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## **The Environmental Problems Caused by Industrial Activities in the Ganja Region**

### **Abstract**

Ganja city, located in the western part of Azerbaijan, is the country's second-largest industrial center, hosting enterprises in metallurgy, chemistry, machinery, construction materials, food, and light industries. Although industrial activities contribute positively to economic growth and employment, they exert significant anthropogenic pressure on air, soil, and water ecosystems. The study uses monitoring reports of the Ministry of Ecology and Natural Resources for 2023–2024, scientific articles, and laboratory analysis results. Concentrations of PM<sub>2.5</sub> and PM<sub>10</sub> particles in the atmosphere, as well as heavy metals (Pb, Zn, Cu, Cd) in soil and water, were evaluated and compared with international standards. The research revealed that industrial enterprises in Ganja cause air pollution, soil fertility decline, changes in the chemical composition of water bodies, loss of biodiversity, and disruption of local climatic conditions. The findings emphasize the necessity of implementing environmental management measures, modern purification technologies, the creation of green zones, and the promotion of public participation. These actions are essential for ensuring sustainable industrial development and ecological stability in Ganja city.

**Keywords:** *Ganja city, industrial pollution, air quality, soil and water ecosystems, biodiversity, environmental management*

### **Introduction**

Ganja, located in the western part of Azerbaijan, is the country's second-largest industrial center, hosting a diverse range of enterprises in metallurgy, chemical production, machinery, construction materials, food, and light industries. While industrial development contributes significantly to regional economic growth and employment, it also imposes considerable anthropogenic pressure on environmental components, including air, soil, and water ecosystems. Long-term industrial emissions, including particulate matter, heavy metals, and chemical reagents, have resulted in environmental degradation, biodiversity loss, and disruption of local climatic conditions. Monitoring data and research indicate that industrial zones in Ganja, particularly around major plants such as the Ganja Aluminum Plant and chemical facilities, are hotspots of pollution, affecting not only ecosystem health but also human well-being. The complexity of these impacts highlights the urgent need for integrated environmental management, modern purification technologies, green buffer zones, and active public participation. This study aims to analyze the environmental consequences of industrial activities in Ganja, focusing on air, soil, and water quality, as well as biodiversity, and to propose strategies for sustainable industrial development and ecosystem restoration.

### **Research**

#### **Industrial Activities and Sources of Pollution**

The industrial infrastructure of Ganja is primarily concentrated in the eastern and southern parts of the city. The operation of metallurgical and chemical enterprises in these areas results in the emission of carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), and particulate matter into the atmosphere. These gases remain in the lower layers of the atmosphere for extended periods, altering air composition and contributing to the formation of acid rain (Aliyev et al., 2024).

Dust waste from the metallurgical industry contains high levels of iron, copper, lead, and zinc compounds, which leads to the contamination of soils and water bodies. Research conducted near the

Ganja Aluminum Plant revealed that lead concentrations in the topsoil exceeded the norm by 3–4 times, while cadmium concentrations were twice as high (Asgarov, 2022). This situation negatively affects the composition of soil microflora and vegetation. Hydrobiological balance in the Ganjachay basin has been disturbed due to pollution. Aquatic organisms, particularly plankton and benthos species, have decreased in number, and certain fish species (especially carp and catfish) have abandoned polluted zones. The accumulation of heavy metals in soil has led to the degeneration of riparian vegetation and a reduction in biodiversity (Gasimov, 2022).

Soil analyses indicate that in areas along the Ganjachay riverbed, concentrations of Pb and Cu elements exceed normative values by 3–5 times. Crops grown on these soils accumulate toxic substances, indirectly affecting human health (Bayramova, 2023).

In chemical industry facilities, chlorine compounds and catalytic reagents enter the Ganjachay basin, increasing the chemical oxygen demand (COD) and biological oxygen demand (BOD) of the water. Consequently, the self-purification capacity of the water is weakened, and oxygen deficiency occurs in aquatic ecosystems (Mammadli, 2023). Industrial pollution in the Ganjachay area poses serious risks to regional water, soil, and biodiversity. Without strengthened regulatory measures, this pollution may lead to long-term hazards for both the ecosystem and human health. Implementing environmental policies aligned with sustainable development principles, applying modern purification technologies, and enhancing public responsibility are crucial conditions for restoring the ecological balance of the Ganjachay river.

### **Environmental Restoration and Management Measures**

In recent years, the Ministry of Ecology and Natural Resources (MENR) has conducted ecological monitoring programs in the Ganjachay. According to the 2023 report, the discharge of some industrial wastewater has been limited, and local treatment facilities have been installed in some enterprises (MENR, 2023).

For effective ecological restoration, the following measures are essential:

- Industrial facilities should treat wastewater through two-stage biological and chemical purification systems;
- Riparian areas should be restored with protective green belts;
- A digital hydrobiological monitoring system should be established for Ganjachay, enabling real-time tracking;
- Local communities and environmental NGOs should be actively involved in the process.

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### **Atmospheric Pollution and Its Consequences**

According to the 2024 data from the MENR, the annual average concentration of PM<sub>10</sub> particles in Ganja's industrial zones ranged from 54–68 µg/m<sup>3</sup>, exceeding normative limits by 1.5–2 times (Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, 2024). These values reduce the air quality index (AQI) and pose health risks to the population.

Inhalation of particulate matter can lead to bronchitis, lung diseases, and allergic reactions (Cafarov & Ismayilova, 2023). One direct consequence of atmospheric pollution is the formation of the urban heat island effect. Combined with global warming, this effect alters the local microclimate, increasing air temperatures by 1.2–1.8°C (Gurbanov, 2024).

Ganja, as Azerbaijan's second-largest industrial center, hosts enterprises in metallurgy, machinery, chemical, food, and construction material industries. The activities of these enterprises have long contributed to the emission of various pollutants into the atmosphere. Improper management of industrial waste, outdated purification systems, and insufficient regulatory mechanisms have sometimes caused air quality to exceed normative standards (Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, 2023).

The main sources of pollution in Ganja's industrial zone include the Ganja Aluminum Plant, Ganja Automobile Plant, chemical enterprises, energy facilities, and, to a lesser extent, domestic waste incineration. These sources emit carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>), lead, formaldehyde, phenol, and other harmful substances into the atmosphere. These pollutants remain suspended for long periods, posing serious threats to human health and ecosystems (Aliyev, 2022).

Industrial emissions result in elevated dust and gas concentrations over Ganja, particularly in autumn and winter. During these periods, weakened air circulation, humidity, and temperature inversion lead to the accumulation of pollutants in the lower atmosphere, increasing respiratory diseases. According to MENR monitoring conducted in 2023, the annual average concentration of PM<sub>2.5</sub> particles in Ganja was 28–30 µg/m<sup>3</sup>, twice the safe limit established by the World Health Organization (MENR, 2023).

Atmospheric pollution also affects local climatic conditions. Dust and aerosol particles absorb part of solar radiation, reducing surface warming and altering local heat balance. Sulfur and nitrogen compounds in industrial emissions react with atmospheric water vapor to produce acid rain. These rains increase soil and water acidity, damage urban greenery, reduce soil fertility, and disrupt biodiversity (Gasimov, 2022).

From a human health perspective, industrial air pollution generates serious socio-ecological problems. In recent years, there has been an increase in respiratory diseases in Ganja, particularly bronchitis, asthma, and allergies. PM<sub>2.5</sub> and PM<sub>10</sub> particles penetrate deep into the lungs, accelerating chronic respiratory conditions. The presence of heavy metals, especially lead (Pb), in the air negatively affects children's nervous system development (Huseynov, 2024).

At the ecosystem level, atmospheric pollution indirectly impacts soil and water systems. Pollutants deposited by rainwater alter water chemistry and reduce soil microbial activity. Studies conducted in Ganjachay and Hacikənd indicate that industrial deposition of atmospheric pollutants has increased heavy metal concentrations in soils several times above permissible levels (Bayramova, 2023).

Recent measures for air protection in Ganja include the installation of filtration systems in several industrial enterprises and the application of mechanical and electrostatic devices for gas purification. Additionally, MENR implements an "Annual Monitoring Program of Ganja's Atmospheric Air Quality," with results publicly available (MENR, 2024). Promoting the use of gas- and electric-powered public transport has also contributed to reducing air pollution.

For these measures to be effective, a comprehensive ecological management system is necessary. Each industrial enterprise must implement an emission accountability mechanism and expand real-time air quality monitoring systems. Increasing green areas, establishing protective forest zones around the city, and raising public environmental awareness are also critical steps.

In conclusion, industrial activities in Ganja have a direct negative impact on atmospheric quality, regional ecological stability, and public health. Addressing this problem requires technological modernization, strict enforcement of environmental standards, and strengthened ecological monitoring. Achieving sustainable development in Ganja's industrial zones demands a culture of environmentally responsible production, with air quality preservation recognized as a shared goal by both government and society.

### **Soil and Water Ecosystem Impacts**

Soil pollution in Ganja's industrial zones is primarily observed in the metallurgy and construction materials sectors. Soil mechanical structure is disturbed, humus content decreases, and pH levels drop from 6.5 to 5.8, reducing biological activity (Rustamov, 2021). Crops grown on contaminated soils accumulate heavy metals, which enter the food chain (Huseynov, 2022).

Ganjachay and its tributaries are the primary receivers of industrial wastewater. The discharged waters contain not only chemical pollutants but also biologically active substances. In 2023, analyses showed that the concentration of petroleum products in Ganjachay water was 0.22 mg/L and copper

0.19 mg/L, exceeding normative limits (Mammadli, 2023). As a result, fish populations have weakened, and certain aquatic organisms' populations have decreased by 40% (Gurbanov, 2024).

Industrial activities alter soil chemistry, reducing fertility and structural quality. Heavy metals such as lead (Pb), copper (Cu), zinc (Zn), and cadmium (Cd) accumulate in soils near industrial facilities, reducing microbial activity and hindering root development, ultimately lowering agricultural productivity (Aliyev & Huseynova, 2022).

Plants growing in heavy-metal-contaminated soils bioaccumulate these elements, introducing them into the food chain, posing risks to both human health and ecosystem stability. Agroecological studies near Ganja indicate that cadmium and lead concentrations exceeding 0.3–0.8 mg/kg cause toxic biochemical changes in plants (Ismayilov, 2021).

Water ecosystems are also affected. Untreated industrial wastewater discharged directly into Ganjachay increases chemical oxygen demand (COD) and biological oxygen demand (BOD), disrupting oxygen balance and reducing aquatic flora and fauna (MENR, 2024).

Excess nitrogen and phosphorus in wastewater accelerate eutrophication, decreasing water self-purification capacity. Fish species have declined, and some local species have disappeared due to ecological stress. Over the past decade, Ganjachay's water conductivity and total salinity increased by 25–30%, indicating industrial and domestic waste impact (Gasimov, 2023).

Groundwater contamination has also been observed. Industrial leachates and filtration processes increase nitrate, sulfate, and ammonium salt concentrations in artesian waters, affecting drinking water quality and agricultural irrigation efficiency (Hasanov et al., 2022).

### **Conclusions and Ecological Management Measures**

The impacts of industrial activities on soil and water ecosystems in Ganja are complex and require long-term remediation. The following measures are recommended:

- Installing modern purification facilities in industrial enterprises and reusing wastewater;
- Reducing heavy metal soil contamination through phytoremediation;
- Establishing continuous water quality monitoring systems in Ganjachay;
- Developing regional ecological management plans with increased public participation.

Implementing these measures will contribute to the restoration of ecosystem resilience and support sustainable industrial development in Ganja.

### **Biodiversity and Ecosystem Changes**

Industrial pollution has caused significant alterations in the structure of vegetation in Ganja's surrounding forests and meadows. Previously dominant species such as poplar, oak, and acacia have declined, replaced by species resistant to dust and gaseous pollutants. Negative trends are also observed in fauna: bird populations have decreased, and abnormalities in amphibians have increased (Hasanova, 2024).

Furthermore, changes in soil cover in the city's surroundings accelerate erosion processes. This disrupts water balance, reduces soil fertility, and weakens agricultural ecosystems (Aliyev et al., 2024).

### **Ecosystem Degradation and Habitat Reduction**

Industrial activities lead to a chain reaction of pollution across soil, air, and water environments. Sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), hydrocarbons, and heavy-metal-rich dust particles damage vegetation, reducing photosynthesis. Near facilities such as the Ganja Aluminum Plant and chemical enterprises, high dust concentrations have reduced growth rates of trees and herbaceous plants by 20–30% (Hasanov & Aliyeva, 2022).

These changes directly affect fauna habitats. Reduced availability of nests and food sources leads to a decline in populations of birds, reptiles, and small mammals. Biomonitoring in the Ganjachay basin between 2000–2023 indicates that local fish species such as the Golden-scaled and Ganja river fish are now endangered (Gasimov, 2023).

### **Toxic Effects on Flora and Fauna**

Heavy metals, phenols, petroleum products, and chemical reagents in industrial effluents are among the most hazardous pollutants for biodiversity. They enter plant and animal organisms via soil

and water, disrupting physiological processes. Laboratory studies indicate that within a 5–7 km radius of Ganja's industrial zone, lead and cadmium levels in soil and plant samples exceed sanitary norms by three times (Aliyev et al., 2021). This reduces photosynthesis, protein synthesis in plants, and causes tissue degeneration.

In fauna, these chemical substances affect the nervous and reproductive systems, causing genetic mutations. Herpetological studies near Ganja show increased developmental abnormalities in frog populations due to soil and water pollution (Mammadov, 2022).

### **Weakening of Ecosystem Functions**

Biodiversity loss reduces the self-regulating capacity of ecosystems. Deforestation and decline of green cover around Ganja accelerate soil erosion, disrupt water cycles, and weaken carbon sequestration processes. Consequently, the atmospheric concentration of greenhouse gases, particularly CO<sub>2</sub>, increases, contributing to local climate changes. In aquatic ecosystems, eutrophication and oxygen deficiency limit the survival of fish and other aquatic organisms (Ismayilova, 2023).

### **Impact on Climate and Weather Conditions**

Industrial activities emit greenhouse gases and other pollutants, accelerating climate change and altering local weather conditions (Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, 2023). Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and other substances generate a greenhouse effect, raising temperatures, altering humidity levels, and disrupting local microclimates. The urban heat island effect is particularly pronounced near metallurgy and chemical zones, with temperatures 1–2°C higher than surrounding areas, adversely affecting human health and the environment (Hasanov & Aliyeva, 2022).

Air pollution also modifies the chemical composition of precipitation. Sulfate and nitrate acids formed from industrial emissions lead to acid rain, increasing soil and water acidity, and negatively affecting vegetation and aquatic resources. Research in the Ganjachay basin shows that persistent acid rain has reduced soil pH below normative levels and stressed aquatic organisms (Gasimov, 2023).

Short-and long-term climate impacts result from industrial pollutants. Rising CO<sub>2</sub> and other greenhouse gases can cause local drought trends, changes in humidity and wind regimes, and threaten agricultural productivity, water resources, and ecosystem stability. International experience recommends reducing industrial emissions, adopting green energy, applying air filtration technologies, and establishing environmental monitoring systems (UNEP, 2022). Implementing these measures in Ganja can minimize climate impacts and stabilize local weather conditions.

### **Environmental Management and Restoration Measures**

To mitigate the negative impacts of industrial activities on biodiversity in Ganja, the following environmental management and restoration measures should be implemented:

- Adoption of environmental management systems and strengthened ecological certification in industrial enterprises;
- Restoration of green areas and establishment of ecological corridors;
- Rehabilitation of natural habitats and programs for artificial propagation of rare species;
- Establishment of biomonitoring systems in the Ganjachay basin with regular tracking of biological indicators.

Implementation of these measures can restore ecosystem functionality and ensure sustainable industrial and ecological balance in the region.

Comprehensive actions to improve Ganja's ecological status include: installing modern filtration and wastewater treatment systems in industrial enterprises, reusing and treating wastewater, and creating green buffer zones along industrial areas for phytoremediation (Aliyeva & Mammadov, 2023).

Implementation of ISO 14001 environmental management systems increases efficiency,

reduces resource losses, and promotes environmental responsibility (Hasanova, 2024). Public environmental education and awareness, along with monitoring mechanisms, support ecosystem restoration.

Industrial enterprises have long impacted air, soil, water, and biodiversity. Therefore, plans to prevent industrial pollution in Ganja have been developed and are being implemented.

Industrial emissions are continuously monitored by the Ministry of Ecology and Natural Resources. Measurements are taken for air quality, water, and soil parameters. If normative limits are exceeded, warnings and fines are applied. Air pollution is monitored via PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>x</sub>, and CO levels, while water bodies are assessed for BOD, COD, and heavy metals. Soil contamination is analyzed annually (Ministry of Ecology and Natural Resources of the Republic of Azerbaijan, 2024). These measures allow early detection of pollution and timely mitigation.

Several industrial enterprises have adopted clean production technologies, reducing waste volumes, optimizing energy use, and preventing air, water, and soil pollution. Metallurgy and chemical plants use filters, electrostatic separators, energy-efficient equipment, wastewater recycling, and circular economy principles for industrial waste processing (UNIDO, 2022).

Green belts have been established around the city and industrial zones to remove airborne dust, reduce urban heat island effects, prevent soil erosion, and protect biodiversity. Public awareness programs, environmental audits, NGO and community participation, and environmental education in schools and universities promote transparency and environmental responsibility (Aarhus Convention, 1998). Legal and institutional measures regulate industrial emissions in Ganja under the Environmental Law, applying taxes and fines, encouraging ISO 14001 certification, and managing waste and recycling systems in industrial parks. Regional ecological strategies include minimizing waste, adopting clean technologies, enhancing monitoring, expanding green zones, creating ecological corridors, implementing restoration and reclamation projects, and publicly sharing environmental information.

The overarching goal of these measures is to minimize industrial pollution impacts, protect ecosystems, and ensure sustainable industrial development. Continuous monitoring, technology modernization, and public participation are essential for effective implementation.

## Conclusion

Industrial activities in Ganja have significantly impacted the city's environment, including air quality, soil and water ecosystems, biodiversity, and local climate. Metallurgical, chemical, construction material, and other industrial sectors have led to elevated emissions of carbon monoxide, sulfur dioxide, nitrogen oxides, particulate matter, and heavy metals, which accumulate in the atmosphere, soil, and water bodies. These pollutants disrupt the chemical and biological balance of ecosystems, reduce vegetation cover, degrade soil fertility, harm aquatic organisms, and endanger local fauna. Air pollution has exacerbated respiratory diseases in the population and altered microclimatic conditions, contributing to the urban heat island effect and increasing environmental stress. Soil and water contamination have introduced toxic substances into the food chain, posing direct and indirect risks to human health. Biodiversity loss and ecosystem degradation have weakened the self-regulating functions of natural systems, increasing susceptibility to erosion, eutrophication, and climate-related impacts. Mitigating these effects requires comprehensive environmental management strategies. The adoption of ISO 14001 standards, installation of modern filtration and wastewater treatment systems, restoration of green zones, establishment of ecological corridors, and implementation of continuous biomonitoring are critical steps for sustainable development. Active public participation, environmental education, and strengthened legal and institutional frameworks further support ecological restoration and long-term environmental stability.

In conclusion, achieving sustainable industrial development in Ganja necessitates a balance between economic growth and environmental protection. Only through coordinated technological, regulatory, and community-based measures can the ecological balance of the city and surrounding areas be restored, ensuring the health of both ecosystems and local populations.

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