

MELIORATIVE CONDITION OF IRRIGATED LANDS IN THE SHIRVAN PLAIN OF THE REPUBLIC OF AZERBAIJAN

Vagif Karimov¹, Ilgar Namazov¹, Jafar Sherifov¹, Sevil Zeynalova, Sabina Magerramova²

¹Azerbaijan State University of Oil and Industry

²Azerbaijan University of Architecture and Civil Engineering

vaqifkerimov68@mail.ru

nurlan.namaz@mail.ru

sherifov.1958@mail.ru

sabinamaharramova@mail.ru

Abstract

It is well known that the meliorative condition of any region, including the Shirvan Plain, located in the central part of the Republic of Azerbaijan and one of the most important agricultural and livestock areas, is determined by a combination of geo-ecological, hydro-geological and anthropogenic factors. The study of the current state of this area is both timely and of great practical and scientific importance. This paper provides a brief history of research into the geological structure of the region, together with a description of the extensive meliorative efforts underway. It presents data on irrigated land and areas equipped with open, closed and vertical drainage systems within the study area. The hydrogeological and meliorative conditions of the irrigated areas of the Shirvan Plain were characterized on the basis of field studies carried out by the Hydrological-Meliorative Service in 2023-2024 under the scientific and methodological supervision of the authors. Changes in groundwater depth across the area have been identified and attributed to various factors, including ongoing climatic changes. Laboratory analyses of borehole samples have determined the degree of mineralization and chemical composition of the groundwater. A soil stratigraphy study was carried out in the Shirvan Plain to determine the distribution of groundwater and confined aquifers, their ionic and salinity composition and mineralization levels. The hydrogeological and hydrological condition of the study area was assessed by visual inspection and analysis of soil samples to evaluate its meliorative condition, salinity level and suitability for agricultural use. The potential for groundwater use for crop irrigation, livestock and settlement water supply was also determined. Analysis of the data shows that soil conditions can be improved through a variety of meliorative measures. Chemical melioration is recommended for the reclamation of highly or very saline irrigated lands in the Shirvan Plain. To increase filtration rates, methods such as leaching with sand mixing, phytomelioration and primary leaching with surface irrigation in conjunction with drainage are suggested. Maps have been prepared and recommendations made to improve the productivity of arable land through leaching.

Keywords: Shirvan Plain, mineralization and chemical composition of groundwater, water resources of Azerbaijan, irrigated lands, irrigation infrastructure

I. Introduction

Currently, environmental changes driven by technogenic factors have impacted all aspects of the geological environment, which in turn has significantly influenced the production of agro-industrial products. The construction of irrigation, hydraulic, and other agricultural structures, along with the expansion of irrigated land areas and the use of organic and chemical fertilizers, has considerably altered the geological environment of irrigated zones in the Lankaran, Kura-Araks, Ganykh-Agrichay, Priaraks, and Qusar-Shabran plains, among others (Table 1).

As of now, the total area of irrigated lands in the Republic of Azerbaijan covers 1,456,544 hectares, of which 616,025 hectares are undergoing comprehensive melioration work, 360,325 hectares are equipped

with open drainage systems, 244,500 hectares with closed drainage, and 11,200 hectares with vertical drainage.

For specific irrigated land masses, it is essential to study the hydrogeological and meliorative conditions in order to clarify the scale and improve the methods of work being carried out.

The Shirvan Plain is located in the central part of the Republic of Azerbaijan, bordered to the north and northeast by the foothills of the Ajinohur in the Greater Caucasus, stretching eastward to the tributary of the Hajiqabul River, with the Kura River forming its southern boundary. Covering an area of 6,740 km², the plain includes several administrative districts: Agdash, Goychay, Ujar, Zardab, and Kurdamir, as well as parts of Yevlakh, Aghsu, Shamakhi, Ismayilli, Hajigabul, and Gobustan [1, 2, 4, 10, 19, 21,22, 25, 28, 34, 36].

The population primarily engages in cereal farming, horticulture, and animal husbandry. Part of the Shirvan Plain lies within the low-altitude zone of the Greater Caucasus foothills, while the remainder occupies the Kura Depression. The highest elevation in the foothill area is +437.5 m, and absolute elevations in much of the plain range from 200 to 220 m. Along the Kura River, in sections near Lake Ajinohur and in the Kurdamir district, elevations reach about -20 m. The main orographic elements include the alluvial cones of the Turianchay, Goychay, Girdimanchay, and Aghsu rivers (Fig. 1).

Table 1: Sources of Groundwater Recharge in the Shirvan Plain

Sources of Recharge	m ³ /s	%
Infiltration from irrigation structures	13.20	19.9
Infiltration from rivers (Kura tributaries)	21.85	32.93
Confined water sources	9.60	14.47
Condensed water	6.75	10.17
Infiltration from mechanically elevated water	3.45	5.20
Infiltration from atmospheric precipitation	4.05	6.10
Groundwater from mountain rock	3.00	4.52
Infiltration from rainfall on mountain slopes	4.20	6.33
Infiltration from irrigation with artesian water	0.20	0.30
Infiltration from kahriz water irrigation	0.05	0.10
TOTAL:	66.35	100

The population primarily engages in cereal farming, horticulture, and animal husbandry. Part of the Shirvan Plain lies within the low-altitude zone of the Greater Caucasus foothills, while the remainder occupies the Kura Depression. The highest elevation in the foothill area is +437.5 m, and absolute elevations in much of the plain range from 200 to 220 m. Along the Kura River, in sections near Lake Ajinohur and in the Kurdamir district, elevations reach about -20 m. The main orographic elements include the alluvial cones of the Turianchay, Goychay, Girdimanchay, and Aghsu rivers (see, Fig.1).

The hydrographic network of the Shirvan Plain primarily consists of the Kura River and its left tributaries- Alinjachay, Turianchay, Goychay, Girdimanchay, and Aghsu, as well as irrigation canals and collectors.

II. Objective of the study

The objective of this study is to determine the hydrogeological and hydrological state of the study area, evaluate the meliorative condition of the soil, assess its suitability for agricultural use, and explore

the potential use of groundwater for irrigation, livestock, and the water supply for settlements. The study also aims to improve soil conditions through various melioration activities.

Initial information on the geological structure of the mountainous areas to the northeast of the Shirvan Plain was provided by N.I. Andrusov. Subsequent research on the geological structure of the surrounding ridges was conducted and documented by V.V. Bogachev (1912), V.P. Rengarten, and F.F. Oswald.

Based on studies by A.N. Shardanov and V.E. Khain, the Kura-Araks lowland is considered a megasycline between the meganticlines of the Greater and Lesser Caucasus, where geological surveying was conducted in specific areas.

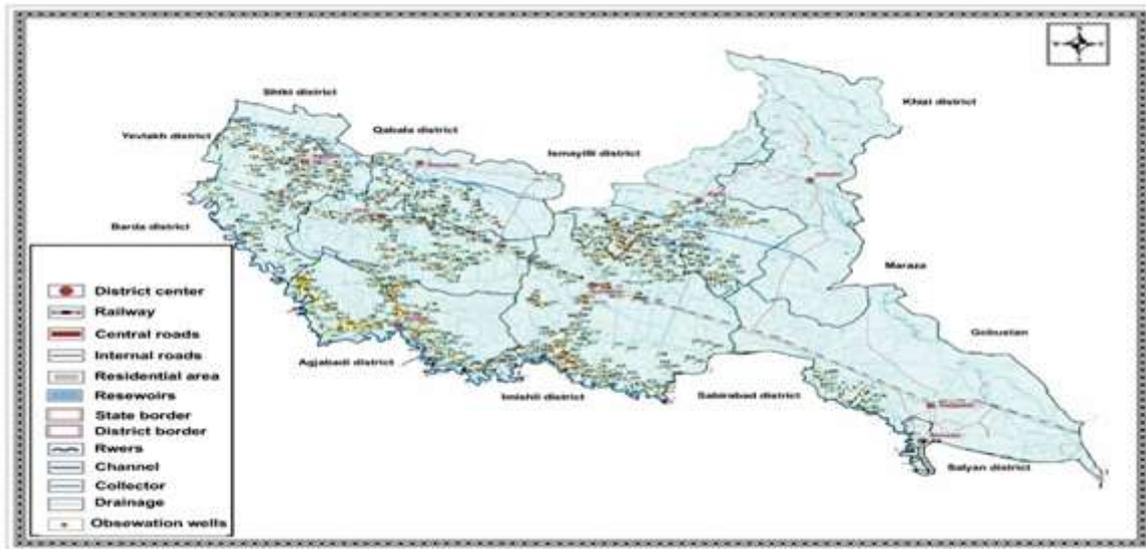


Figure 1. Diagram of the irrigation and drainage network in the Shirvan irrigation area

The upper layer of the Shirvan Plain's deposits (up to 1,400 m) consists of Quaternary sediments, with underlying Neogene, Paleogene, and Cretaceous formations identified through oil exploration drilling. These deposits, which cover the entire plain, consist primarily of alluvial sands, sandstones, clays, and alluvial-proluvial clays. In addition, proluvial-deluvial clays, sands, gravels, and pebbles are also present on the southern slopes of the Greater Caucasus, where the modern layer thickness reaches 40 m [6, 7, 8, 11, 15, 18, 27, 29, 30].

Since the 1920s, with the expansion of geological research, more intensive studies of the Shirvan Plain have been conducted. Following the establishment of the Water Management Authority of Azerbaijan in 1927, these studies took on a broader scope. The findings resulted in the creation of mineralization and hydroisogyps maps at a scale of 1:200,000.

In 1929, F.P. Savarensky published works on soil and groundwater salinization processes in the Kura-Araks lowland. During these years, studies on the groundwater regime began under V.A. Priklonsky's leadership, with exploratory wells drilled. Additionally, V.Sh. Sokhadze conducted new research into the causes of bog formation in the plains.

In our republic, 266,313 hectares of irrigated land are in the Shirvan Plain. Of these, 153,300 hectares are equipped with drainage systems: 40,400 hectares with open-horizontal drainage and 112,900 hectares with closed-horizontal drainage systems.

The groundwater table depth on irrigated lands spans various levels: under 1 m on 2,230 hectares (0.83%), 1.0-1.5 m on 15,581 hectares (5.85%), 1.5-2.0 m on 72,946 hectares (27.40%), 2.0-3.0 m on 116,510 hectares (43.75%), 3.0-5.0 m on 42,485 hectares (15.96%), and over 5.0 m on 16,561 hectares (6.21%) (Fig. 2).

On irrigated lands, groundwater salinity can be divided into categories distributed as follows: below 1 g/L on 59,665 hectares (22.40%), 1.0-3.0 g/L on 113,542 hectares (42.63%), and above 3 g/L on 112,498 hectares (34.97%) (Fig. 3).

Research findings reveal that drainage waters are fed not only by irrigation waters but also by groundwater and confined waters that are hydraulically connected to atmospheric precipitation, rivers, and irrigation water sources.

According to chemical analysis, 97% of the sampled water represents irrigation conditions ($\text{SO}_4^{2-} - \text{Na}^+$), 2% represents marine conditions ($\text{Cl}^- - \text{Mg}^{2+}$), and 1% represents deepwater and continental conditions ($\text{HCO}_3^- - \text{Na}^+$).

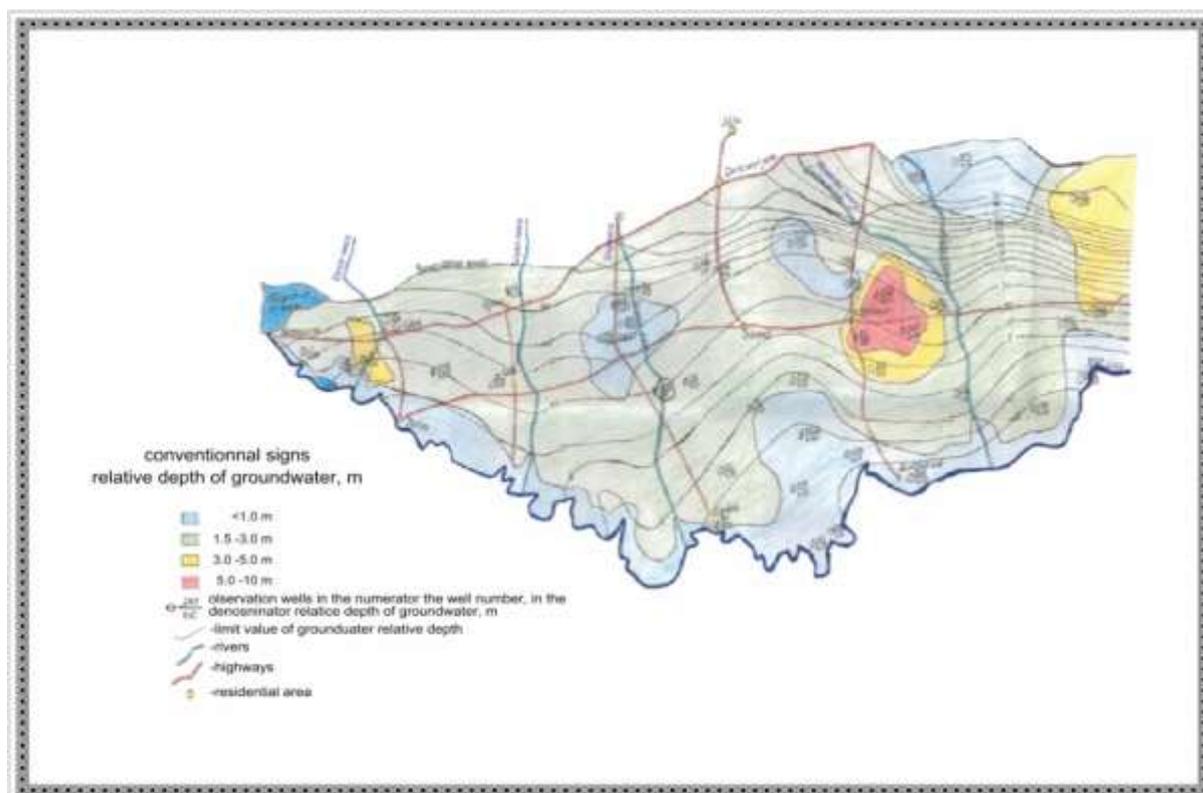


Figure 2: Schematic map of hydroisogyps and groundwater depths in the Shirvan Plain

III. Research Methods

Groundwater levels in drilled wells were measured, water samples were collected and then analyzed in laboratory conditions. Visual inspection and studies of soil cover samples were also conducted.

To remediate the salinity of irrigated lands in the Shirvan Plain, especially in areas with high and very high salinity, chemical reclamation should be used to increase the filtration coefficient. This can include leaching with sand mixing, phytomelioration, and surface irrigation techniques [12, 14,21, 31].

Chemical reclamation is applied as the main method for improving saline soils in the following cases: for improving alkali and neutral soils (where carbonate and gypsum layers lie at depths of 40-50 cm and contain more than 10% exchangeable sodium), for releasing carbon dioxide generated from carbonate reserves within the soil, and as an auxiliary method for intensifying self-purification processes to combat secondary salinization during irrigation.

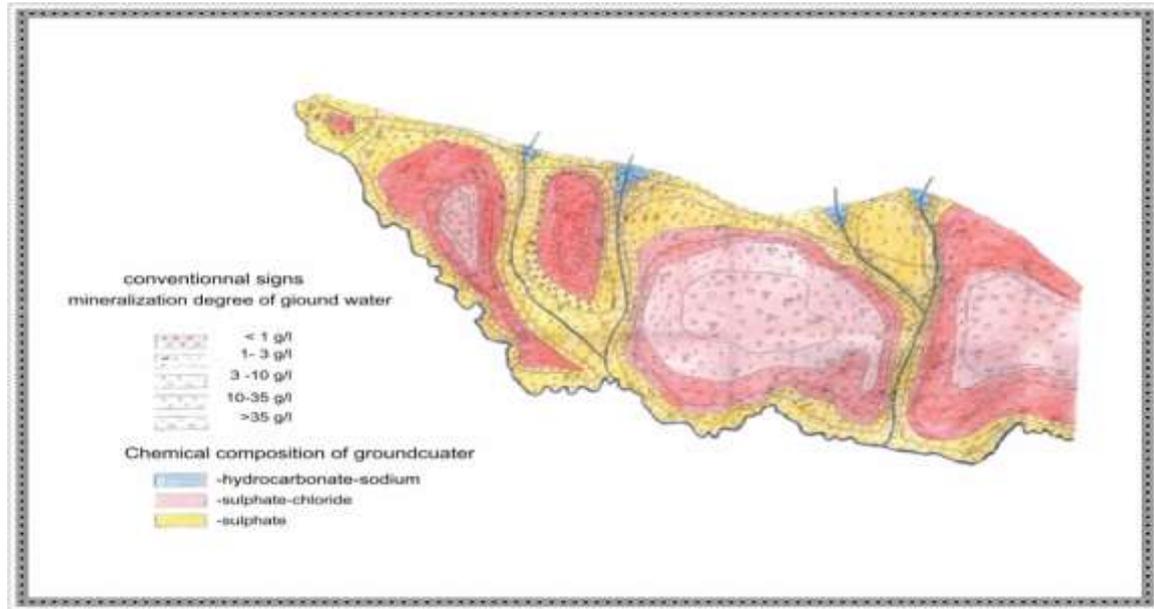


Figure 3: Map of the chemical composition and mineralization of groundwater in the Shirvan Plain

In applying this method to saline soils, compounds like calcium, acids, or acidic ameliorants are introduced into the stratified soil layer using specialized machinery (sprayers and spreaders for dry and liquid fertilizers), followed by plowing or cultivating with heavy disc harrows. Chemical reclamation is used both in irrigated areas and, in the absence of irrigation, in regions with an annual precipitation exceeding 300-350 mm. Ameliorants can be applied either across the entire area or to locally selected, saline spots. When distribution over localized spots are impractical, ameliorants are applied across the entire area. The ideal conditions for applying ameliorants are in the spring and summer, when the soil still retains enough moisture for effective incorporation and mixing with ameliorants.

During chemical reclamation in conjunction with irrigation, ameliorants dissolve and interact more effectively with soil, helping to remove exchange products from the ameliorated layer. Doses of chemical ameliorants are calculated based on the amount of exchangeable sodium in the saline soil layer. For alkali soils, it is also necessary to account for the amount of ameliorant required for full neutralization of soda. Dosage rates are divided into two types: ameliorative (calculated to replace exchangeable sodium and fully mitigate salinity's negative effects over 10-20 years) and agronomic (designed to provide similar ameliorative effects within one or two crop rotations) [26, 35].

Generally, the agronomic dose is half the ameliorative dose. The most common chemical ameliorants include gypsum, phosphogypsum (a by-product of phosphoric acid production), sulfuric acid (only with irrigation), and acidic ameliorants such as sulfur, iron, and aluminum sulfates. Other calcium compounds (e.g., calcium chloride, chalk) and industrial by-products are also used.

There are several empirical formulas for calculating the required amount of gypsum for saline areas. A typical gypsum dose calculation formula (D_g) is as follows (1).

$$D_g = 0,086 \cdot n \cdot d \cdot (Na_n - Na_k) \quad (1)$$

where n is the thickness of the amelioration layer (cm), d is soil density (g/cm^3), Na_n is the initial exchangeable sodium, and Na_k is the sodium level after reclamation (mmol per 100 g soil). If a non-pure gypsum ameliorant is used, the dosage is adjusted based on its gypsum content. Gypsum application rates vary from 5 to 70 tons/ha, with typical field doses between 10-20 tons/ha.

For soil reclamation, 0.6-1.0% sulfuric acid is applied with irrigation water. The washing rate must be sufficient to displace and remove exchangeable sodium from the treated soil layer. Acid is stored and transported in acid-resistant containers, and it is introduced gradually over a period of up to 20 days, with washing potentially lasting up to 6 months. The sulfuric acid dose (D_g) is calculated as follows:

$$D_g = 0.049 \cdot n \cdot d \cdot K \cdot (OKO) \cdot (Na_n - Na_k) + S + CO_2 \quad (2)$$

where K is a factor accounting for the concentration of sulfuric acid, OKO is the cation exchange capacity (mmol per 100 g soil), S is the sum of CO_3 and HCO_3 ions, and CO_2 is the carbonate content.

The effectiveness of chemical reclamation in arid and semi-arid zones decreases significantly without irrigation due to low moisture, rendering the costs higher than the benefits. Therefore, deep ameliorative tillage, using natural soil gypsum and carbonates, is the primary method in such areas, as it mechanically breaks the saline layer and promotes calcium-sodium exchange.

The reclaimed carbonate layer depth (H_k) is calculated as (3):

$$H_k = 0,58 \cdot D_g \cdot 10 ; (CO_2 \cdot \gamma) \quad (3)$$

where: 0,58 – conversion coefficient from gypsum to calcium carbonate; D_g – the applied dose of gypsum; 10 – solubility correction coefficient for calcium carbonate; CO_2 – carbonate content in the carbonate layer (%); γ – density of the gypsum layer (g/cm^3).

The depth of the plowed portion of the gypsum layer (H_k) is calculated using the formula $H_k = D_g / (\alpha \cdot \gamma)$, where α represents the amount of gypsum in the gypsum layer. During reclamation plowing of low-humus saline areas, it is recommended to add “organic fertilizer” to the reclamation layer to activate microbial activity and increase the concentration of carbon dioxide in the soil air. This results in the transformation of calcium carbonate into more soluble calcium bicarbonate, enhancing the effectiveness of reclamation. The following deep soil treatments are used: plantation plows, three-step plows, and in-soil rotary (milling) treatments. Plowing typically takes place after the top 15-20 cm soil layer is cut using heavy disk drills. Effective reclamation plowing is possible under the following conditions: soil moisture at 10-12%, hardness of 8 MPa, specific resistance of 0.13 MPa, and surface slope not exceeding 8°.

Analyses of the chemical composition of natural waters in the Shirvan Plain demonstrate that irrigation with different water sources alters the primary chemical composition of groundwater. Due to the current use of alternative water sources for irrigating the region, aggressive hydrochemical types of water are forming, which land users need to consider.

In peripheral sections of alluvial fans, groundwater recharge is complicated due to the abundance of clay in the soil, minimal precipitation, and a low hydraulic gradient. Intensive irrigation, meanwhile, contributes to the rising groundwater level. The spread of high-salinity groundwater is linked to an absence of river recharge and a drop in groundwater levels, resulting in systematic salt accumulation in the soil. Furthermore, prolonged evaporation under changing hydrological conditions also leads to salt accumulation. The presence of sulfate-sodium ($SO_4^{2-} - Na^+$), sulfate-calcium ($SO_4^{2-} - Ca^{2+}$), and chloride-sulfate-magnesium-sodium ($Cl^- - SO_4^{2-} - Mg^{2+} - Na^+$) salt types in the aeration zone indicates that capillary rise of groundwater in the soil contributes to salt accumulation [23, 32, 33, 37].

Notably, while all types of soil salinization are present in Azerbaijan, a comprehensive classification of the degree and type of soil salinity has not yet been developed. This gap poses certain challenges in addressing agricultural production issues, impacting scientific problem-solving (e.g., mapping, determining leaching rates, appropriate crop allocation according to soil salinity, etc.). Various scholars [19, 31] have proposed classifications for soil salinity, but their approaches differ.

In the past, results from tests conducted across the former USSR were synthesized by specialists and reissued with new instructions mandatory for implementation in local areas. These guidelines, though possibly effective in Russia, southern Ukraine, Central Asia, and other regions, are unsuitable for Azerbaijani conditions, a situation that persists today. Specialists often select unsuitable classification methods for Azerbaijan’s saline soils, making further study on this issue essential.

To classify soil salinity in the Kura-Araks Lowland, including the Shirvan Plain, experiments were conducted in areas with varying soil hydro-physical characteristics. Test plots, each measuring 0.1-0.3 ha and differing in salinity type and degree, were selected. Soil cuts corresponded to the developmental

stages of cultivated crops, and samples were taken from saline patches with sparse or no vegetation, with each sample area tested three times. Comprehensive water extract analyses were performed on samples to clarify salinity degree and types, as well as determine pH and base saturation in cuts.

Irrigated soil on the Shirvan Plain, classified by salinity level, includes: 183,467 ha (68.89%) non-saline, 51,549 ha (19.35%) slightly saline, 16,853 ha (6.33%) moderately saline, and 14,444 ha (5.43%) highly and severely saline soils. Studies in Azerbaijan's cotton-growing regions have found that yields of 22-24 centners/ha of cotton or grain can be achieved in soils with 0.6-0.7% salinity of sulfate, chloride, and chloride-sulfate types.

Currently, many landowners (farmers) lack the means to flush saline soils to acceptable conditions due to limited resources and machinery. Farmers are thus encouraged to improve saline soil parts through agro-reclamation (crop rotation). Since leveling is essential for flushing, plots scheduled for flushing should be pre-leveled. Proper leveling ensures efficient use of irrigation water and uniform salt leaching. Adequate leveling, irrigation, and salt flushing are among the factors that improve the rationality of sowing operations. During irrigation, increased evaporation in higher areas and water pooling in lower areas cause a rise in groundwater levels. To mitigate this, plots should be leveled annually.

Between 1971 and 1975, 156,800 ha of irrigated land in the Azerbaijan Republic underwent reclamation, 88,000 ha were flushed, and 274,400 ha received deep salt flushing. Post-land privatization, capital investment in such activities has declined.

Given the high temperatures in the Shirvan Plain, it is essential to consider optimal sowing timing. Delayed autumn sowing promotes weed growth, which, without additional agrotechnical measures, reduces crop yields [16, 24, 29].

Analysis of water samples from drainage networks in advanced labs reveals that nitrate levels are below regulatory limits, indicating the need for appropriate fertilizers to improve soil productivity. Soil used for agriculture loses fertility over time, so timely application of organic and mineral fertilizers is necessary. Practice shows that 12 tons of organic fertilizers per hectare (e.g., manure, composts) help maintain soil fertility, meaning 12 tons/ha of organic and mineral fertilizers are required.

For increased soil fertility, crop rotation is vital, though challenging on small plots. Nonetheless, small farms should aim to rotate at least three crops, changing plant locations to preserve soil fertility. New plots should undergo deep plowing, leveling, cultivation, pest control, and timely fertilizer application at appropriate depths.

On irrigated lands, typically plowed to 20-25 cm, soil compacts over time due to two factors: water infiltration clogging pores with fine particles and the weight of agricultural machinery, which drives over the land 20-30 times, compacting lower soil layers. Agricultural crops cannot penetrate the compacted layer, limiting root depth to 20-25 cm and hampering nutrient uptake. Soil fertility on compacted plots decreases by 30-40%. Thus, periodic plowing to a depth of 100 cm (at least every five years) is recommended.

To maintain plowed soil fertility, organic and mineral fertilizers should be applied separately. Irrigation volumes must not exceed the required level for each crop, and the same crops should be cultivated within a single irrigation system to optimize water use.

IV. Conclusions

1. The Shirvan Plain is climatically characterized by high air temperatures and a lack of moisture. Under such conditions, agriculture is considered possible only with the application of artificial irrigation. The high mineralization and the close proximity of groundwater to the earth's surface, as well as the poor drainage of the studied area, indicate the necessity of artificial irrigation. Most of the groundwater evaporates and is used by plants for transpiration, leading to soil salinization. Therefore, it is important to periodically reassess the hydrogeological conditions of the region every few years.

2. The underground waters consist of groundwater, low-pressure, and high-pressure water horizons extending to a depth of 350 meters. Groundwater is mainly replenished by atmospheric precipitation, river and irrigation waters, as well as artesian waters lying below. The process of water discharge into them is associated with evaporation, transpiration by plants, underground runoff into the Kura River, and drainage systems. The depth of these waters varies from 20-25 meters in the north to 0.5-1.0 meters in the south.

3. The degree of mineralization of underground waters ranges from 0.4 g/L to 50 g/L (or more). Fresh groundwater (with a mineralization level up to 1.0 g/L) is observed in the upper parts of river cones and near irrigation canals. As the direction of the underground flow progresses, the salinity of groundwater increases, and its chemical composition changes to a bicarbonate-sodium-magnesium type.

4. Observations of the long-term regime show a constant rise in the groundwater level, which can only be explained by the influence of irrigation. On the one hand, the impact of fresh irrigation water contributes to the reduction of groundwater mineralization; on the other hand, the rise in groundwater level leads to increased evaporation and the accumulation of salts in the aeration zone. Therefore, the primary task of land reclamation should be the removal of high-mineralized waters from the area through artificial drainage (via collector drains) and the lowering of groundwater levels.

5. In most parts of the area, pressurized waters are characterized by high mineralization. Their mineralization increases from north to south. This pattern is disrupted in the western part of the Kurin strip, and the cause is the influx of fresh waters from the powerful Karabakh artesian basin located in the southeast, which has a mineralization of less than 0.5 g/L. Throughout the year, the groundwater of the plain, covering an area of 2400 km², receives additional replenishment amounting to 691.2 million m³ from the pressurized waters located below.

6. Agricultural plants cannot penetrate through the compacted layer and spread in the upper 20-25 cm layer of soil, which is insufficient for their nourishment. In compacted soils, plant productivity decreases by 30-40%, so the soil layer should be periodically (at least every 5 years) plowed to a depth of 100 cm.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

References

- [1] Alekseev, V.I. (2020). Study of changes in the global climate as a complex system using wavelet phase-frequency functions, phase-frequency and phase-time characteristics of heliocosmic and climatic variables. Part 1–2. // Bulletin of the Tomsk Polytechnic University. Engineering of georesources, 331, 7, 238–250.
- [2] Alimov, A.K. (2001). Irrigation canals and their impact on the ecological situation. Baku: Elm, 36-44.
- [3] Aliyev, F.Sh. (2000). Underground waters of the Azerbaijan Republic, utilization of reserves and geological problems. geological problems. Baku: Chashyogly, 81-89.
- [4] Amalfitano, S., Bon, A.D., Zoppini, A., Ghergo, S., Fazi, S., Parrone, D., Casella, P., Stano, F., Preziosi E. (2014). Groundwater geochemistry and microbial community structure in the aquifer transition from volcanic to alluvial areas. Water Resources. 65, 384–394. DOI: 10.1016/j.watres.2014.08.004
- [5] Barthel, R.A. Call for more fundamental science in regional hydrogeology. // Hydrogeology Journal. 2014, 22, 3, 507-510. DOI: 10.1007/s10040-014-1101-9
- [6] Basavaraju, B., Dodda2021iah, N., Sudeep, S.R. (2024). Assessment of Groundwater Quality Index (GWQI) of Taraka Watershed, H D Kote Taluk, Mysuru District, Karnataka, India. // Journal of Geology, Geography and Geoecology. 33, 2, 234-243. DOI: <https://doi.org/10.15421/112421>
- [7] Bondarenko, L.V., Maslova, O.V., Belkina, A.V., Sukhareva, K.V. (2018). Global climate change and its aftermath. Herald of the Russian Economic University named after B. Plekhanova. 2, 84-93.

- [8] Gadzhiev B.A., Namazov I. Sh. (2014). Engineering-geological conditions of the Absheron Peninsula and factors influencing its formation. // News of Higher Technical Educational Institutions of Azerbaijan. ADNA. 4(92), paragraphs 7-14.
- [9] Geology of Azerbaijan. 2008. Vol. VIII. Hydrogeology. Baku, Nafta-Press. 380.
- [10] Gladilshchikova, A.A., Semenov, S.M. Fundamental and Applied Climatology. Intergovernmental Panel on Climate Change (IPCC): Sixth Assessment Report Cycle. 2017, P. 13–25.
- [11] Gruza, G.V., Rankova, N.A. Detection of climate change: state, variability and extremeness of climate. // Meteorology and hydrology, 2004, 4, 50–66.
- [12] Gulmammadov, C.J. Engineering-geological conditions of the Shirvan Steppe of the Kura-Aras Lowland of Azerbaijan Republic and the influence of the Upper-Shirvan Canal on it. // Journal of Geology, Geography and Geoecology, 2024, 33 (3), 463-474, DOI <https://doi.org/10.15421/112443>
- [13] Gyulmamedov, Ch.D. (2021). Influence of the Upper Shirvan Canal on the change in hydrogeological and reclamation conditions of the Shirvan steppe of Azerbaijan. Bulletin of the Tomsk Polytechnic University. // Georesource engineering. 332, 10, 116–126.
<https://doi.org/10.1007/s11015-023-01480-w>
- [14] Imanov, F.A., Alekbarov, A.B. Modern changes and integrated water resources management in Azerbaijan. Baku. 2017.
- [15] Ingershal, G.R., Venugopal, T. Spatial mapping for Groundwater Vulnerability to Pollution Risk Assessment Using DRASTIC Model in Ponnaiyar River Basin, South India. // Journal of Geology, Geography and Geoecology, 2021, 30, 2, 355-364. <https://doi.org/10.15421/112132>
- [16] Ismailova, M.M., Maharramov, F.F., Karimov, V.M., Sharifov, J.J. Prospects for using thermal water in Kalbajar district and other regions (Azerbaijan) as an alternative energy. // Reliability: Theory and Applications Special Issue, 2022, № 3 (66). 17, 113-118.
<https://doi.org/10.24412/1932-2321-2022-366-113-118>
- [17] Israfilov, Yu.H, Israfilov,R.H., Guliyev, H.H., Efendiyev, G.M. (2016). Risk assessment of the water resources losses of the Azerb. Republic due to climate changes. // News of ANAS, Earth Sciences, 3-4.
- [18] Kenechukwu, A.I., Elizabeth, O., Okechukwu, E.A., Onwe, I.M., Ogechukwu, B.O. (2021). Using Geo-electric Techniques for Vulnerability and Groundwater Potential Analysis of Aquifers in Nnewi, South Eastern Nigeria. // Journal of Geology, Geography and Geoecology, 30, 1, 43-52. DOI: <https://doi.org/10.15421/112105>
- [19] Kovda, V.A. General theory of soil-forming process, book 1, M.: Nauka, 1973, 104-109.
- [20] Lee, W., Son, Y. (2017). Low carbon development pathways in Indian agriculture. Change Adaptation Socio – Ecological Systems, 3, 18–26.
- [21] Listengarten, V.A. (1987). Formation of groundwater resources in alluvial-proluvial plains. Baku: Elm. 143-144.
- [22] Manyuk, V.V. (2023). Geodiversity, geological heritage and renewal of the network of geosites of the Dnipropetrovsk region. 32.(2). // Journal of Geology, Geography and Geoecology. 326-341. <https://doi.org/10.15421/112330>
- [23] Montcoudiol, N., Molson, J., Lemieux, J.M. (2014). Groundwater geochemistry of the Outaouais Region (Quebec, Canada): a regional-scale study. // Hydrogeology Journal. 23, 2, 377–396.
- [24] Poongodi, R., Venkateswaran, S., Suresh, R.V. Appraisal of the Quality Parameters of the Groundwater used for Domestic and Irrigation Purposes in the Hard Rock Aquifer System of the Vasishta subbasin of the Vellar River, Tamil Nadu. // Journal of Geology, Geography and Geoecology, 2021, 32, 3, 706-717. DOI <https://doi.org/10.15421/112165>
- [25] Seidov, V.M., Aghayeva, M.A. (2024). Algorithm for constructing unmeasured logging curves (pseudo-logging) in wells of developed fields. // Journal of Geology, Geography and Geoecology, 33(3), 562-570. <https://doi.org/10.15421/112452>
- [26] Selvaggi, R., Damianić, B., Goretti, E., Pallottini, M., Petroselli, C., Moroni, B., La Porta, G., & Cappelletti, D. (2020). Evaluation of geochemical baselines and metal enrichment factor values through

high ecological quality reference points: a novel methodological approach. // *Environmental Science and Pollution Research*. 27, 1, 930-940.

[27] Sudeep, (2023). S.R., Doddaiah, N., Pradeeppraju, N., Poorigali, C.N., Sreenivasa, A. (2023). Hydrogeochemical and water quality index (WQI) evaluated in Beedanahalli watershed T narasipura taluk mysore district, Karnataka, India. // *Journal of Geology, Geography and Geoecology*. 32, 3, 620-631. <https://doi.org/10.15421/112355>

[28] Tagiev, I.I., Kerimov, V.M., Sharifov, D.D. (2021). Characteristics of the hydrogeological massifs of the Greater, Lesser Caucasus and Talysh (Azerbaijan) taking into account global climate change. *Visnyk of Taras Shevchenko National University of Kyiv: Geology*, 3(94), 95-102.

[29] Tagiyev I.I., Ismailova M.M., Karimov V.M., Sharifov J.J. (2022). Groundwater of Ganikh-Ayrichay foothills on the prospects of use. // *Reliability: Theory and Applications*. 3(66), 17, 76-81. <https://doi.org/10.24412/1932-2321-2022-366-76-81> .

[30] Tetiana, O. K., Iryna, V. K. (2023). Hydrogeochemical features of groundwaters of the Ukrainian shield fractured crystalline rocks on the example of Zhytomyr and Vinnytsia regions. // *Journal of Geology, Geography and Geoecology*. 32, 3, 525-539. DOI: <https://doi.org/10.15421/112341>

[31] Volobuev, V.R. (1981). All-Union scientific and technical meeting. Progressive methods of melioration and development of heavy saline lands. development of heavy saline lands. Moscow: Central Bureau of Water Management of the USSR Ministry of Water Resources, 23- 26.

[32] Wang J., Zuo R., Caers J. Dickovering geochemical patterns by faktor-based cluster analysis. // *Journal of Geochemical Exploration*, 2017, 181, 106–115.

[33] Wang, S. Lee, W., Son, Y. (2017). Low carbon development pathways in Indian agriculture. // *Change Adaptation Socio-Ecological Systems*, 2017, 3, 18-26.

[34] Yungmeister, D.A., Gasimov, E.E. (2021). Drill rig with a down-the-hole hammer for regulating the drilling rate by changing the air flow. *E3S Web of Conferences*. EDP Sciences. 326.

[35] Yungmeister, D.A., Timofeev, M.I., Isaev, A.I., Gasymov, E.E. (2023). Improvement of tunnel boring machine S-782 cutter head. // *Mining Informational and Analytical Bulletin*. 1.107-118. DOI: 10.25018 / 0236_1493_2023_1_0_107.

[36] Zeynalova, S.A. Manyuk, V.V. Karimzade, F.R. Shahbazov, R.A. Zahidova, T.E. (2024). Substantiating of oil and gas prospects of Mesozoic sediments based on the geochemical model of mud volcanoes in the Shamakhi-Gobustan structural element of the South Caspian megadepression. // *Journal of Geology, Geography and Geoecology*, 33(3), 617-629. DOI <https://doi.org/10.15421/1124357>

[37] Zhukov, I.A., Martyushev, N.V., & Zyukin, D.A. Modification of Hydraulic Hammers Used in Repair of Metallurgical Units. // *Metallurgist*, 2023, 66, 1644–1652.