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ASSESSMENT OF THE RESILIENCE OF BIODIVERSITY OF ECOSYSTEMS AROUND THE GANJA ALUMINUM PLANT DURING CLIMATE CHANGE

Corresponding Members of ANAS Vagif Novruzov, Aynur Bayramova

Ministry of Science and Education of the Respublic of Azerbaijan, Ganja State University
aynur.bayramova@gdu.edu.az, vaqif.novruzov@gdu.edu.az

Summary: *Research work carried out to determine the level of environmental pollution in the city of Ganja and its surrounding areas, as well as to eliminate the negative effects, is of great scientific and practical importance. Studies show that industrial waste, especially heavy metals and radioactive strontium, spreads to the city of Ganja and its surrounding areas, polluting the soil and vegetation of the region. As a result of pollution, the biological and ecological state of the environment is disrupted, negatively affecting human health and creating conditions for the increase of various diseases. The ecologically rich natural environment of Ganja city is caused by industrial activity, anthropogenic impacts, weakening of ecosystem functions and reduction of biological diversity. Among the industrial enterprises operating in Ganja city, "Azeraluminium" MMC is of particular importance in terms of its serious negative impact on the environment due to heavy metals in its waste. It was found that the flora of Ganja city and surrounding areas consists of 43 families, 112 genera and 221 species. The flora is mainly composed of cereals (Poaceae-43 species), legumes (Fabaceae-38 species), asteraceae (Asteraceae-30 species), and perennial herbaceous plants (110) species. The article provides information on the results of the investigation of the environmental impact of "Azeraluminium" MMC and ways to eliminate them.*

Keywords: *Azeraluminum, biodiversity, ecosystem, species, genus, family*

Introduction

By the Decree of the President of the Republic of Azerbaijan dated February 2, 2021, one of the five national priorities for the socio-economic development of Azerbaijan until 2030 is "A country of clean environment and green growth", and by the Decree of the President of Azerbaijan Ilham Aliyev dated December 25, 2023, 2024 was declared the "Year of Solidarity for the Green World" in the country. In this direction, the restoration of polluted areas, the protection of forested areas as well as flora and fauna, the fertilization and greening of lands in dry areas, and the reduction of the harmful effects of climate change are always in the spotlight as the main action programs. In the era of climate change, one of the global environmental problems of our time is the assessment of the impact of industrial waste generated as a result of technological processes on the environment and the study of methods for eliminating their negative effects. As a result of the incomplete optimization of technological processes, waste generated during the production stage pollutes atmospheric air, water bodies, soil and vegetation, causing serious environmental consequences for society. Heavy metals contained in waste spread to the environment through the atmosphere and water, poisoning soil and vegetation, and also affecting the human body, leading to the emergence of health problems. Research work carried out in the direction of the country's second largest population and volume of industrial production is of great importance. The waste dust from the plant contains heavy metals, aluminum compounds and other industrial components. This pollution causes a decrease in vegetation cover and a change in the structure of phytocenoses from a

distance of 10 km. Changes in the adaptation mechanism of plants, weakening of the morphophysiological indicators and a decrease in photosynthesis are observed. These effects indicate that the plant's activity creates a long-term anthropogenic load on ecosystems [1].

An important institutional step has been taken towards expanding the country's industrial potential and accelerating the socio-economic development of the regions by the Decree of the President of the Republic of Azerbaijan dated January 15, 2026 "On the Establishment of the Western Industrial Park". According to paragraph 4.1.1 of the Decree, for the operation of the Western Industrial Park, it is envisaged to provide the Agency with the right to permanently use and lease 81.8 hectares of land, which is located on the Yevlakh highway in Ganja city and is under the management of the Azerbaijan Investment Holding, and is included in the category of industrial, transport, communication, defense and other designated lands belonging to state ownership [13].

The mentioned normative-legal document indicates that the functional load of the Ganja industrial zone will increase, and in particular, aluminum production and related industries will expand. In this regard, the ecological-geographical and biological studies conducted around “Azeraluminium” MMC, including the assessment of the impact of industrial activity on vegetation, soil ecosystems and urban biodiversity, are of particular relevance in the modern era. In this regard, it was considered appropriate to conduct a study on the assessment of the sustainability of the biodiversity of ecosystems around the Ganja Aluminum Plant during the creation of the Western Industrial Park.

The Ganja-Gazakh zone is of strategic importance in terms of agriculture and plays a special role in the country's food supply. Soil pollution in these areas leads to reduced productivity, poor food quality, and indirect impacts on human health. In such a situation, assessing the health of the soil-plant system and developing sustainable management strategies play an important role in the state's environmental policy [9,11].

Climate change analyses show that rising temperatures, decreasing water resources, and increasing stress on biodiversity are accelerating soil erosion and desertification processes, as well as posing serious environmental risks to agriculture and natural ecosystems [4]. When these changes coincide with pollution from industrial facilities such as the Ganja Aluminum Plant, they weaken the ecological resilience of vegetation in several ways: Increased stress levels in plants, decreased soil productivity, a predominance of anthropogenically tolerant species in phytocenoses, and a decrease in biodiversity. In such circumstances, assessing the ecological resilience of vegetation and identifying risk zones is of significant scientific and practical importance [3,5].

Studies conducted on the impact zone of the Ganja Aluminum Plant show that the most serious pollution around the plant is observed at a distance of 0-3 km, and this zone is classified as a high pollution area, moderate pollution is noted at a distance of 3-7 km, and a weak pollution zone is noted at a distance of 7–10 km. Botanical studies confirm the presence of such phenomena as a weakening of the photosynthesis apparatus, a decrease in seed productivity, and an increase in morphophysiological stress indicators. In such conditions, it is important to increase the resistance of vegetation to both industrial pollution and additional stress factors caused by climate change.

At the scientific conference on "Industrial Waste and Environment of the Western Region" held in Ganja in 2024, it was emphasized that industrial pollution due to climate change is the main environmental problem for the region. In accordance with the themes of COP29, the issues of neutralizing industrial impacts and protecting ecosystems were specifically mentioned. Anthropogenic pollution around the Ganja aluminum plant causes serious changes in the structural and functional characteristics of vegetation. Climate

change strengthens these effects and doubly weakens the stability of ecosystems.

Material and methodology of the study: The study was conducted in Ganja city and its surrounding areas, especially in the Ganja "Azeraluminium" MMC impact zone. The study area was divided into high, medium and low pollution zones covering a distance of 0-10 km from the plant. Soil and vegetation samples were taken from each zone, and morphophysiological indicators of both local and anthropogenic tolerant species, photosynthetic activity and seed productivity were assessed. At the same time, the chemical composition of alunite and bauxite waste, especially heavy metals and radioactive elements, was determined using X-ray fluorescence spectroscopy, atomic absorption spectrometry and ICP-MS.

To assess the ecological sustainability of vegetation, the composition of phytocenoses, biodiversity index and the share of anthropogenically tolerant species were analyzed, and the impact of waste zones was determined using GIS and distance-based interpolation methods. The impact of climate variability was assessed using statistical correlation and regression analyses of stress indicators of temperature and precipitation variability and soil productivity based on meteorological data. This approach allows for a systematic study of the impact of industrial pollution and climate variability on the sustainability of vegetation.

Discussion of the case: It is known that the production area of "Azeraluminium" MMC is mainly based on the complex processing of alunite ore extracted from the Zaylik alunite deposit, which ranks second in the world in terms of the amount of natural resources, using the reduction-alkaline method, and as a result of this process, clay-soil, potassium sulfate fertilizer, sulfuric acid and other products were produced. Recently, the production of clay-soil from alunite has been stopped and bauxite imported from foreign countries has been used as raw material. However, as a result of technological shortcomings during the complex processing of alunite, the territories of Ganja city and nearby regions were polluted with alunite dust and sulfurous gases.

Despite the current suspension of the complex production of alunite, large amounts of industrial waste generated from the processing of alunite and bauxite at the combine site still pose a potential threat to the environment. According to the latest data, 11.5 million tons of waste from alunite processing and 9.7–10 million tons of waste from bauxite processing were accumulated and stored on an area of 241 and 82 ha, respectively. The direct contact of these wastes with soil cover and vegetation negatively affects the morphophysiological indicators of plants. In this case, a weakening of photosynthesis, a decrease in seed productivity, an increase in stress indicators, and a predominance of anthropogenically tolerant species in the structure of phytocenoses are observed. Thus, the wastes of "Azeraluminium" MMC weaken the ecological stability of vegetation and negatively affect the biological diversity of the environment.

During the study, targeted scientific research is being conducted to study the composition of these wastes, especially the types and amounts of heavy metals, and to determine the damage they cause to the environment and the human body.

For this purpose, the current state of the vegetation of the ecologically polluted areas around the city of Ganja was studied. Ganja and its surrounding areas (Goygol, Samukh, Goranboy, etc.) are one of the regions distinguished by the richness of the flora of Azerbaijan. However, as a result of the activities of large industrial enterprises such as the Ganja Aluminum Plant, the flora here has been exposed to various anthropogenic and climatic influences for many years. It was found that the flora of the city of Ganja and its surrounding areas consists of 43 families, 112 genera and 221 species. The basis of the flora is cereals (Poaceae-43 species), legumes (Fabaceae-38 species), asteraceae (Asteraveae-30 species), perennial herbaceous plants (110) species.

Within a radius of 10 km from the plant, anthropogenic impacts are mainly observed in the accumulation of heavy metals in the soil, increased stress symptoms in plants, and the proliferation of weeds. The unique vegetation of the study area includes a number of perennial, annual and biennial plants that are found in various vegetation types. The ephemeral group includes Bromus japonicus Thunb., Anisanta rubens (L.) Nevsky, Lolium rigidum Gaudin, Eromoporum orientale (L.) Jaub. et Spach, Hordeum leporinum Link, Avena clauda Durieu., Poa bulbosa L. etc., which are dominant and subdominant in the semi-desert vegetation of the area. In the group of long-vegetated annual herbs and grasses, Peganum harmala L, Alhagi pseudoalhagi (Bieb.) Desv., Artemisia fragrans Willd and Salsola dendroides Pall., etc. are often found in the flora of phytocenoses. All cenoses in the vegetation cover have a 2- and 3-layer geobotanical structure. The design cover in phytocenoses varies between 35-65%, depending on ecological and anthropogenic influences [2].

We believe that in the greening of Ganja "Azeraluminium" MMC, preference should be given to local trees and shrubs that have passed the test. In addition to exotic plants, Quercus iberica, Fagus orientalis, Carpinus orientalis, Tilia caucasica, Platanus orientalis, Alnus glutinosa, Betulia pendula, Mespilus germanica, Fraxinus echkelsior, Crataegus orientalis, etc. trees and shrubs can be used. The trees and shrubs used in greening should meet the requirements for improving the quality of urban ecosystems in the current era of climate change [1,2,3,6].

Pine plantations (Pinus eldarica Medw) should be expanded in eroded areas.

The study revealed that the development of Pinus sylvestris in the early stages of succession in polluted areas was at a low level. As a result of the deterioration of development conditions, a decrease in the density of the canopy and rapid shedding of conifers-defoliation, loss of the natural color of the canopy-dechromation were observed. As a result of the conducted studies, the dependence of hidden fluctuations in trees of different age groups on ecological-cenotic stresses was determined. The number of severely weakened and dried trees (more than 50%) in the study area exceeded the number of total trees. In general, the response of the species' populations to such reactions to ecological, anthropogenic, and technogenic influences in the environment is the main indicator of biological processes [2].

As a result of EPR analyses of soil and plant samples taken from conventionally accepted zones in Ganja city, spectra belonging to metal compounds were obtained in these samples. Biological analyses conducted with ms-GIE induction curves and fluorescence spectra showed that changes occur in the photosynthetic apparatus during the effect of different concentrations of Al dust on Dunaliella salina algae. The effect of different concentrations of Ganja Aluminum Plant waste dust on plant development was studied. It was determined that the addition of Al dust to the soil causes morphological changes in plants growing there [9,10].

Table 1 below presents the results of chemical composition analyses of wastes generated from the processing of alunite and bauxite.

Table 1

Chemical compositions of alunite and bauxite wastes

Name of waste	Chemical composition, %									
	SiO	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3	KKİ
Alunite	76,00	10,21	5,90	-	0,53	-	-	1,77	1,4	3,4
Bauxite	24,72	6,48	42,02	5,10	-	-	3,07	2,20	-	18,31

Alunite waste: with high SiO_2 and low Fe_2O_3 levels, it is less toxic to the soil, but long-term dusting can cause physical damage to vegetation and weaken the photosynthetic apparatus. This indicates that bauxite waste has a higher alkalinity and biological activity, which can pose a risk to soil and vegetation.

Bauxite waste: with high Fe_2O_3 and TiO_2 content, as well as the level of KKI, it has a more serious negative impact on plant roots, morphophysiological indicators and phytocenoses by increasing soil acidity. Both types of waste carry a risk in terms of soil structure, mineral balance and ecological stability of vegetation, but the toxic and biological impact of bauxite waste is stronger.

It should be noted that in order to prevent the spread of these wastes by wind, the technological process provides for covering their surface with water. However, this measure cannot be considered a complete solution in terms of environmental protection. Since chemical compounds contained in the waste can pass into the underground layers with water and cause groundwater pollution. In addition, since it is not possible to cover the entire surface of the waste area with water, dusting is observed even in weak wind conditions and carries a potential risk to the environment.

Within the framework of the United Nations Environment Program (UNEP), approved in 1980, special attention was paid to heavy metals for monitoring industrial and environmental pollution. The program considered lead (Pb), cadmium (Cd) and mercury (Hg) as the main polluting elements, and in subsequent years, elements such as copper (Cu), tin (Sn), vanadium (V), chromium (Cr), molybdenum (Mo), manganese (Mn), cobalt (Co), nickel (Ni), uranium (U), arsenic (As) and selenium (Se) were added, forming a comprehensive monitoring system for metals with high potential for creating environmental hazards. This approach is used as a scientific basis for assessing soil, water and vegetation pollution resulting from industrial activities and determining environmental risks. The alunite and bauxite waste generated from the Ganja "Azeraluminium" MMC production area contains several of these elements in high concentrations and spreads to the environment through wind, water and soil, negatively affecting the morphophysiological indicators of vegetation. The monitoring and assessment approaches proposed by the UNEP program provide a scientific basis for systematically studying the effects of such industrial impacts on both soil and vegetation and for identifying ecological risk zones [6,12].

Table 2 below shows the percentage amounts of heavy metals in wastes generated from alunite and bauxite processing and their permissible limit values.

Table 2

Amounts of heavy metals in the composition of alunite and bauxite wastes and their permissible limit values

Name of waste	Chemical composition, %								
	Sr	**Ti**	**Cr**	**V**	**Cu**	**Pb**	**F**	**Al_2O_3**	**Hg**
Alunite	0,050	0,200	0,006	0,040	0,005	0,004	0,030	63,0	-
Bauxite	-	0,100	0,030	0,010	0,001	0,003	-	-	0,000003
Releasable concentration of heavy and radioactive elements	0,006	0,180	0,005	0,015	0,005	0,0015	0,04	11,5	0,000005

As shown in Table 2, the percentage of heavy and radioactive elements in the industrial waste generated from alunite and bauxite processing and their permissible limit values are presented in a comparative manner.

In bauxite waste, these indicators are close to the normative level and can only affect soil and vegetation to a limited extent. Lead (Pb) is at the level of 0.004% in alunite waste and exceeds the normative (0.0015%). In bauxite waste, Hg (0.000003%) is lower than the normative (0.000005%), but its long-term accumulation in sensitive ecosystems poses a potential risk. In alunite waste, F (0.030%) is within the normative (0.04%), but the Al_2O_3 content is high at 63%, which can negatively affect soil pH changes and morphophysiological indicators of plants [8].

In general, the amounts of chromium, vanadium, lead and other heavy metals in alunite and bauxite waste are 1-4 times higher than the permissible limit, while titanium, copper and lead are 8 times higher than the norm. These high concentrations poison the soil and vegetation, leading to a weakening of photosynthesis, a decrease in seed productivity and changes in the structure of phytocenoses. As a result, the stability of the ecosystem in the Western region is disrupted, biodiversity is reduced, and environmental consequences arise, such as risks to human health and an increase in various diseases.

As emphasized in scientific conferences and within the framework of COP29, neutralization of industrial impacts, restoration and protection of ecosystems are considered priority environmental issues both regionally and globally. In this context, the studies conducted around the Ganja Aluminum Plant are not only considered as a localized ecological assessment, but also provide scientifically based practical recommendations for increasing resilience to ecosystem stress resulting from industrial pollution and climate change. Also, systematic measures are being taken in our country to eliminate the environmental consequences caused by waste and to involve it in recycling and production.

For this, floristic complexes should be taken under state control as a whole, observations should be made on populations at the monitoring level, phyto-ameliorative measures should be implemented to timely prevent anthropogenic anomalies that may occur in the vegetation cover of the areas surrounding the Ganja Aluminum Plant, and trees and shrubs should be selected and planted in accordance with the natural soil and climatic conditions of the area.

Conclusion

The results of the study show that industrial wastes, especially heavy metals and radioactive elements from alunite and bauxite processing, in the zone of influence of the Ganja "Azeraluminium" MMC combine have a negative impact on the morphophysiological indicators of soil and vegetation. In areas of high pollution, photosynthesis activity weakens, seed productivity decreases, and the share of anthropogenically tolerant species in the structure of phytocenoses increases, resulting in a decrease in biodiversity. The high Fe_2O_3, TiO_2 and KKI content of bauxite waste increases soil acidity, further weakening the ecological stability of vegetation. The range of rare and locally endemic species around the plant has narrowed, and a number of species are at risk of extinction. Restoration of damaged soils and vegetation is possible with phytoremediation measures. This industrial pollution, coinciding with climate change, further increases the stress level of vegetation, reduces soil fertility, and disrupts the functional stability of ecosystems. As a result, the biodiversity of ecosystems in Ganja city and its surrounding areas is weakening as a result of long-term anthropogenic impact and climate stress. Existing studies show the importance of taking scientifically based scientific and practical measures both for the protection of the region's biodiversity and the restoration of polluted areas

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İQLİM DƏYİŞKƏNLİYİ DÖVRÜNDƏ GƏNCƏ ALÜMİNİUM ZAVODU ƏTRAFI EKOSİSTEMLƏRİN BİOMÜXTƏLİFLİYİNİN DAYANIQLIĞININ QİYMƏTLƏNDİRİLMƏSİ

Vaqif Novruzov, Aynur Bayramova

Xülasə: *Tədqiqatın məqsədi iqlim dəyişkənliyi dövründə Gəncə Alüminium zavodu ətrafı ekosistemlərin biomüxtəlifliyinin dayanıqlığının qiymətləndirilməsindən ibarətdir. İqlim dəyişkənliyi dövründə dövrümüzün qlobal ekoloji problemlərindən biri də, texnoloji proseslərin nəticəsində yaranan sənaye tullantılarının ətraf mühitə təsirinin qiymətləndirilməsi və onların mənfi təsirlərinin aradan qaldırılma üsullarının tədqiqidir. Gəncə şəhəri və yaxın ərazilərdə ətraf mühitin çirklənmə səviyyəsinin müəyyənləşdirilməsi, eləcə də yaranmış mənfi təsirlərin aradan qaldırılması istiqamətində aparılan tədqiqatlar elmi və praktiki əhəmiyyət kəsb edir. Sənaye tullantılarının, xüsusilə ağır metalların və radioaktiv stronsiumun tərkibi Gəncə şəhəri və onun ətraf ərazilərinə yayılaraq regionun torpaq və bitki örtüyünü çirkləndirir. Gəncə şəhərinin sənaye müəssisələri arasında tullantıların tərkibindəki ağır metallarla ətraf mühitə ciddi mənfi təsir göstərməsi baxımından "Azəralüminium" MMC xüsusi önəm daşıyır. Aşkar olunmuşdur ki, Gəncə şəhəri və ətraf ərazilərin florası 43 fəsilə, 112 cins, 221 növdən ibarətdir. Floranın əsasını taxıllar (Poaceae-43 növ), paxlalılar (Fabaceae-38 növ), mürəkkəb çiçəklilər (Asteraceae-30 növ), çoxillik ot bitkiləri (110) növ təşkil edir. Məqalədə "Azəralüminium" MMC ətraf mühitə təsirinin nəticələri və onların aradan qaldırılması yolları barədə məlumat verilir.*

Açar sözlər: *Azəralüminium, biomüxtəliflik, ekosistem, növ, cins, fəsilə*

ОЦЕНКА УСТОЙЧИВОСТИ БИОРАЗНООБРАЗИЯ ЭКОСИСТЕМ ВОКРУГ ГЯНДЖИНСКОГО АЛЮМИНИЕВОГО ЗАВОДА В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА

Вагиф Новрузов, Айнур Байрамова

Аннотация: *Целью исследования является оценка устойчивости биоразнообразия экосистем вокруг Гянджинского алюминиевого завода в период изменения климата. Одной из глобальных экологических проблем нашего времени в период изменения климата является оценка воздействия промышленных отходов, образующихся в результате технологических процессов, на окружающую среду и изучение методов устранения их негативных последствий. Исследования, проводимые для определения уровня загрязнения окружающей среды в городе Гянджа и прилегающих районах, а также для устранения негативных последствий, имеют научное и практическое значение. Состав промышленных отходов, особенно тяжелых металлов и радиоактивного стронция, распространяется по всему городу Гянджа и его окрестностям, загрязняя почву и растительность региона, окружающую среду из-за содержащихся в его отходах тяжелых металлов. Было установлено, что флора города Гянджа и окрестностей включает 43 семейства, 112 родов и 221 вид. Флора в основном состоит из злаковых (Poaceae – 43 вида), бобовых (Fabaceae – 38 видов), астровых (Asteraceae – 30 видов) и многолетних травянистых растений (110 видов). В статье представлена информация о последствиях воздействия ООО «Азералюминий» на окружающую среду и способах их устранения.*

Ключевые слова: *биоразнообразие, экосистемы, вид, род, семейства, Азералюминий*