IRSTI 628.112 https://doi.org/10.26577/JGEM801202612

A.G. Guliyev [1], Ch.T. Bakhshiyeva [1], T.M. Babayeva [2], T.I. Yelmarli [1], N.M. Guliyev [1]

[1]Institute of Soil Science and Agrochemistry of the Ministry of Science and Education of the Republic of Azerbaijan, Baku, Azerbaijan
[2]Sumgayit State University, Baku, Azerbaijan
*e-mail: elovset_q@mail.ru

HYDRAULIC HERITAGE: QANATS AND LANDSCAPE DYNAMICS IN THE LIBERATED KARABAKH TERRITORIES

Qanat systems are traditional underground channels designed for water transportation and play a vital role in providing reliable water sources for both drinking and irrigation purposes. Over the past two years, monitoring was conducted in the territories of Karabakh liberated from occupation to assess the condition of qanats after a 30-year period. The findings revealed that many qanats still show traces of past military activities. A comprehensive study was undertaken to evaluate the technical condition and restoration potential of the qanats. In parallel, land reclamation, hydrogeological, and agro-soil investigations were carried out across the entire qanat distribution area. The results indicated that conditions varied significantly among the Agdam, Fuzuli, and Jabrayil districts. Recommendations include regular monitoring of water and soil quality, implementation of effective qanat rehabilitation methods, and the optimal utilization of qanat water for both domestic and agricultural purposes. This study emphasizes the importance of qanat systems for arid and semi-arid regions and offers practical recommendations for the sustainable management of water and land resources, to enhance the socio-economic well-being of local communities.

Keywords: Qanat, irrigation, hydraulic structure, degradation, restoration.

А.Г. Гулиев[1], Ч.Т. Бахшиева[1], Т.М. Бабаева[2], Т.И. Елмарлы[1], Н.М. Гулиев[1]

[1] Әзірбайжан Республикасы Ғылым және білім министрлігінің Топырақтану және агрохимия институты, Баку, Әзірбайжан
[2]Сумгаит мемлекеттік университеті, Баку, Әзірбайжан
***e-mail: elovset_q@mail.ru**

Гидравликалық мұра: Карабақтың азат етілген аймақтарындағы рапс және ландшафт динамикасы

Қанат жүйелері – су тасымалдауға арналған дәстүрлі жерасты арналары және ауыз су және суару мақсаттары үшін сенімді су көздерін қамтамасыз етуде маңызды рөл атқарады. Соңғы екі жылда оккупациядан босатылған Қарабақ аумақтарында 30 жылдық кезеңнен кейін қанаттардың жағдайын бағалау үшін мониторинг жүргізілді. Зерттеу нәтижелері көптеген қанаттарда әлі де өткен әскери әрекеттердің іздері бар екенін көрсетті. Қанаттардың техникалық жағдайын және қалпына келтіру әлеуетін бағалау үшін кешенді зерттеу жүргізілді. Сонымен қатар, қанаттың бүкіл таралу аймағында жерді мелиорациялау, гидрогеологиялық және агротопырақ зерттеулері жүргізілді. Нәтижелер Агдам, Физули және Джабраил аудандарында жағдайлардың айтарлықтай өзгеретінін көрсетті. Ұсыныстарға су мен топырақ сапасын үнемі бақылау, қанатты қалпына келтірудің тиімді әдістерін енгізу және қанат суын тұрмыстық және ауылшаруашылық мақсаттары үшін оңтайлы пайдалану кіреді. Бұл зерттеу құрғақ және жартылай құрғақ аймақтар үшін қанат жүйелерінің маңыздылығын атап көрсетеді және жергілікті қауымдастықтардың әлеуметтік-экономикалық әл-ауқатын жақсарту үшін су мен жер ресурстарын тұрақты басқару бойынша практикалық ұсыныстар ұсынады.

Түйін сөздер: Қанат, суару, гидравликалық құрылым, тозу, қалпына келтіру.

А.Г. Гулиев[1*], Ч.Т. Бахшиева[1], Т.М. Бабаева[2],
Т.И. Елмарлы[1], Н.М. Гулиев[1]

[1]Институт почвоведения и агрохимии Министерства науки
и образования Азербайджанской Республики, Баку, Азербайджан
[2]Сумгаитский государственный университет, Баку, Азербайджан
*e-mail: elovset_q@mail.ru

Гидравлическое наследие: канаты и динамика ландшафта на освобожденных территориях Карабаха

Канаты – это традиционные подземные каналы, предназначенные для транспортировки воды и играющие жизненно важную роль в обеспечении надежных источников воды как для питьевых, так и для ирригационных целей. В течение последних двух лет на территориях Карабаха, освобожденных от оккупации, проводился мониторинг состояния каналов после 30-летнего периода. Результаты показали, что многие каналы до сих пор сохраняют следы прошлой военной деятельности. Было проведено комплексное исследование для оценки технического состояния и потенциала восстановления каналов. Параллельно были проведены мелиоративные работы, гидрогеологические и агропочвенные исследования по всей зоне распространения каналов. Результаты показали, что условия значительно различаются между Агдамским, Физулинским и Джабраильским районами. Рекомендации включают регулярный мониторинг качества воды и почвы, внедрение эффективных методов восстановления каналов и оптимальное использование воды из каналов как для бытовых, так и для сельскохозяйственных целей. Данное исследование подчеркивает важность систем канатов для засушливых и полузасушливых регионов и предлагает практические рекомендации по устойчивому управлению водными и земельными ресурсами для повышения социально-экономического благополучия местных общин.

Ключевые слова: канат, ирригация, гидротехническое сооружение, деградация, восстановление.

Introduction

In the context of arid and semi-arid climates, which characterize much of the Near and Middle East, water supply has historically been a matter of life-sustaining importance. Within these environments, ovdans, wells, and qanats emerged as unique hydraulic structures–underground irrigation channels, designed to provide long-term and sustainable water supply for both human populations and agricultural lands. A Qanat (Kahriz) is a type of subterranean hydraulic system constructed on the principle of gravity-driven groundwater flow, which channeling water from depths exceeding 20 meters to the surface.

While the operating principle of a qanat is straightforward, its construction depends on numerous geological and hydrological factors. The system consists of vertical shafts connected by horizontal galleries, which collect water from underground aquifers and convey it to the surface. These structures represent some of the earliest forms of artificial irrigation and demonstrate the remarkable engineering sophistication of ancient societies. Guliyev examined the "Ganat" terms within Nakhchivan's folklore and literature, highlighting their role in the region's cultural and linguistic heritage (Guliyev, 2007).

In the territory of modern southern Kazakhstan, near the city of Turkestan–approximately 50 km from the fortress settlement of Saurana (Savran)–and in Azerbaijan, qanats were already recorded at the initial stage of the formation of the Great Silk Road, with their most widespread distribution dating to the 5th–7th centuries (Guliyev, 2014). Comparative analyses of historical and archaeological data classify qanats as long-term irrigation systems that played a key role in the economic life of the population. Their presence facilitated not only the expansion of agriculture but also the establishment of sustainable settlements in regions with limited natural resources.

Recent studies have highlighted the importance of traditional qanat systems in arid and semi-arid regions, both as sustainable water supply infrastructures and as cultural heritage. For instance, Bahraseman et al. investigated effective approaches for revitalizing qanats in the dry and semi-arid areas of Razavi Khorasan province, Iran (Guliyev, 2017).

Their research identified 27 factors affecting the restoration of qanats and emphasized the crucial role of a holistic approach in reviving these systems. The study suggests that reforming water governance policies and establishing independent institutions for qanat restoration are vital strategies for sustainable water management. In a concise publication for

an Iranian academic audience, Guliyev presented an overview of ancient heritage monuments in Nakhchivan, highlighting their historical significance within a broader regional context (Guliyev, 2007).

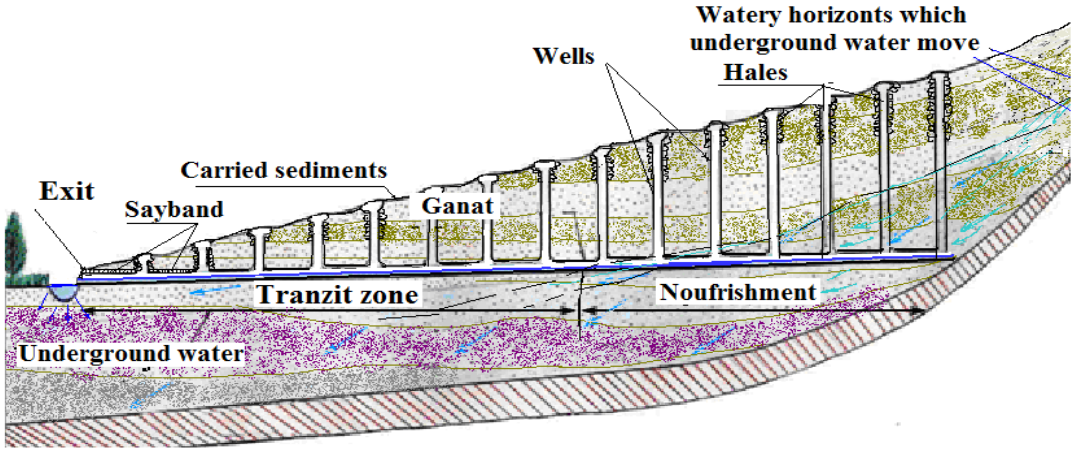
Similarly, Kowkabi examined the revitalization of qanats in District 7 of Tehran, focusing on their potential role in urban regeneration (Guliyev, 2017). The study proposed the integration of qanat routes into public open spaces to enhance social activities and connect urban areas with nature. Kowkabi emphasized that revitalizing these traditional infrastructures can improve the quality of life in urban settings by providing sustainable water sources and promoting ecological awareness. These studies underscore the multifaceted value of qanat systems, encompassing technical, ecological, and socio-cultural dimensions. They provide a framework for assessing qanat systems from both technical and socio-ecological perspectives, forming the foundation for the present investigation in the liberated territories of Karabakh.

This study aims to analyze the physicochemical properties of water from selected qanats in Azerbaijan's Karabakh region to determine its quality and suitability for domestic and agricultural use. By measuring key parameters–including pH, electrical conductivity, total dissolved solids, and major ions–the research assesses the current hydrochemical state of these waters. The findings are intended to inform sustainable management and restoration strategies for these traditional groundwater systems.

Research object and methodology

A qanat (Figure 1) is an ancient underground water management system developed to transport groundwater from an aquifer or water-bearing layer to the surface for irrigation and domestic use. This system spread to many regions, including Central Asia, the Middle East, North Africa, and even parts of southern Europe. A typical qanat consists of the main components including 1) Mother Well (Main Shaft), 2) Underground Tunnel (Gallery), 3) Vertical Shafts and 4) Outlet (Surface Channel).

Figure 1
Pic. Schematic Description of the Nourishment and Transit Zones in Qanats



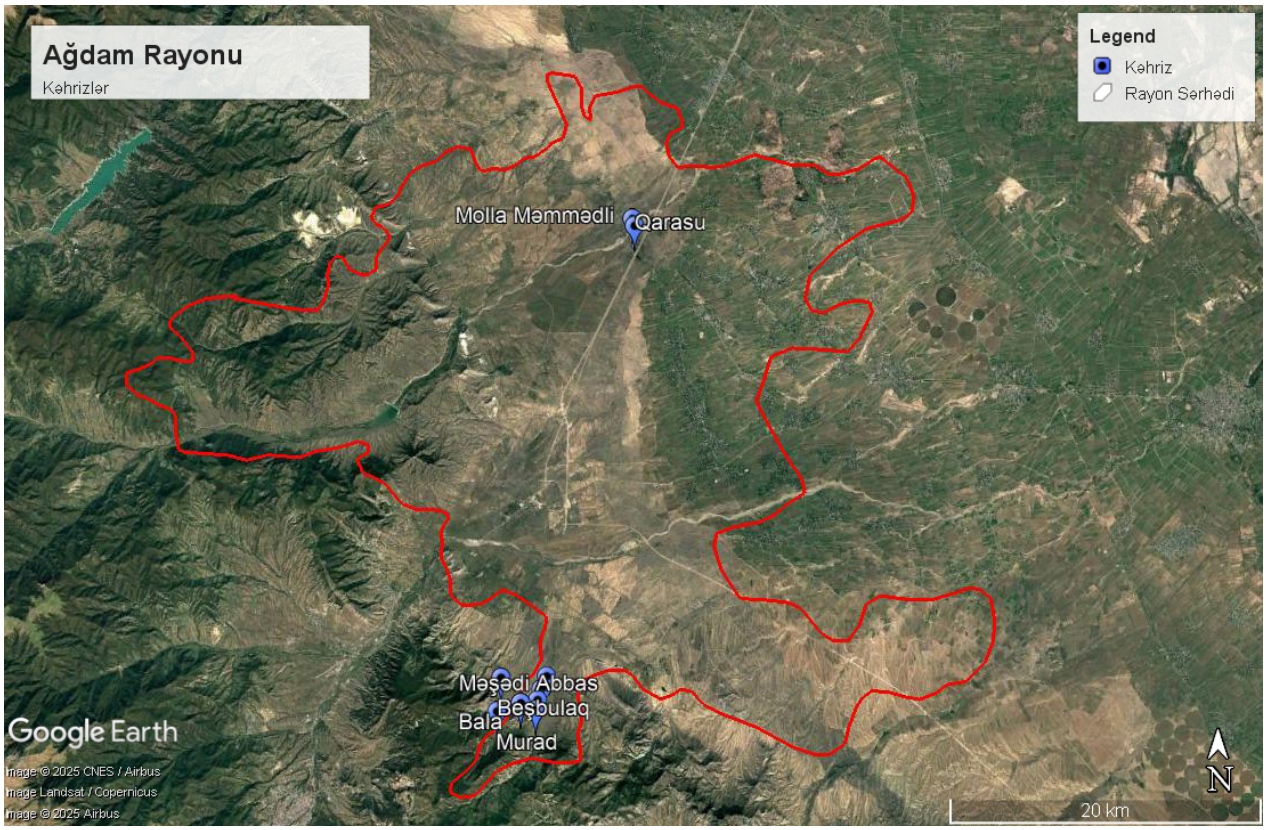
Note: Compiled by the author.

The ancient qanat systems of the Karabakh region in Azerbaijan represent a remarkable example of historical water resource management and their enduring relevance to contemporary water quality challenges. These underground channels, designed to convey water from aquifers to the surface, have for centuries played a crucial role in sustaining agriculture and supporting the livelihoods of local communities in arid regions (Antonov, 1959).

Over the past two years, a comprehensive research project has been conducted in the liberated territories of Karabakh to assess the technical condition and operational potential of the qanat systems.

The study focused primarily on the Fuzuli, Agdam and Khojavend districts, where over 50 qanats across 22 settlements were documented and surveyed. The research methodology included visual monitoring, GPS mapping, and technical, archaeological, and hydrogeological assessments (Figure 2).

Figure 2
The study area map



Note: Compiled by the author.

The findings revealed that many qanats still bear traces of military activity, with walls damaged by mines, explosions, and firearms. Following three decades of occupation, a significant portion of these systems had been destroyed or rendered non-functional. This deterioration has been further exacerbated by environmental factors such as overgrown vegetation, the accumulation of animal bones, and the blockage of channels. Addressing these issues through the restoration and preservation of the qanats is a priority task. This endeavor carries not only technical importance but also profound socio-economic and ecological significance for the region.

The conducted analysis of water (chemical composition) from qanats in both districts revealed that the concentrations of major components are within permissible sanitary standards. In certain qanats, such as the Molla-Mahmud qanat in the Agdam district, water mineralization levels do not exceed maximum allowable values and do not pose a threat to public health. Measurements of the radiation background showed stability and compliance with regulatory norms. A key parameter was the concentration of dissolved oxygen in the qanats, ranging from 2.74 to 9.11 mg/L, indicating sufficient oxygen saturation, which reflects the favorable condition and biological stability of the water.

Within the framework of the research, not only the hydrogeological but also the technical condition of the qanats was studied, along with a comprehensive analysis of water and soils. As a result, it was found that in some villages of the Agdam district, there are significant differences in the schemes and layouts of qanats. These differences are determined

not only by natural factors but also by the lithological characteristics of soils and substrates. Prolonged absence of agricultural activity in the liberated territories (for example, in the villages of Ahmedagali and Bash Gervend) has led to land being overgrown with various shrubs and trees. Figure 3 presents two graphs for the wells of the Mollamammadali Qanat in Bash Gervend village, Agdam District.

Figure 3
Wells of the Mollamammadali Kahriz located in Bash Gervend village, Agdam District.

Note: Compiled by the author.

Methods

During observations, we recorded tunnel collapses in sections of the qanat at depths of only 2–3 meters, leading to cessation of its operation. At present, an official appeal has been submitted to the authorities regarding the activities of the construction companies. Despite our appeals to the relevant authorities, no conclusions or actions have been taken so far.

We were able to conduct water analyses in the demined territories within the combat zone in collaboration with the Institute of Radiation Problems. The objective was to determine whether heavy metals and other harmful substances had entered the qanat waters as a result of military aggression. Consequently, the analysis of qanat water collected from the combat zone was performed in a specialized laboratory at the Institute of Radiation Problems. The results of the analysis are presented in the table and in explanatory form.

During the course of the study, it was established that qanats of hereditary historical significance were destroyed during military actions, with their walls bearing traces of damage from mines, explosions, and firearms. As a result of 30 years of occupation, a significant portion of the systems had been destroyed or rendered nonfunctional. Their current condition has been further exacerbated by overgrown vegetation, accumulation of animal remains, blockages, and clogged channels.

Results and discussion

This section presents the results of the study conducted on the Molla-Mammadali Qanat in Bash Gervend Village, Agdam District. At the initial stage of monitoring the qanats in the liberated and demined territories, water samples were collected from qanats in the study area and analyzed in the accredited laboratories. The analyses were conducted under conditions that complying with current standards. As shown in Tables 1 and 2, the results of the physicochemical analysis of water samples collected from the villages of Dash Veisally (Bala qanat), Kavdar (Agalarbek qanat), Chereken (Tavega qanat), Khorovlu (Shikhi qanat), Khalifa Valley qanat, Asker qanat, and Orta (Middle Kahriz and Guzey qanats in the village of Guyjak, Jabrayil district)–demonstrated that these

waters are fully suitable for both drinking and irrigation purposes.

The turbidity of the qanat waters ranges from 0.21 to 2.5 mg/L, which does not exceed the maximum permissible concentration of 2.6 mg/L. Only the turbidity value of the water sample taken from the Bala qanat in the village of Dash Veysally slightly exceeded the permissible limit, measuring 2.71 mg/L. This deviation is likely associated with urban development and restoration activities carried out by certain Turkish companies in the area.

In qanat wells with depths less than 4–5 meters, structural collapses have been observed due to the impact of heavy machinery operating near or above the tunnels. Overall, the results of the conducted studies indicate that the qanat water remains fully suitable for both drinking and domestic water supply purposes (Akimtsev, 1928; Bekzhanov, 2020; Mukanova, 2024).

Figure 4
Outlets of the Karasu (a) and Mollamammadali (b) Qanat wells in Bash Qervend village.

a) *b)*

Note: Compiled by the author.

Addressing the aforementioned challenges related to the restoration and preservation of qanats is a priority task of not only technical, significance but also socio-economic and ecological importance. The analysis of the chemical composition of qanats water showed that the concentrations of major components remain within permissible sanitary standards. In certain qanats, such as the Molla-Mahmud qanat (Agdam district), the sodium concentration reached 90 mg/L.

This indicates adequate oxygen saturation, reflecting the overall favorable condition and biological stability of the water. Within the framework of this study, not only was the hydrogeological condition of the qanats examined, but a comprehensive analysis of the agrochemical properties of the soils was also conducted. The results revealed significant variations in soil agrochemical properties were observed across several villages in the Agdam district. These differences are attributed not only by natural factors but also by the prolonged absence of agricultural activity in the liberated territories (for example, the villages of Ahmedaghali and Bash Gervend).

Khojavend District After analyzing the distribution of Qanatsystems, their current condition, and their interaction with the landscape in the Aghdam and Fuzuli districts, the Khojavend district was selected as a logical continuation of the research. The territory of the Khojavend district is characterized by specific orographic and hydrogeological conditions, which lends particular scientific significance to a comparative study of the influence of Qanatsys-

tems on landscape dynamics in the liberated territories of Karabakh.

Comprehensive monitoring and laboratory investigations of springs and Qanatsystems located in various villages and settlements of the Khojavend district made it possible to scientifically substantiate the assessment of their hydrogeological characteristics, hydrogeochemical composition, and existing potential for utilization. The research covered the villages of Kish, Khanoba, Zogalbulag, and Tugh, as well as the settlements of Gizil-Bazar and Hadrut, with the physicochemical parameters of water being comparatively analyzed across the selected sites. The diversity of relief and geological structure of these areas provided an opportunity for a more detailed study of the conditions of Qanat formation and their interaction with the landscape.

The results of the conducted analyses indicate that the waters of springs and Qanat systems in the Khojavend district are formed predominantly within a hydrogeological environment composed of carbonate and partially dolomitic rocks. This is confirmed by the dominance of calcium and magnesium in the cationic composition of the water: the equivalent concentration of calcium ranges from 38.5 to 50.9 %-eq, while that of magnesium varies between 12.7 and 26.7 %-eq. Sodium and potassium occupy a secondary position (22.4–48.8 %-eq), exhibiting a generally balanced character. These indicators suggest that water formation occurs mainly under the influence of natural hydrogeochemical processes, with limited anthropogenic impact.

The anionic composition of the water provides important information about its formation conditions. According to laboratory analysis results, bicarbonate ions (HCO_3^-) are the dominant anionic component in all samples, with equivalent concentrations ranging from 49.3 to 77.2 %-eq, which allows the waters of Qanat systems and springs to be classified as the bicarbonate–calcium type. Sulfate ions (SO_4^{2-}) are present at concentrations of 18.9–37.6 %-eq; relatively elevated values observed in some samples indicate the involvement of gypsum and sulfate-bearing rocks within the recharge zone. Chloride ion (Cl^-) concentrations range from 3.1 to 13.1 %-eq, confirming the minimal influence of technogenic and domestic pollutants. The absence of carbonate ions (CO_3^{2-}) in all samples is an important hydrogeochemical indicator, reflecting water formation under neutral environmental conditions.

The total mineralization of water from Qanat systems and springs ranges from 402 to 972 mg/L, allowing these waters to be classified mainly as moderately mineralized, and in some cases as relatively highly mineralized. The highest mineralization values are observed in areas with an intensive distribution of carbonate rocks, indicating prolonged water–rock interaction. Total water hardness varies between 4.38 and 13.39 meq/L, classifying the waters as moderately hard to hard; the formation of hardness is largely обусловлено the high concentrations of calcium and magnesium ions, which are directly related to the geological structure of the region.

Analysis of sanitary-chemical parameters revealed important insights into the ecological condition of the waters of Qanat systems and springs in the Khojavend district. Nitrite (NO_2^-) and ammonium (NH_4^+) ions were not detected in any of the samples, indicating minimal influence from anthropogenic sources of pollution. This confirms the preservation of the natural filtration mechanisms of the Qanat systems and the satisfactory sanitary and hygienic condition of the water bodies. In addition, water transparency, the absence of odor, and normal organoleptic characteristics ensure their suitability for domestic and household use.

Overall, the conducted studies demonstrate that the Qanat systems and springs of the Khojavend district constitute an important component of the hydraulic heritage of the liberated territories of Karabakh. These water systems are formed in close interconnection with the natural dynamics of the landscape, playing a significant role both in the sustainable use of water resources and in maintaining the ecological balance of the region. The Qanat systems of the Khojavend district possess substantial scientific and practical importance not only for local water supply, but also for the restoration of historical hydraulic systems of Karabakh and the development of future water resource management strategies.

The Qanat systems existing in the liberated territories of Karabakh, as an important component of the region's hydraulic heritage, simultaneously play a key role in shaping the "soil–water–landscape" interactions. The study of the physical and chemical properties of soils located within the zone of influence of Qanat systems is of particular importance for assessing soil fertility, identifying potential nutrient deficiencies, or detecting processes of excessive mineralization. Such investigations are especially relevant for territories that remained unused for a long period in the post-war era and were subjected to the destruction of vegetation cover and the

impact of erosion processes, as they make it possible to determine the current condition of soil structure, organic matter reserves, and the content of major macroelements.

Soil analyses also provide an important informational basis for maintaining soil health, assessing the risks of salinization and acidification, and for the scientifically grounded planning of irrigation and fertilization strategies. For this purpose, within the framework of the study, soil samples were collected from areas adjacent to Qanat systems located in various villages of the Aghdam and Fuzuli districts, followed by laboratory analysis.

In the Aghdam district, soil characteristics exhibit more pronounced differentiation among rural settlements. In the villages of Bash Gyaravend and Gyaravend, soils are characterized by a high level of fertility: humus content ranged from 2.6 to 3.8 %, and the reserves of nitrogen, phosphorus, and potassium were sufficient for the normal growth of agricultural crops. In the villages of Gyulably, Yusifjanly, and Ahmedagaly, soil fertility was assessed as medium to low; humus content varied between 0.8 and 3.1 %, and the distribution of nutrients was unstable and uneven.

In terms of mechanical composition, the predominance of heavy clay soils in certain areas limited aeration and water infiltration processes. At the same time, in the villages of Bash Gyaravend and Gyaravend, soils with a medium mechanical composition contributed to the formation of more favorable agroecological conditions.

Overall, the results of the conducted soil analyses indicate that the soils located within the influence zone of Qanat systems in the Fuzuli and Aghdam districts possess significant potential for agricultural activity. These studies provide a scientific basis for the objective assessment of soil fertility, the determination of the spatial distribution of nutrients, and the advance evaluation of potential risks in landscape dynamics, including salinization, acidification, and structural degradation of soils. The development of differentiated agrotechnical measures and soil restoration programs for each settlement is considered a necessary condition for the sustainable and scientifically grounded revival of agriculture in the liberated territories.

The studies conducted in the Fuzuli district indicate a significant differentiation of soils among rural settlements. Humus content ranged from 1.7 to 3.5 %, while the availability of phosphorus and potassium was characterized by uneven distribution across plots. In terms of mechanical composition, the soils were mainly classified as light and medium loamy types, with the proportion of clay and sand fractions determining their water-retention capacity and aeration conditions. Areas with elevated ammonium nitrogen content indicate relatively high biological activity of the soils. Overall, based on the conducted analyses, it can be concluded that the soils within the influence zone of Qanat systems in the Fuzuli district are favorable for agriculture; however, some plots exhibit uneven distribution of nutrients.

he conducted physico-chemical analyses indicate that water samples collected from the qanats located in the Horovlu, Kavdar, Chereken, Quycaq, and Daş Veyselli villages, as well as within the territory of the city of Jabrayil, are characterized by high sanitary–hygienic quality. All samples were odorless, with an odor intensity of 0 at 20°C, confirming the absence of organic contamination.

Turbidity values remained within the норматив limit (2.6 mg/L), while pH ranged between 6.83 and 7.7, indicating neutral to slightly alkaline water characteristics. Electrical conductivity values (404–828 μS/cm) were significantly below the permissible threshold, reflecting low to moderate levels of mineralization.

Total hardness, mineralization (340–713 mg/L), and total dissolved solids (225–537 mg/L) across all qanats were within acceptable standards. Concentrations of calcium, magnesium, sodium, and potassium ions did not exceed allowable limits. The low concentrations of bicarbonates, sulfates, and chlorides indicate that the ionic composition of the waters is predominantly of natural origin.

Nitrogen compounds (ammonium, nitrites, and nitrates) were detected at very low levels, with the maximum nitrate concentration (11 mg/L) remaining well below the regulatory limit. Fluoride (0–0.43 mg/L) and cyanide (0–0.003 mg/L) concentrations were also within permissible standards. (Table 1)

Table 1
Physicochemical *Characteristics of Water Samples Collected from Qanats in the* Jabrayil District

№	Indicator Name	Unit of Measure-ment	AZS 929:2023 Standard	Conclusion								
				Khorovlu Village – Shykhy Kahriz	Khorovlu Village – Khalifa Valley Kahriz	Khorovlu Village –Asker Kahriz	Khorovlu Village – Middle Kahriz	Kavdar Village – Agalarbek Kahriz	Jabrayil city Chinar Kahriz	Chereken Village – Tavake Kahriz	Village Guydzhag – Gyuzey Kahriz"	Dash Veysally Village – Small Kahriz
1	At 200°C – good	score	< 2	0	0	0	0	0	0	0	0	0
2	Turbidity	mg/L	< 2.6	0.21	0.77	0.26	0.30	2.50	0.45	1.29	0.44	2.71
3	pH value	pH	6.5–9.5	7.64	7.00	7.07	6.83	7.66	6.90	7.70	7.4	7.33
4	Electrical conductivity (25°C)	μS/cm	< 2500	828	802	650	732	740	404	556	792	498
5	Total hardness	mmol/L	350	360	300	295	350	270	185	230	300	170
6	Total mineralization (∑i)	mg/L	1000	713.6	669.9	537.9	640.5	611.2	340.4	440.1	617.6	419.4
7	Dry residue	mg/L	1000	537	524	416	488	471	225	324	483	297
8	Calcium (Ca^{2+})	mg/L	< 130	108.2	88.2	86.2	100.2	76.2	56.1	72.1	96..2	56.1
9	Magnesium (Mg^{2+})	mg/L	< 65	21.9	19.5	19.5	24.3	19.5	10.9	12.2	14.6	7.3
10	Sodium + Potassium ($Na^+ + K^+$)	mg/L	200 (Na^+)	54.0	69.5	30.6	36.6	65.6	14.5	27.8	54.3	46.5
11	Hydrocarbonate (HCO_3^-)	mg/L	1000	353.8	292.8	244.0	305.0	280.6	231.8	231.8	268.4	244.0
12	Sulfates (SO_4^{2-})	mg/L	500	159	174	147	165	141	18	76	153	48.0
13	Chlorides (Cl^-)	mg/L	350	14.5	17.4	1.4	1.4	21.6	1.4	8.9	23	11.7
14	Ammonium nitrogen (NH_4^+-N)	mg/L	0.5	0.15	0.25	0.16	0.12	0.16	0.17	0.16	0.18	0.2
15	Nitrates (NO_3^-)	mg/L	50	1.9	6.0	8.2	7.0	6.2	6.9	11.0	7.4	5.4
16	Nitrites (NO_2^-)	mg/L	3	0.019	0.041	0.021	0.018	0.025	0.012	0.006	0.022	0.013
17	Phosphates (PO_4^{3-})	mg/L	3.5	0.10	2.18	0.11	0.13	0.07	0.12	0.15	0.05	0.014
18	Fluorides (F^-)	mg/L	1.5	0.01	0.02	0.43	0.30	0.25	0.22	0	0.43	0
19	Cyanides (CN^-)	mg/L	0.035	0	0.002	0.007	0.002	0.002	0.001	0.002	0.003	0.03

Note: Compiled by the author.

Water and soil samples were collected from seven qanat systems and analyzed for a range of physicochemical parameters. The water quality assessment included measurements of pH, electrical conductivity, hardness, mineralization, and the concentrations of calcium, magnesium, sodium, and other ions. Soil analyses focused on determining pH, electrical conductivity, organic matter content, salinity levels, and the presence of key ions such as sulfates and nitrates. [Mustafayev, et al., 2022]. The results indicated that the qanat water is generally of high quality, with pH values suitable for both drinking and irrigation purposes. However, several qanat systems showed elevated levels of electrical conductivity and mineralization, suggesting potential salinization risks for sensitive agricultural crops (Mustafayev, et al., 2025; Ahmadova, et al., 2025).

The soil samples exhibited favorable agricultural conditions, including optimal pH values, low salinity, and relatively high organic matter content. Overall, the analysis revealed a strong correlation between water quality and soil properties, underscoring the importance of an integrated approach to sustainable water and land resource management (Hamilton, 2012). To assess the current condition of qanat systems in the Fuzuli , Agdam and Khojavend districts, evaluate their technical potential, and determine restoration possibilities, comprehensive field studies were carried out. Guliyev and Valiyev documented and analyzed the archaeological remains of the ancient ganat (qanat) water systems in Nakhchivan, emphasizing their significance as historical monuments of hydro-engineering and cultural heritage (Guliyev, 2004).

Table 2
Radiation Measurements of Qanats in the Fuzuli District

No	Point description	pH	COND	TDS	SAL	DO	DO	T	Rad	Rn
			µsm/cm	*mg/L*	*%*	*%*	*mg/L*	*oC*	µ*Sv/cm*	Bq/L
1	Horadiz Nırja kahriz	7,87	697	348	0,04	100,2	8,80	19,2	0,052	0,058
2	Gorazilli–Haji Shukur Kahriz	6,59	572	286	0,03	85,7	7,75	19,3	0,048	0
3	Gochahmadli – Chinar Kahriz	6,95	589	294	0,03	87,1	7,89	19,4	0,050	0
4	Gochahmadli –Jamal Kahriz	6,75	361	181	0,02	89,5	8,14	19,3	0,044	0,115
5	Qochehmedli Shirlan kahriz	6,82	573	286	0,03	92,8	8,44	19,5	0,042	0,402
6	Upper Abdulrahmanli Chereken River	7,76	661	329	0,03	87,3	7,96	19,3	0,051	0
7	Lower Abdulrahmanli – Ahmad Ali Kahriz	7,13	1029	515	0,05	75,2	6,88	19,0	0,049	0
AZS 929:2023 Drinking Water: Hygienic Requirements		6.5-9.5	<2500	1000 -1500		60.52	5,00	<20		11

Note: Compiled by the author.

The primary aim of the research was to document the contemporary existence of the region's historical water infrastructure, particularly qanats, and to provide a scientific evaluation of their hydrogeological, technical, and ecological status. Guliyev studied the interconnected roles of ganats (subterranean aqueducts) and the "girkhpillalar" ("forty stages") as integral components of the ancient cultural and infrastructural heritage in the region (Guliyev 2004).

Azizbayov conducted a foundational study on the geology and petrography of the northeastern Lesser Caucasus region, providing critical insights into the area's lithological composition (Azizbayov 1947).

Within the framework of the study, visual monitoring, GPS mapping, assessment of hydrogeological conditions, and analysis of the lithological properties of soil substrates, as well as water sampling and laboratory analyses, were conducted, alongside water sampling and laboratory analyses of more than 50 qanats across 22 villages. Certified laboratories evaluated water samples for physicochemical parameters, including pH, mineralization, electrical conductivity, salinity, and major ion concentrations, as well as radiological indicators such as back-

ground radiation and organoleptic characteristics, providing comprehensive evaluation data for each qanat. During the investigation of qanat systems, particularly their above-ground structures, traces of shells, bullet holes, and damage resulting from occupation and prolonged neglect were documented, along with partially destroyed stone constructions. At several outlet wells, wild trees and vegetation, as well as accumulated debris and animal remains, were observed.

These factors are crucial indicators, requiring evaluation of qanats not only from a technical restoration perspective but also from ecological and cultural-historical viewpoints. Fieldwork in the surveyed villages included research in the Fuzuli district, specifically the village of Dilagarda. Dilagarda Historically, Dilagarda has been known for its population engaged in agriculture and livestock farming over many years. Qanat systems played a key role in supplying water to the village. The main sources were the Behbetli qanat and a spring locally known as "Arıg-Bulag". Both sources were historically utilized for drinking and irrigation purposes. However, during the war and occupation, the lack of proper maintenance led to the deterioration of these systems over time. Currently, water flow in the qanats is weakened during certain seasons, although circulation in some wells remains active. Partial blockages caused by accumulated soil and stone debris were observed in several tunnel sections of the qanats. Precise identification of the head and outlet wells, along with geodetic measurements, provided a necessary preliminary information base for qanat restoration. Guliyev, et al analyzed the specific restoration challenges facing the historic ganat systems of Azerbaijan's Ganja-Gazakh region, framing their preservation as a critical issue for both cultural heritage and agricultural sustainability (Guliyev, 2016; Mustafayev, *et al*., 2025).

Water samples were collected from the qanat for physicochemical and radiological analyses. The Behbetli qanat exhibited a pH of 7.30, electrical conductivity of 1089 µS/cm, total dissolved solids (TDS) of 546 mg/L, and total mineralization of 696 mg/L. Meanwhile, the sample from the "Arıg-Bulag" spring showed a pH of 7.16, TDS of 437 mg/L, and mineralization of 503 mg/L. These results indicate that the water is characterized by high mineralization and medium hardness. The concentration of sodium and potassium ions ($Na^+ + K^+$) was 142 mg/L in the Behbetli qanat and 98 mg/L in the spring, indicating relatively high salinity, although still within permissible sanitary standards. Bicarbonate content (HCO_3^-) measured 458 mg/L and 311 mg/L, respectively, confirming the natural filtration of the water. Sulfate levels (SO_4^{2-}) were 135 mg/L for the Behbetli qanat and 98 mg/L for the spring, indicating suitability for technical use and limited drinking purposes.

Based on the analysis results, no organoleptic impairments were detected in either water source, and radiological indicators fully complied with established standards. The dissolved oxygen (DO) levels were 9.13 mg/L for the Behbetli qanat and 9.10 mg/L for the spring, indicating favorable ecological condition of the water. Consequently, the Behbetli qanat and the "Arıg-Bulag" spring in Dilagarda village, following technical restoration, can be considered suitable water sources for agricultural use, potable water supply, and ecological purposes. The liberated Agdam district, being one of the economic centers of the Karabakh region, holds strategic significance both historically and economically. Guliyev evaluated the potential opportunities and continued relevance of the historic Aylis ganat systems, proposing their significance for contemporary regional development and sustainable water resource utilization (Guliyev, 2005).

As part of monitoring and geodetic surveys, ancient qanats in several villages of the district were inspected, and their current condition, technical potential, and restoration feasibility were evaluated. Most qanats in the district had been used for both irrigation and drinking purposes for many years; however, during the war and occupation, they fell out of use due to a lack of maintenance (Yusifov, 2003). Reporting on practical knowledge transfer, Gashimova notes in the "East Gate" newspaper that the restoration methodologies developed for the historic ganats of Nakhchivan are slated to be applied in upcoming ganat rehabilitation projects in Uzbekistan (Gashimova, 2014).

Figure 5
Photo taken in the field during the research work.

Note: Compiled by the author.

Bash-Gervend, one of the ancient settlements in the Agdam district, historically supplied the local population, engaged in agriculture and livestock farming, with a primary water source. In this village, the Molla-Mammadali, Gojja, Karasu, and Molla-Mahmud qanat systems were utilized for both drinking and irrigation purposes for many years. However, during the occupation, these systems gradually deteriorated due to the absence of proper maintenance. During field monitoring, the qanat systems were inspected on-site, their technical condition was assessed, and geodetic measurements were carried out. The investigation revealed the presence of wet zones in the Molla-Mammadali and Gojja qanats, indicating that the underground water circulation had not completely ceased and that these qanats retain potential for restoration. Water samples were collected from all four qanats, and their physicochemical and radiological characteristics were analyzed. According to the analyses:

Molla-Mammadali qanat: pH 6.71, TDS 195 mg/L, electrical conductivity 388 µS/cm, mineralization 315 mg/L, $Na^+ + K^+$ 32 mg/L, HCO_3^- 244 mg/L, SO_4^{2-} 74 mg/L, hardness 4.44.

Gojja qanat: pH 7.47, TDS 215 mg/L, electrical conductivity 429 µS/cm, mineralization 303 mg/L, $Na^+ + K^+$ 19 mg/L, HCO_3^- 232 mg/L, SO_4^{2-} 72 mg/L, hardness 4.85.

Karasu qanat: pH 7.35, TDS 234 mg/L, electrical conductivity 468 µS/cm, mineralization 410 mg/L, $Na^+ + K^+$ 53 mg/L, HCO_3^- 293 mg/L, SO_4^{2-} 111 mg/L, hardness 5.18.

Molla-Mahmud qanat: pH 7.36, TDS 274 mg/L, electrical conductivity 548 µS/cm, mineralization 482 mg/L, $Na^+ + K^+$ 90 mg/L, HCO_3^- 384 mg/L, SO_4^{2-} 102 mg/L, hardness 4.90.

These indicators suggest that water in all qanats is neutral and of moderate hardness, with mineralization levels suitable for both potable and technical use. Notably, the elevated sodium concentration in the Molla-Mahmud qanat (90 mg/L) indicates a tendency toward increased salinity; however, this value remains within permissible sanitary limits. Radiological analyses revealed no organoleptic impairments, and all measurements complied with the established standards. Dissolved oxygen (DO) levels ranged from 2.74 to 9.11 mg/L, indicating varying degrees of oxygen saturation across different qanats.

Figure 6
Jamal Qanat, Gochahmadli village, Fuzuli district.

Note: Compiled by the author.

Conclusions

In conclusion, the qanat systems in Bash-Gervend village demonstrate significant rehabilitation potential from both hydrogeochemical and technical perspectives. The water exhibits a balanced and clean composition, indicating that, following technical reconstruction and structural reinforcement, these qanats can be effectively reused for agricultural purposes and limited potable water supply. The observed heterogeneity of the qanats, including variations in water quality, structural condition, and underground circulation, underscores the necessity of developing individualized restoration programs. Such an approach allows for the consideration of local specificities, ensuring that restoration measures are technically feasible, environmentally sustainable, and socio-economically beneficial.

Integrating scientific research into the practical restoration of these historical water systems provides a foundation for sustainable management of water resources in the region. This integration not only supports agricultural productivity but also strengthens food security and creates new socio-economic opportunities for local communities. Consequently, the rehabilitation of qanat systems can contribute to the revitalization of post-conflict territories and promote long-term regional development, preserving both cultural heritage and ecological balance.

The results of comprehensive hydrogeological and environmental studies indicate that the qanat systems that existed in the Karabakh and East Zangezur regions functioned for many years as a natural drainage mechanism, playing a significant role in regulating groundwater levels and preserving soil fertility. In particular, through the qanat network formed in the foothill areas of the Jabrayil, Aghdam, and Fuzuli districts, approximately 122 million m³ of groundwater resources were brought to the surface annually, and these resources were used efficiently for both drinking water supply and irrigation purposes.

Studies demonstrate that over the past 30 years, as a result of occupation, the vast majority of qanats have been severely destroyed, and in some cases the mining of wells and contamination with military waste have turned them into potential sources of danger. In this regard, the restoration of qanats must be carried out strictly with the participation of ANAMA and in full compliance with all safety requirements. At the same time, observations show that weak leakages are present in most of the destroyed qanats, which makes it necessary to conduct design-survey works and scientifically substantiated technical measures for their restoration.

Research also indicates that the failure of qanat waters to reach the ground surface leads to a rise in groundwater levels in downstream areas, thereby

increasing the risk of emerging new hydrological problems. Despite the fact that the Main Karabakh Canal has maintained the stability of filtration processes over many years, the restriction of the functional operation of qanats has caused fundamental changes in the structure of underground water flows.

As a result, the region's qanats possess significant water supply potential and, under the conditions of the expected water scarcity in the near future, have strategic importance as a reliable and sustainable alternative water source. Their restoration should be regarded as essential in terms of ensuring the country's water security, preserving ecological balance, and supporting the sustainable development of agriculture.

In this context, the urgent passportization of qanats in the liberated territories and the establishment of a unified qanat cadastre emerge as key priorities. This cadastre should include information on the historical, technical, and hydrogeological characteristics of each qanat, water discharge rates, the results of chemical and bacteriological analyses, as well as records of repair and restoration activities.

In particular, during the restoration of qanats with historical and architectural significance, the preservation of their original structural and architectural features should be adopted as a fundamental principle, and all interventions should be carried out in accordance with the requirements for the protection of cultural heritage.

Acknowledgement

This work was suppored by the Azerbaijan Science Foundation (Grant No. AEF-MQM-QA2-2023-3(45)-05/05/3-M-05). The authors also wish to express their gratitude to the anonymous reviewers, whose insightful comments and suggestions significantly contributed to the improvement of this manuscript

Author Contributions

Conceptualization, X.X. and Y.Y.; Methodology, X.X.; Software, X.X.; Validation, X.X., Y.Y. and Z.Z.; Formal Analysis, X.X.; Investigation, X.X.; Resources, X.X.; Data Curation, X.X.; Writing – Original Draft Preparation, X.X.; Writing – Review & Editing, X.X.; Visualization, X.X.; Supervision, X.X.; Project Administration, X.X.; Funding Acquisition, Y.Y.

References

Ahmadova, M. A., Mustafayev, M. G., Gafarbayli, K. A., Nuriyeva, K. Q., Kuliyeva, Y. N., & Ahmadova, A. R. (2025). Diagnostic specifics of the chemical elemental composition of meadow-gray soils in the Mughan steppe, Azerbaijan. *Sabrao Journal of Breeding and Genetics, 57*(5), 2139–2146. https://doi.org/10.54910/sabrao2025.57.5.34

Akimtsev, V. V. (1928). Soils of the Ganja town. In *Materials of regionalization of Azerbaijan SSR* (p. 180). Baku.

Antonov, B. I. (1959). Little Caucasus. In *Geology of Azerbaijan* (pp. 192–250). Academy of Sciences of the Azerbaijan SSR.

Azizbayov, Sh. A. (1947). *Geology and petrography of the north-eastern part of the Little Caucasus*. Academy of Sciences of the Azerbaijan SSR.

Bekzhanov, S. Zh., Mustafayev, M. G., Tokhetanova, L. A., & Torebekov, R. G. (2020). Organization of a green conveyor system based on local forage crops. *Bulletin of Korkyt Ata Kyzylorda University*, (1), 43–50.

Gashimova, M. (2014, November 21). Nakhchivan experiment will be used in ganat restoration work in Uzbekistan. *East Gate Newspaper*.

Guliyev, A. G. (2004). Ancient heritage monuments, ganats and "girkhpillalar" (forty stages). *Works of the Azerbaijan University of Architecture and Construction*, (1), 37–41.

Guliyev, A. G. (2005). Potential opportunities of the Aylis ganat systems. In *Science and Regional Problems* (pp. 540–544). Nurlan.

Guliyev, A. G. (2007a). Ancient heritage monuments in Nakhchivan. *Bridge*, (52), 34.

Guliyev, A. G. (2007b). Ganat terms in Nakhchivan folklore. *Literature*, (3), 147–150. Ankara.

Guliyev, A. G. (2017). Ganats in Nakhchivan Autonomous Republic. In *Geography of Nakhchivan* (pp. 248–287). Nakhchivan.

Guliyev, A. G., & Aliyev, K. A. (2014). Report of the monuments on ganat systems for sustainability. *Ecology and Water Farming*, (2), 36–41.

Guliyev, A. G., & Valiyev, V. Z. (2004). Ancient ganat system monuments of Nakhchivan. In *Culture World: Scientific-Theoretical Collection* (Vol. 8, pp. 121–125). Elm.

Guliyev, A. G., Mirsalahov, M. M., & Allahverdiyeva, K. E. (2016). Azerbaijan ganats and their restoration problems (Ganja-Gazakh region example). In *Proceedings of the Republic Scientific-Practical Conference* (pp. 17–21). Ganja.

Hamilton, P. A., & Miller, T. L. (2012). Agriculture and water quality: A perspective. *Agricultural Sciences, 3*(2), 245–252.

Hansen, R. P. (2004). Kariz: Subsoil water source of Turhan. *Knowledge and Utopia*, (123), 19–23.

Mukanova, G. A., Kakimzhanov, E. Kh., Shimshikov, B. E., Tukenova, Z. A., Mustafayev, M. G., Oshakbay, A. A., & Khasenova, A. N. (2024). Analysis of environmental degradation due to anthropogenic impact in Western Kazakhstan. *Journal (Geographical Series)*, (1), 98–118.

Mustafayev, M. G., Alizade, Ş. V., Mustafayev, F. M., Akhundov, A. Y., & Hasanova, A. X. (2025). Anthropogenic impact on soil salinization and its management in irrigated areas of the Mughan plains, Azerbaijan. *Sabrao Journal of Breeding and Genetics, 57*(4), 1688–1698. https://doi.org/10.54910/sabrao2025.57.4.35

Mustafayev, M. G., Sadigov, R. A., Mirsalahov, M. M., Gurbanov, E. A., Jalilova, L. Z., & Mustafayev, F. M. (2025). Salts deposition and groundwater mineralization effect on soil salinization in Shirvan plain and Ganja-Gazakh massif, Azerbaijan. *Sabrao Journal of Breeding and Genetics, 57*(5), 2147–2155. https://doi.org/10.54910/sabrao2025.57.5.35

Mustafayev, M. G., Tukenova, Z., Alimzhanova, M., Ashimuly, K., & Mustafayev, F. (2022). Influence of fertilisation on the water-salt regime in the Mughan-Salyan massif, Azerbaijan. *Journal of Water and Land Development*, (55), 276–285. https://doi.org/10.24425/jwld.2022.142330

Semsar, A. A., & Khaneiki, M. L. (Eds.). (2012). *Qanats in its cradle: Situation of qanat (kariz, karez, falaj) in the world* (Vol. 1). ICOHHS, UNESCO.

Semsar Yazdi, A. A., & Labbaf Khaneiki, M. (2017). *Qanat knowledge: Construction and maintenance*. Springer. https://doi.org/10.1007/978-94-024-0957-4

Semsar Yazdi, A. A., & Labbaf Khaneiki, M. (2018). Qanāts of Iran: Sustainable water supply systems. In F. Sulas & I. Pikirayi (Eds.), *Water and society from ancient times to the present: Resilience, decline, and revival* (pp. 211–229). Routledge. https://doi.org/10.4324/9781315560144

Yusifov, V., & Baghirov, V. (2003). *Ordubad*. Adiloghlu.

Information about the authors:

Alovsat G. Guliyev – Professor, Head of the Institute of Soil Science and Agrochemistry, Ministry of Science and Education of the Republic of Azerbaijan (Baku, Azerbaijan, e-mail: elovset_q@mail.ru).

Chimnaz T. Bakhshiyeva – Lead Researcher, Institute of Soil Science and Agrochemistry, Ministry of Science and Education of the Republic of Azerbaijan (Baku, Azerbaijan, e-mail: cimnazbaxsiyeva77@mail.ru).

Tunzala M. Babayeva – PhD in Agrarian Sciences, Head of the Department of Chemical Engineering and Ecology, Sumgayit State University (Sumgayit, Azerbaijan, e-mail: tunzala.babayeva@sdu.edu.az).

Tarlan I. Yelmarli – Researcher, Institute of Soil Science and Agrochemistry, Ministry of Science and Education of the Republic of Azerbaijan (Baku, Azerbaijan, e-mail: terlan.yelmarli099@gmail.com)

Nijat M. Guliyev – Doctoral Student, Institute of Soil Science and Agrochemistry, Ministry of Science and Education of the Republic of Azerbaijan (Baku, Azerbaijan, e-mail: n.m.guliyev1@gmail.com).

Авторлар туралы мәлімет:

Алевсат Г. Гулиев – профессор, Әзірбайжан Республикасы Ғылым және білім министрлігінің Топырақтану және агрохимия институтының директоры (Баку қ., Әзірбайжан, e-mail: elovset_q@mail.ru).

Чимназ Т. Бахшиева – жетекші ғылыми қызметкер, Әзірбайжан Республикасы Ғылым және білім министрлігінің Топырақтану және агрохимия институты (Баку қ., Әзірбайжан, e-mail: cimnazbaxsiyeva77@mail.ru).

Тунзала М. Бабаева – ауыл шаруашылығы ғылымдарының PhD докторы, Сумгаит мемлекеттік университетінің Химиялық инжиниринг және экология кафедрасының меңгерушісі (Сумгаит қ., Әзірбайжан, e-mail: tunzala.babayeva@sdu.edu.az).

Тарлан И. Елмарлы – ғылыми қызметкер, Әзірбайжан Республикасы Ғылым және білім министрлігінің Топырақтану және агрохимия институты (Баку қ., Әзербайжан, e-mail: terlan.yelmarli099@gmail.com).

Ниджат М. Гулиев – докторант, Әзірбайжан Республикасы Ғылым және білім министрлігінің Топырақтану және агрохимия институты (Баку қ., Әзірбайжан, e-mail: n.m.guliyev1@gmail.com).

Сведения об авторах:

Алевсат Г. Гулиев – профессор, директор Института почвоведения и агрохимии Министерства науки и образования Азербайджанской Республики (Баку, Азербайджан, e-mail: elovset_q@mail.ru).

Чимназ Т. Бахшиева – ведущий научный сотрудник Института почвоведения и агрохимии Министерства науки и образования Азербайджанской Республики (Баку, Азербайджан, e-mail: cimnazbaxsiyeva77@mail.ru).

Тунзала М. Бабаева – PhD по аграрным наукам, заведующая кафедрой химической инженерии и экологии Сумгаитского государственного университета (Сумгаит, Азербайджан, e-mail: tunzala.babayeva@sdu.edu.az).

Тарлан И. Елмарлы – научный сотрудник Института почвоведения и агрохимии Министерства науки и образования Азербайджанской Республики (Баку, Азербайджан, e-mail: terlan.yelmarli099@gmail.com).

Ниджат М. Гулиев – докторант Института почвоведения и агрохимии Министерства науки и образования Азербайджанской Республики (Баку, Азербайджан, e-mail: n.m.guliyev1@gmail.com).

Поступила: 15 января 2026 года
Принята: 10 марта 2026 года