level cooperation agreements (e.g. Memorandum of Understanding with WindEurope) and financial support from the European Bank for Reconstruction and Development (EBRD)/European Investment Bank (EIB) are actively integrating the European side's strategy in this direction and expanding the possibilities of technical assistance (Khanayev et al., 2025, pp. 803–805).

Our analyzes show that it is advisable to implement the alternative energy potential formed in the territory of Azerbaijan along three main technical-geographical routes for export after internal integration. The first and currently most realistic route is the Azerbaijan-Georgia-Turkey line. This route is dependant on the existing transmission infrastructure and is being gradually strengthened. The energy from East Zangezur is first transmitted to the western regions via the domestic main network, and from there to the Turkish energy system via Georgia. Turkey plays the role of a transit country on this route for access to both consumer and European markets.

The second main route is the East Zangezur-Nakhchivan-Turkey route. This route is of particular strategic importance because, in addition to strengthening the energy supply of Nakhchivan, it creates a new energy integration between the continental part of Azerbaijan and Nakhchivan and, in the medium term, forms the opportunity for direct access to European energy markets via Turkey.

The third and long-term strategic route is the Central Asia-Caspian-Azerbaijan-Europe green energy corridor. This model envisages the transmission of renewable energy produced in Kazakhstan and Uzbekistan across the Caspian basin to Azerbaijan, and from there to Europe via Georgia and the Black Sea. Among the three routes mentioned, the second—the strategic East Zangezur–Nakhchivan–Turkey line—has priority in the transport and logistics sector, carrying significance for the region, the country, and the wider South Caucasus.

Conclusion

As a result of the conducted comprehensive research, it was determined that the East Zangezur economic region is one of the areas with high potential for the diversified development of renewable energy sources. The mainstay of the green energy system in the region should be SHP and PV. The mountainous terrain of the economic region and the density of the river network create favorable conditions for the development of small hydroelectric power stations (SHP). Lachin and Kalbajar regions are the most favorable areas for the development of hydropower cascades. The abundant river systems and mountainous-valley terrain allow for the construction of small powerful hydroelectric power stations on the principle of sequential cascade. Existing and prospective hydropower nodes located on Tartar, Hakari and their tributaries are considered priority areas for the construction of SHP. However, the territorial organization of SHP in the regions belonging to the region differs significantly from each other. For example, the sequential formation of modular HPP blocks in the

Zangilan region plays a distinctive role in the regional energy system. Here, the parallel operation of several stations with a capacity of 10.5 MW simplifies operational management and creates stable energy blocks. This model strengthens uninterrupted power supply for the agricultural and processing sectors and creates technical stability for connection to the export grid.

In the Gubadly district, the Gulabird HPP and other small hydro facilities are the mainstays of energy supply to agricultural areas. The joint use of HPPs along the Gubadly-Lachin line allows for minimizing network losses and more efficient organization of energy supply. Jabrayil region is distinguished by its large hydropower complexes and solar-hydro hybrid model. The phased connection of Khudaferin (200 MW) and Giz Galasi (80 MW) HPPs strengthens the energy map of the region and enables export-oriented energy production. These facilities increase Azerbaijan's competitiveness in regional energy markets by ensuring energy transmission to Turkish and European markets through the Jabrayil Energy Hub.

The mountainous and foothill areas of the Kalbajar, Gubadly and Lachin regions with high and medium solar radiation act as the main priority zones for the placement of large-scale solar power plants (SPPs). The high annual number of sunny hours in these areas, the relatively low suitability of the land cover for agriculture, and the possibility of connecting to power transmission lines make it possible to efficiently organize photovoltaic stations on the territory. When organizing solar energy on the territory, the differentiation of the optimal inclination angles of the panels by relief and altitude zones, as well as the selective application of tracking systems, are of great importance in terms of increasing energy production.

Wind energy should play a supporting role in the green energy balance in the East Zangezur economic region. The limited area of areas with high wind potential in the region and the presence of complex mountainous terrain limit the construction of large wind power plants (WPPs) from an economic point of view. Nevertheless, it is considered advisable to install small and medium-power wind turbines in the high mountainous areas located in the western part of the Kalbajar region and along separate watersheds. These turbines should be considered mainly as an integral part of local energy supply, electrification of mountainous settlements and hybrid (solar-wind) energy systems.

Geothermal energy resources are of particular strategic importance in the territorial organization of green energy in the East Zangezur economic region. The Istisu and Bagirsag thermal fields located in the Kalbajar region should be used as low and medium temperature geothermal resources mainly for thermal energy production, greenhouse farms, sanatorium-resort infrastructure and municipal heating systems.

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Evaluation of Granulometric Characteristics and Biogenic Element Diagnostic Indicators of Mountain Gray-Brown Soils in the Gazakh-Tovuz Economic Region According to the Wrb System

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Abstract. *This article presents the results of comprehensive investigations conducted between 2020 and 2025 on mountain gray-brown soils within the Gazakh-Tovuz economic region of western Azerbaijan, focusing on the Shamkir administrative district. The research covered an area of 10,522.55 ha and aimed to evaluate the morphological, physicochemical, and spatial characteristics of these soils using conventional soil survey methods integrated with modern geospatial technologies. Detailed field and laboratory analyses were carried out on representative soil profiles, particularly sections 12, 19, 25, and 98, supplemented by observations from additional target sites. Morphological assessments were supported by analyses of key diagnostic indicators, including humus content, total nitrogen, available phosphorus and potassium, granulometric composition, soil reaction (pH), and calcium carbonate (CaCO₃) content. Statistical methods were applied to determine the variability and relationships among soil properties. Geographic coordinates of representative soil sections were established using a Garmin GPSMAP 62s device to ensure accurate spatial referencing. A high-resolution digital elevation model (DEM) was generated through interpolation of elevation data obtained from topographic maps, and a detailed relief model of the study area was developed using ArcGIS 10.3 software. The integration of soil analytical data with GIS-based spatial modeling enabled a comprehensive characterization of mountain gray-brown soils. The findings provide a scientific basis for soil classification, land evaluation, sustainable land management, and agricultural planning aimed at improving land-use efficiency and agricultural productivity in the region. Key finding: The study revealed that mountain gray-brown soils in the Shamkir region exhibit moderate humus content, slightly alkaline pH, and variable nutrient distribution, with noticeable differences across soil profiles influenced by relief and parent material. Spatial analysis based on DEM and GIS modeling confirmed that topography plays a significant role in shaping soil properties and their distribution patterns. Overall, the integration of field data and geospatial techniques provided a reliable basis for accurate soil classification and more efficient land use planning in the Gazakh-Tovuz economic region.*

Keywords: *mountain gray-brown soils, granulometric composition, biogenic elements, WRB soil classification, soil diagnostics, Gazakh-Tovuz economic region*

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Qazax-Tovuz iqtisadi bölgəsindəki dağ boz-qəhvəyi torpaqlarının qranulometrik xüsusiyyətlərinin və biogen element diaqnostik göstəricilərinin WRB sisteminə görə qiymətləndirilməsi

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Xülasə. Məqalədə Azərbaycanın qərb hissəsində yerləşən Qazax-Tovuz iqtisadi rayonunun Şəmkir inzibati rayonu ərazisində yayılmış dağ boz-qəhvəyi torpaqlar üzrə 2020–2025-ci illərdə aparılmış kompleks tədqiqatların nəticələri təqdim edilmişdir. Tədqiqat 10 522,55 ha ərazini əhatə etmiş və müasir geoməkan texnologiyaları ilə integrasiya olunmuş ənənəvi torpaq tədqiqat metodları əsasında həmin torpaqların morfoloji, fiziki-kimyəvi və məkan xüsusiyyətlərinin qiymətləndirilməsini hədəfləmişdir. Nümayəndə torpaq profillərində, xüsusilə 12, 19, 25 və 98 nömrəli kəsirlərdə ətraflı sahə və laboratoriya tədqiqatları aparılmış, əlavə müşahidələr isə seçilmiş hədəf sahələrində davam etdirilmişdir. Torpaqların morfoloji xüsusiyyətləri humusun miqdarı, ümumi azot, mütəhərrik fosfor və kalium, qranulometrik tərkib, torpaq reaksiyası (pH) və kalsium karbonatın (CaCO_3) miqdarı kimi əsas diaqnostik göstəricilərin təhlili ilə səciyyələndirilmişdir. Tədqiq olunan torpaq göstəricilərinin dəyişkənliyinin və qarşılıqlı əlaqələrinin müəyyən edilməsi məqsədilə statistik təhlil metodlarından istifadə olunmuşdur. Məkan məlumatlarının dəqiqliyinin təmin edilməsi üçün nümayəndə torpaq kəsirlərinin coğrafi koordinatları Garmin GPSMAP 62s cihazı vasitəsilə müəyyən edilmişdir. Topoqrafik xəritələrdən əldə edilmiş yüksəklik məlumatlarının interpolasiyası əsasında yüksək ayırdetmə qabiliyyətinə malik rəqəmsal yüksəklik modeli (DEM) yaradılmış, ArcGIS 10.3 proqram təminatında tədqiqat ərazisinin ətraflı relyef modeli hazırlanmışdır. Torpaq analizlərinin nəticələrinin CİS əsaslı məkan modelləşdirməsi ilə integrasiyası dağ boz-qəhvəyi torpaqların hərtərəfli xarakteristikasının müəyyən edilməsinə imkan vermişdir. Əldə olunan nəticələr torpaqların təsnifatı, qiymətləndirilməsi, davamlı torpaq idarəçiliyi və kənd təsərrüfatının elmi əsaslarla planlaşdırılması üçün mühüm elmi baza formalaşdırır, həmçinin regionda torpaqdan istifadənin səmərəliliyinin və kənd təsərrüfatı məhsuldarlığının artırılmasına xidmət edir.

Açar sözlər: dağ boz-qəhvəyi torpaqları, qranulometrik tərkib, biogen elementlər, WRB torpaq təsnifatı, torpaq diaqnostikası, Qazax-Tovuz iqtisadi rayonu

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Introduction

Soil resources play a fundamental role in ensuring agricultural productivity, ecological stability, and sustainable land use, particularly in regions with diverse natural and geomorphological conditions. In mountainous and foothill areas, soil formation is strongly influenced by relief, parent material, climate, and land use practices, resulting in high spatial variability of soil properties. Comprehensive assessment of soil morphological, physicochemical, and spatial characteristics is therefore essential for accurate soil classification, land evaluation, and the development of effective management strategies (Waghorn, 2008; Shukurov et. al., 2025).

The western region of the Republic of Azerbaijan, particularly the Gazakh-Tovuz economic region, is of considerable importance for national agricultural development due to its favorable agroclimatic conditions and long-standing tradition of crop production. However, increasing anthropogenic pressure, combined with complex relief and erosion-prone landscapes, necessitates detailed soil investigations to support sustainable land use planning. Among the dominant soil types of this region, mountain gray-brown soils are widely distributed and form the basis of agricultural activity, yet their diagnostic properties and spatial variability remain insufficiently studied under modern classification frameworks (Mueller-Harvey, 2006; Huseynov et. al., 2025).

Recent advances in soil science emphasize the integration of classical field and laboratory methods with geospatial technologies, such as geographic information systems (GIS), global positioning systems (GPS), and digital elevation models (DEMs). These tools enable more precise spatial analysis of soil properties and improve the reliability of soil mapping and land resource assessments. Moreover, the application of internationally recognized soil classification systems, such as the World Reference Base for Soil Resources (WRB), allows for standardized soil characterization and facilitates comparison with soils from other regions (Mammadov et. al., 2025).

Against this background, the present study aims to provide a comprehensive evaluation of mountain gray-brown soils in the Shamkir administrative region within the Gazakh–Tovuz economic zone. The research focuses on the assessment of morphological features, physicochemical properties, and key diagnostic indicators, including humus content, nutrient status, granulometric composition, soil reaction, and carbonate content. By combining detailed field observations, laboratory analyses, and geospatial modeling techniques, this study seeks to improve the understanding of soil variability and to establish a scientific basis for soil classification, land evaluation, and sustainable agricultural planning in the region (Interstate standard, 2019; Mustafayev et. al., 2025; Sadigov et. al., 2026a).

Materials and Methods

This study analyzes and synthesizes the results of long-term soil investigations conducted in the Gazakh-Tovuz economic region Shamkir administrative district since 2020. The research was conducted using large-scale topographic maps, geographic information system (GIS) software, and biogeographic route survey methods. Soil investigations were based on the soil–geographic comparative approach and morphological diagnostics carried out in accordance with FAO guidelines. Soil profile descriptions and horizon identification were performed following the international soil classification system of the World Reference Base for Soil Resources (WRB). Laboratory analyses were conducted using generally accepted and standardized soil analysis methods. The research focused on mountain gray-brown soils, which were correlated with the World Reference Base for Soil Resources (WRB) classification system. Based on this correlation, a digital soil map was compiled using the ArcGIS software package (Jabroil et al., 2013).

During field investigations, soil horizons were identified and indexed according to genetic principles, and their characteristics were harmonized with WRB diagnostic criteria and the national land classification parameters of Azerbaijan. The main objective of the study was to assess the current condition of mountain gray-brown soils formed within the Gazakh–Tovuz economic region through field surveys, determination of diagnostic indicators, and morphogenetic evaluation (State Standard of the Republic of Azerbaijan, Soil Quality, 2013).

Mountain gray-brown soil occupies an area of 10,522.55 hectares within the Gazakh-Tovuz economic region. The present research examined soil plots located in adjacent areas along predetermined survey routes during the period 2020-2025. Soil sections were established using modern georeferencing techniques, and their geographic coordinates were determined with a Garmin GPSMAP 62s device. In total, four representative soil profiles were described and analyzed. Soil horizons were differentiated within each profile, and key morphological features-including color, structure,

hardness, and horizon thickness-were recorded. Granulometric composition was also determined as a major diagnostic parameter (Sleugh et al., 2020).

Laboratory analyses were performed at the Ecology laboratory at the Azerbaijan State University of Economics using standardized methods. Soil humus content was determined by the Dry Combustion method following ISO 10694. Total nitrogen concentration was measured using the Dumas combustion technique. Available phosphorus was quantified using the Olsen or Bray extraction methods, as appropriate for the soil conditions. The granulometric composition of the soil was determined by laser diffraction particle-size analysis. Hygroscopic moisture content was assessed using automated thermogravimetric analyzers (TGA). Soil pH was measured potentiometrically in soil-water and soil-KCl suspensions using a digital pH meter in accordance with ISO 10390 (Figure 1) (Nelson and Sommers, 1996; Houba et al., 2000; Eshel et al., 2004; International Organization for Standardization, 1998; 2012; 2019; 2021).

Results and Discussion

The granulometric composition of soils is regarded as one of their principal genetic characteristics, exerting a significant influence on both physical and chemical soil properties. Along with texture, humus content and other biogenic elements constitute the basis of key morphological and diagnostic features of soils. In the present study, a comparative analysis of diagnostic indicators was conducted for all soil sections established within the study area, taking into account differences in erosion intensity. On this basis, the investigated soil profiles were evaluated accordingly (Khalilov et al., 2023; Huseynov et al., 2026).

Soil section No. 12 was established within an area occupied by mountain brown soils, with the primary objective of conducting a comparative assessment of their diagnostic indicators relative to those of mountain gray-brown soils. The results of physicochemical analyses of the non-eroded soil profile (Table 1) indicate that the soils are characterized by a heavy clay texture in the upper 0–16 cm layer, where the clay content reaches 76%. Throughout the profile, the proportion of physical clay particles (<0.01 mm) ranges from 71.60% to 72.0% in the middle and lower horizons, confirming the heavy clayey nature of the soil. The content of fine silt (<0.001 mm) varies from 32.00% in the surface horizon to 31.60–38.40% in the deeper layers. Soil bulk density averages 1.25 ± 0.12 g/cm³ (Gumbatov et al., 2024; Sadigov et al., 2026b).

Hygroscopic moisture content within the soil profile ranges from 6.95% to 7.19%. The thickness of the cultivated layer is 40–45 cm, while the sowing layer extends to a depth of 25–30 cm. The humus horizon is dark brown in color, with a humus content of 2.71% in the surface 0–16 cm layer, which is assessed as sufficient. A pronounced decrease in humus content is observed with increasing depth. In the middle horizons (44–73 cm), humus content decreases to 1.64%, corresponding to low humus status, while in the parent material at depths of 73–91 cm, it declines further to 0.77%, which is classified as very low. This vertical distribution of humus is characteristic and reflects typical pedogenetic processes (Haynes and Naidu, 1998).

The carbon-to-nitrogen (C:N) ratio remains relatively low, ranging from 9.6 to 9.0, indicating that soil organic matter is comparatively well supplied with nitrogen. Soil reaction throughout the profile is neutral, with pH values ranging from 7.12 to 7.40. The carbonate (CaCO₃) content in the surface horizon (0–16 cm) is 16.06%, decreasing slightly to 15.22% in the middle horizons (44–73 cm) and further to 13.36% in the parent material. Overall, the soils are classified as carbonated (Table 2) (Ayubov et al., 2025; Mirzezadeh et al., 2025).

The total amount of absorbed bases in the soil adsorption complex exhibited moderate variability along the soil profile. In the upper 0–16 cm horizon, the content of absorbed bases was 28.80 mmol eq·100/g soil, increasing to 31.0 mmol eq·100/g soil in the middle 39–57 cm layer, and further rising slightly to 33.7 mmol eq·100/g soil in the lower 101–137 cm horizon. Overall, the soil adsorption capacity was

evaluated as moderate. Based on the composition of exchangeable cations, the studied soils were classified as calcium–magnesium type.

Calcium (Ca) was the dominant cation within the adsorption complex throughout the profile. Its content amounted to 24.1 mmol eq·100/g soil (83.68%) in the upper horizon, 26.8 mmol eq·100/g soil (86.45%) in the middle layer, and 25.9 mmol eq·100/g soil (76.85%) in the lower horizon. In contrast, magnesium (Mg) contents were considerably lower, reaching 4.7, 4.2, and 7.8 mmol eq·100/g soil in the upper, middle, and lower horizons, respectively, corresponding to 16.32%, 13.55%, and 23.15% of the total absorbed bases (Table 2).

Consistent with the vertical distribution of humus, total nitrogen content showed a distinct decreasing trend with increasing depth. The highest total nitrogen concentration (0.21 %) was recorded in the upper 0–16 cm layer, declining to 0.168% in the middle part of the profile and to 0.048% in the parent material. Overall, the distribution pattern of nutrients in mountain gray-brown soils indicates a gradual reduction in nutrient availability with depth.

In non-eroded soils of this type, ammonium nitrogen (NH_4^+ -N) content was relatively high in the surface horizon (0–16 cm), reaching 121.16 mg/kg, and decreased to 86.45 mg/kg in the middle 39–57 cm layer and 64.37 mg/kg in the lower 101–137 cm horizon. In comparison, the content of mobile phosphorus (P_2O_5) was markedly lower, amounting to 24.44 mg/kg in the upper layer, 15.55 mg/kg in the middle layer, and 7.77 mg/kg in the parent material. Exchangeable potassium (K_2O), however, was present in relatively high concentrations, with values of 398.44 mg/kg in the upper horizon, 241.18 mg/kg in the middle horizon, and 126.52 mg/kg in the lower horizon (Table 2).

The diagnostic indicators of soil section No. 19, established on mountain gray-brown soils not subjected to erosion, were analyzed along the soil profile (Tables 1 and 2). The granulometric composition indicates that the upper 0–11 cm horizon is medium-textured clay soil, with a clay fraction of 69.0%. The proportion of physical clay (<0.01 mm) gradually increases toward the middle and lower horizons, reaching 75.40% in the 28–56 cm layer and 85.20% in the lower 82–105 cm layer, classifying these horizons as heavy clayey soils. The physical silt fraction (<0.001 mm) varies from 30.20% in the surface layer to 34.00–40.40% in the deeper layers. Soil bulk density averages $1.25 \pm 0.12 \text{ g/cm}^3$, and hygroscopic moisture content ranges between 5.45% and 6.69%. The cultivated layer has a thickness of 30–35 cm, while the sowing layer extends to 25–30 cm.

The humus layer exhibits a gray-brown color, with humus content of 1.86% in the upper horizon, assessed as low. Humus content decreases progressively with depth, reaching 1.45% in the middle horizon (28–56 cm) and 0.98% in the lower 82–105 cm layer, which is classified as very low. The C:N ratio ranges from 9.6 to 10.1. Soil reaction increases from weakly alkaline to moderately alkaline along the profile, with pH values ranging from 7.64 to 8.69. Carbonate content (CaCO_3) shows minimal variation along the profile, ranging from 14.16% to 17.75%, and the soils are thus classified as carbonate (Sadigov et al., 2026 c).

The total content of absorbed bases in the soil adsorption complex varies along the profile, being 25.60 mmol eq·100 g soil in the upper horizon, increasing slightly to 26.1 mmol eq·100 g in the middle horizon, and decreasing to 22.9 mmol eq·100 g in the lower horizon, corresponding to a sufficient absorption capacity. Calcium (Ca) is the dominant cation, with concentrations of 18.3 mmol eq·100 g in the surface horizon and 16.1 mmol eq·100 g in the lower horizon, representing 71.48% and 70.30% of total bases, respectively. Magnesium (Mg) contents are lower, ranging from 7.3 mmol eq·100 g in the surface layer to 6.8 mmol eq·100 g⁻¹ in the lower horizon (28.52–29.70%).

The vertical distribution of total nitrogen follows the humus pattern, decreasing from 0.112% in the upper 0–11 cm layer to 0.084% in the middle horizon and 0.056% in the parent material. Ammonium nitrogen (NH_4^+ -N) also declines with depth, from 51.34 mg/kg in the surface horizon to 42.09 mg/kg in the middle horizon and 26.38 mg/kg in the lower layer. Mobile phosphorus (P_2O_5) is relatively low,

with values of 11.11 mg/kg in the upper layer, 7.77 mg/kg in the middle horizon, and 4.44 mg/kg in the parent rock. In contrast, exchangeable potassium (K_2O) is high compared to other nutrients, amounting to 409.16 mg/kg in the surface layer, 351.49 mg/kg in the middle horizon, and 283.45 mg/kg in the lower horizon (Table 2).

The physical and chemical characteristics of soil section No. 25, established on uneroded mountain gray-brown soils in the Seyfali village area, were analyzed along the soil profile. Based on the granulometric composition, the upper 0–16 cm horizon is heavy clayey, with a clay fraction of 72.0%. In the middle part of the profile (33–92 cm), the clay content (<0.01 mm) increases to 78.40%, while in the lower 92–108 cm horizon, it decreases to 68.80%, corresponding to a medium-textured clay soil. The silt fraction (<0.001 mm) varies from 33.20% in the surface layer to 40.80–44.00% in the lower horizons. Hygroscopic moisture in the soil profile ranges from 4.82% to 5.93% (Mammadova et al., 2025; Sadigov et al., 2025).

Humus content in the upper 0–16 cm horizon is 2.59%, classified as sufficient, and decreases progressively with depth to 1.24% in the 33–92 cm layer (low humus) and 0.87% in the 92–108 cm horizon (very low humus), a typical pattern in these soils. Soil reaction along the profile is alkaline, with pH values ranging from 8.14 to 8.69. Carbonate content ($CaCO_3$) is relatively uniform, ranging from 11.61% in the surface layer to 11.81–10.97% in the lower horizons, indicating carbonated soils.

The total amount of absorbed bases in the soil adsorption complex varies along the profile. In the upper horizon, it is 22.90 mmol eq·100 g soil (sufficient), increasing to 50.8 mmol eq·100 g in the middle layer, and 44.1 mmol eq·100 g in the lower layer, classified as high. According to the cation composition, these soils are calcium–magnesium type. Calcium predominates, with concentrations of 16.1 mmol eq·100 g in the upper layer, 40.7 mmol eq·100 g in the middle horizon, and 30.4 mmol eq·100 g in the parent rock, accounting for 70.31%, 80.11%, and 64.96% of the total absorbed bases, respectively. Magnesium contents are also relatively high, ranging from 8.3 mmol eq·100 g in the surface horizon to 17.2 mmol eq·100 g in the 92–108 cm horizon, and 16.4 mmol eq·100 g below 108 cm, corresponding to 38.42%, 39.0%, and 35.04% of the total bases. The C:N ratio ranges from 9.7 to 11.8, indicating that humus is relatively well supplied with nitrogen.

Total nitrogen follows a decreasing trend with depth, ranging from 0.154% in the surface layer to 0.070% in the middle horizon and 0.048% in the parent rock. Similarly, ammonium nitrogen (NH_4^+-N) decreases from 23.34 mg/kg in the upper horizon to 16.49 mg/kg in the middle layer and 9.50 mg/kg in the lower horizon. Mobile phosphorus (P_2O_5) is relatively low, with values of 14.44 mg/kg in the surface horizon, 12.20 mg/kg in the middle horizon, and 8.90 mg/kg in the parent rock. Exchangeable potassium (K_2O) is relatively high compared to other nutrients, with concentrations of 410.15 mg/kg in the upper layer, 325.29 mg/kg in the middle layer, and 187.23 mg/kg in the lower horizon (Table 2).

The diagnostic indicators of soil section No. 98, established on uneroded mountain gray-brown soils, were analyzed along the soil profile. Based on granulometric composition, the upper 0–18 cm horizon is heavy clayey, with 74.0% clay content (<0.01 mm). In the middle 41–63 cm layer, clay content increases to 78.80%, and in the lower 87–110 cm horizon it reaches 83.60%, confirming the heavy clayey texture of these soils. The silt fraction (<0.001 mm) varies from 34.00% in the surface layer to 37.20% in the middle horizon and 38.80% in the parent rock. Hygroscopic moisture content in the upper horizon is 5.23%, and varies between 5.03% and 6.72% in the deeper layers.

The humus layer is gray-brown, with 2.64% humus in the upper 0–18 cm horizon, assessed as sufficient. Humus content decreases sharply with depth, reaching 0.67% in the middle 41–63 cm horizon (very low) and 0.41% in the 87–110 cm horizon (almost negligible). Soil reaction is moderately alkaline, with pH values ranging from 8.25 to 8.63 along the profile. The C:N ratio varies from 8.1 to 17.4 in the middle and lower horizons, indicating relatively high nitrogen availability in

the organic matter. Carbonate content (CaCO_3) is relatively uniform, ranging from 15.41% to 16.68%, classifying these soils as carbonated.

The total amount of absorbed bases in the soil adsorption complex is 27.40 mmol eq·100 g in the upper horizon (sufficient), decreases to 18.4 mmol eq·100 g in the middle horizon, and rises again to 21.6 mmol eq·100 g in the lower horizon, assessed overall as sufficient. Calcium predominates, with values of 16.9 mmol eq·100 g in the upper horizon, decreasing slightly to 13.7 mmol eq·100 g in the parent rock, accounting for 61.67% and 63.42% of the total absorbed bases, respectively. Magnesium shows higher values in the upper horizon (10.5 mmol eq·100 g), decreases to 3.7 mmol eq·100 g in the middle layer, and increases to 7.9 mmol eq·100 g in the parent rock, corresponding to 38.33% and 36.58% of the total bases.

Total nitrogen decreases along the profile from 0.164% in the surface layer to 0.048% in the middle horizon and 0.014% in the parent rock, consistent with the distribution of humus. Ammonium nitrogen ($\text{NH}_4^+\text{-N}$) decreases from 19.37 mg/kg in the upper horizon to 14.52 mg/kg in the middle horizon and 6.21 mg/kg in the lower horizon. Mobile phosphorus (P_2O_5) is low, ranging from 10.00 mg/kg in the upper layer to 7.77 mg/kg in the middle horizon and 5.60 mg/kg in the parent rock. Exchangeable potassium (K_2O) is relatively high compared to other nutrients, with concentrations of 241.56 mg/kg in the surface horizon, 165.12 mg/kg in the middle layer, and 106.42 mg/kg in the lower horizon (Tables 2 and 3).

The morphogenetic characteristics of mountain gray-brown soils in the Shamkir region were assessed considering natural climatic conditions and anthropogenic influences, with classification harmonized according to the international WRB system. Four representative uneroded and anthropogenically influenced soil sections (Soil sections: 12, 19, 25, and 98) were analyzed.

Section 12 - Shamkir, Tazakend village

Classified as Someric Calcic Kastanozems (Clayic, Humic), this soil exhibits a mollic layer (<20 cm) with high humus content in the upper 0-6 cm (3.52%) and 6-39 cm (3.31%). The humus layer is dark brown, granular, or nut-grained. Carbonate content (CaCO_3) ranges between 14.36-17.52%. The granulometric composition is silty clay, with particle-size fractions of <0.001 mm (28.00-42.00%), <0.01 mm (72.00-86.00%), and 0.005-0.001 mm (26.80-36.40%). The upper layers are rich in humic substances, reflecting a well-developed mollic horizon.

Section 19 - Shamkir, Sabirkand village

This section corresponds to Calcic Kastanozems (Clayic). The carbonate content varies between 14.16-17.75%. The granulometric composition is silty clay, with <0.001 mm fraction ranging from 33.20-40.40%, <0.01 mm from 74.80-88.40%, and 0.005-0.001 mm from 29.60-36.80%. The soil demonstrates typical characteristics of uneroded mountain gray-brown soils, with a moderately developed humus layer.

Section 25 - Shamkir, Seyfali village

Classified as Calcic Kastanozems (Clayic, Humic), this soil has a carbonate content of 10.97-11.81%. The granulometric composition is silty clay loam, with <0.001 mm fraction of 33.20-44.00%, <0.01 mm fraction of 68.80-76.40%, and 0.005-0.001 mm fraction of 22.00-27.20%. Humus content is high in the upper layers, reflecting good soil fertility and a well-preserved mollic horizon.

Section 98 - Shamkir, Seyidkand village

This section represents Terric Calcic Kastanozems (Anthric, Clayic, Humic). The carbonate content ranges from 15.41-16.68%. The soil exhibits Anthric properties due to long-term anthropogenic influence, including viticulture and grazing, which has impacted vegetation cover. The granulometric composition is silty clay, with <0.001 mm fraction of 28.80-39.60%, <0.01 mm fraction of 73.20-84.00%, and 0.005-0.001 mm fraction of 30.80-36.40%. The humic layer is relatively thick and nutrient-rich in the upper horizon, supported by anthropogenically improved forest strips.

Conclusion

The comprehensive study of mountain gray-brown soils in the Shamkir administrative region of the Gazakh-Tovuz economic region provides a detailed understanding of their morphogenetic, physical, and chemical characteristics. Field and laboratory analyses of four representative soil sections (Soil sections: 12, 19, 25, and 98) revealed that these soils are predominantly heavy clayey to medium-textured clay soil, with a significant proportion of fine clay and silt particles, which strongly influence their physical and chemical properties.

The morphogenetic diagnostics indicate that the studied mountain gray-brown soils are predominantly clayic and humus-rich in the upper horizons, with variation in carbonate content and anthropogenic influence reflecting local land use practices. These observations provide a robust framework for soil classification, land evaluation, and sustainable management in the Gazakh-Tovuz economic region.

Integration of granulometric, chemical, and morphogenetic analyses, together with geospatial mapping, provides a solid foundation for soil classification, land evaluation, and sustainable agricultural planning in the Gazakh–Tovuz region. The results highlight the potential of mountain gray-brown soils for productive agriculture while emphasizing the need for careful management of nutrients and erosion control to preserve soil fertility.

Table 1

Granulometric composition of uneroded mountain gray-brown soils, in %

№ of soil sections	Location	Genetic layers and depth, Cm	Particle diameter, mm							
			1-0,25	0,25-0,05	0,05-0,01	0,01-0,005	0,005-0,001	<0,001	<0,01	
1	2	3	4	5	6	7	8	9	10	
12	Shamkir	AUvz	0-16	1.19	6.81	16.00	13.40	30.60	32.00	76.00
	Tazakend village	AYvz	16-39	3.19	8.41	16.20	15.00	27.20	30.00	72.20
		Bvp	39-57	3.91	6.69	17.80	14.00	26.00	31.60	71.60
		B/Cca	57-101	3.00	4.80	19.20	13.60	31.40	28.00	73.00
		Cca	101-137	4.79	2.81	20.40	6.80	26.80	38.40	72.00
19	Shamkir	AYvaz	0-11	3.30	9.70	18.00	13.00	25.80	30.20	69.00
	Sabirkand village	AYaz	11-28	2.60	7.40	17.20	12.20	28.40	32.20	72.80
		Bca	28-56	2.50	7.50	14.30	13.80	27.60	34.00	75.40
		B/Ccap	56-82	0.61	2.59	11.60	10.80	34.40	40.00	85.20
		Cca	82-105	0.37	0.43	10.80	11.20	36.80	40.40	88.40
25	Shamkir	Ayvz	0-16	0.08	3.12	24.80	11.60	27.20	33.20	72.00
	Seyfali village	A/Bv	16-33	0.14	1.86	26.00	10.80	25.20	36.00	72.00
		Bvca	33-92	0.77	0.43	20.40	10.40	27.20	40.80	78.40
		B/Ccap	92-108	2.05	3.55	25.60	2.40	22.80	43.60	68.80
		Cca	below 108	0.38	1.62	21.60	10.40	22.00	44.00	76.40
98	Shamkir	AYvz	0-18	0.16	2.64	23.20	13.60	26.40	34.00	74.00
	Seyidkand village	A/Bcs	18-41	0.26	3.74	22.80	11.20	33.20	28.80	73.20
		Bca	41-63	0.27	1.73	19.20	9.20	32.40	37.20	78.80
		B/Cca	63-87	0.26	0.94	20.00	8.40	30.80	39.60	78.80
		Cca	87-110	0.17	1.03	15.20	11.60	33.20	38.80	83.60

Table 2

Indicators of humus and basic biogenic elements of uneroded mountain gray-brown soils

№ of soil sections	Location	Genetic layers and depth, cm	Hygroscopic moisture %	Humus %	C:N	CaCO ₃ %	pH	Absorbed bases (in 100 g. soil), mmol.eq.		Total absorbed bases, mmol.eq. per 100g soil	
								Ca	Mg		
1	2	3	4	5	6	7	8	9	10	11	
12	Shamkir	AUvz	0-16	6.35	3.52	9.7	17.11	7.10	24.1	4.7	28.8
	Tazakend village	AYvz	16-39	6.14	3.31	9.8	16.68	7.35	24.6	7.3	31.9
		Bvp	39-57	6.57	2.74	9.4	17.32	7.40	26.8	4.2	31.0
		B/Cca	57-101	4.60	1.14	9.4	17.52	7.73	22.8	9.1	31.9
		Cca	101-137	6.67	0.77	9.3	14.36	8.20	25.9	7.8	33.7
19	Shamkir	AYvaz	0-11	5.45	1.86	9.6	14.16	7.60	18.3	7.3	25.6
	Sabirkand village	AYaz	11-28	5.88	1.71	10.1	14.56	7.80	20.1	3.7	23.8
		Bca	28-56	6.47	1.45	10.0	14.16	8.10	18.7	7.4	26.1
		B/Ccap	56-82	6.09	1.08	8.9	17.75	8.64	15.5	9.7	25.2
		Cca	82-105	6.69	0.98	10.1	16.27	8.69	16.1	6.8	22.9
25	Shamkir	Ayvz	0-16	5.44	2.59	9.7	11.61	8.14	13.3	8.3	21.6
	Seyfali village	A/Bv	16-33	5.04	1.71	10.1	10.97	8.26	25.1	10	36.2
		Bvca	33-92	5.71	1.24	10.3	11.61	8.65	40.7	10.1	50.8
		B/Ccap	92-108	4.82	1.14	11.8	11.81	8.69	26.9	17.2	44.1
		Cca	below	5.93	0.87	10.5	11.18	8.63	30.4	16.4	46.8
98	Shamkir	AYvz	0-18	5.23	2.64	9.9	16.27	8.25	16.9	10.5	27.4
	Seyidkand village	A/Bcs	18-41	5.44	1.81	9.4	16.27	8.38	17.3	2.0	19.3
		Bca	41-63	5.03	0.67	8.1	15.41	8.57	14.7	3.7	18.4
		B/Cca	63-87	6.26	0.62	12.8	15.84	8.63	17.4	6.9	24.3
		Cca	87-110	6.72	0.41	17.4	16.68	8.47	13.7	7.9	21.6

Table 3

Assessment of mountain gray-brown soils according to diagnostic indicators (0-25 cm) (according to R.H. Mammadov)

Indicators	Assessment		
	Uneroded	Weakly eroded	Moderately eroded
Granulometric composition, <0.01mm, %	74.00	67.60	60.40
Carbonate CaCO ₃ , %	heavy clay	Medium-textured clay	Medium-textured clay
	16.27	15.21	13.95
	carbonated	carbonated	carbonated
Humus, %	2.64	1.94	1.66
	Enough	Low humus	Low humus
pH (in water solution)	8.25	8.15	7.45
	Medium alkaline	Medium alkaline	Low alkaline
Total absorbed bases, mmol.eq.	27.4	24.3	24.6
	Enough	Enough	Enough
Total Ca	16.9	16.0	17.3
	Medium calcium	Medium calcium	Medium calcium
Mg	10.5	8.3	7.9
	Low magnesium	Low magnesium	Low magnesium

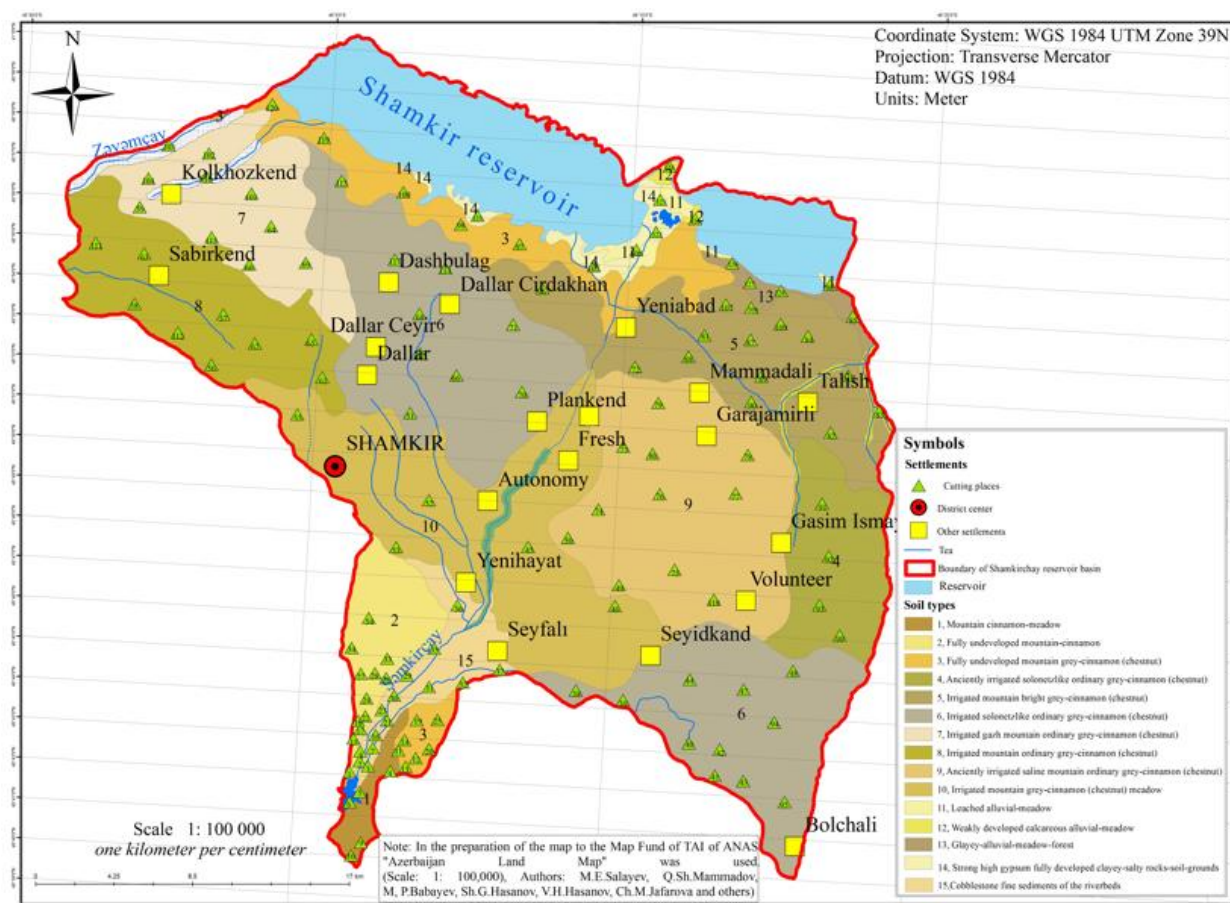


Figure 1
Land map of Shamkir district

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Age-Related Dynamics of Liver Morphometric Changes and Hemostasis Parameters in Rats Following Prenatal Hypoxia

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Abstract. To study the long-term consequences of severe intermittent prenatal hypoxia on liver structure and hemostatic system dynamics in rats at different postnatal developmental stages. Pregnant Wistar rats were exposed to normobaric hypoxia (5% O₂, 20 min/day) during embryonic, pre-fetal, or fetal gestation periods. Liver morphometric parameters (hepatocyte and nuclear areas, nuclear-cytoplasmic ratio) and hemostatic indicators (fibrinogen, activated partial thromboplastin time [aPTT], and plasma heparin tolerance [PHT]) were evaluated in offspring at 1, 3, and 6 months of age. At 1 month, hypoxia-exposed animals showed a 19–25% liver mass decrease versus controls ($p < 0.001$), hydropic hepatocyte degeneration, increased cell size, and systemic hypocoagulation. By 3 and 6 months, hepatocyte and nuclear sizes normalized. However, relative liver mass remained elevated ($p < 0.01$), with histology revealing persistent sinusoidal congestion and venous stasis. Concurrently, an age-related inversion from hypocoagulation to a procoagulant state occurred. In 6-month-old rats, fibrinogen increased, aPTT shortened, and PHT decreased to 56–77% of control values ($p < 0.01$). Severe prenatal hypoxia induces a biphasic adaptive response. Despite morphometric parenchymal recovery, hepatic vascular remodeling and microcirculatory disorders persist into adulthood, likely driving the development of a long-term procoagulant phenotype.

Keywords: blood coagulation, fetal programming, hepatocytes, microcirculation, venous stasis

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Prenatal hipoksiya təsirinə məruz qalmış siçovullarda qaraciyərin morfometrik göstəricilərinin və hemostaz sistemi parametrlərinin yaş dinamikası

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Xülasə. Tədqiqatın məqsədi postnatal inkişafın müxtəlif mərhələlərində kəskin prenatal hipoksiyanın siçovullarda qaraciyərin strukturuna və hemostaz sisteminin dinamikasına göstərdiyi uzunmüddətli təsirləri öyrənmək olmuşdur. Boğaz Wistar cinsli siçovullar rüşeym, dölünü və döl inkişaf mərhələlərində normobarik hipoksiyaya (5% O₂, gündə 20 dəqiqə) məruz qoyulmuşdur. 1, 3 və 6

aylıq yaş dövrlərində qaraciyərin morfometrik göstəriciləri (hepatositlərin və nüvələrin sahəsi, nüvə-sitoplazma nisbəti) və hemostaz parametrləri (fibrinogen, aktiv parsial tromboplastin müddəti və plazmanın heparinə tolerantlığı) qiymətləndirilmişdir. Bir aylıq yaşda prenatal hipoksiyaya məruz qalmış heyvanlarda nəzarət qrupu ilə müqayisədə qaraciyərin kütləsinin 19–25% azalması ($p < 0,001$), hepatositlərdə vakuolizasiya, hüceyrə ölçülərinin artması və sistemik hipokoaqulyasiya müşahidə olunmuşdur. Üç və altı aylıq yaşlarda hepatositlərin və onların nüvələrinin ölçüləri normallaşmışdır. Bununla belə, qaraciyərin nisbi kütləsi yüksək olaraq qalmış ($p < 0,01$), histoloji müayinədə isə sinusoidlərin davamlı dolğunluğu (konqestiyası) və venoz durğunluq aşkar edilmişdir. Eyni zamanda, yaş artdıqca hemostaz sistemində hipokoaqulyasiya vəziyyətindən hiperkoagulyasiya vəziyyətinə keçid baş vermişdir. Altı aylıq siçovullarda fibrinogenin konsentrasiyası artmış, aktiv parsial tromboplastin müddəti qismən qısalmış, plazmanın heparinə tolerantlığı isə nəzarət göstəricilərinin 56–77%-nə qədər azalmışdır ($p < 0,01$). Beləliklə, kəskin prenatal hipoksiya iki mərhələli adaptiv cavab reaksiyasının formalaşmasına səbəb olur. Qaraciyər parenximasının morfometrik göstəriciləri bərpa olunsada, qaraciyər damar sisteminin yenidən qurulması və mikrosirkulyasiya pozğunluqları yetkinlik dövründə davam edir və ehtimal ki, uzunmüddətli prokoagulyant fenotipin inkişafının əsas patogenetik mexanizmlərindən biri kimi çıxış edir.

Açar sözlər: qanın laxtalanması, dölün inkişafı, hepatositlər, mikrosirkulyasiya, venoz durğunluq

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Introduction

Prenatal hypoxia (PH) remains one of the most frequent causes of intrauterine developmental disorders and adverse perinatal outcomes. Oxygen deficiency during critical periods of ontogenesis can exert a long-term influence on the formation of fetal organs and systems. According to the Developmental Origins of Health and Disease (DOHaD) concept, adverse exposures during early developmental periods can program an increased susceptibility to various diseases in adulthood (Glukman et al., 2016). Experimental studies demonstrate that the consequences of prenatal hypoxia persist far beyond the neonatal period and are associated with an elevated risk of metabolic, cardiovascular, and neuroendocrine disorders (Vetrovoy et al., 2020; Vetrovoy et al., 2021, Smith et al., 2022, Ducsay et al., 2018). Recent studies in large animals also indicate that hypoxic pregnancy is accompanied by the development of fibrotic and metabolic changes in the fetal liver (McGuckin et al., 2025).

The fetal liver—a central metabolic organ that plays a crucial role in metabolism, hematopoiesis, and hemostasis regulation—is one of the primary targets of hypoxic injury. Accumulated data suggest that prenatal hypoxia can disrupt the growth and differentiation of hepatocytes, alter the formation of hepatic tissue, and lead to long-term metabolic consequences (McGuckin et al., 2025, Cao et al., 2019). Furthermore, antenatal hypoxic exposure has been shown to induce structural alterations in the liver, affecting not only the parenchyma but also the stromal-vascular component of the organ (Zotova et al., 2024).

Morphometric research methods are widely used to quantitatively assess the nature and severity of structural changes in the liver. Analysis of hepatocyte dimensions, their nuclear size, and the nuclear-cytoplasmic ratio allows for an objective evaluation of cell damage, compensatory hypertrophy,

polyploidization, and regeneration of liver tissue (Prus et al., 2021, Donne et al., 2021, Matsumoto et al., 2022).

The potential link between structural changes in the liver and disorders of the hemostatic system is of particular interest. Since the liver is the primary site for the synthesis of most clotting factors, fibrinogen, and natural anticoagulants, any changes in its structural and functional state can potentially alter the coagulation profile of the body (Tsaousi et al., 2023). It has previously been shown that prenatal hypoxia can lead to long-lasting alterations in the hemostatic balance of the offspring (Jafarova 2023). Structural damage to the sinusoidal endothelium of the liver, the development of endothelial dysfunction, and microcirculatory disorders are considered among the possible mechanisms underlying these impairments (Gracia-Sancho et al., 2021).

Despite a substantial body of research dedicated to the consequences of intrauterine hypoxia, most studies focus predominantly on the early postnatal period or isolated aspects of metabolic disorders. Meanwhile, the age-related dynamics of liver structural remodeling after prenatal hypoxia, the specifics of its postnatal recovery, and the potential relationship between morphological changes and hemostatic disorders remain insufficiently understood. In addition, the question of whether the gestational timing of the hypoxic exposure influences the nature and severity of long-term consequences remains unresolved.

In view of this, the objective of the present study was to investigate the age-related dynamics of liver morphometric parameters and hemostatic system indicators in rat offspring following exposure to severe intermittent prenatal hypoxia during different periods of intrauterine development.

Materials and Methods

Animals and Study Design. The study included 120 male Wistar rat offspring, examined at 1, 3, and 6 months of age. All procedures complied with EU Directive 2010/63/EU and were approved by the local Bioethics Committee (Protocol No. 3, April 27, 2021). Animals were housed under standard vivarium conditions (22 ± 2 °C, 50–60% humidity, 12-h light/dark cycle) with ad libitum access to water and pelleted feed. Pregnant females ($n = 74$) were randomly assigned to a control group (standard conditions) and three experimental groups exposed to prenatal hypoxia during specific gestational windows: embryonic (days 1–7), pre-fetal (days 8–14), and fetal (days 15–21) (Vetrovoy et.al., 2021, Graf et.al., 2022). To minimize litter effects and prevent pseudoreplication, only 1–2 males were randomly selected per litter. Each age and exposure subgroup comprised 10 independent biological replicates.

Modeling of Prenatal Hypoxia. Severe intermittent prenatal hypoxia was induced using a normobaric chamber. Pregnant females were exposed daily to a 5% O₂ / 95% N₂ gas mixture for 20 min during their assigned gestation period (Vetrovoy et al., 2021). Oxygen levels were continuously monitored using a gas analyzer. This established protocol effectively replicates severe hypoxic stress and placental insufficiency (Salyha & Oliynyk, 2023).

Biological Sample Collection. Under intramuscular ketamine anesthesia (0.1 mL/100 g body weight), blood was drawn from the inferior vena cava into 0.1 M sodium oxalate at a 10:1 ratio. The animals were then euthanized via an anesthetic overdose. Livers were rapidly excised, weighed to determine absolute mass, and sampled for histology.

Histological Examination and Liver Morphometry. Liver tissues were fixed in 4% neutral buffered formalin, paraffin-embedded, and sectioned (5 µm) for standard hematoxylin and eosin staining (Korzhevsky & Gilyarov, 2010). Sections were examined using an NU-2 Carl Zeiss microscope (Jena, Germany) equipped with a Motic digital camera. Blinded morphometric analysis was performed using Motic Images Plus 3.0. For each animal, at least 50 intact hepatocytes across five

non-overlapping fields ($\times 500$) were analyzed for cell and nuclear diameters and areas. The nuclear-cytoplasmic index (NCI) was calculated. Additionally, binucleated hepatocytes were counted across 50 random fields at $\times 500$ magnification (Prus et al., 2021).

Hemostasis System Assessment. Blood was centrifuged to isolate plasma. Coagulation parameters reflecting the coagulation potential and hepatic protein synthesis—fibrinogen concentration, activated partial thromboplastin time (aPTT), and plasma heparin tolerance (PHT)—were measured using a Coatron M semi-automated coagulometer (TECO Medical Instruments, Germany) and commercial Hemostat kits (Human GmbH, Germany).

Statistical Analysis. Data were analyzed in jamovi (v. 2.6.44) (jamovi project. 2024) and expressed as mean $\pm$ standard deviation ($M \pm SD$). Normality and variance homogeneity were verified using the Shapiro-Wilk and Levene's tests, respectively. Age-specific comparisons were conducted using one-way ANOVA with Tukey's post hoc test, or Welch's ANOVA with the Games-Howell post hoc test for heteroscedastic data. Statistical significance was set at $p < 0.05$.

Results

Liver Morphometric Changes

Changes in One-Month-Old Animals. At one month of age, the offspring exposed to prenatal hypoxia exhibited a statistically significant decrease in both absolute and relative liver mass compared to the control group (Table 1). The absolute liver mass was 19–25% lower than the control values ($p < 0.001$), while the relative organ mass decreased by 20–22% ($p < 0.001$). No statistically significant differences were found between the groups exposed to hypoxia at different gestational stages ($p > 0.05$).

Histological examination of the liver in control animals revealed a preserved parenchymal architecture with clearly contoured hepatocytes and centrally located nuclei. In the experimental groups, moderate vacuolization of the hepatocyte cytoplasm was observed, along with an increase in the size of the cells and their nuclei (Fig. 1A). The results of the morphometric analysis corroborated the histological findings. Hepatocyte diameter in the experimental groups exceeded the control values by 16–20% ($p < 0.01$ – 0.001), and the cell area was larger by 44–49% ($p < 0.05$) (Table 1). Similar changes were recorded for the nuclear apparatus: the nuclear diameter increased by 32–34%, and the nuclear area increased by 75–78% compared to the control.

The nuclear-cytoplasmic ratio was significantly elevated in the pre-fetal period group ($p < 0.05$), while a similar trend was observed in the other experimental groups. Furthermore, an increase in the number of binucleated hepatocytes was noted in the livers of the experimental animals (Fig. 1B). No statistically significant differences were detected among the experimental groups for the majority of the morphometric parameters ($p > 0.05$).

Table 1

Liver morphometric parameters in one-month-old offspring under normal development and after prenatal hypoxia at different stages of embryogenesis

Morphometric indicator	Control (n=10)	Embryonic period (n=10)	Pre-fetal period (n=10)	Fetal period (n=10)
Absolute liver mass, mg	2554.0 $\pm$ 53.9	1910.0 $\pm$ 12.6 ***	2010.0 $\pm$ 5.9 ***	2058.0 $\pm$ 54.5 ***
Relative liver weight, %	4.27 $\pm$ 0.04	3.32 $\pm$ 0.01 ***	3.40 $\pm$ 0.07 ***	3.41 $\pm$ 0.02 ***
Hepatocyte diameter, μ m	16.5 $\pm$ 0.9	19.2 $\pm$ 1.7 **	19.8 $\pm$ 1.9 ***	19.5 $\pm$ 1.1 ***

Nuclear diameter, μm	6.67 ± 0.50	$8.83 \pm 1.52^{**}$	$8.91 \pm 1.08^{***}$	$8.89 \pm 1.54^{**}$
Hepatocyte area, μm^2	206.7 ± 27.4	$297.0 \pm 73.6^*$	$307.8 \pm 90.8^*$	$298.5 \pm 87.4^*$
Nuclear area, μm^2	34.9 ± 18.4	$61.2 \pm 5.5^{**}$	$61.2 \pm 6.0^{**}$	$62.3 \pm 16.8^*$
NCI	0.20 ± 0.04	0.24 ± 0.02	$0.26 \pm 0.02^*$	0.24 ± 0.01

Note. Data are presented as $M \pm \text{SD}$. NCI — nuclear-cytoplasmic index. Statistical significance of differences compared to the control group: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Changes in Three-Month-Old Animals. By three months of age, the absolute liver mass of the animals in the experimental groups did not differ significantly from the control values ($p > 0.05$) (Table 2). However, the relative liver mass remained significantly higher in the embryonic ($p = 0.045$) and pre-fetal ($p < 0.001$) exposure groups. In most cases, the morphometric parameters of hepatocytes and their nuclei did not differ among the groups. The cell diameter and area, as well as the nuclear dimensions, were comparable to the control values (all $p > 0.05$).

In the pre-fetal exposure group, a significant decrease in the nuclear-cytoplasmic index was noted compared to the control ($p = 0.004$). In the other groups, the values of this parameter did not differ from those of the control. Despite the absence of pronounced differences in the primary morphometric parameters, histological examination of the livers from the experimental groups revealed sinusoidal dilation and blood stasis in the vascular bed (Fig. 1C).

Table 2

Liver morphometric parameters in three-month-old offspring under normal development and after prenatal hypoxia at different stages of embryogenesis

Morphometric indicator	Control (n=10)	Embryonic period (n=10)	Pre-fetal period (n=10)	Fetal period (n=10)
Absolute liver mass, mg	5600 ± 606.7	5283 ± 418.3	5300 ± 104.9	5237 ± 86.2
Relative liver weight, %	4.06 ± 0.05	$4.12 \pm 0.03^*$	$4.23 \pm 0.07^{***}$	4.12 ± 0.04
Hepatocyte diameter, μm	20.2 ± 2.95	20.8 ± 2.4	20.1 ± 2.1	20.3 ± 1.7
Nuclear diameter, μm	11.0 ± 1.09	11.3 ± 1.03	11.0 ± 1.2	11.2 ± 1.7
Hepatocyte area, μm^2	324.3 ± 89.9	350.0 ± 79.4	317.1 ± 62.5	323.5 ± 71.2
Nuclear area, μm^2	96.0 ± 18.6	101.7 ± 17.5	94.9 ± 16.1	98.5 ± 17.3
NCI	0.30 ± 0.02	0.28 ± 0.01	$0.26 \pm 0.02^{**}$	0.28 ± 0.01

Note. Data are presented as $M \pm \text{SD}$. Statistical significance of differences compared to the control group: $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Changes in Six-Month-Old Animals. At six months of age, the absolute liver mass did not differ among the studied groups (Table 3). At the same time, the relative liver mass remained significantly higher in the embryonic ($p = 0.005$) and pre-fetal ($p = 0.008$) exposure groups compared to the control. The diameter and area of hepatocytes, as well as their nuclear dimensions, exhibited no statistically significant differences among the groups (all $p > 0.05$).

The nuclear-cytoplasmic index was significantly lower than the control values in the pre-fetal and fetal exposure groups ($p < 0.01$).

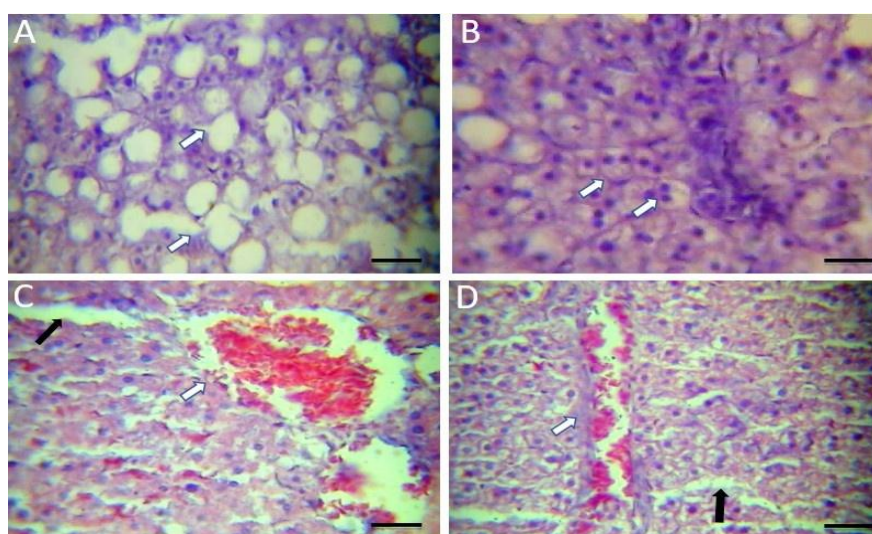
Table 3

Liver morphometric parameters in six-month-old offspring under normal development and after prenatal hypoxia at different stages of embryogenesis

Morphometric indicator	Control (n=10)	Embryonic period (n=10)	Pre-fetal period (n=10)	Fetal period (n=10)
Absolute liver mass, mg	9583 ± 421.5	9250 ± 160.4	9373 ± 179.6	9271 ± 212.2
Relative liver weight, %	3.72 ± 0.09	3.87 ± 0.07 **	3.85 ± 0.01 **	3.73 ± 0.03
Hepatocyte diameter, µm	22.67 ± 2.1	22.83 ± 1.8	22.71 ± 2.1	22.80 ± 2.0
Nuclear diameter, µm	12.3 ± 0.82	12.6 ± 1.24	12.3 ± 1.14	12.2 ± 1.7
Hepatocyte area, µm ²	406.0 ± 74.8	409.1 ± 83.1	404.9 ± 71.6	408.1 ± 73.8
Nuclear area, µm ²	119.8 ± 16.7	124.6 ± 17.9	118.7 ± 16.7	116.8 ± 14.5
NCI	0.30 ± 0.01	0.30 ± 0.02	0.28 ± 0.01 **	0.28 ± 0.01 **

Note. Data are presented as M ± SD. Statistical significance of differences compared to the control group: *p < 0.05, **p < 0.01, ***p < 0.001.

Histological examination of the livers from the animals in the experimental groups revealed persistent sinusoidal dilation and signs of venous congestion (Fig. 1D).

**Figure 1**

Representative photomicrographs of liver tissue in rats exposed to prenatal hypoxia: (A) hydropic vacuolization of hepatocytes and (B) binucleated hepatocytes in 1-month-old animals; (C) sinusoidal dilatation and blood stasis in 3-month-old animals; (D) sinusoidal dilatation and blood stasis in 6-month-old animals. Hematoxylin and eosin staining. Scale bars = 50 µm.

Hemostasis Parameters

One-Month-Old Animals. At one month of age, the fibrinogen concentration was significantly lower than the control values in all experimental groups (p < 0.001) (Fig. 2). The lowest values were recorded in the embryonic exposure group. Intergroup differences were also statistically significant (p < 0.001). The aPTT values in all experimental groups exceeded the control values (p < 0.001) (Fig. 3). The maximum values were registered in the animals of the embryonic exposure group. Plasma tolerance to heparin was also significantly higher than the control level in all experimental groups (p

< 0.001) (Fig. 4). However, there were no differences among the embryonic, pre-fetal, and fetal exposure groups ($p > 0.05$).

Three-Month-Old Animals. By three months of age, the fibrinogen concentration in all experimental groups exceeded the control values ($p < 0.001$); however, no differences were detected among the experimental groups. The aPTT value remained significantly lower than the control level in all prenatal hypoxia groups ($p \leq 0.006$). Analysis of plasma tolerance to heparin revealed statistically significant differences among the groups (Welch's ANOVA, $p < 0.001$). In the embryonic and pre-fetal exposure groups, the values of this parameter were lower than those of the control, whereas no statistically significant differences from the control were observed in the fetal exposure group.

Six-Month-Old Animals. At six months of age, the fibrinogen concentration remained above the control level in all experimental groups ($p < 0.001$). The maximum values were recorded in the animals of the fetal exposure group. The aPTT value in all experimental groups remained lower than the control values. The lowest values were found in the embryonic exposure group, which differed significantly from the other experimental groups ($p < 0.001$). Plasma tolerance to heparin was reduced in all prenatal hypoxia groups compared to the control (Welch's ANOVA, $p < 0.001$). Furthermore, statistically significant differences were identified among all experimental groups: the maximum values were noted in the embryonic exposure group, while the minimum values were in the fetal exposure group.

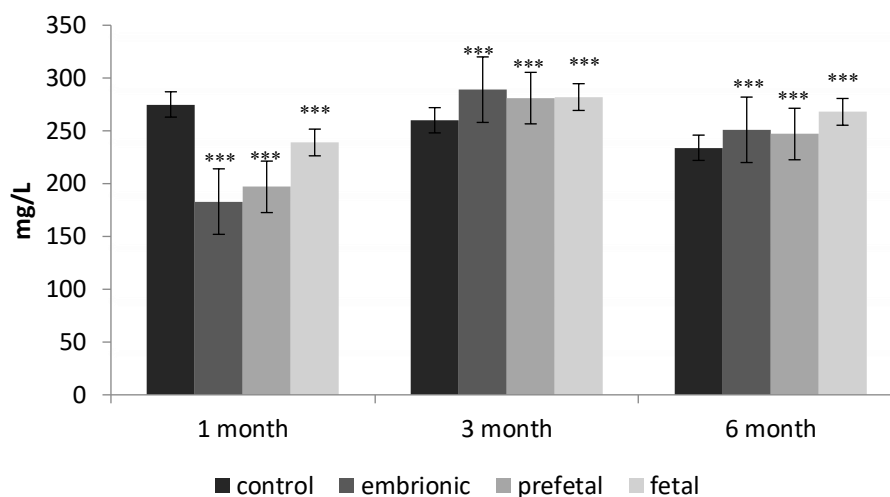


Figure 2
Age-related changes in plasma fibrinogen concentration in offspring rats after prenatal hypoxia

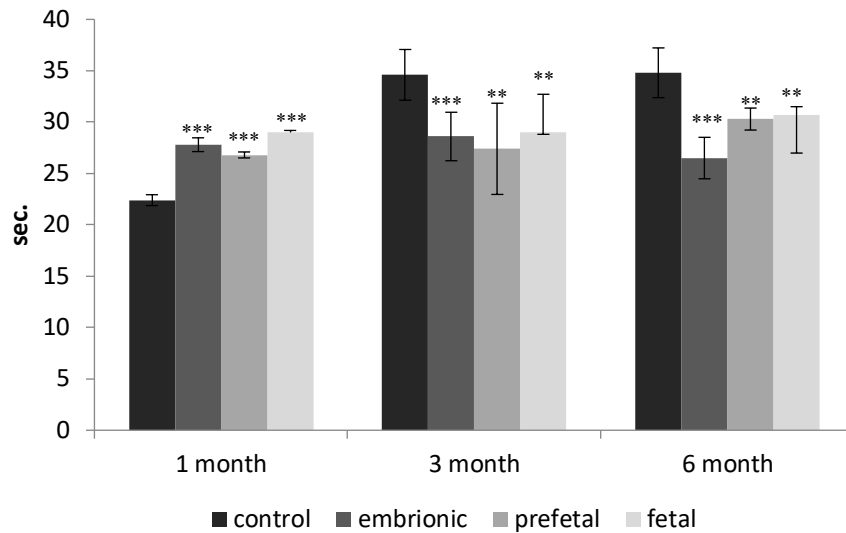


Figure 3

Age-related changes in activated partial thromboplastin time (aPTT) in offspring rats after prenatal hypoxia

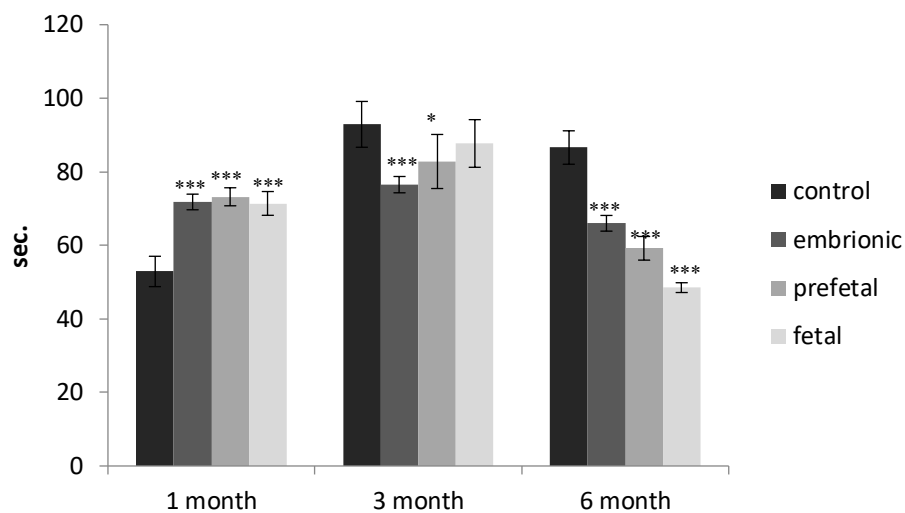


Figure 4

Age-related changes in plasma heparin tolerance (PHT) in offspring rats after prenatal hypoxia

Discussion

The main finding of the present study is the identification of the biphasic nature of postnatal adaptation of the liver and hemostatic system to severe prenatal hypoxia. The obtained data indicate an age-related inversion of the coagulation profile in rat offspring—a transition from early hypocoagulation to a persistent procoagulant state in adulthood. The findings suggest that this condition is associated with persisting histological signs of intrahepatic microvascular bed dilation, which remains even against the background of substantial, albeit incomplete, morphometric recovery of the parenchyma.

Our results expand upon the classical DOHaD (Developmental Origins of Health and Disease) concept (Gluckman et al., 2016). It has been previously shown that prenatal hypoxia is associated with long-term metabolic, cardiovascular, and neuroendocrine disorders in offspring (Sutovska et al., 2022). However, the present data indicate that the consequences of prenatal hypoxia affect not only

the hepatic parenchyma but also the vascular component of the liver. Based on the obtained findings, a two-stage hypothetical model for the pathogenesis of the identified disorders can be proposed.

During the first month of life, the most obvious consequence of the experienced hypoxia was severe liver hypoplasia (the organ mass deficit was 19–25%). The mass reduction was combined with hydropic degeneration of hepatocytes, which is a classic consequence of hypoxic injury associated with impaired energy metabolism and water-electrolyte balance (Kumar et al., 2020). The obtained morphometric data may indicate the activation of compensatory mechanisms: hepatocyte hypertrophy, an increase in the nuclear-cytoplasmic index, and the formation of binucleated cells. These features reflect the activation of polyploidization processes—an evolutionarily conserved mechanism for rapid adaptation and functional mass increase without complete mitosis (Donne et al., 2021). Nevertheless, this structural immaturity translates directly into a functional deficit. The systemic hypocoagulation recorded in one-month-old animals (decreased fibrinogen levels, prolonged aPTT) is logically explained by the suppression of the protein-synthetic activity of immature hepatocytes.

By three and six months of age, hepatocyte sizes and their nuclear parameters had largely approached the control values. Although the sizes of most cells and nuclei normalized, persistent changes in the nuclear-cytoplasmic ratio were recorded in some groups. Nonetheless, the observed dynamics confirm the significant regenerative potential of the liver, ensuring the restoration of parenchymal cellular homeostasis (Ma et al., 2025). However, the normalization of hepatocyte morphology was not accompanied by the restoration of the vascular component. In adult animals, the persistence of sinusoidal dilation and venous stasis was histologically confirmed. The relative liver mass in certain experimental groups remained elevated. This aligns with current data indicating that the specific features of vascular network formation in the early neonatal period determine the final organ size and can contribute to its long-term remodeling (Azizoglu et al., 2025, Brancatelli et al., 2018, Haddadin et al., 2024).

Particular attention should be given to the identified association between persistent sinusoidal dilation and the development of hypercoagulation in adult rats (increased fibrinogen levels, shortened aPTT, decreased plasma tolerance to heparin). Similar long-term impairments in hemostatic regulation following antenatal hypoxic exposure have been previously described in both experimental and clinical studies (Tsauosi et al., 2023, Jafarova, 2023); however, the mechanisms maintaining them remain a subject of debate. Liver sinusoidal endothelial cells (LSECs) act as key regulators of vascular tone and homeostasis (Gracia-Sancho et al., 2021, Qu et al., 2024). Chronic alterations in sinusoidal architecture can disrupt endothelial mechanosensitivity and attenuate its anticoagulant properties (Gao et al., 2024). Histological signs of venous stasis may reflect local hemodynamic disturbances. According to the literature, such architectural changes are consistent with the development of LSEC dysfunction and local hypoxia (Gao et al., 2024), which is hypothesized to act as a prothrombotic trigger mediating systemic hypercoagulation (Ortega-Ribera et al., 2023). In this context, the progressive decrease in plasma tolerance to heparin may align with the hypothesis of weakened endothelial anticoagulant properties.

Despite the general trend of the changes, individual parameters varied depending on the timing of the intrauterine hypoxic exposure. This confirms the existence of specific "windows of vulnerability" in the developing liver and requires targeted investigation in future studies. The limitations of this study include the lack of direct molecular assessment of LSEC dysfunction markers and angiocrine signaling. Future work should focus on deciphering the specific molecular cascades (including, for example, the HIF-1 α signaling pathway) (Qing et al., 2024) linking vascular remodeling to hemostatic complications.

Conclusion

Thus, the study results demonstrate that prenatal hypoxia induces a biphasic adaptive response involving early liver hypoplasia and hypocoagulation, followed by the recovery of hepatocyte morphometric characteristics but with the persistence of vascular remodeling signs and the development of a procoagulant phenotype. The obtained data suggest that long-term impairments of hepatic microcirculation may serve as a crucial link connecting intrauterine hypoxic exposure with delayed hemostatic disorders in adulthood.

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Results of Genetic Studies Conducted on Pome Fruit Plants in the Northern Regions of Azerbaijan

Nazaket Huseynova 

Abstract. *This work examines the genetic diversity of local and introduced fruit crop varieties common in the mountainous regions of Azerbaijan, analyzes their current status, examines their biomorphological features, identifies them using molecular markers, and determines their degree of genetic relatedness. The degree of genetic similarity between varieties was assessed using cluster analysis. Genotypic assessment of the gene pool was conducted using hybridological analysis, differential staining, and PCR analysis of chromosomes. Fruit plants collected from orchards were selected according to relevant regulations. In this study, we conducted a genetic evaluation of material including 14 apple and 15 pear varieties. Genetic diversity of the breeding samples was analyzed using six SSR markers. SSR marker polymorphism ranged from two to eight alleles per locus. The SSR markers used in the study proved to be a reliable genotyping tool for the studied crops. Furthermore, based on the high observed heterozygosity values of the selected varieties, it can be concluded that the parental pairs selected for the cross are genetically distinct. Thus, the study and genetic analysis of the tested genomes allows us to identify the most effective genes and preserve the genetic diversity of cultivated samples and avoid genetic depletion of the gene pool. A comprehensive study of a collection of apple and pear trees using six SSR markers revealed a high number of heterozygotes, indicating significant genetic diversity in the parental pairs. The analysis conducted in this study, in turn, makes it possible to establish kinship relationships within the sample under evaluation. Thus, genetic analysis using SSR is a reliable means for reliably assessing parental forms. Conserving the genetic diversity of cultivated pear and apple varieties, as well as introduced forms of these plants, is a key focus in the development of new varieties in modern horticulture. When developing a variety, selecting parental pairs that possess a combination of positive traits is crucial. Years of research on these traits have resulted in the identification of varieties of interest for use in breeding research.*

Keywords: *genotype, gene pool, genetic markers, selection, clustering, genetic diversity*

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Azərbaycanın şimal bölgələrində tumlu meyvə bitkiləri üzərində aparılmış genetik tədqiqatların nəticələri

Nəzakət Hüseynova 

Xülasə. *Bu tədqiqat Azərbaycanda dağlıq bölgələrdə geniş yayılmış yerli və introduksiya olunmuş meyvə bitkisi sortlarının genetik müxtəlifliyinin öyrənilməsinə, onların mövcud vəziyyətinin təhlilinə, biomorfoloji xüsusiyyətlərinin araşdırılmasına, molekulyar markerlər vasitəsilə identifikasiyasına və*

genetik qohumluq dərəcəsinin müəyyən edilməsinə həsr edilmişdir. Sortlar arasında genetik oxşarlıq dərəcəsi klaster analizi əsasında qiymətləndirilmişdir. Genofondun genotipik qiymətləndirilməsi hibridoloji analiz, xromosomların differensial boyanması və PZR (PCR) analizi vasitəsilə həyata keçirilmişdir. Bağlardan toplanmış meyvə bitkiləri müvafiq normativ tələblərə uyğun olaraq seçilmişdir. Tədqiqat çərçivəsində 14 alma və 15 armud sortunu əhatə edən materialın genetik qiymətləndirilməsi aparılmışdır. Seleksiya materiallarının genetik müxtəlifliyi altı SSR markeri vasitəsilə təhlil edilmişdir. SSR markerlərinin polimorfizmi hər lokus üzrə iki ilə səkkiz allel arasında dəyişmişdir. Tədqiqatda istifadə olunan SSR markerləri öyrənilən bitki nümunələrinin genotipləşdirilməsi üçün etibarlı vasitə olduğunu təsdiq etmişdir. Bundan əlavə, seçilmiş sortlarda müşahidə olunan yüksək heteroziotluq göstəricilərinə əsasən belə nəticəyə gəlmək olar ki, hibridləşdirmə üçün seçilmiş valideyn cütlükləri genetik baxımdan əhəmiyyətli dərəcədə fərqlənirlər. Beləliklə, tədqiq olunan genomların öyrənilməsi və genetik təhlili ən effektiv genlərin müəyyən edilməsinə, becərilən nümunələrin genetik müxtəlifliyinin qorunmasına və genofondun genetik tükənməsinin qarşısının alınmasına imkan verir. Alma və armud kolleksiya nümunələrinin altı SSR markeri əsasında aparılmış kompleks tədqiqatı yüksək heteroziotluq səviyyəsini aşkar etmiş və bu da valideyn cütlüklərinin yüksək genetik müxtəlifliyə malik olduğunu göstərmişdir. Aparılmış analiz qiymətləndirilən nümunələr daxilində qohumluq əlaqələrinin müəyyən edilməsinə də imkan yaratmışdır. Beləliklə, SSR markerləri əsasında aparılan genetik analiz valideyn formalarının etibarlı qiymətləndirilməsi üçün etibarlı üsul hesab edilə bilər. Becərilən alma və armud sortlarının, eləcə də bu bitkilərin introduksiya olunmuş formalarının genetik müxtəlifliyinin qorunması müasir bağçılıqda yeni sortların yaradılmasının əsas istiqamətlərindən biridir. Yeni sortların yaradılması prosesində müsbət təsərrüfat əhəmiyyətli əlamətlərin optimal kombinasiyasına malik valideyn cütlüklərinin seçilməsi mühüm əhəmiyyət kəsb edir. Bu xüsusiyyətlər üzrə uzunmüddətli tədqiqatlar seleksiya işlərində istifadə üçün perspektivli sortların müəyyən edilməsinə imkan vermişdir.

Açar sözlər: *genotip, genofond, genetik markerlər, seleksiya, klasterləşmə, genetik müxtəliflik*

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Introduction

Global changes in weather and climate conditions are prompting a new perspective on work carried out in the fields of genetics and breeding, leading to the creation of new varieties, the renewal of fruit plants, and the development of more resilient species. Taking into account the changing climatic factors of nature, new requirements are emerging for varieties cultivated in horticulture and fruit growing. Today, the species of fruit plants, including local and introduced samples, are expected to demonstrate high adaptability, complex resistance to major diseases, as well as increased productivity and production capacity (Gurbanov, 2014). Breeding is the main tool in creating new generations of fruit plants. Both classical and modern selection methods form the basis of breeding. By using these methods, it has become possible to obtain new elite forms, varieties, clones, and so on. Alongside classical selection, one of the methods for expanding the range of fruit plants has been introduction (Ərəbzadə, 2021). During the introduction process, the adaptation of plants of different ecological and geographical origin to specific conditions is determined. More adaptive varieties are observed to adapt more quickly to certain conditions. The genetic diversity of plants, especially the creation of resistant forms of pome fruit crops (apple, pear, quince), the comparative analysis of their genomes, and their adaptation to ecological changes are of great importance. Year by year, nature, climate, and soil cover change and undergo modification; the use and potency of pesticides increase, and their

application causes continuous and serious damage to the environment, human health, and biodiversity. From this point of view, it is highly relevant to carry out scientific research in several directions. First, the complete preservation of the gene pool of the studied plants is essential so that it can serve as a basis in the future for creating new species with more resilient genes. Second, diversity in natural habitats and cultivated areas is decreasing day by day. One of the main tasks is the purposeful collection of a significant part of plant genetic diversity from across the entire country, its comprehensive study using modern methods, and its reliable conservation. Characterization of the collected genetic material, identification of the potential of plants based on key biological and breeding traits, genetic passportization of each sample in the collection, evaluation according to quality indicators, and the investigation of the immunological and molecular-genetic bases of resistance all contribute to the formation of a genetic foundation. Research is also being carried out to measure genetic variability, in other words, the degree of polymorphism, for the study and use of plant diversity (Hüseynova, 2024).

At present, fruit plant varieties are identified according to morphological traits. This has certain shortcomings. Morphological features appear late during development stages and may be influenced by environmental conditions. They make it difficult to distinguish closely related genotypes and to control the varietal purity of planting material. The difficulties of morphological identification make it necessary to search for new, more convenient, and reliable identification methods. DNA identification methods are a justified choice because of their advantages over classical methods. Molecular methods make it possible to detect differences between genotypes at the DNA level, where such differences are represented most completely. They do not require phenotypic expression of a trait, can be used at any stage of plant development, and significantly reduce the time required for varietal identification, which is especially important for perennial plants. However, at present, universal DNA identification methods for fruit plants do not exist. This is partly due to the lack of knowledge about the genetic diversity of varieties cultivated in different countries and the level of polymorphism in individual regions of fruit crop genomes. The territory of the Republic of Azerbaijan is located in subtropical and partly temperate climatic zones. Of the 11 climate types existing on Earth, 9 and most soil types are found within the country.

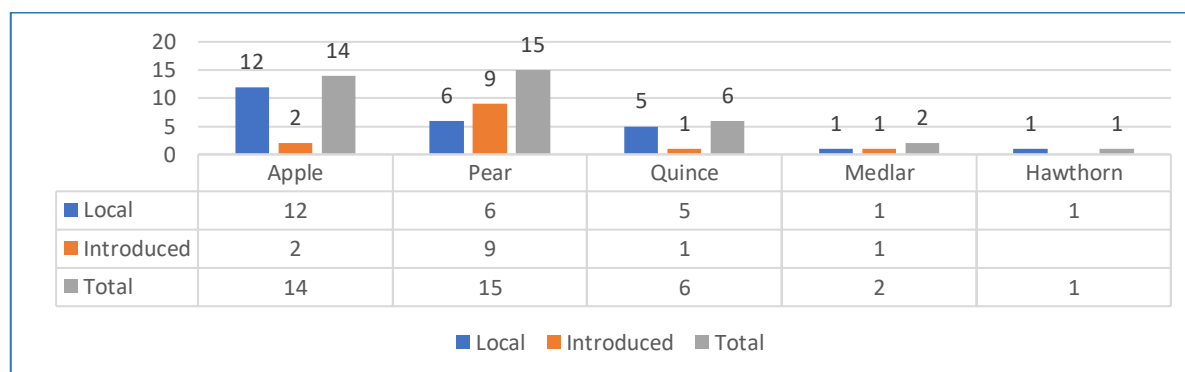
The main soil types in our country include mountain-meadow, brown mountain-forest, chestnut mountain-forest, yellow, chestnut, gray and gray-brown soils, saline soils, and solonchaks, among others. Fruit growing is a major branch of agriculture in Azerbaijan and plays a key role in supplying the population with fruit products and industry with raw materials. Agriculture accounts for 35–40% of the gross domestic product (Sadigov, 2019, Sadigov, 2023). The research presents the results of a comprehensive evaluation of the primary material. The main aim of the work was to increase the efficiency of breeding by incorporating genetic methods into the breeding process, evaluating the gene pool and its influence on the genotype, and significantly improving varietal parameters in terms of fruit adaptability, productivity, and commercial quality. The genotypic evaluation of the gene pool was carried out using hybridological analysis, differential staining, and PCR analysis of chromosomes. Given the considerable value of pome fruit plants, it is important to systematically study and conserve the rich gene pool of both wild and cultivated forms of these fruit trees. Genetic diversity is an important component of the genetic characteristics of a population, a group of populations, or species. Assessing genetic diversity is important for monitoring genetic variability in both wild and cultivated plant species and populations; the genetic data obtained provide information for developing strategies for their conservation and sustainable use.

The study of genetic diversity is based on morphological, biochemical, and molecular markers. Molecular markers are genetic markers analyzed at the DNA level. Classical genetic terms such as locus, allele, and dominant and codominant inheritance patterns apply to them. The alleles of marker loci are different forms of the same marker located at the same positions (loci) on homologous chromosomes, differing in nucleotide length and/or nucleotide substitutions. The main objectives in

selecting fruit plants collected from orchards are as follows: the creation of varieties with high universal commercial quality, frost resistance, drought resistance, and high productivity. The main methods of classical breeding of fruit plants are intraspecific and distant hybridization, which make it possible to obtain new genotypes in generative generations as a result of gene recombination (Urbanovich, 2015). The fruit plants used in the study are presented in Diagram 1. This article presents the results of the genetic analyses of two species—apple and pear. The genetic results of other plants will be presented in the next article.

Diagram 1

Species of the fruit plants studied



apple – 14, pear – 15, quince – 6, medlar – 2, hawthorn - 1.

The numbers shown along the x-axis represent the number of varieties

Materials and Methods

Starting from 2015, the soil and climatic conditions of the Guba–Gusar, Khachmaz, and Sheki–Zagatala regions of the republic were analyzed, and it was noted that they are fully suitable for the cultivation of the studied fruit crops—apple and pear. Under the conditions of the northern region of our republic, the economic and biological characteristics of a number of previously known and newly introduced varieties of two fruit species (apple and pear) were studied under different cultivation practices, planting schemes, and types of orchards (Huseynova & Asadova, 2024). To identify genetic diversity and kinship relationships among fruit plant samples, their DNA was extracted according to the CTAB protocol proposed by Rogers. PCR reactions were performed, and the obtained amplification products were analyzed by electrophoresis in agarose gels (Rogers, 1985). PCR products were analyzed using an ABI 3500 capillary electrophoresis system.

Nuclear DNA extraction from apple and pear genotypes was carried out in the Biotechnology Laboratory. 2 grams of leaf samples were taken from each genotype, ground into powder using liquid nitrogen, and collected in 2 ml Eppendorf tubes for DNA extraction. DNA extraction was carried out according to the CTAB (cetyltrimethylammonium bromide) protocol proposed by S.O. Rogers (1985), in the following sequence (Rogers, 1985).

1. 100 mg of the obtained plant powder was poured into a 2 ml tube. 1000 µl of CTABx2 (2% CTAB, 0.1 M Tris HCl (pH=8.0), 1.4 M NaCl, 20 mM EDTA) solution and 1% β-mercaptoethanol (pH=8.0) pre-heated at 65°C are added to 100 mg of plant powder poured into Eppendorf tubes and mixed well using a vortex until a homogeneous mass is formed;
2. The resulting suspension is placed in a water bath (65°C) for 20 minutes, inverting every 5 minutes;
3. After removing the tubes from the water bath and cooling them at room temperature for 5-10 minutes, 700 µl of chloroform (isoamyl alcohol (24:1) (XIS)) is added to the suspension, inverted 20-25 times, and then kept on ice for 30 minutes. In this way, all remaining protein and phenol-containing compounds, except for nucleic acids, are dissolved;

4. The mixture is centrifuged at 14,000 rpm for 5 minutes, and then the supernatant obtained is poured into a new 2 ml tube;
5. XIS is added again to repeat this step;
6. In order to precipitate the DNA, 800-850 µl of cold isopropanol is added to the supernatant obtained, and the Eppendorf tube is covered with parafilm, mixed thoroughly, and placed in a refrigerator to remain at -20°C for 1 day;
7. Samples from -20°C are centrifuged at 14000 rpm for 1 minute; 8. After pouring the supernatant into a new tube, cold washing solution (76% ethanol and 10 mM ammonium acetate) is added to it twice and placed in the centrifuge again;
8. The obtained DNA should be kept at room temperature for 30 minutes to dry and 100 µl of TE (ph:8) should be added to it. This DNA solution is used as a stock solution;
9. After measuring the amount of DNA in a spectrophotometer, 1 µl of RNase is added and kept at 37°C for 30 minutes.

The quality of the extracted DNA was checked on a 1% agarose gel prepared in TBEx1 (18 mM Tris-HCL, 18 mM Boric acid, 100 mM EDTA, pH 8.0) buffer. The mixture prepared for quality checking consisted of 2 µl of extracted DNA, 4 µl of dye, and 1.5 µl of distilled water. The gel was stained with 0.5 µg/ml ethidium bromide solution, viewed under ultraviolet light, and images were visualized using the Bio-Rad Gel Documentation system. The total volume of the PCR mixture was 20 µl. The volume of each reaction mixture was 2 µl of DNA, 2 µl of 10X buffer [10 mM Tris-HCl pH 8.0, 50 mM KCl, 1.5 mM MgCl₂], 2 µl of dNTP (at 5 mM), 0.5 µl of enzyme. O3 to H3.O3-, 0.2 µl of Taq polymerase were used. The polymerase chain reaction was initiated by denaturing the DNA at 94°C for 5 minutes in the amplification apparatus and was performed in 3 conditions– 1 minute at 94°C for denaturation, 45 seconds at 40-60°C (and 5 minutes) for annealing the used primer to the DNA.

After the reaction was prepared, the Eppendorf tubes were placed in a PCR apparatus (Gene Amp 9700 Applied Biosystems thermocycler). The polymerase chain reaction began with DNA denaturation at 94°C for 3 minutes after placement in the amplifier and continued in three stages. These three stages were repeated one after the other for 35 cycles. It ended with incubation at 72°C for 5 minutes. Genotyping based on SSRs with fluorescent labeling, determination of allele sizes, and characterization of polymorphic loci were carried out according to the method proposed by Schuelke (Edwards, Johnstone, Thompson, 1991; Karaca, 2008). PCRs were conducted using dyes 6-FAM, NED, PET, and VIC (Bavykin, 2017).

The study of genetic parameters using SSR markers was carried out using the PowerMarker V3.25 software (Schuelke, 2000). The number and frequency of alleles, expected heterozygosity, observed heterozygosity, genetic diversity, and polymorphism information content (PIC) were calculated based on genetic parameters amplified with SSR primers.

Using ISSR primers, statistical parameters such as polymorphism information content (PIC) (Garkava-Gustavsson, 2008), effective multiplex ratio, marker index (MI) (Powell, 1996), resolving power (RP), and mean resolving power (MRP) were calculated to assess the efficiency of genetic analysis in fruit samples. Genetic parameters based on ISSR markers were analyzed using the DARwin 6.0 software (Reales, 2010). Cluster analysis was performed using ISSR and SSR primers. The Jaccard genetic similarity index was determined using UPGMA, and genetic distance indices were analyzed using the NTSYS software.

Results and Discussion

The similarity of fruit genotypes cultivated under natural mountainous conditions was evaluated based on their quantitative traits. In addition, the application of SSR and ISSR molecular marker technologies has proven to be more effective in studying polymorphism and genetic diversity within fruit collections. SSR and ISSR molecular markers are independent of environmental factors and are

highly important because they allow evaluation at any stage of plant development. Thus, the analysis of morphological traits and molecular analyses of fruit genotypes makes it possible to identify genetically similar genotypes and avoid ineffective combinations in the breeding process. At the same time, apple varieties such as Golden Ahmed, Shirvan Gozali, Sini, Rajabi, Karbalayi Jafar, Vahidi, Sari Tursh, Cir Haji, Aq Alma, Arazbeyi, Sari Sinab, Gusar Alma, Papirovka, Slava Pobeditelyan, which were selected for their fruit taste and durability, can be used in the creation of new varieties on farms. For genetic analysis, leaf samples were collected from varieties and forms of fruit plants characterized by their biodiversity and biomorphological traits across different regions. Information on allele combinations of SSR markers in the studied apple varieties is presented in Table 1. The sizes of the amplified fragments are given in base pairs.

Table 1
Allelic polymorphism of SSR markers in apple varieties

No.	Variety / locus	CH03d04	CH582493	CH04a03	CH03f02	Hi16e02	CH02b03a
1	Qizil Ahmædi	97/99	200/202	189	143	134/154	157
2	Shirvan gozeli	97/103	190/200	190	84	141/158	164
3	Sini	118/120	202/218	86	125/126	145	168
4	Recebi	102/103	200/208	192	143	143	169
5	Kerbalayi Cafar	106	194/212	200	140	141	165
6	Vahidi	105	202/204	189	142	144	166
7	Sari tursh	114/118	192/208	184	127/128	143	165
8	Cir Haci	95/105	200	185	130	144/166	165
9	Ag alma	103	192/202	184	123	143	173
10	Arazbeyi	95/100	190/196	196	140	141	164
11	Sari sinab	105/116	208	193	128	145	166
12	Qusar alma	96/102	208	190	125	142	165
13	Papirovka	104	193/203	185	123	145	170
14	Slava pobeditelyan	95/100	192/196	198	143	143	168

It can be observed from the table that the values of heterozygosity, characterized by the simultaneous presence of two amplification fragments of different sizes, vary significantly. The maximum level of heterozygosity was detected at the CH03d04 and CH582493-SSR loci. In contrast, low levels of heterozygosity were observed at the CH03f02, Hi16e02, and CH02b03a loci. At the CH04a03 locus, a homozygous state was identified in all studied varieties. Based on comprehensive information on the sizes of amplification sequences and allele frequency, the degree of genetic similarity among the studied apple varieties was evaluated. For this purpose, cluster analysis was applied, and the results of clustering were reflected in a dendrogram.

Based on the second direction of analysis of genetic diversity of apple varieties and species, an optimal set of SSR markers was developed, allowing for reliable identification of individual samples. The information content of each marker, the frequency of alleles among varieties, and the ease of analysis of amplification fragments were taken into account (Table 2).

Table 2

Allele characteristics calculated for apple species and hybrid samples

Marker name	Number of alleles A_s	Observed heterozygosity H_e	Expected heterozygosity H_g	Effective number of alleles A_{ef}	Wright's index R	Quantity of unique genotypes	Proportion of unique genotypes	Marker Assisted Selection MAS
CH03d04	15	0.82	0.49	5.2	0.42	37	0.336	0.9022
CH582493	13	0.85	0.74	5.9	0.14	35	0.308	0.9283
CH04a03	9	0.77	0.62	4.4	0.32	20	0.178	0.8702
CH03f02	16	0.82	0.58	5.2	0.32	38	0.345	0.9220
Hi16e02	42	0.92	0.72	16.68	0.28	84	0.770	0.9844
CH02b03a	19	0.90	0.46	9.08	0.51	37	0.335	0.9412
Average	19	0.85	0.60	7.7	0.33	41.8	0.378	0.9248

A_s – number of calculated alleles, H_e – observed heterozygosity, H_g – expected heterozygosity, A_{ef} – effective number of alleles, R – Wright's index, number and proportion of unique genotypes, and marker discriminating power (MAS). Using the proposed set of 6 SSR markers, the average number of detected alleles among the studied samples was 19, while the average number of unique genotypes was 41.8. The proportion of unique genotypes averaged 0.378, and MAS was 0.9248.

DNA identification using SSR markers enables effective and reliable identification of apple genotypes obtained through cross-pollination. However, clonal mutants of apple trees are also known, which differ phenotypically from the original forms and from each other in fruit size and color, crown shape and size, branching patterns, etc. Some of these can be classified as independent varieties, which is of great practical importance in identifying clonal mutants of apple trees. In modern intensive horticulture, the mobilization and conservation of genetic diversity of cultivated pear varieties and their wild relatives is one of the key aspects in the development of new varieties. Parent selection—choosing pairs with a combination of desirable traits—is very important in breeding diversity (Plugatar et al., 2018).

In the studied regions, 15 pear species were investigated. Of these, 6 are local varieties—Abbasbeyi, Chirnadiri, Aday pear, Nar pear, Ahmad Ghazi, and White Ordubadi; while 9 are introduced varieties—Williams, Red Williams, Bere Bosc, Kure, Clapp's Favorite, Bere Ardanpon, Pass Crassan, Forest Beauty, and Devechi (Table 3). The best rootstocks for pear varieties are wild pear species, quince, hawthorn, and bird pear. Pear varieties in Azerbaijan, including the Caucasian wild pear, are derived from wild pear species. In arid mountainous areas, willow-leaved wild pear develops well and serves as a good rootstock for cultivated varieties. The fruits of cultivated pears are larger, juicier, and more delicate than those of wild pears.

Studies demonstrate a high level of genetic diversity, confirming that pear is a valuable breeding resource.

Table 3
Some agrobiological characteristics of pear plant species

Plant	Variety	Origin	Ripening period	Leaf area (cm ²)	Fruit weight (g, avg)		Fruit diameter (cm)	Fruit height (cm)	Quality indicators				
					average	maximum			Dry matter (%)	Total sugar %	Vitamin C (mg%)	Marketable yield (%)	Storage period (days)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
PEAR	1. Abbasbeyi	Local selection	Summer	22.4	6	7	5.2	7.5	14.5	7.7	4.7	70	23
	2. Chirnadiri		Summer	21.5	110	115	5.3	7.4	13.6	7.6	5.3	75	25
	3. Aday pear		Summer	22.0	75	83	4.8	6.3	12.5	6.5	6.3	70	22
	4. Nar pear		Autumn	24.4	53	64	11.4	11.3	13.3	8.4	5.5	75	56
	5. Ahmad Ghazi		Autumn	24.5	125	153	10.4	11.3	14.3	7.6	5.5	79	30
	6. White Ordubadi		Summer	22.0	134	156	5.6	7.4	12.3	8.3	5.7	83	27
	7. Williams		Summer	21.3	115	121	6.9	7.4	10.1	8.3	8.2	76	30
	8. Red Williams	Introduced variety	Summer	24.0	124	130	6.6	7.3	10.3	8.5	8.7	77	28
	9. Bere Bosc		Winter	22.5	120	128	6.1	7.5	12.4	8.3	7.3	70	60
	10. Cure		Winter	21.2	130	135	6.1	7.5	13.1	7.6	7.5	70	65
	11. Clapp's Favorite		Summer	26.2	108	119	7.3	9.5	12.1	8.4	6.6	75	23
	12. Bere Ardanpon		Winter	23.5	120	133	7.2	8.5	12.2	7.5	7.3	75	60
	13. Pass Crassan		Autumn	27.7	113	121	8.5	12.9	12.2	8.3	5.6	73	32
	14. Forest Beauty		Summer	26.5	135	139	6.8	10.5	14.1	7.7	4.6	75	34
	15. Devechi		Autumn	23.0	115	125	6.4	7.1	12.6	8.1	4.5	77	63

The average observed heterozygosity (H_e) for pear varieties across the studied loci was 0.78, while for apple varieties it was 0.85. Pear varieties, like apple varieties, are characterized by a relatively high level of heterozygosity ($H_g = 0.60$, $F = 0.33$), which is facilitated by cross-pollination typical for both pear and apple. The average number of informative alleles among pear varieties was 6.49, which is slightly lower than that of apple (7.5). Among pear samples, the maximum values for this indicator were obtained using the CH582493 and CH03f02 markers—11.09 and 5.26, respectively; for apple, the maximum value was obtained using the CH04h04 marker—16.68.

The genetic distance among samples ranged from 0.11 to 0.30. Similarity was detected in the genomes of some pear varieties, indicating that these varieties form a separate group. A more detailed explanation of these findings will be provided in the next article.

Table 4

Allelic characteristics calculated for pear species and hybrid samples

Marker name	Number of alleles A_s	Observed heterozygosity H_e	Effective number of alleles A_{ef}	Expected heterozygosity H_g	Wright's index R	Quantity of unique genotypes	Proportion of unique genotypes	Marker Assisted Selection MAS
CH03d04	8	0.70	3.50	0.77	0.07	18	0.397	0.8740
CH582493	20	0.90	11.09	0.47	0.45	34	0.814	0.9682
CH04a03	10	0.76	4.35	0.61	0.24	17	0.373	0.8710
CH03f02	12	0.79	5.26	0.46	0.43	20	0.444	0.8958
Hi16e02	15	0.68	3.33	0.52	0.29	16	0.396	0.7573
CH02b03a	16	0.88	9.09	0.76	0.18	26	0.654	0.9342
Average	13	0.78	6.10	0.59	0.27	22.0	0.513	0.8835

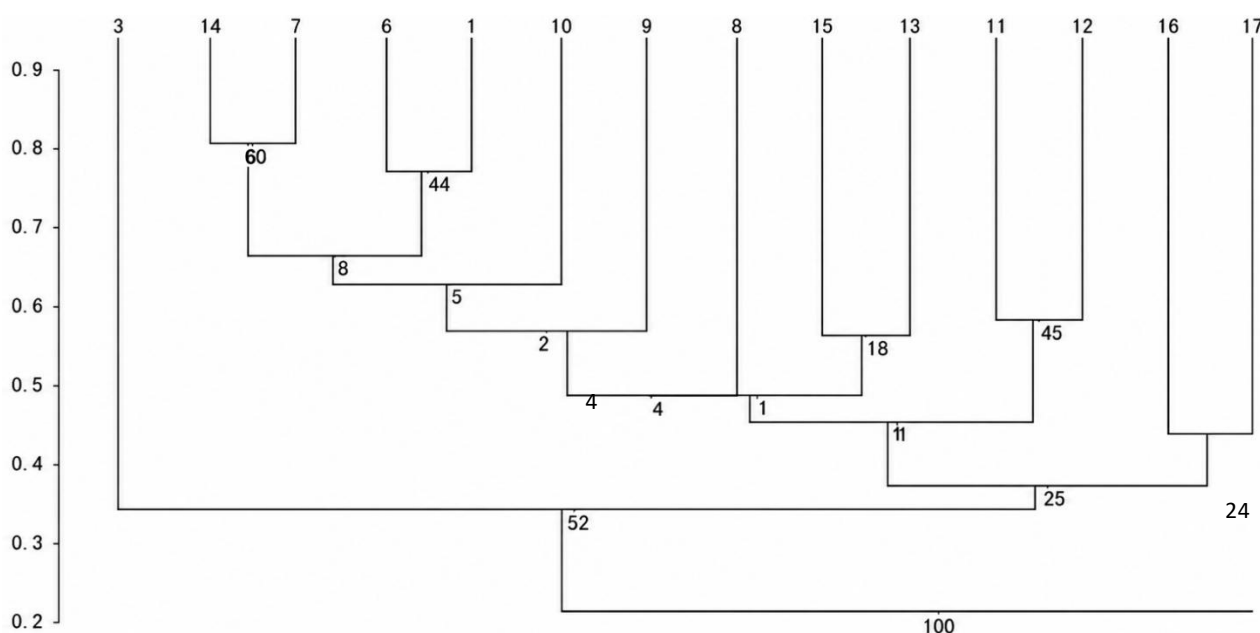
A_s – number of calculated alleles, H_e – observed heterozygosity, H_g – expected heterozygosity, A_{ef} – effective number of alleles, R – Wright's index, number and proportion of unique genotypes, marker discriminating power (MAS).

The analysis of marker informativeness for DNA identification of pear varieties resulted in the selection of six highly polymorphic SSR markers that demonstrated successful performance in identifying apple varieties. This marker set revealed a high proportion of unique genotypes among pear samples (0.513) (Table 4). The discriminating power (MAS) of the markers was high across all loci, ranging from 0.7573 for the Hi16e02 marker to 0.9682 for the CH582493 marker, with an average value of 0.8835. Indicators characterizing the informativeness of individual markers in pear and apple genomes showed slight differences. The calculations presented in the table indicate that the marker set CH03d04, CH582493, CH04a03, CH03f02, Hi16e02, CH02b03a is effective for identifying pear genotypes.

Based on the polymorphism data of SSR markers, an analysis of the degree of genetic similarity among the studied pear varieties was carried out, allowing the evaluation of genetic relationships within the studied genotype samples (Khlestkina, 2013). To analyze genetic polymorphism in the studied group consisting of 15 varieties, six microsatellite DNA markers were used. SSR markers showed significant variation in the level of polymorphism: from 3 alleles (for the CH582493 marker) up to 11 alleles per locus. Cultivated apple varieties are genetically highly diverse. They form different groups, including both modern and traditional varieties, as well as varieties bred abroad.

According to the results of cluster analysis, two main groups (clusters) can be identified among the studied varieties. Cluster 1 includes Aday pear, White Ordubadi, Nar pear, Chirnadiri, and Ahmad Ghazi pear varieties. Cluster 2 includes Williams, Red Williams, Bere Bosc, Cure, Clapp's Favorite, Bere Ardanpon, Pass Crassan, Forest Beauty, and Devechi pear varieties. The Abbasbey pear variety forms a separate branch in the dendrogram.

According to the results of cluster analysis, although not completely, there is a relationship between the grouping of samples within subclusters and the regions where they were collected. The microsatellite markers used in this study can be applied in the future for the identification and differentiation of fruit tree genotypes.



Picture 1
Clustering of pear varieties

Based on the results of the cluster analysis, it can be noted that although not completely at the cluster level, a relationship is observed between the grouping of samples within subclusters and the districts where they were collected. The microsatellite markers used in our study can be applied in the future not only for distinguishing apple and pear genotypes but also for other pome fruit species. Genetically highly distinct forms that were isolated in the dendrogram and formed independent groups were identified. The varieties Williams and Forest Beauty, located in Cluster 2, possess rare alleles and can be used as important varieties in future breeding and genetic studies. Within each geographical region, both genetically close and distant genotypes were identified. The Bere Bosc and Pass Crassan varieties collected from the Guba region were placed in the same group, showing a higher degree of similarity. The Abbasbey pear variety was separated into an independent branch of the cluster and is distinguished by its rare alleles.

The expected heterozygosity level of pear varieties reached a minimum value of 0.46 at the CH03f02 locus. The highest heterozygosity level was observed for the CH02b03a locus (0.76). The average heterozygosity level for the studied genotypes was 0.52. In the studied apple samples, the heterozygosity level at the same locus was, on average, 0.58. In this study, a marker-assisted selection strategy was applied to obtain hybrid apple seedlings with комплекс resistance to scab, powdery mildew, fire blight, and red gall aphid, as well as to identify genotypes associated with extended storage life of apples.

Conclusion

1. Gene blocks of fruit plant varieties responsible for certain biologically valuable traits were identified using DNA and PCR analysis, partially passportized, and genotyped.
2. Approaches for the development, identification (using marker traits), and preservation of valuable genotypes used in the creation of new fruit plant varieties, pure lines, and hybrids characterized by high morphological and biological uniformity, productivity, and marketability were examined.
3. Modern molecular genetic and biotechnological approaches, along with the acceleration of hybridization and selection processes, were demonstrated. Additionally, a system for genotype identification and DNA certification of the studied apple and pear varieties was developed. The applied method is based on the use of SSR markers detected via polymerase chain reaction (PCR).

This method is suitable for performing genetic analysis of any plant organ at various stages of ontogenesis.

4. For developing DNA identification methods for fruit plant varieties, an SSR-based approach is recommended. The choice of identification method is based on criteria such as efficiency, reliability, stability, accuracy, high reproducibility, and ease of result documentation. Apple species, varieties, and hybrids cultivated in the studied regions of Azerbaijan are characterized by high genetic diversity at microsatellite loci observed heterozygosity (H_e) = 0.85, expected heterozygosity (H_g) = 0.60, effective number of alleles (A_{ef}) = 7.7, Wright's index (R) = 0.3, number of alleles (A_s) = 19. Rare and wild species contribute significantly to the overall allelic diversity.

5. A set of 20 SSR markers, experimentally validated for effectiveness, is recommended for clarifying the pedigree and origin of apple varieties. A DNA identification system for apple varieties and species genotypes has been developed. The method is based on six highly informative SSR markers: CH03d04 (MAS = 0.9022), CH582493 (MAS = 0.9283), CH04a03 (MAS = 0.8702), CH03f02 (MAS = 0.9220), Hi6e02 (MAS = 0.9844), and CH02b03a (MAS = 0.9412). This method allows the creation of a unique molecular genetic profile for apple genotypes and enables the identification of apple varieties, interspecific hybrids, and wild species. The proposed method also allows verification of apple varieties for compliance with DUS (Distinctness, Uniformity, Stability) criteria.

6. Pear varieties cultivated in Azerbaijan are characterized by high genetic diversity of SSR loci alleles (H_e = 0.78, H_g = 0.59, A_{ef} = 6.10, R = 0.27, A_e = 13). Both closely related and genetically distant varieties, as well as interspecific hybrids, were identified.

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TEXNİKA ELMLƏRİ
TECHNICAL SCIENCES

Gasohydrodynamic Testing of Gas and Gas-Condensate Reservoirs and Wells

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Abstract. *The article outlines the steady-state gasohydrodynamic methods used for testing gas and gas-condensate reservoirs and wells. To select downhole equipment for wells characterized by abnormally high reservoir pressure, indicator diagrams were constructed in the form of curved lines. As a result of these studies, all reservoir and well parameters, including optimal flow rates, drawdowns, allowable dynamic bottomhole pressures, the amount of mechanical impurities, reservoir pressure and temperature, were determined. A two-term inflow equation was used, and the coefficients a and b were determined graphically. In addition, formulas for calculating these coefficients for hydrodynamically complete (perfect) wells are provided. For hydrodynamically incomplete (imperfect) wells, formulas for the incompleteness coefficients C_1 , C_2 , C_3 , and C_n , as well as for the inflow equation parameters a and b , are presented. The values of these coefficients and parameters were also determined using numerical methods, and the corresponding formulas are provided. The indicator diagrams, i.e., the curves showing the dependence of gas flow rates on dynamic bottomhole pressures, were linearized, and the parameters a and b of the inflow equation were determined graphically. The indicator curves pass through the origin, are concave with respect to the flow-rate (abscissa) axis, and represent monotonically increasing functional relationships.*

Keywords: *gas reservoirs, gas-condensate reservoirs, gas wells, gas-condensate wells, two-term inflow equation, equation parameters, imperfection coefficients, degree of reservoir penetration, nature of reservoir penetration*

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Qaz və qaz-kondensat laylarının və quyularının qazohidrodinamik tədqiqatları

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Xülasə. Məqalədə qaz və qaz-kondensat laylarının və quyularının qazohidrodinamik tədqiqatının stasionar üsulları şərh edilmişdir. Anomal yüksək lay təzyiqinə malik bu quyular üçün quyudaxili avadanlığın seçilməsi məqsədilə indikator diaqramları ayrılər şəklində qurulmuşdur. Bu tədqiqatlar nəticəsində layın və quyunun bütün parametrləri (optimal debitlər, depressiyalar, buraxıla bilən dinamik dib təzyiqləri, mexaniki qarışıqların miqdarı, lay təzyiqi, lay temperaturu və s.) müəyyən edilmişdir. İkihədli axın tənliyindən istifadə edilmiş, tənliyin a və b əmsallarının qiymətləri qrafiki yolla təyin edilmişdir; bu əmsalların hesablanması üçün hidrodinamik tamamlanmış quyulara aid düsturlar da verilmişdir. Hidrodinamik tamamlanmamış quyular üçün C_1 , C_2 , C_3 və C_n natamamlıq əmsallarının, həmçinin a və b əmsallarının hesablanması üçün lazım olan düsturlar təqdim edilmişdir. Bu əmsalların qiymətləri ədədi üsullarla da təyin edilmişdir (müvafiq düsturlar verilmişdir). Indikator ayrıləri, yəni qaz debitlərinin quyudibi dinamik təzyiqlərdən asılılığını göstərən ayrılər qurulmuş, axın tənliyinin a və b əmsalları qrafiki yolla təyin edilmişdir. Indikator ayrıləri koordinat başlanğıcından keçir, debitlər (absis) oxuna nisbətən çökəkdir və artan monoton funksional asılılıqları ifadə edir.

Açar sözlər: qaz layları, qaz-kondensat layları, qaz quyuları, qaz-kondensat quyuları, ikihədli axın tənliyi, tənliyin parametrləri, natamamlıq əmsalları, layın açılma dərəcəsi, layın açılma xarakteri

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Introduction

To select modern downhole equipment for gas and gas-condensate wells with abnormally high reservoir pressure, it is necessary to test the wells using gasohydrodynamic methods under steady-state filtration regimes. These methods are based on determining the relationships between the flow rates and dynamic bottomhole pressures of various wells. As a result of these studies, the following are determined: the dependence of the gas flow rate on the drawdown applied to the reservoir, and the changes in wellhead pressure, bottomhole pressure, annulus pressure, and temperature as a function of the well flow rate; the amount of liquid and solid impurities produced during various operating regimes of the well; deformations and failures of the bottomhole zone of the reservoir; the accumulation and removal of failure products, and filtration resistance; the technological regime of well operation, taking various factors into account; the hydraulic resistance coefficient; and the effectiveness of remedial and preventive maintenance during additional perforations in the well, bottomhole consolidation, bridge setting, etc (Ahmed, 2006; Ahmed, 2019; Briksman et al., 1996). Testing under steady-state regimes is conducted starting from lower flow rates and moving toward higher flow rates (forward course). In each regime, complete stability of pressure and flow rate must be achieved. The acquired data are used to construct indicator diagrams. The first point is selected

where the pressure and flow rate remain unchanged. After measuring the stabilized pressure, flow rate, and temperature at the bottomhole, wellhead, and annulus, and determining the amount of liquid and solid impurities in the given regime, the well is shut in until P_{res} (reservoir pressure) is reached. The pressure buildup process is also continuously recorded. After processing (interpreting) the obtained pressure buildup curve, the reservoir parameters are determined. Here, it is also established whether there is a reservoir pressure anomaly; by comparing it with the normal reservoir pressure, it is determined whether it is greater or smaller (Craft & Hawkins, 1959).

Materials and Methods

This method is conducted with no fewer than 4–5 forward regimes and 2–3 reverse regimes. Under steady-state filtration regimes, the two-term formula for processing test results has the following form:

$$P_{res}^2 - P_{wf}^2 = aQ + bQ^2 \quad (1)$$

Where a and b are the filtration resistance coefficients, respectively, which depend on the design parameters of the bottomhole zone of the reservoir; Q is the well flow rate; P_{res} and P_{wf} are the reservoir and dynamic bottomhole pressures, respectively (Gimatudinov, 1978; Katz et al., 1959; Lee, 2003). For hydrodynamically complete wells under radial filtration, coefficients a and b are expressed by the following formulas:

$$a = \frac{\mu z P_{at} T_{res}}{\pi k h T_{st}} \ln \frac{R_c}{r_w} \quad (2)$$

$$b = \frac{P_{at}^2 P_{at} T_{res}}{2\pi^2 l h^2 T_{st} r_w} \left(1 - \frac{r_w}{R_c}\right) \quad (3)$$

For an incomplete well, based on the degree and nature of reservoir penetration, these coefficients are expressed as follows:

$$a = a^* \left(\ln \frac{r_w}{R_c} + C_1 + C_2 \right), a^* = \frac{\mu z P_{at} T_{res}}{2\pi^2 \ln T_{st}} \quad (4)$$

$$b = b^* \left(\frac{1}{r_w} - \frac{1}{R_c} + C_3 + C_4 \right), b^* = \frac{P_{at} z P_{at} T_{res}}{2\pi^2 \ln T_{st}} \quad (5)$$

Where C_1 , C_2 and C_3 , C_4 are the incompleteness coefficients determined according to the degree and characteristics of reservoir penetration, respectively:

$$C_1 = \frac{1}{h} \ln \bar{h} + \frac{1-\bar{h}}{\bar{h}} \ln \frac{b}{R_s} \quad (6)$$

$$C_2 = 1/\bar{h} \quad (7)$$

Where $\bar{h} = h_{penet}/h$ is the relative penetration thickness of the reservoir;

$$R_s = r_w/h \text{ is the relative radius of the well, and } \delta = 1,6(1 - \bar{h}^2).$$

The values of coefficients C_1 , C_2 depend significantly on the non-uniformity of the porous medium's permeability. For uniform anisotropic reservoirs:

$$C_1 = \frac{1}{v} \ln \frac{\bar{R}^v - x}{\bar{h}} - \ln \bar{R} \quad (8)$$

$$C_2 = (C_1 + \ln \bar{R})/\bar{h} \ln \bar{R} \quad (9)$$

Where $v = \sqrt{\frac{k_v}{k_h}}$ is the anisotropy parameter; k_v and k_h are the vertical and horizontal permeabilities of the reservoir, respectively; $\bar{R} = R_c/r_w$ is the dimensionless radius, and $x = 1 - \bar{h}$.

Taking into account the filtration resistance coefficients from (8) and (9), incomplete wells penetrating anisotropic reservoirs based on the degree of reservoir penetration are determined by the following formula (Dake, 1978):

$$a = \frac{a^*}{v} \ln \frac{R^v - x}{\bar{h}} \quad (10)$$

$$b = b^* \frac{\ln(R^v - x)/\bar{h}}{\bar{h} v \ln \bar{R}} \quad (11)$$

Determining coefficients C_3 and C_4 is quite complex, which is related to the shape and dimensions of the perforation holes and their changes during well operation (Guo et al., 2007; Horne, 1995; Ikoku, 1984). Studies have shown that the productivity of gas wells depends on the relative surface area of the holes f , meaning:

$$f = F_{st}/F \quad (12)$$

Where F_{st} is the surface area of the perforation holes;
 F is the surface area of 1 meter of the wellbore.

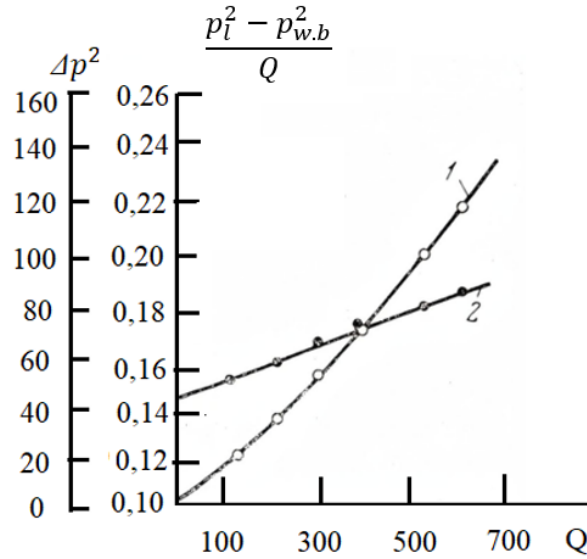


Figure 1

Indicator diagrams in coordinates:

- 1) $\Delta p^2 = p_l^2 - p_{w.b}^2 \rightarrow Q$;
- 2) $(p_l^2 - p_{w.b}^2)/Q \rightarrow Q$

The maximum increase in well productivity occurs within the interval $\bar{f} = 0 - 0,150$.

$$C_3 = h/nR_0; C_4 = h^2/3n^2R_0^2 \quad (13)$$

Where h is the reservoir thickness, m; n is the number of perforation holes; R_0 is the cavity radius (Mammadova, 2014; Matthews & Russell, 1967).

In Figure 1, the indicator diagrams are given in the coordinates

$$1) \Delta p^2 = p_l^2 - p_{w.b}^2 \rightarrow Q; \quad 2) (p_l^2 - p_{w.b}^2)/Q \rightarrow Q$$

The well test results under steady-state filtration regimes are interpreted according to formula (1); coefficients a and b are determined analytically or graphically (Iskandarov et al., 2025; Ismayilov et al., 2025).

When determining graphically, coefficient a is found as the intercept cut by the straight line 2 on the ordinate axis, and coefficient b is found as the tangent of the slope angle of this straight line to the abscissa axis (Mustafayev, & Mikailova, 2017).

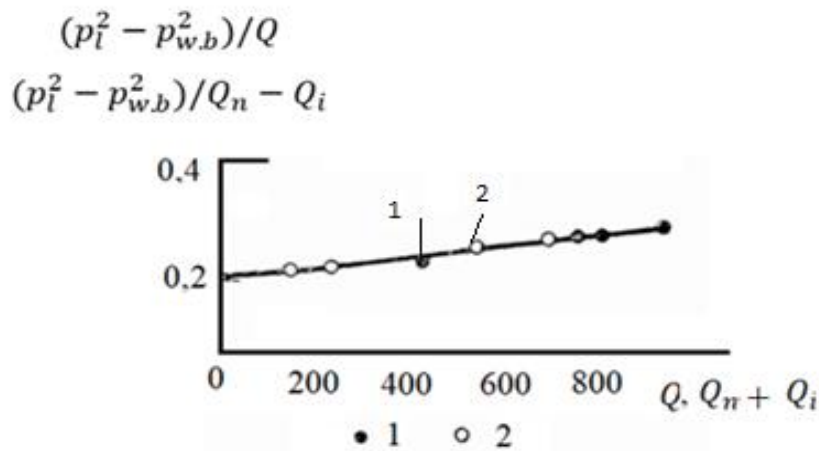


Figure 2

Dependencies at unknown reservoir pressure:

$$1) \frac{p_l^2 - p_{w.b}^2}{Q} \text{ from } Q; \quad 2) \frac{p_l^2 - p_{w.b}^2}{Q_n - Q_i} \text{ from } Q_n + Q_i$$

The values of these coefficients are determined numerically using the following formulas:

$$a = \frac{\sum \frac{\Delta P^2}{Q} \sum Q^2 - \sum Q \sum \Delta P^2}{N \sum Q^2 - (\sum Q)^2} \quad (14)$$

$$b = \frac{N \sum \Delta P^2 - \sum Q \sum \frac{\Delta P^2}{Q}}{N \sum Q^2 - (\sum Q)^2} \quad (15)$$

Where N is the number of regimes.

$$\begin{aligned} & \sum \frac{P_{w.b.i}^2 - P_{w.b.n}^2}{Q_n - Q_i} \sum (Q_n - Q_i)^2 - \sum (Q_n - Q_i) \sum \frac{(P_{w.b.i}^2 - P_{w.b.n}^2)(Q_n + Q_i)}{Q_n - Q_i} \quad (16) \\ & N_1 \sum (Q_n - Q_i)^2 - \left[\sum (Q_n - Q_i) \right]^2 \\ & b = \frac{N_1 \sum \frac{(P_{w.b.i}^2 - P_{w.b.n}^2)(Q + Q_i)}{Q_n - Q_i} - \sum (Q_n + Q_i) \sum \frac{P_{w.b.i}^2 - P_{w.b.n}^2}{Q_n - Q_i}}{N \sum Q^2 - (\sum Q)^2}, \end{aligned}$$

$$N_1 \sum (Q_n + Q_i - [\sum (Q_n + Q_i)])^2 \quad (17)$$

Where N_1 is the number of combinations and determined by this formula:

$$N_1 = \sum (m - 1)$$

Figure 3 shows the dependence of $P_{res}^2 - P_{w.b}^2$ on Q .

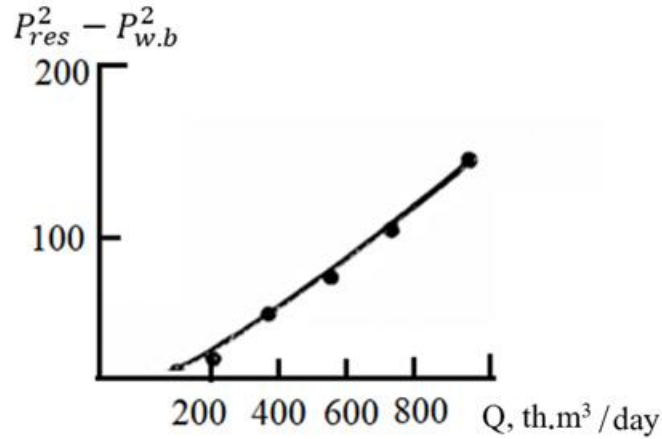


Figure 3
Dependence of $P_{res}^2 - P_{w.b}^2$ on Q

Various factors influence the shape of the indicator diagrams: inaccuracies in reservoir (especially abnormal) and bottomhole pressures, the presence of liquid in the wellbore, errors in determining the hydraulic resistance coefficient, etc. In such cases, approximate methods for processing test results are utilized (Mirzajanzade, Kovalev, et al., 1962).

1. Reservoir pressure is not fully restored

Assume that the actual reservoir pressure differs from the true one by a value δ_1 . Then:

$$P_{res} = P'_{res} - \delta_1 \quad (18)$$

Where P'_{res} is the measured (actual) reservoir pressure.

$$P_{res}^2 - P_{w.b}^2 = aQ + bQ^2 - \Delta P_{res} \quad (19)$$

$$\Delta P_{res} = P'_{res}\delta_1 + \delta_1^2 \quad (20)$$

In this case, the indicator curve should be processed in coordinates

$(P_{res}^2 - P_{w.b}^2)Q$ and Q coordinates.

Then the true reservoir pressure is found as follows:

$$P_{res} = \sqrt{P_{res}'^2 + \Delta P_{res}} \quad (21)$$

2. Bottomhole dynamic pressure is not restored. Assume that the bottomhole pressure has not stabilized by δ_2 , meaning:

$$P_{w.b} = P_{w.b}' - \delta_2 \quad (22)$$

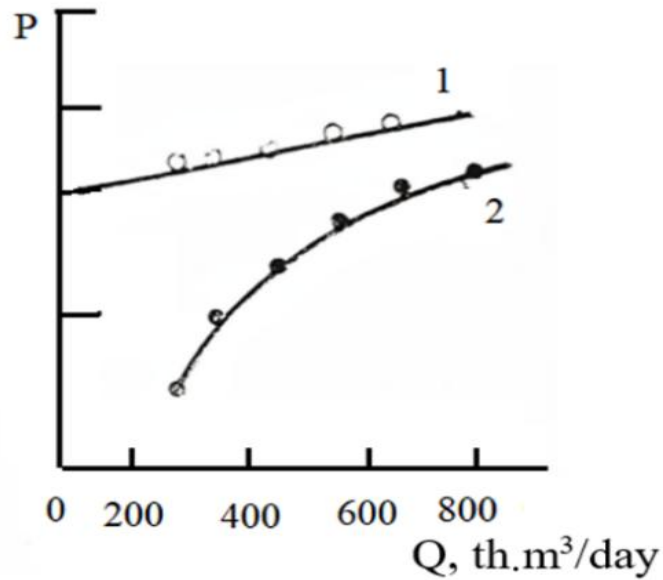


Figure 4
Indicator curves in coordinates

$$1) \frac{P_{res}^2 - P_{w.b}^2 + \Delta P_{res}}{Q}; Q; \quad 2) (P_{res}'^2 - P_{w.b}^2)/Qw$$

Figure 4 shows the indicator curves as a function of Q in coordinates 1) $(P_{res}^2 - P_{w.b}^2 + \Delta P_{res})Q$; 2) $(P_{res}'^2 - P_{w.b}^2)Q$, or graphically. Here, $i=1,2,3,\dots, m$ is the number of regimes, and n is the serial number of the regimes.

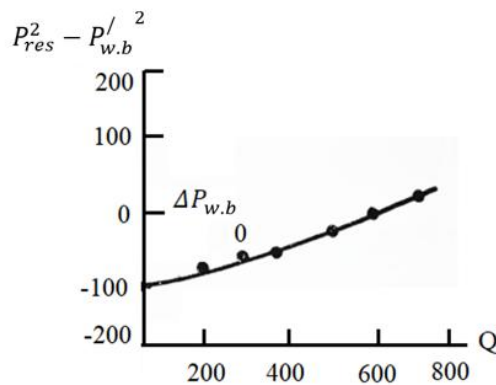
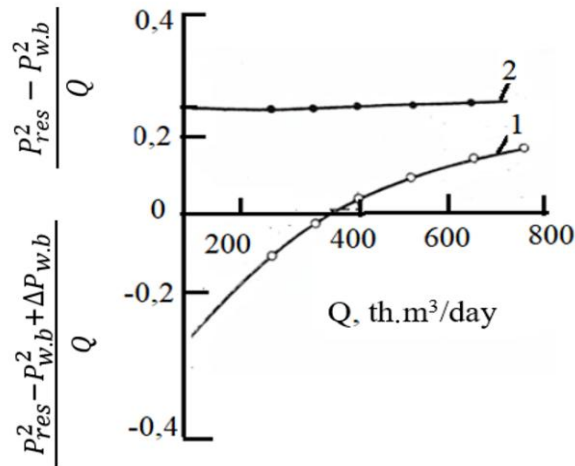


Figure 5
Indicator curve in coordinates $P_{res}^2 - P_{w.b}'^2$

In Figure 5, the indicator curves are selected in Q coordinates $P_{res}^2 = P_{w.b}'^2$.

**Figure 6***Dependency graphs*

$$1) (P_{res}^2 - P_{w.b}'^2)/Q; Q; \quad 2) \frac{(P_{res}^2 - P_{w.b}'^2 - P_{w.b})}{Q}; Q$$

In Figure 6, the dependencies 1) $(P_{res}^2 - P_{w.b}'^2)/Q$ and Q ; 2) $\frac{(P_{res}^2 - P_{w.b}'^2 - P_{w.b})}{Q}$ vs Q are given. Then, by analogy with the previous case, it is determined:

$$P_{res}^2 - P_{w.b}'^2 = aQ + bQ^2 - \Delta P_{res} \quad (23)$$

Where,

$$\Delta P_{w.b} = 2P_{w.b}'\delta_2 - \delta_2^2 \quad (24)$$

In this case, the curve of the dependence of $P_{res}^2 - P_{w.b}'^2$ on Q will look like the form shown in Fig. 5. As can be seen, a segment equal to $\Delta P_{w.b}$ is intercepted on the ordinate axis (when $Q = 0$).

$$\Delta P_{w.b0} = 2P_{res}\delta_2 + \delta_2^2 \quad (25)$$

As a result of processing indicator curve 2 (Fig. 6), coefficients a and b are determined, and the $\Delta P_{w.b}$ value can be found for each regime according to the known δ_2 .

3. The hydraulic resistance coefficient is known.

In this case:

$$P_{res}^2 - P_{w.b}^2 e^{2s} = aQ + (b + \theta)Q^2 \quad (26)$$

Where,

$$s = 0,03415 \frac{\bar{\rho}h}{z_{av}T_{av}} \quad (27)$$

$$\theta = 0,0133\lambda \frac{z_{av}^2 T_{av}^2}{D^5} (e^{2s} - 1) \quad (28)$$

Figure 7 presents indicator diagrams based on the test results in the following coordinates:

$$1), 3) (P_{res}^2 - P_{w.b}^2); (P_{res}^2 - P_{w.b}^2)/Q; Q;$$

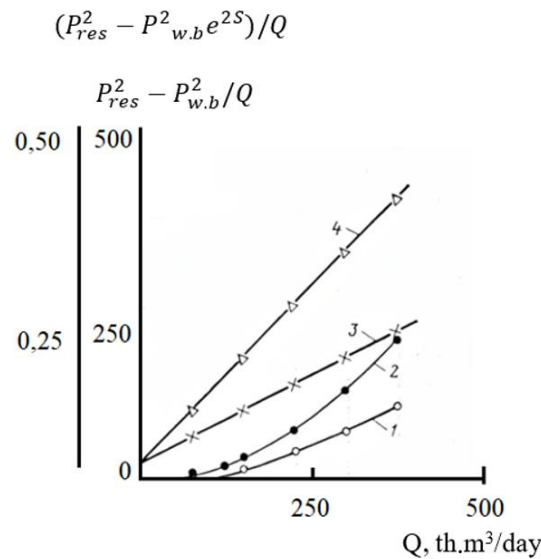


Figure 7
Indicator diagrams of survey results with coordinates

- 1) $(P_{res}^2 - P_{w.b}^2)$; 3) $(P_{res}^2 - P_{w.b}^2)/Q; Q$
2) $(P_{res}^2 - P_{w.b}^2 e^{2s})$; 4) $(P_{res}^2 - P_{w.b}^2 e^{2s})/Q; Q$

Based on the test results, the indicator diagram of the dependence of

2) $(P_{res}^2 - P_{w.b}^2 e^{2s})$; 4) $(P_{res}^2 - P_{w.b}^2 e^{2s})/Q$ on Q is constructed.

The straight line obtained intercepts a segment on the ordinate axis corresponding to a , and the tangent of the slope of this straight line is equal to $b + \theta$.

As Figure 7 presents, coefficient a is identical for both processing methods, while the tangent of the slope angle of straight line 4, determined according to formula (26), is larger by θ compared to the tangent of the slope angle of line 3 (Mustafayev et al., 2017; Rasulov, 2008; Society of Petroleum Engineers, n.d.; Zotov & Tverkovsky, 1970).

Conclusion and Discussion

The article outlines the gasohydrodynamic testing methods used for gas and gas-condensate reservoirs and wells.

1. To select downhole equipment for wells characterized by abnormally high reservoir pressure, gasohydrodynamic testing is conducted under steady-state filtration regimes, and indicator diagrams are constructed.
2. As a result of these studies, all reservoir and well parameters, including optimal flow rates, drawdowns, allowable dynamic bottomhole pressures, the amount of mechanical impurities, and other relevant characteristics, are determined, and the optimal operating regime for the well is established.
3. A two-term inflow equation is used, and the coefficients a and b are determined graphically. Formulas for calculating these coefficients for hydrodynamically complete wells are also provided.
4. For hydrodynamically incomplete wells, the necessary formulas for the incompleteness coefficients C_1 , C_2 , C_3 , and C_n , as well as for the coefficients a and b , are presented. The values

of these coefficients are also determined numerically, and the corresponding formulas are provided. The indicator curves, i.e., the curves showing the dependence of gas flow rates on dynamic bottomhole pressures, are linearized, and the coefficients a and b of the inflow equation are determined graphically.

5. The indicator curves pass through the origin, are concave with respect to the flow-rate (abscissa) axis, and represent monotonically increasing functional relationships.

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The Role of Oxygen and Peroxide Initiators in High-Pressure Polyethylene Production

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Abstract. In this study, the effect of oxygen and initiator systems on LDPE properties under high-pressure conditions was investigated. Oxygen reduces molecular weight (MW) and increases chain branching, leading to reduced thermal stability; however, at optimal concentrations, it can contribute to the formation of a more stable polymer structure under controlled conditions. Peroxide systems improve control of molecular weight distribution (MWD) and increase mechanical strength by 15–20%. Di-tert-butyl peroxide (DTBP) regulates melt flow index (MFI) and molecular weight (MW) of the polymer by generating active radicals as a result of thermal decomposition and helps maintain product stability. Compared to oxygen-based systems, peroxide-based initiation increases mechanical strength by approximately 15–20% and elongation by 10–15%, while providing improved control of molecular weight distribution. In addition, peroxy-radical reactions occurring in the presence of oxygen can affect the composition of the radical pool in the system and change the course of the initiation phase under certain process conditions. However, such reactions also increase the likelihood of the formation of hydroperoxide and carbonyl-type oxidation products, which negatively affect quality parameters such as polymer stability, color indicators, and odor. The results of the conducted studies show that the type of initiator used and its concentration are among the main factors determining the physical and mechanical properties of the synthesized polymer. These findings provide practical guidance for optimizing initiator selection and dosage in high-pressure polyethylene production.

Keywords: polyethylene, initiator, polymerization, oxygen, di-tert-butyl peroxide (DTBP)

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Yüksək təzyiqli polietilen istehsalında oksigen və peroksid inisiatorlarının rolu

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Xülasə. Bu tədqiqatda yüksək təzyiq şəraitində oksigen və inisiator sistemlərinin aşağı sıxlıqlı polietilenin (LDPE) xassələrinə təsiri araşdırılmışdır. Oksigen molekulyar kütləni (MW) azaldır və zəncirlərin şaxələnməsini artırır ki, bu da termiki sabitliyin azalmasına səbəb olur. Bununla belə, optimal konsentrasiyalarda və nəzarət olunan şəraitdə oksigen daha sabit polimer strukturunun formalaşmasına töhfə verə bilər. Peroksid sistemləri molekulyar kütlə paylanmasına (MWD) nəzarəti yaxşılaşdırır və mexaniki möhkəmliyi 15–20 % artırır. Di-tert-butil peroksid (DTBP) termiki parçalanma nəticəsində aktiv radikallar əmələ gətirməklə polimerin ərinti axıcılıq indeksini (MFI) və molekulyar kütləsini (MW) tənzimləyir və məhsulun sabitliyinin qorunmasına kömək edir. Oksigen əsaslı sistemlərlə müqayisədə peroksid əsaslı inisiasiya mexaniki möhkəmliyi təxminən 15–20 %, nisbi uzanmanı isə 10–15 % artırmaqla yanaşı, molekulyar kütlə paylanmasına daha yaxşı nəzarəti təmin edir. Bundan əlavə, oksigenin iştirakı ilə baş verən peroksi-radikal reaksiyalar sistemdəki radikalların tərkibinə təsir göstərə və müəyyən proses şəraitində inisiasiya mərhələsinin gedişini dəyişə bilər. Lakin belə reaksiyalar hidroperoksid və karbonil tipli oksidləşmə məhsullarının əmələ gəlmə ehtimalını da artırır ki, bu da polimerin sabitliyi, rəng göstəriciləri və qoxusu kimi keyfiyyət parametrlərinə mənfi təsir göstərir. Aparılmış tədqiqatların nəticələri göstərir ki, istifadə olunan inisiatorun növü və onun konsentrasiyası sintez edilmiş polimerin fiziki-mexaniki xassələrini müəyyən edən əsas amillərdəndir. Bu nəticələr yüksək təzyiqli polietilen istehsalında inisiatorun seçilməsi və dozasının optimallaşdırılması üçün praktik istiqamətlər təqdim edir.

Açar sözlər: polietilen, inisiator, polimerləşmə, oksigen, di-tert-butil peroksid (DTBP)

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Introduction

Polymeric materials occupy an important place in modern industrial production, and polyethylene is considered one of the leading materials in this direction due to its production volume, economic importance, and wide application areas. Polyethylene properties depend on initiator systems (Peacock, 2000; Baird & Collias, 2014). However, comparison of oxygen and peroxide systems remains insufficiently studied. In particular, there is limited systematic analysis of how oxygen- and peroxide-based initiator systems influence molecular weight distribution (MWD), chain branching, and thermal stability under high-pressure conditions. This research gap highlights the need for a comparative evaluation of initiator systems in terms of their impact on polymer structure and process stability.

Although oxygen- and peroxide-based initiators have been investigated in previous studies, their effects on polyethylene formation are often discussed separately and under different process conditions. In this context, the present study brings together available findings and evaluates these initiator systems from a comparative perspective. Particular attention is given to their influence on molecular weight distribution, chain branching behavior, thermal stability, and overall process performance under high-pressure polymerization conditions. Such an approach makes it possible to

identify common trends and differences that are not always evident when individual initiator systems are considered independently.

The main objective of this study is to scientifically analyze the polymerization technologies and initiator systems used in the production of polyethylene under high-pressure conditions. In particular, the production of low-density polyethylene (LDPE) by free-radical polymerization is of great industrial importance. Modern scientific studies show that process parameters directly affect the molecular structure of polymer chains and the quality indicators of the final product (Bocare et al., 2019; Zhu et al., 2019). As a result of the conducted research, the influence of different initiator systems on the high-pressure polymerization process was comprehensively investigated, and their effects on process kinetics were scientifically substantiated. This study provides a comparative evaluation of oxygen- and DTBP-based initiation systems under high-pressure LDPE production conditions. It was determined that polymer yield reaches 27–28% in peroxide-based systems, whereas in oxygen-based systems this value remains at 17–18%. This difference was attributed to the specific characteristics of the decomposition kinetics of the initiators.

Unlike previous studies that mainly focused on individual initiator systems, this work comparatively evaluates oxygen- and DTBP-based initiation under the same technological framework and relates radical generation mechanisms directly to polymer microstructure and product quality. The scientific novelty of this study lies in the comparative evaluation of oxygen- and di-tert-butyl peroxide-based initiator systems in high-pressure LDPE production. Particular attention is given to their influence on molecular weight distribution, crystallinity, thermal properties, and polymer conversion. The study provides an integrated assessment of the relationship between radical generation mechanisms and the resulting polymer characteristics.

Materials and Methods

Object and Subject of Research

The object of the study is the process of producing polyethylene by radical polymerization of ethylene monomer. This process, carried out under various technological conditions, provides the synthesis of materials with different structural properties, such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), and linear low-density polyethylene (LLDPE). LDPE is obtained mainly by high-pressure polymerization methods, while HDPE is produced by low-pressure polymerization methods. The technological parameters of these processes directly determine the properties of the final product.

The subject of the study is the interaction between the main technological parameters used in polyethylene production—temperature, pressure, type and concentration of the initiator, and catalyst amount—and the physical, chemical, and mechanical properties of the resulting polymer.

Polymerization Process and Initiators

Low-density polyethylene (LDPE) is mainly produced on an industrial scale by free-radical polymerization of ethylene under high pressure. The process is carried out at temperatures of 150–300°C and pressures of 1000–3000 bar. Oxygen and di-tert-butyl peroxide (DTBP) are used as initiator systems (Bocare et al., 2019; Zhu et al., 2019; Azmi & Aziz, 2016). The polymerization process begins with the introduction of ethylene into the reactor under high pressure. The initiator decomposes at elevated temperature, generating free radicals that initiate chain reactions. Polymer chains are formed through the sequential addition of ethylene molecules. Temperature and pressure are monitored throughout the process, and the final product is cooled and collected as LDPE.

Process Flow Diagram and Operating Principle

The technological scheme of high-pressure LDPE production consists of several interconnected stages, including ethylene purification, compression, polymerization, product separation, and final

processing. Initially, ethylene is purified to remove moisture, carbon dioxide, and other impurities that may negatively affect polymerization performance. The purified gas is then compressed to high pressure using multistage compressors before being introduced into the reactor.

In tubular reactors, initiator systems are injected at selected points along the reactor length. The decomposition kinetics of the initiator and the temperature profile determine the distribution of active radicals and consequently influence polymer chain formation. Due to the plug-flow characteristics of tubular reactors, temperature and conversion vary along the reactor axis, affecting reaction kinetics and polymer properties.

The reaction mixture leaving the reactor is directed to a separation unit, where unreacted ethylene is separated from the polymer and recycled back into the process. The polymer product is subsequently cooled, homogenized in an extruder, and converted into granules for further processing. Proper control of each technological stage is essential for obtaining polyethylene with the desired molecular weight distribution, branching degree, mechanical strength, and thermal stability.

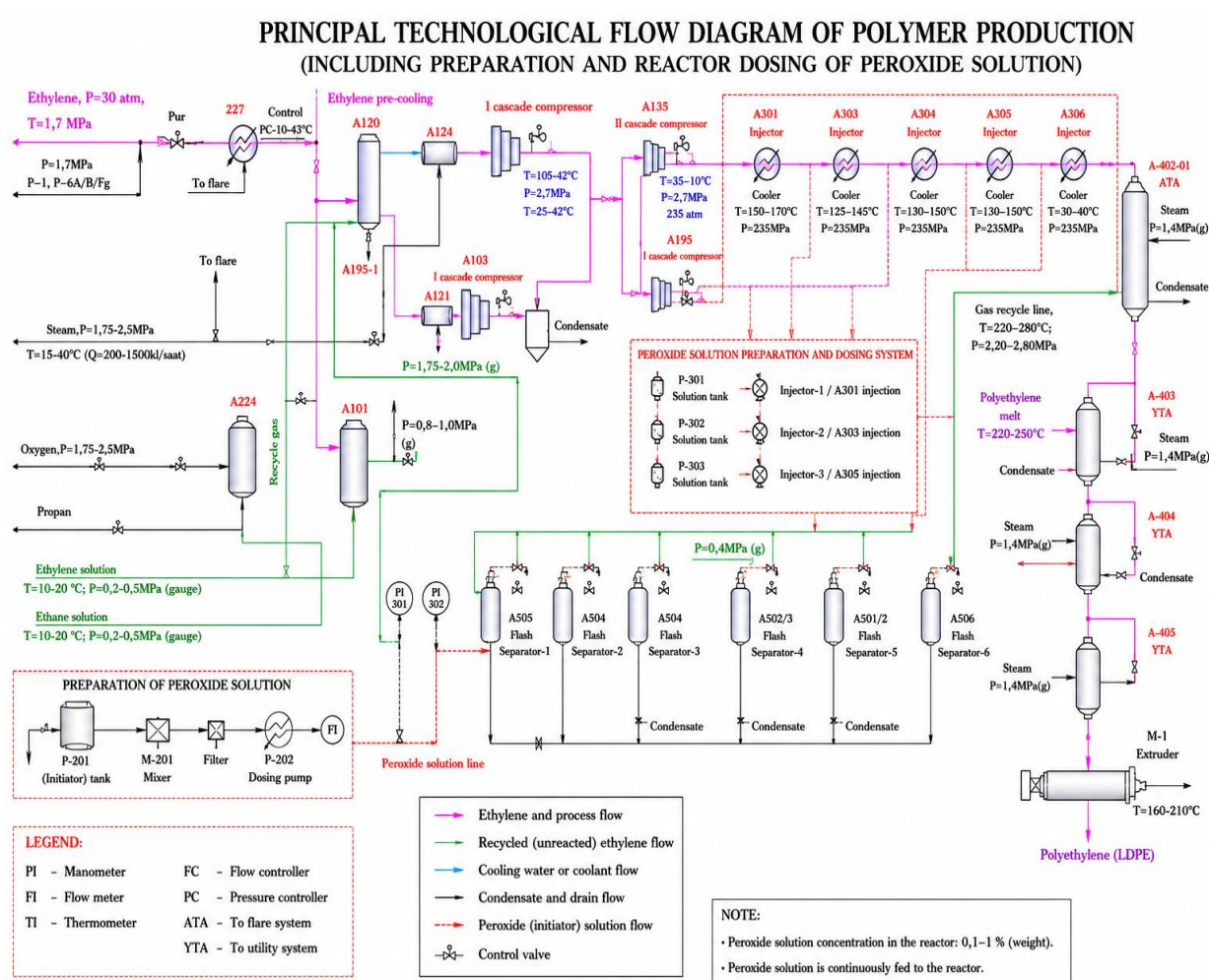


Figure 1
Principal technological flow diagram of high-pressure LDPE production including preparation and reactor dosing of the peroxide initiator solution

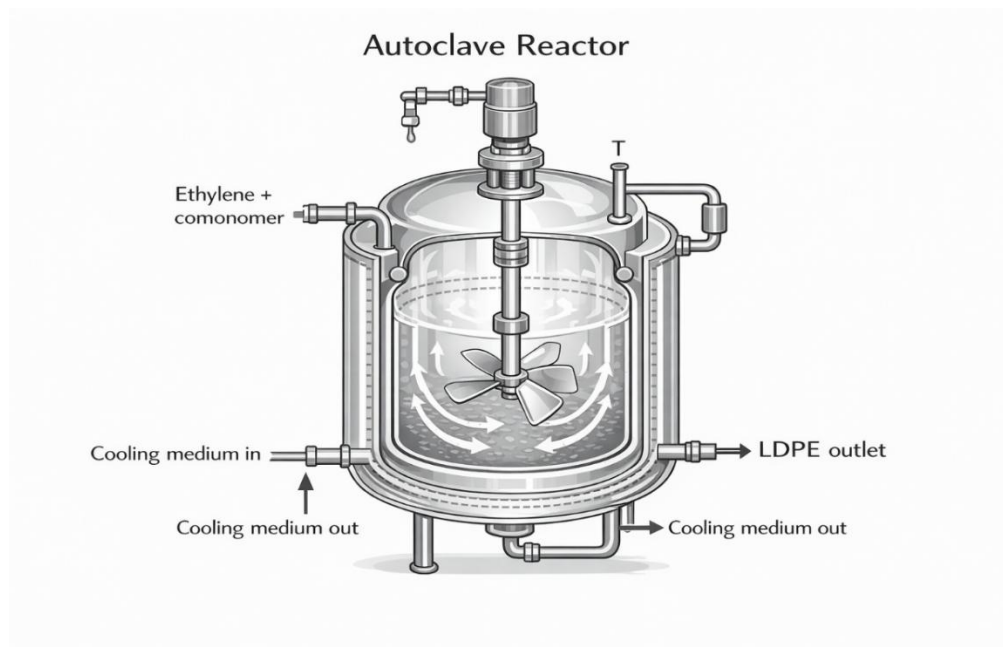
As shown in Figure 2, the high-pressure LDPE production process consists of ethylene purification, compression, peroxide initiator preparation and dosing, polymerization, separation of unreacted ethylene, recycle operations, and final polymer recovery. The methodological framework of this study is based on the examination and comparison of scientific data related to polyethylene production by

free-radical polymerization of ethylene. The research focuses on the technological conditions applied during LDPE synthesis and their influence on the characteristics of the resulting polymer. The study considers industrial polymerization processes carried out in high-pressure reactor systems, particularly tubular and autoclave reactors. Operating conditions reported in the literature, including temperatures ranging from 150 to 300°C and pressures between 1000 and 3000 bar, were analyzed to evaluate their effect on reaction behavior and product formation.

Special attention was given to the role of initiator systems, such as oxygen and di-tert-butyl peroxide, in the initiation and development of polymer chains. The analysis also included the influence of reactor design on heat transfer, mixing efficiency, residence time, and monomer conversion. To assess the relationship between process conditions and polymer properties, information obtained from published studies was organized and comparatively evaluated. Key parameters such as molecular weight distribution, degree of branching, polymer conversion, and product stability were examined as indicators of polymer quality. The interpretation of the results was carried out using principles of polymer reaction engineering and reactor analysis. Published experimental observations and modeling results were compared to identify common trends and determine the technological factors that have the greatest impact on polyethylene structure and performance.

In recent years, modeling of kinetics, heat transfer, and hydrodynamics in tubular and autoclave reactors has received significant attention (Van Steenberg et al., 2022; Zhang, 2021). Axial temperature and conversion variations in tubular reactors, as well as mixing intensity and residence time distribution (RTD) in autoclave reactors, are key factors influencing polymer microstructure. Modern approaches aim to predict key quality indicators such as molecular weight distribution (MWD/PDI), chain branching, and product stability (Kryven et al., 2022).

The formation of the internal structure of the polymer directly depends on the type of reactor used.



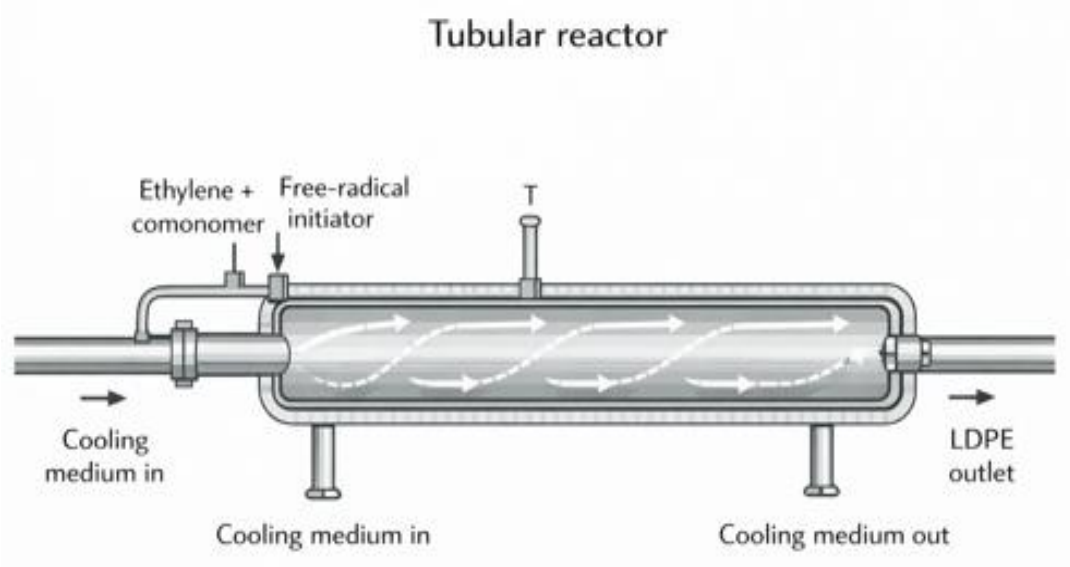


Figure 2
*Schematic representation of autoclave and tubular reactors
 used in high-pressure LDPE production*

Results

Studies have shown (Zhu et al., 2019; Michelsen & Møllerup, 2020; Alvarez et al., 2021; Gao et al., 2023) that in autoclave reactors, where intensive mixing is provided, the distribution of radicals is more homogeneous, resulting in a narrower molecular weight distribution (MWD). Compared to tubular reactors, the MWD is reduced by approximately 20–30%. This condition causes the polymerization to proceed in a more even kinetic environment. The even distribution of radicals results in more frequent activation and termination of chains, leading to polymers with relatively low average molecular weight.

In tubular reactors, the flow regime is mainly plug-flow, so the temperature and pressure are distributed unevenly throughout the reactor. Under these conditions, radical concentration and reaction rate vary along the axis, resulting in the formation of polymer chains under different kinetic conditions and a broader molecular weight distribution. Gel Permeation Chromatography (GPC) and Differential Scanning Calorimetry (DSC) analyses demonstrated that the type of initiator has a significant influence on the molecular and thermal properties of polyethylene. According to the GPC results, the weight-average molecular weight (M_w), number-average molecular weight (M_n), and polydispersity index (PDI) of the DTBP-based sample were 210,000 g/mol, 78,000 g/mol, and 2.7, respectively. For the oxygen-based sample, M_w , M_n , and PDI were determined to be 185,000 g/mol, 42,000 g/mol, and 4.4, respectively. DSC analysis revealed that the peroxide-based sample exhibited a melting temperature of 113°C and a crystallinity degree of 51%, whereas the oxygen-based sample showed corresponding values of 108°C and 42%, respectively.

Experimental results show that switching to peroxide-based initiation increases mechanical strength by 15–20% and elongation by 10–15%, while also improving the optical performance of the product (Brandão et al., 2020; Zhang et al., 2021; Sadeghi & Grady, 2024; Azmi & Aziz, 2016). The results presented in this study demonstrate that initiator type significantly affects the structural and thermal properties of LDPE. The peroxide-based system exhibited higher melting temperature and crystallinity compared with the oxygen-based system, indicating the formation of a more ordered polymer structure.

DSC (Differential Scanning Calorimetry) Analysis

Table 1

Thermal properties and degree of crystallinity of polyethylene samples

Initiator	Melting Temperature (°C)	Crystallinity (%)
Oxygen	108	42
DTBP (Peroxide)	113	51

Furthermore, peroxide initiation was associated with improved polymer conversion and enhanced control of polymer characteristics, confirming its advantages for high-pressure polyethylene production. As can be seen, the polyethylene sample produced using DTBP (peroxide) exhibited a higher melting temperature and degree of crystallinity than the oxygen-based sample. These results indicate the formation of a more ordered polymer structure with a higher degree of crystallinity in the peroxide-based system. The lower crystallinity observed in the oxygen-based sample may be attributed to a greater degree of structural irregularities within the polymer chains.

The experimental investigations performed within the framework of this study confirmed that the initiator system significantly influences both the kinetics of ethylene polymerization and the quality characteristics of the resulting polyethylene. The oxygen-based initiation system exhibited less controlled radical generation, which contributed to a broader molecular weight distribution and lower structural uniformity of the polymer. In contrast, the DTBP-based initiation system provided more stable and controlled radical formation throughout the polymerization process, resulting in improved regulation of chain growth and polymer structure development. GPC analysis revealed that the peroxide-based sample possessed a higher weight-average molecular weight ($M_w = 210,000$ g/mol) and number-average molecular weight ($M_n = 78,000$ g/mol) compared with the oxygen-based sample ($M_w = 185,000$ g/mol; $M_n = 42,000$ g/mol), while the polydispersity index decreased from 4.4 to 2.7, indicating a narrower molecular weight distribution. Thermal characterization by DSC further demonstrated that the peroxide-initiated polyethylene exhibited a higher melting temperature (113°C) and crystallinity degree (51%) than the oxygen-initiated sample (108°C and 42%, respectively). In addition, polymer conversion increased from approximately 17–18% in the oxygen-based system to 27–28% in the peroxide-based system. These results demonstrate that peroxide initiation provides more favorable conditions for obtaining polyethylene with enhanced structural homogeneity, improved thermal characteristics, and higher process efficiency under high-pressure polymerization conditions.

Discussion

To reduce this non-uniformity, multiperoxide initiator systems are widely used in tubular reactors. The stepwise introduction of peroxides with different decomposition temperatures makes radical generation more balanced, reduces the risk of local temperature maxima, and ultimately allows for more stable polymer structure formation.

In high-pressure polymerization technologies, the choice of initiator is one of the main factors that directly affects the process kinetics, reactor safety, and the physical and mechanical properties of the resulting polymer. In the early stages of industrial development, oxygen was a widely used initiator. Although its economic availability and the absence of the need for additional reagents provide certain advantages, its high reactivity makes it difficult to control the process stably and kinetic instability occurs. Oxygen leads to broader molecular weight distribution (MWD) and reduced thermal stability. In addition, reactions involving oxygen increase the likelihood of the formation of oxidized functional groups, which can lead to a decrease in the thermal stability of the material, deterioration of color properties, and weakening of mechanical strength. This behavior is associated with the uncontrolled radical generation and increased chain transfer reactions in oxygen-based systems, which lead to

broader molecular weight distribution and reduced thermal stability. Similar trends have been reported in previous studies (Bocare et al., 2019; Zhu et al., 2019). In contrast, peroxide systems provide controlled radical generation and improved process stability.

Peroxide-based initiation systems are widely used. The combination of peroxides with different decomposition temperatures allows for stepwise regulation of radical generation throughout the reactor. This approach leads to more balanced formation of polymer chains, narrowing of the molecular weight distribution, and increased structural homogeneity. Similar effects of peroxide-based systems on polymer structure, thermal properties, and material performance have also been reported in recent studies (Cardoso et al., 2021; Yolsal et al., 2024).

As a result, peroxide-based initiation systems are widely used in modern high-pressure polyethylene production. These systems not only improve the mechanical and thermal properties of the product, but also increase the safety and technological stability of the process. The obtained results demonstrated that the peroxide-based system produced polyethylene with higher molecular weight, narrower molecular weight distribution, and a higher degree of crystallinity. Therefore, the experimental findings confirmed that peroxide-based initiator systems provide more favorable technological performance and superior product characteristics in high-pressure polyethylene production. Overall, the differences between oxygen and peroxide initiator systems can be explained by their distinct radical generation mechanisms, which directly influence molecular weight distribution, chain branching, and thermal stability of LDPE.

The observed differences between oxygen- and peroxide-based initiation systems originate from their distinct radical generation pathways. Under high-pressure polymerization conditions, oxygen reacts rapidly with ethylene and intermediate radicals, producing highly reactive oxygen-containing species. These reactions may promote chain transfer and termination processes, resulting in greater variability in chain length and consequently a broader molecular weight distribution. Furthermore, oxygen-containing radicals can facilitate the formation of oxidized structures within the polymer matrix, which may negatively affect thermal stability and long-term material performance.

Peroxide initiators decompose thermally at predictable rates, generating radicals in a more controlled manner. When several peroxides with different decomposition temperatures are applied simultaneously, radical formation can be distributed throughout the reactor volume and over different stages of the polymerization process. Such behavior contributes to a more uniform chain-growth mechanism, improved control of branching reactions, and a narrower molecular weight distribution. Similar observations have been reported in studies investigating the relationship between initiator decomposition kinetics and polyethylene microstructure, where peroxide-based systems were associated with enhanced structural homogeneity and improved thermal and mechanical characteristics.

The discussion of the obtained results demonstrates that the differences between oxygen- and peroxide-based initiation systems originate from their distinct radical generation mechanisms. These mechanisms directly affect molecular weight distribution, branching behavior, crystallinity, and thermal stability of LDPE. The GPC and DSC results obtained in this study are consistent with literature data reported for peroxide-initiated high-pressure polyethylene production, confirming the ability of peroxide systems to provide more controlled polymerization kinetics and improved structural homogeneity. Therefore, the experimental findings support the theoretical understanding of radical polymerization processes and highlight the advantages of peroxide-based initiator systems for industrial LDPE production.

Conclusion

1. Differential Scanning Calorimetry (DSC) analysis revealed that the peroxide-initiated polyethylene exhibited a higher melting temperature (113°C) and crystallinity degree (51%) than the oxygen-initiated sample (108°C and 42%, respectively), indicating the formation of a more ordered polymer structure.
2. The experimental results confirm that peroxide-based initiation provides improved control of radical generation and polymerization kinetics, resulting in enhanced molecular uniformity, higher crystallinity, and improved material performance. Literature data further indicate that peroxide initiation may increase mechanical strength by approximately 15–20% and improve thermal stability.
3. From an industrial perspective, the application of peroxide-based initiator systems can contribute to increased process stability, improved product quality, reduced recycle flow, lower compressor loads, and higher reactor productivity. These advantages make peroxide initiation a promising approach for modern high-pressure LDPE production.
4. Future research should focus on optimization of initiator concentration, peroxide combinations, reactor operating conditions, and detailed investigation of molecular weight distribution and branching characteristics in order to further improve product performance and process efficiency.

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