



SALTS DEPOSITION AND GROUNDWATER MINERALIZATION EFFECT ON SOIL SALINIZATION IN THE SHIRVAN PLAIN AND GANJA-GAZAKH MASSIF, AZERBAIJAN

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SUMMARY

For investigating salt composition, the collected soil samples in the Shirvan Plain underwent study for groundwater depth and its minerality and the soil's granulometric composition. Soil analysis revealed a higher salt content and minerality of groundwater based on the groundwater depth and closeness to the surface. In the Shirvan Plain, the soils were considerably of sulfate type, although the amount of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) exceeds 2.0% without covering a large area. The most common salt was sodium sulfate (Na_2SO_4) in slightly saline soils, sodium hydrogen carbonate (NaHCO_3), calcium sulfate (CaSO_4), and magnesium chloride (MgCl_2) in moderately saline soils, and Na_2SO_4 , NaHCO_3 , NaCl , and CaSO_4 in highly saline soils. The contents of NaCl , CaSO_4 , Na_2SO_4 and magnesium sulfate (MgSO_4) were evident. The study further enunciated that soil salinization processes have covered a large area in the region with higher soil salt content and mineralization of groundwater. In the study area, salinization processes appeared more intense in areas where salt content was above 2.0% and the groundwater mineralization was higher than 30 g/l.

Keywords: Soil salinization, salt deposits, granulometric structures, groundwater mineralization

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Key findings: In Azerbaijan, the Shirvan Plain and Ganja-Gazakh Massif sustain considerable effects from soil salinization. This article explores the key factors contributing to soil salinization in these regions, including groundwater salinity, soil characteristics, and human activities.

INTRODUCTION

Soil salinization is a major environmental issue affecting crop productivity in arid and semi-arid regions. The Shirvan Plain and Ganja-Gazakh Massif, Azerbaijan, have incurred significant effects from soil salt accumulation, primarily influenced by groundwater mineralization and soil salt content (Figures 1 and 2). The presented study explores the key factors contributing to soil salinization in these regions, including groundwater salinity, soil characteristics, and human activities (Sadigov, 2018a; Ministry of Agriculture of Azerbaijan State Land Management Project Institute, 2020).

Groundwater with high mineralization is one of the primary drivers of soil salinization in the Shirvan Plain and Ganja-Gazakh Massif. In the Shirvan Plain, the groundwater is typically shallow (1–3 meters deep) and contains the highest concentration of dissolved salts, such as sodium chloride (NaCl), calcium sulfate (CaSO₄), and magnesium sulfate (MgSO₄). With considerable evaporation, the salts from groundwater accumulate in the upper soil layers, leading to salinity stress in crops (Ghanbarian and Daigle, 2015; Sadigov, 2018a, 2018b; FAO, 2020).

In contrast, the Ganja-Gazakh Massif has deeper groundwater; however, salinization occurs in those areas where the water table is high and the drainage is inadequate. In this region, the mineral composition of groundwater varies, and some areas experiencing moderate to high salinity levels contribute to soil degradation (Dospekhov, 1984; Babaev *et al.*, 2011; Aliev, 2021).

The soil cover of the target area preceded studies based on comparative analysis using previously conducted research observations. These studies, characterizing the general zone, were small-scale (1:600,000; 1:1,000,000) and were not complex in nature.

The studies conducted on such a scale revealed most of the soil fragments did not fall into new study areas. However, it was notable that various differences occurred in the soils and in the degree of mineralization of the groundwater for a long time (repeated salinization of soils, rise in groundwater levels, increase in their mineralization, and alteration in eco-bio-morphogenic diagnostic signs). In the study area, the number of salts in the soil varied, ranging from 0.2% to 4.0%, and the groundwater mineralization was 20–50 g/l or higher (Babaev *et al.*, 2011).

The soil type and natural salt content also play a crucial role in determining the extent of salinization. Since the analysis of some factors is unavailable in small-scale studies, the obtained findings cannot meet the requirements of scientific and practical significance. Therefore, it is necessary to conduct complex studies to assess some soil factors on the large and medium scales (1:100000) in the research area (Sadigov *et al.*, 2024).

The study purpose was to determine the types of soils, their granulometric structures, the reaction of the soil environment, humus content, salinity, absorbed bases, absorbed Na, salt types, groundwater depth, and the degree of mineralization. Moreover, it sought to discover the effect of all these factors on soil salinization to develop a complex system of measures to prevent them (Kulhánek *et al.*, 2019; Mtyobile *et al.*, 2020). This research examines changes in soil bioavailable phosphorus content in a long-term field fertilization experiment. Over time, different fertilization treatments influence phosphorus availability, affecting soil fertility and crop productivity. Understanding these changes is crucial for optimizing sustainable fertilization practices (Zhapyayev *et al.*, 2023).



Figure 1. Location map of the Shirvan Plain, Azerbaijan.



Figure 2. Location map of the Ganja-Gazakh massif, Azerbaijan.

MATERIALS AND METHODS

In the Shirvan Plain, the dominant soil types include alluvial-meadow and gray soils, which have poor drainage and a high capacity for salt accumulation. It makes them particularly susceptible to secondary salinization, especially in irrigated fields where waterlogging occurs. The Ganja-Gazakh Massif, characterized by chernozem and meadow-chernozem soils, generally has better natural drainage. However, in low-lying areas with poor irrigation systems, salts accumulate in the crops' root zone, reducing soil fertility. The varying permeability of soils affects how quickly leaching of salts occurs and their retention in the soil profile in this region.

The study of the soil comprised soil cuttings made at the depth of 2–3 m at every 5–10 km. The groundwater level measurement ensued, with water samples taken to determine their mineralization. Soil sections' description relied along the profile on the genetic horizons in target locations. Salinity, granulometric composition, pH, humus content, absorbed bases, and heavy metals reached determination in samples collected from the study area. A salinity map of the study area as compiled had a graph characterizing the level of groundwater, and its mineralization's compilation depended on the data obtained. A complex system of measures

succeeded in developing for the improvement of saline soils based on the depth of groundwater, the degree of mineralization, and the compiled salinity map.

Performing short water gravity analysis continued on soil samples taken from 76 sections, with HCO_3 , Cl , SO_4 , and dry residue analyzed. The full water gravity analysis proceeded on the other sections. In addition to the above-mentioned ions, determining Ca , Mg , and $\text{Na}+\text{K}$ ions was successful. Thus, in the soil, knowing the total amount of salt and its chemical composition was remarkable.

Information on the groundwater depth and its mineralization in the Absheron and Ganja-Gazakh regions came from the Ministry of Ecology and Natural Resources of Azerbaijan and the Institute of Geology, Azerbaijan National Academy of Sciences, wherein a comparative analysis followed. In the study area, drilling of 11 hydrogeological wells transpired in the Kur-Araz lowland, with the depth of groundwater measured, detecting mineralization (total amount of salt and the chemical composition of groundwater) in them.

Furthermore, the identification of granulometric composition, volume, and specific gravity; the sum of absorbed bases; the nominal amount of Na ions shared in their sum; the pH index for the reaction of soil solution; and the humus content characterizing

the fertility of the soil in 28 sections of the soils located in the study area took place.

All the laboratory analyses performed used the following widely applied methods: full and short water gravity analyses (Y.V. Arinushkina); granulometric composition, volumetric, and specific gravity (N.A. Kachinsky and S.I. Dolgov); absorbed Ca and Mg (D.V. Ivanov); absorbed Na (Hedroits); ordinary humus (I.V. Turin); and pH-potentiometer (pH-meter) (Dospekhov, 1984; Babaev *et al.*, 2011; Aliev, 2021; Sadigov *et al.*, 2024). In mitigating the soil salinization in the Shirvan Plain and Ganja-Gazakh Massif, several strategies required implementation (Babaev *et al.*, 2011; Sadigov *et al.*, 2024; Mammadov *et al.*, 2025).

Improving drainage systems, constructing, and maintaining drainage networks can help lower the water table and prevent excessive salt accumulation in the soils. Leaching salts from the soil by applying controlled irrigation with fresh water can help flush excess salts from the root zone. Using salt-tolerant crops—growing salt-resistant crops, such as barley and sunflower—can help maintain crop productivity in saline soils. Monitoring groundwater levels by the regular assessment of groundwater mineralization and depth could help predict and prevent salinity-related issues. Sustainable irrigation practices, such as implementing drip and regulated irrigation, can reduce excessive water application and minimize the salt buildup in the arable soils.

RESULTS AND DISCUSSION

Primarily, human activities, particularly non-regulated and unsustainable irrigation practices, have intensified soil salinization in both regions. Overuse of irrigation water, combined with inadequate drainage, has led to rising groundwater levels and eventually increasing salt accumulation in the soil. In some cases, irrigation itself is moderately saline and further exacerbating the salinity problem (Jaboil *et al.*, 2013; Moitzi *et al.*, 2020; Dai *et al.*, 2021; Gumbatov *et al.*, 2024).

The salinization effect on the crops was severe, as it reduced soil fertility and limited crop productivity. Crops, such as wheat, cotton, and vegetables, struggle to thrive in saline soil, leading to lower yields and economic losses for the farming community. Furthermore, prolonged exposure to a higher salt concentration degrades the soil structure, making it more compact and less permeable, which, in turn, affects the crops' root growth and water infiltration (Sadigov, 2019). In the study area, soil salinity was higher in the upper layer (0–100 cm) in some target locations than in the lower layers in some areas. Therefore, during heavy rainfall, water seeping into the soil dissolves the salt both in the upper and lower layers and forms a solution.

The degree of mineralization of the saline solution, depending on the salt content in the soil, could range from 10–15 to 100 g/l (in soils with higher salinity). Undoubtedly, in the soils, the saline solutions with high salinity boost the salinization process, and the soils become saline (State Standard of the Republic of Azerbaijan, Soil quality, 2013). The studies carried out in different regions of the Kur-Araz lowland in previous years revealed some part of the solution seeped into the soil, reached the groundwater during heavy rains, and fed them. The rainfall feeds the groundwater with different ratios in soils and with different mechanical structures.

The proportion of precipitation feeding groundwater should not be more than 20%, 15%, and 10% of the total soil mass for light (physical clay content < 0.01 mm = 30%–40%), medium (< 0.01 mm = 45%–60%), and heavy granulometric soils (< 0.01 mm = 78%), respectively, considering the groundwater. The figures provided for the groundwater were at the depth of 2.0–2.5 m above the soil surface. In locations where groundwater was less than 2.0–2.5 m above the surface, the proportion of precipitation feeding groundwater was greater than the above figures, while in places where it was more than 2.0–2.5 m below the surface, the rainfall ratio became less.

In the study area of Absheron, the salt content in the soil layer (0–200 cm) varies between 1.0% and 3.0%. Since the average

annual precipitation was low (195 mm in Baku, 110 mm in Puta, and 177 mm in Bayil), the salt solution formed in the soil cannot reach the groundwater by passing more than 200 cm of the soil layer. Therefore, one can conclude that the upper soil layers in the target area could become saline because of the salts affecting the Absheron part. The average annual precipitation was 310 mm in the Absheron area. The variations in the number of soil salts due to atmospheric precipitation do not have an annual character in the soil. In summer, due to the higher air temperature during this period, precipitation evaporates. The saline solution formed in the upper soil layer (50–60 cm) remains on that horizon.

In study areas, the climatic parameters, vegetation cover, soil salts' content and types, mineral content of the groundwater, and applied cultivation methods are the primary factors in soil protection. These processes are also of particular importance in increasing soil fertility and productivity. The rainfall in autumn and winter increased soil humidity, spring rainfall leaks into low layers, and moisture reaches the whole humid capacity. Therefore, the solution developed because of the salt dissolving in the soil reaches the subsoil waters. The salt complexes, which exist in the Kur-Araz Lowland, comprise CaCl_2 , MgCl , NaCl , Na_2SO_4 , MgSO_4 , Na_2CO_3 , and CaSO_4 . The soils of the Shirvan Plain contain several other salts, except for Na_2CO_3 (sodium). Among these

salts, CaSO_4 (gypsum) is the most harmless in terms of its impact on the environment and soil structure. Noteworthy, all these salts are easily soluble in water (CaSO_4).

The information about the salts in the soil solution, its features, and their effects on crop plants and black metals appears in Table 1. The CaCO_3 (limestone), MgCO_3 (dolomite), and CaSO_4 (gypsum) emerged as poorly soluble salts, with minor negative effects. The Na_2CO_3 (sodium), MgCl_2 , and MgSO_4 occurred to be easily soluble and toxic salts. The Na_2CO_3 was prominent in the research area in the Yevlakh Region. The MgCl_2 and MgSO_4 were also more abundant in the Shirvan Region.

The NaCl stands after the salts (MgCl_2 and MgSO_4) in the toxicity line. The quantity of the last three salts was higher in those places where the soil salinity was high. Toxicity of Na_2SO_4 was lower than NaCl , MgSO_4 , and MgCl_2 ; however, its quantity was more than other salts in the Shirvan part. The CaCl_2 toxicity was not high, but it proved harmful with a higher quantity. Several studies revealed the degree of the solution mineralization formed due to atmospheric precipitation accelerating the erosion processes (Mustafayev *et al.*, 2017). The water pressure has high mineralization at the depth in some places, salinizing the soil by flooding the surrounding areas. The presented research revealed the soil of the Shirvan Plain possesses salinity with different degrees, and the saline type was sulfatic.

Table 1. Soil solutions with salts, their features, and effects on the crop plants and black metals.

Salt	Soluble ability and concentration of unsaturated solution	Creating solution reaction	Effects	
			On crop plant	On metal (iron and steel)
CaCO_3	Difficult (10 mg/l)	Alkaline	Not toxic (harmless)	No effect
MgCO_3	Very weak (0.106 g/l)	Alkaline	Toxic (harmful)	No effect
Na_2CO_3	Good (200 g/l)	High alkaline	Very toxic	High corrosion ability
CaCl_2	Good (200 g/l)	Weak acid	Harmful in a high concentration	Corrosion ability
MgCl_2	Very good (353 g/l)	Near to Neutral	Very toxic	High corrosion ability
NaCl	Good (264 g/l)	Near to Neutral	Toxic	Can expose to corrosion
CaSO_4	Weak (2 g/l)	Weak acid	Not toxic	Harmless, no effect
MgSO_4	Good (262 g/l)	Weak acid	Very toxic	High corrosion ability
Na_2SO_4	Very good (280 g/l)	Near to Neutral	Toxicity (Toxicity was lower in comparison with MgSO_4)	Corrosion ability

Note: Apart from CaCO_3 , MgCO_3 , and CaSO_4 , all salts found in the soil have weak to highly harmful properties.

Table 2. Mineralization of the soil solution occurring in connection with the atmospheric rainfalls in the different granulometric structural soil where salinity was low, moderate, and high, and subsoil mineralization in same places.

Granulometric structure of the soil	Average value of rainfalls over weather stations	A part of the rainfall that feeds subsoil water		Soil salinity (%)	Mineralization of the solution (g/l)	Mineralization of subsoil water (g/l)
		%	m ³ /ha			
Light	310	20	62.0	1.0-1.5	25-30	20-25
				2.0-2.5	45-55	32-35
				3.0-4.0	75-85	65-75
Average	310	15	46.5	1.0-1.5	20-25	18-20
				2.0-2.5	40-65	28-30
				3.0-4.0	65-75	60-65
Heavy	310	10	31.0	1.0-1.5	15-20	16-18
				2.0-2.5	35-40	26-28
				3.0-4.0	60-70	57-60

Even though the soil of the Shirvan plain appeared sulfatic in type, the quantity of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) exceeded 2.0%. However, the largest spreading salts were Na_2SO_4 , NaHCO_3 , CaSO_4 , and MgCl_2 in the little saline soil; Na_2SO_4 , NaHCO_3 , NaCl , and CaSO_4 in the moderate saline soil; and NaCl , CaSO_4 , Na_2SO_4 , and MgSO_4 in the high saline soil. The quantity of the soil forms 0.6% and 0.8% in the sulfatic type of uncolonized and weakly salinized soil. The plant with weak salt tolerance develops normally in both salinity gradations. Knowingly, from the consequences of the experiments, that at the beginning of leaching of monoliths from the salt, the mineralization of philtre in low (1.0%–1.5%), moderate (2.0%–2.5%), and high (3.0%–4.0%), respectively, was 25–30, 45–55, and 75–85 g/l in light granulometric structural soil; 20–25, 40–45, and 65–75 g/l in moderate granulometric structural soil; and 15–20, 35–40, and 60–70 g/l in heavy mechanic structural soil.

Mineralization parameters of the solution occurred because of dissolved salts in the soil, which possess a different mechanical composition during atmospheric rainfalls. The solution surfaces because of dissolution in connection with the atmospheric rainfalls of the different granulometric structural soils, of which salinity was low, moderate, and high (Table 2). The mineralization of the filtrate, which occurred at the previous stage of washing the monoliths from the salts, was

slightly higher than the mineralization of water observed in the Shirvan part. The fraction of atmospheric precipitation reaching groundwater was minimal (in light, moderate, and heavy granulometric structural soils: 62.0, 46.5, and 31.0 m³/h). When a small amount of water passes through a saline layer with a density of 2.0–3.0 m, the salt dissolved in water increases.

It is clear that the salts' quantity in the soil possessing salinity gradations can develop a danger (>1.0%–1.5%), especially if not considering uncolonized and weakly salinized soils. The salinity gradations received for sulfatic type salinized soil had 2.0% of gypsum (Table 3). In the Ganja-Gazakh Massif, saline soils were evident in small areas near Ganja and Goranboy. However, the mineralization of groundwater does not exceed 15–18 g/l. In other areas, the low salt content (0.06%–0.25%) was notable in the soil, with the placement of groundwater at depth observed.

Some information has been available about the types of salinization, anion and cation structure, mineralization, and slope depths of groundwater in those areas. Since the groundwater was deeper than the surface in some parts of the Absheron and Ganja-Gazakh massifs, its impact on salinization processes was minimal. In the Shirvan Region, the groundwater depth was 2.8–3.3 m in the summer and autumn. No variation in their level was apparent in the summer months, since the atmospheric precipitation also cannot bring the

Table 3. Salinity gradations of the sulphatic type of salinized soil (Azizov, 2002).

Names of the gradations	Gradation parameters (%)
Non-salinized	0.6-0.8
Weak salinized	0.8-1.0
Mean salinized	1.0-1.5
Strong salinized	1.5-2.2
Very strong salinized	2.2-3.0
Saline	>3.0

Table 4. Water-lifting ability of the capillary according to the granulometric structure of the soils (Kovda, 1973).

Granulometric structure of the soil	A quantity of physical clay in the soil (<0.01mm; %)	Water-lifting height of the capillary (m)
Pure thin sand	No	0.3-0.4
Light	25-30	1.5-2.0
Middle	35-50	2.0-3.0
Heavy	50-70	3.0-4.0
Very heavy	>70	4.0-6.0

3.0-m layer of soil to full productivity. In summer, because of atmospheric precipitation and irrigation in the surrounding area, their level may slightly rise. However, in any case, this change cannot exceed 0.5–0.6 m.

In the Shirvan Region, due to the influence of groundwater, soils in an interconnected system have a certain amount of porosity. When water enters one part of the system, it moves to the other part with less moisture. This phenomenon occurs under the influence of meniscus-capillary force. The water movement in capillaries bore direction from below to the surface of the soil. Its water-lifting ability depends on the size of the particles that make up the soil. Depending on the size of the particles, the diameter of the capillary tubes differed. When the soil size that makes up the particles was small, the size of the pores between them was little, and in small-sized porous soil, the diameter radius of the capillaries was also tiny. The water-lifting ability of the capillaries was in obstinate proportion with its radius, as defined with the following formula (Kashinsky, 1970):

$$H_{\text{groundwater level}} = 2a/\mu g$$

Where, $H_{\text{groundwater level}}$ is a capillary-lifting ability, a - being a parameter of the water surface tension and equal to 74 din/cm,

μ - is a capillary radius, and g - is a free slump acceleration.

It is evident from the formula that the less capillary radius, the more ability of water lifting. The soil of the Shirvan part has some physical parameters, and the soil was heavy. Given the heavy soil nature, the capillary radius was small, and the water-lifting capacity was large. Kovda (1973) expresses the water-lifting ability of the capillaries in the soil possessing physical characters (Table 4).

One should also note that the water-lifting ability of the capillary in the sand and light soil was low, and the quantity and velocity of the water lifted were great. In the heavy soils, the capillary water-lifting ability can reach the $H_{\text{groundwater level}} = 6.0$ m. However, its lifting velocity was very low, which took months. The water-lifting ability of the capillary and water movement velocity in soil with moderate mechanical structure was sufficient. The subsoil water level in some places does not remain constant and varies with the influence of the various factors, including atmospheric rainfall, water pressure, irrigative water, and the water entering from outside. In the Kur-Araz lowland, the groundwater level formation has a maximum depth of 3.0 meters from the soil surface. In the Shirvan Plain, since the distance from the Caspian Sea seemed greater, the depth of groundwater determined resulted

from the analysis, and the maximum depth is below 3.0 meters.

In the Shirvan Plain and based on the above facts, one can conclude that the solution formed because of the dissolution of salt in the soil during atmospheric precipitation, and the groundwater mineralization affects the salinization process. In those areas, where the salts range from 1.0% to 1.5%, it was visible that the salinization process was taking place. The salts and mineralization of the solution formed during atmospheric precipitation can range from 15–20 to 25–30 g/l. In such places, groundwater mineralization also varies from 16–18 to 25 g/l.

In areas with 1.5%–2.0% salt content in the soil and 20–25 g/l groundwater mineralization, the soils were severely saline and required complex agro-ameliorative measures to improve them. Areas with soil salt content of 2.0–2.5 and groundwater mineralization of 28–35 g/l were also severely saline soils, with a proposal to apply hydrotechnical, agrotechnical, and agro-ameliorative measures to enhance them. In areas with a salt content of 3.0%–4.0% and groundwater mineralization of 50–60 g/l, the recommendation is to carry out additional washing and use them under salt-tolerant plants after washing. In the promising field research and chemical analysis, the study found that the salinity of most of the soils in the Shirvan Region was high, and the collector-drainage network was unfavorable (Table 4).

The torrents incurred development during strong atmospheric rainfalls for the first group; however, the soil salts and subsoil water with high mineralization arose for the second group of soils. The results showed that in the areas of the Shirvan Plain where soil salts exceeded 2.0% and groundwater mineralization was higher than 30 g/l, particularly if the areas contain salts at 3%–4% and the groundwater mineralization was 50–60 g/l, planting crops becomes difficult using such soils. For improving these lands, the collector-drainage system requires developing with effective functioning in those areas where washing should proceed with large water norms (15,000–20,000 cubic meters) against the drainage background to remove salt from

the area and lower the groundwater level. If these measures reached implementation, it would be possible to gradually improve those areas with land reclamation.

CONCLUSIONS

Soil salinization primarily results from groundwater mineralization, soil salt content, and human agricultural practices in the Shirvan Plain and Ganja-Gazakh Massif. The combination of shallow, saline groundwater and a poor drainage system makes it highly vulnerable to salt accumulation in the Shirvan Plain. The Ganja-Gazakh Massif experiences the localized salinization in areas with improper irrigation and water management. For sustainable and better crop productivity, effective soil and water management strategies require adoption, including improved drainage, leaching techniques, and better irrigation practices. Addressing these issues will be crucial for ensuring long-term soil health and food security in the region.

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