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APPLIED PROBLEMS OF ARID LANDS DEVELOPMENT

Saline Soils and Identification of Salt Accumulation Provinces in Kazakhstan

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Abstract—Saline soils are widespread in the southern and central parts of Kazakhstan. In these arid areas, the annual precipitation is 100–150 mm, while the evaporation exceeds the precipitation. The soils in these areas are medium and highly saline. In the framework of this study, numerous cartographic materials pertaining to the saline soils of Kazakhstan and Central Asia have been reviewed and researched. Four soil–halo–geochemical salt accumulation provinces have been identified in Kazakhstan on the basis of generalization and analysis of the available materials. The provinces differ from each other by their genesis, composition, and salt transportation patterns. ArcMap software was used as the main tool for the analysis of the soil–halo–geochemical provinces and the production of a salt accumulation map of Kazakhstan. The research of the salt accumulation geochemistry in the soils, mineral rocks, and groundwaters, salt accumulation types, and patterns of soil migration in the biosphere are the basis for the assessment of regions with irrigation activities. Therefore, the research of the saline soils and salt accumulation processes is of high practical importance.

Keywords: soil salinization, salt accumulation provinces, Kazakhstan

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INTRODUCTION

Soil salinization issues are widespread in arid and semiarid regions, although soil salinization processes are developing extensively in areas with humid climate as well, especially in coastal regions where the seawater enters through estuaries and rivers and with groundwaters causing soil salinization in large areas. Soil salinization is also a serious issue in regions where groundwaters with a high salt content are used for irrigation (Kovda, 2008).

Saline soils are a mandatory element of steppe and desert landscapes (Borovskii, 1978, 1982); these are widespread in arid and semiarid regions of the world. According to the International Institute for Environment and Development and World Resources Institute, saline soils occupy some 10% of the continents. They are mostly located in arid areas and in dry and desert steppe zones (Kovda, 2008; Lopatovskaya and Sugachenko, 2010). Saline soils are toxic due to the high concentration (over 0.25%) of highly soluble salts in all of the soil layers and affect plant growth (Munns, 2009). The formation of saline soils in arid regions depends on many factors and matters, including the geological structure and composition of the rocks (saline parent material), topography and negative relief forms, groundwater depth and salinity (mineralization), distance from the sea (aeolian transportation of salts from the sea to the land), hydrological regime, precipitation, use of highly mineralized water for irrigation, vegetation composition (halophytes), economic use of the area (ineffective irrigation), and wind regime of the area (aeolian transportation).

In total, saline soils occupy 20% of the developed lands, while one half of the irrigated lands undergo intense salinization. Furthermore, a soil salinization growth trend still persists: 900 million ha of lands worldwide are considered to be lands undergoing salinization. This equals some 6% of the total soils of the world, or 20% of the developed lands worldwide (Flowers, 2004; Gamalero et al., 2009). Saline soils are a growing problem in irrigated agricultural lands (Kovda, 2008).

Saline soils are widespread mostly in Central Asia and Kazakhstan; they are also present in western Siberia and western China. The majority of saline soils in 70% of the Commonwealth of Independent States are located in Kazakhstan. Numerous research studies dedicated to the saline soil genesis, development, and formation conditions were performed in Kazakhstan (Glinka, 1931; Gedroits, 1955; Borovskii, 1982). Soil salinization is one of the most well-known land degradation processes. The anthropogenic impact on the soil cover and ecosystems of Kazakhstan in all the geographical zones is increasing year by year. The inefficient use of natural resources leads to environmental disturbances.

The total area of Kazakhstan is 272 million ha; of that amount, 180 million ha (60% of the country) are currently under the threat of degradation. The degradation is accompanied by intense soil salinization, leading to the growth of saline desert areas in inland drainage basins and the salinization of irrigated lands (Orlova and Saparov, 2009). The soil degradation processes are progressing, as well as soil erosion and blowing (over 30 million ha), salinization, chemical pollution and soil alkalinization (60 million ha), and dehumification of arable lands (over 10 million ha) (Medeu, 2010). Therefore, this study dedicated to the saline soils of Kazakhstan is of high importance for the forecasting and monitoring of soil salinization.

The main purpose of the study was to research the salt accumulation provinces in Kazakhstan and to produce a map showing those on its territory. In addition, this study assists in the solution of some issues pertaining to the halogenesis and material migration the pedosphere.

MATERIALS AND METHODS

The Republic of Kazakhstan is rapidly developing; it is the youngest independent state in world. Kazakhstan is located between the Siberian taiga on the northern and Central Asian deserts on the south; it borders the Caspian Sea on the west and mountain ridges of the Tian Shan and Altai on the east (UNDP, 2002). Plains occupy some 60% of the Kazakh territory. Deserts and semideserts occupy some 50% of the country; the majority of those are located on the Turan plain. Arid areas are expanding from the Caspian Sea to piedmont plains of the Zhetysu (Dzhungar), Alatau, and Tian Shan mountains. The northern parts of Kazakhstan are covered by steppes and forest steppes (Danayev, 2008).

The climate of Kazakhstan is extremely continental with an uneven distribution of precipitation within its territory. Plain areas are mostly dry; the annual precipitation varies there from 100 mm on the southwest to 400 mm on the north. Saline soils are widespread on plains. In mountainous areas, the precipitation is 400 to 1600 mm per year (*Asian Development Bank...*, 2003; Almaganbetov and Grigoruk, 2008). The average temperature in January is −18°C in the north and −3°C in the south. The average temperature in July gradually increases from 19°C on the north to 28–30°C on the south. The climatic regime significantly affects salt migration in soils.

Kazakhstan belongs to the arid regions. The geographical zones of Kazakhstan are characterized by a substantial excess of evaporation in comparison with precipitation. Except for some mountainous areas, evaporation in the vast territory of Kazakhstan exceeds precipitation significantly (by two to three times in the north and 10–20 times in the south); this results in a long, hot, and dry summer (Uteshev, 1959). The climate aridity is high, and the probability of soil salinization is therefore also high (Borovsky, 1982).

Saline soils are present almost everywhere in Kazakhstan. Vast areas in the central, southern, and western parts of Kazakhstan are covered by saline soils that are also prevalent in the desert steppe and desert zones (Faizov, 1980). In the deserts of Kazakhstan and Central Asia, the evaporation exceeds the precipitation by 10–20 times. Therefore, the arid areas are soil accumulation areas; the salts are transferred by surface and groundwaters and through the aeolian transportation (Borovskii, 1978). In addition, saline soils occupy the Caspian plain and Aral Sea region covered by marine and alluvial deltaic soil parent materials, which lie close to the surface with mineralized groundwaters. These saline soils belong to intrazonal soils (Borovsky, 1978). The intrazonal soils occur both in the horizontal and vertical ranges of the geographical zoning. The share of saline soils in the structure of the soil cover of Kazakhstan is pretty large due to the high aridity of the area.

Numerous cartographic materials and map charts (Borovskii, 1978, 1982) have been used in this study in order to produce a map of the soil–halo–geochemical provinces of Kazakhstan. The produced map makes it possible to identify the salt washout and transit zones and complete salt accumulation areas in Kazakhstan.

ArcMap software was used as the main tool for the analysis of the soil–halo–geochemical provinces and the production of the salt accumulation map of Kazakhstan.

RESULTS AND DISCUSSION

Saline soils of Kazakhstan. Saline soils are distributed unevenly in Kazakhstan. The majority of saline soils in 70% of the Commonwealth of Independent

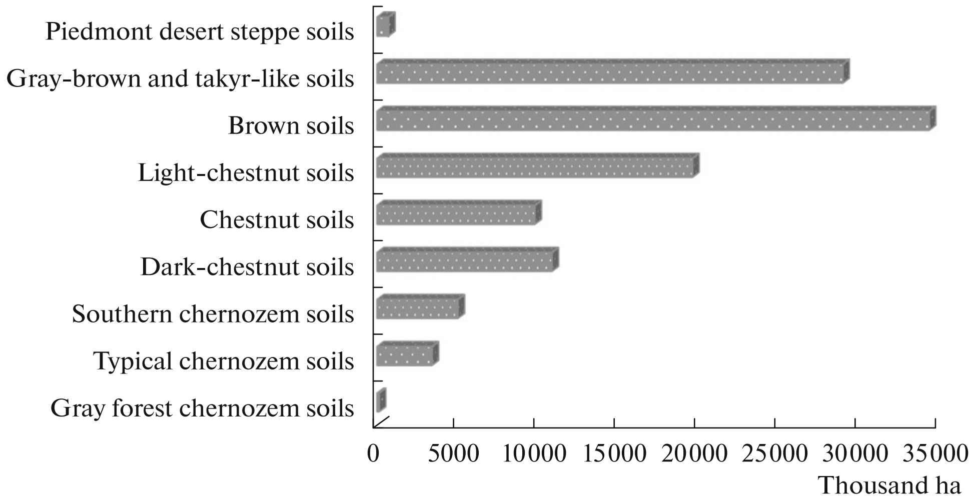

Fig. 1. Distribution of saline soils by the soil zones and subzones of Kazakhstan.

States are located in Kazakhstan. According to the Agency on Land Resources Management of the Republic of Kazakhstan, saline, solonetz, and solonchak soils (salt marshes) cover more than 111 × 104 km^2 of the 272.3 × 104 km^2, or 41% of the total area, especially in arid steppe and desert steppe zones (Table 1) (Asanbaev and Faizov, 2007; Faizov et al., 2006). Normally, saline soils are located in the zones of brown, gray-brown, takyr-like, and light-chestnut soils (Fig. 1). In addition, saline soils occur among chernozem, chestnut, and other soils of the steppe zone of Kazakhstan.

The territorial and geographic distribution of the saline soils is uneven. These constitute 29–30% of the leached chernozem soils and 37% of the southern chernozem soils, while the share of saline soil reaches 51% in the more arid conditions of the light-chestnut soils and 55% in the brown desert soils. However, in the most arid and desert conditions of the gray-brown and takyr-like soils, saline soils occupy only 46% of the total subzone area (Table 1). The saline soils include solonchak, solonetz, and solod soils.

Types of saline soils in Kazakhstan. Solonchak soils are the most salinized; salts are accumulated directly on their surface. Solonchak soils occupy over 8.5 × 104 km^2 out of the 272.3 × 104 km^2 of the Kazakh territory. These soils are mostly located in the brown and gray-brown soil zones (Borovsky, 1978; Kovda, 2008). Solonchak soils are abundant in the desert zones and occupy the majority of plain areas in Kazakhstan (Faizov, 1980; Asanbaev and Faizov, 2007).

Solonchak soils constitute a small share (0.3–1.0%) of chernozem and chestnut soils and 1.6% of light-chestnut soils in the steppe zone. However, the share of solonchak soils in brown and gray-brown soil zones increases by several times and reaches 7.9% and 5.0% respectively. The share of solonchak soils in the total area of saline soils varies in the range of 1–3% in steppe zones and 13.2–7.2% in the desert zone. As can be seen, solonchak soils are mostly located in the desert zone of Kazakhstan. The ratio between solonetz and solonchak soils in the steppe zone is 1 : 50, while in the desert zone, it is about 1 : 3 (Table 2).

Solonchak soils of various types are especially abundant in the southern part of Kazakhstan: in the desert zone in deltas of the Syrdarya, Talas, Asa, and Ile Rivers and in the lower stream of the Zhaiyk River. Extensive solonchak areas are located in small and large water bodies, including the Dead Kultuk (a bay in the eastern part of the Caspian Sea) and saline shores of the Aral Sea and Lake Balkash. The content of soluble salts in the crust–fluffy layer of the solonchak soils is 15000–40000 t/km^2 in the upper one-meter-deep soil layer (Orlova and Seifullina, 2006).

In addition to the solonchak soils, solonetz soils are widespread in Kazakhstan as well. These soils contain water-soluble salts not in the uppermost horison but at some depth; this is the difference between the solonetz and solonchak soils. The solonetz soils are abundant in the steppe zone, especially in the western part of the desert zone and, to a lesser degree, in the desert, but they rarely occur among the sierozem (gray desert) soils in the northern and central parts of Kazakhstan. Normally, solonetz soils occur in combinations with zonal and intrazonal soils and rarely occur in large soil bodies. Solonetz and solonetzic soils occupy over 70 × 10^4 km^2 (especially in dry steppe and desert steppe zones). Soil complexes with solonetz soils (10–30%) are predominant in the sierozem soils. The areas of solonetz soils and complexes in the steppe zone increase towards the south and occupy one quarter of the total area of the typical chernozem soils and almost half of the area in the light-chestnut soil subzone. The solonetz soils and complexes encompass over 90% of the total saline soils in Kazakhstan. Based on the research data, the

Table 1. Areas of saline soils in Kazakhstan and their distribution by the soil zones and subzones (thousand ha), Borovskii, 1982

Types of saline soils	Gray forest leached chernozem soils	Typical chernozem soils	Southern chernozem soils	Dark- chestnut soils	Chestnut soils	Light- chestnut soils	Brown soils	Gray-brown and takyr-like soils	Piedmont desert steppe soils	Total saline soils
Solonchak soils	3.2	31.2	64.2	245.3	238.1	615.6	4524.2	2085.8	700.0	**8507.6**
Complexes with over 50% of solonetz soils	27.8	929.9	1635.3	2495.5	3620.1	7761.8	8688.5	1789.2	–	**26948.1**
Complexes with 30–50% of solonetz soils	–	334.1	511.4	1816.5	1369.8	2125.3	1168.5	83.2	–	**7408.8**
Complexes with 10–30% of solonetz soils	28.4	1614.5	2662.9	6011.3	4169.6	8315.5	6117.0	5417.3	–	**34336.5**
Solod soils	56.3	451.9	71.8	7.3	–	1.8	–	–	–	**589.1**
Meadow and flood plain–meadow soils combined with solonetz and meadow solonchak soils	0.8	25.6	45.2	242.7	364.6	686.8	989.3	1367.9	–	**3722.9**
Meadow–swamp soils with solonchak soils	5.3	12.9	11.0	18.9	14.3	47.2	568.1	1075.7	–	**1752.5**
Brown solonetzic and solonchak-like soils	–	–	–	–	–	–	11008.5	–	–	**11008.5**
Gray-brown solonetzic and solonchak-like soils	–	–	–	–	–	–	–	11114.4	–	**11114.4**
Takyr soils with complexes of takyr-like solonchak soils	–	–	–	–	–	–	165.9	173.6	–	**339.5**
Takyr-like solonchak-like and solonetzic soils combined with residual solonchak soils	–	–	–	–	–	–	57.7	5764.2	–	**5821.9**
Total saline soils	121.8	3400.1	5001.8	10837.5	9775.6	19554.0	34287.2	28871.6	700.0	**11550.1**
(%) of the total zone/subzone area	30	29	37	40	40	51	55	46	5	**41**
Total area of zones and subzones	400	11700	13600	27700	24300	38400	57400	61900	16800	**252200***

* Not including the mountain soils, the area of which is 20.1 million ha (the total area of Kazakhstan is 272.3 million ha).

Table 2. Shares of saline soils in the soil cover structure of Kazakhstan (Borovskii, 1982)

Soil zones and subzones	Solonchak soils, % of the total area of			Solonetz soils, % of the total area of		Meadow and meadow swamp saline soils, % of the total area of	
	zones and subzones	saline soils	solonetz soils	zones and subzones	saline soils	zones and subzones	saline soils
Leached chernozem and gray forest soils	0.8	2.6	5.7	14.0	25.6	1.5	5.0
Typical chernozem soils	0.3	0.9	1.1	24.3	84.5	0.3	1.1
Southern chernozem soils	0.5	1.3	1.3	35.4	97.2	0.4	1.1
Dark-chestnut soils	0.9	2.2	2.3	36.3	95.0	2.3	2.4
Chestnut soils	1.0	2.4	2.6	37.6	94.5	1.6	3.9
Light-chestnut soils	1.6	3.1	3.4	46.2	91.9	1.9	3.7
Brown soils	7.9	13.2	28.4	27.8	46.5	2.6	4.5
Gray-brown and takyr-like soils	5.0	7.2	28.6	17.4	25.2	5.8	5.8
Average	**3.2**	**7.6**	**12.3**	**29.3**	**60.6**	**2.3**	**4.9**

Kazakh steppes may be named a solonetz realm (Borovskii, 1982).

Salt accumulation provinces in Kazakhstan. Four saline soil provinces have been identified in Kazakhstan on the basis of the halo–geochemical soil structure. These territories differ from each other by the genesis, composition, and soil transportation patterns (Fig. 2). Three of those are located in the southern part of Kazakhstan: (1) the Caspian Sea drainage basin with a predomination of sulfate–chlorides and chlorides; (2) the Aral Sea drainage basin with an accumulation of chloride–sulfates; and (3) the Lake Balkash drainage basin with soda–sulfate salt accumulation. These three provinces are characterized by increasing soil and groundwater salinity in the direction of the geochemical flow, advancing to the salt receiving basin (the seas and lake). The Kara Sea drainage basin province (4) with predomination of chloride–sulfate salt accumulation encompasses the entire northern Kazakhstan and parts of central and eastern Kazakhstan, while the main part of this province is located in western Siberia.

Areas of the complete and partial soil accumulation and transportation have been designated on the map of the soil–halo–geochemical provinces (Fig. 2).

Sulfate–chloride salt accumulation province of the Caspian Sea basin. The Caspian plain has been a salt accumulation area over a long geological period of time. Soft sediments of various ages constitute the major part of the salt migrants in the basin. As the salinity increases in the soils and groundwaters of the chloride province of the Caspian Sea drainage basin, a progressing accumulation of chlorides (mostly sodium chlorides) is taking place, while salts containing boron are registered in toxic concentrations. The saliferous rocks of the Permian period are important for the assessment of salt accumulation processes in the Caspian plain. These rocks are abundant throughout its entire area (Bochkareva and Sadykov, 1973). In the desert zone, sulfate–chloride and chloride soil types are predominant in depressions and near the seashore and shores of salt lakes. Numerous hydrological analyses show that the surface water flowing to the Caspian plain belongs to the chloride type by its chemism (Kovda, 1950; Berkaliev, 1959; Pachikina et al., 1975). In summer and fall, the content of chlorides in the surface flow is times higher than contents of all other salts. The flows of continental rivers transport up to 350 tons of salt per year containing no less than 50% of chlorides (Kovda, 1950). Salts dissolved in the water of the Caspian Sea contain 62.15% of NaCl, while the annual inflow of salts to the sea with the river flow is 7.93×10^7 tons (Strahov et al., 1954). The aeolian transportation of salts from the sea to the land is important in the salt balance of the Caspian Sea basin. Very large amounts of salts (2×10^7 tons) are transported by the aeolian process to areas adjacent to the Caspian Sea with the predomination of chlorides among other salts (Strahov et al., 1954).

Therefore, there are three main soil accumulation sources: (a) dissolution of salts contained in marine sediments of saliferous rocks of the Permian period; (b) inflow of salts with surface and groundwater flows (hydrochemical flow); and (c) impulverization (salt transportation from sea areas to the land). All three sources have a chloride composition and mainly trans-

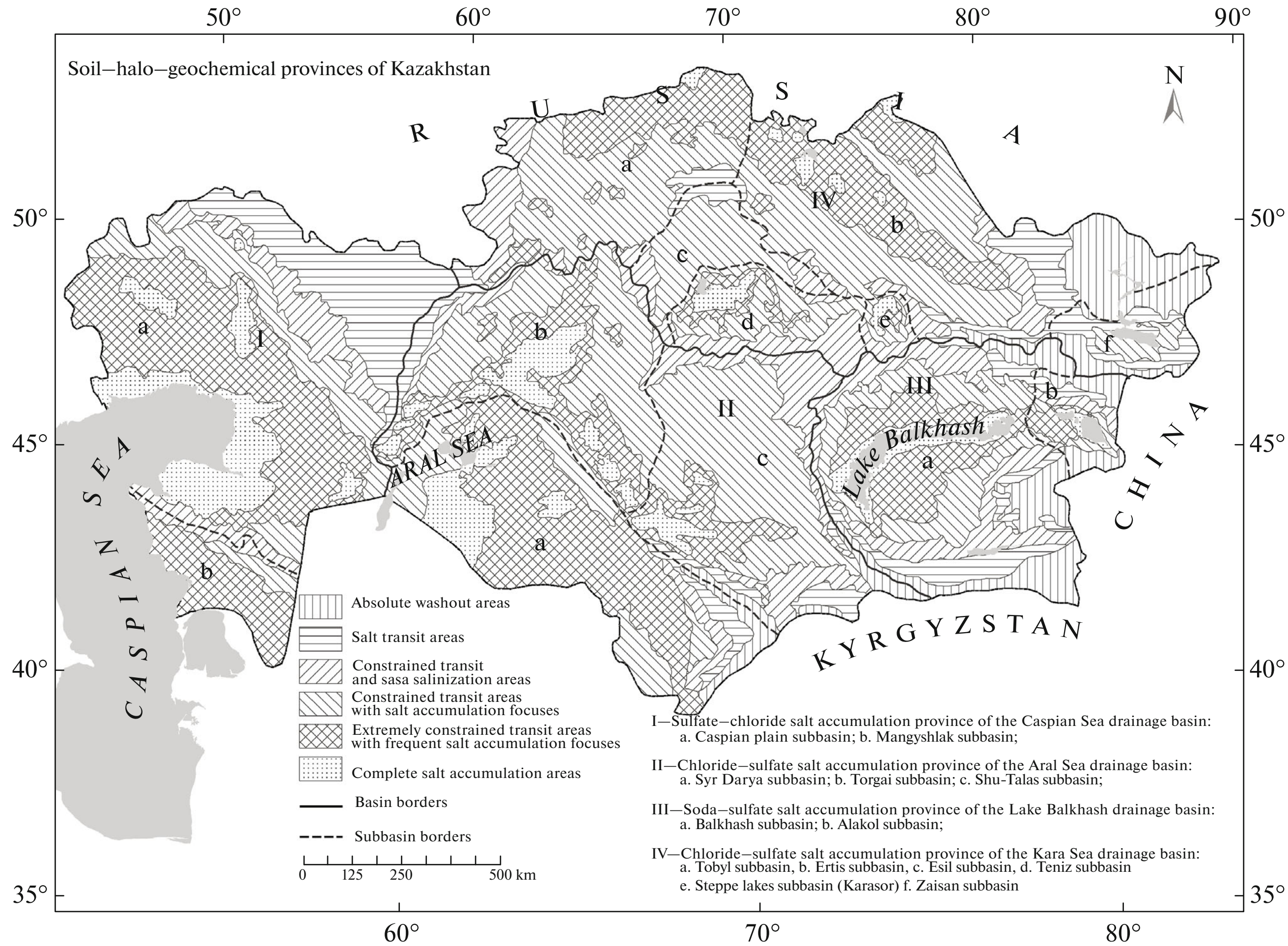

Fig. 2. Salt accumulation provinces/soil–halo–geochemical provinces of Kazakhstan.

port sodium and, to a lesser degree, magnesium chlorides to the Caspian plain (Borovskii, 1982).

Chloride–sulfate salt accumulation province of the Aral Sea basin. The Aral Sea basin is located in the southern part of the temperate belt/zone and almost in the middle of Eurasia. Recurrent high plains and plateaus cover a major part of the basin. The desert Ustyurt Plateau, which is covered by sandy loam and alkaline gray-brown soils with predominant absinthian–saltwort vegetation, borders the western shores of the sea. The Mugalzhary Hills, a southern extension of the Urals, are located in the northern part of the Aral Sea basin. These hills play an important role in the formation of atmosphere currents of cold weather fronts. Significant fluctuations of the average annual temperatures are typical for the climate of the Aral Sea region. The average annual temperature varies in the range of 8.4 to 18°C. The average temperature in January is –9.7 to 3.6°C, while the average temperature in July is 25.4 to 32.4°C. The precipitation is intensive mostly in winter and spring periods and amounts to 90 to 450 mm/year on the plains, including low foothills. The climate in the region contributes to salt preservation and partial accumulation in the soils and groundwaters (Pankova et al., 1996).

The Aral Sea basin covers a vast area from the Ustyurt Plateau on the west to the Shu-Ile Mountains and Lake Balkash region on the east; it stretches from the Aral–Siberian watershed on the north to the south beyond the southern border of Kazakhstan. It encompasses almost the entire Northern and Southern Tian Shan, Kyzylkum Desert, a part of the Karakum desert, Alai Ridge, and northern parts of the Pamir Mountains and Afghanistan where Amudarya tributaries originate. This vast area is the main basis for the irrigated agriculture in the republic. The total area of irrigated lands in Kazakhstan reaches 2.3×10^4 km^2 including 1.6×10^4 km^2 in the southern regions of the republic; over 30% of these lands are used for crop farming in Kazakhstan (Almaganbetov and Grigoruk, 2008).

As the salt accumulation develops in the chloride–sulfate salt accumulation province of the Aral Sea basin, the chloride content (mostly sodium chlorides) increases in the groundwaters, while the sulfate content increases in the soils. In the course of groundwater mineralization in this basin, mostly the accumulation of sodium chlorides occurs, and the groundwaters have the typical chloride composition.

Sulfates predominate in comparison with chlorides in the semidesert and dry steppes and are associated with more or less solonchak and solonetz soil complexes. The soils of the Aral Sea basin are very diverse: from alpine meadow soils in nival zones of high mountainous regions of the Tian Shan to sierozem soils in the foothills. The plain areas feature takyr and gray-brown desert soils with a broad range of hydromorphic soils flooded by river valleys and deltas. The northern part of the basin features chestnut and brown soils on the southern slope of the Kazakh Hummocks (the Central Kazakhstan hillocky area) and gray-brown soils on the Paleogenous–Cretaceous plateau adjacent to the valleys of the Shu and Syrdarya Rivers (Borovsky, 1982).

Soda–sulfate salt accumulation province of the Lake Balkash basin. The Lake Balkash basin occupies a large area in the southeastern part of Kazakhstan and borders the Kazakh Hummocks (the Central Kazakhstan mounded area) and Tarbagatai Ridge on the north and west, Shu-Ile Mountains on the southwest, Ile-Alatau on the south, and Zhetysu (Dzungar) Alatau on the east. The Balkash province features a similar differentiation of chlorides and sulfates with the Aral Sea basin province, but soluble boron salts with higher soda bicarbonate contents contribute to the salinization in the Lake Balkash province as well (Borovskii, 1982).

In the Kara Sea basin, the soils are mostly salinized with sulfates (sodium sulfates), while the groundwaters are rich with sodium chloride, but, as the geochemical flow advances to the Kara Sea, the soils and groundwaters desalinize.

Four soil accumulation provinces have been identified in Kazakhstan through the comparison of the soil, geological, and hydrogeological data. These provinces differ from each other by their genesis, composition, and salt transportation patterns. Three provinces, which belong to the basins of the Caspian and Aral Seas and Lake Balkash, are characterized by increasing soil and groundwater salinity in the direction of the geochemical flow advancing to the seas and lake (the salt-receiving basins). Chlorides (mostly sodium chlorides) gradually accumulate in the soils and groundwaters of the chloride salt accumulation province of the Caspian Sea; salts containing boron are registered in toxic concentrations in this province as well. The chloride content (mostly sodium chlorides) increases in the groundwaters of the chloride–sulfate salt accumulation province of the Aral Sea, while sulfates (mostly, sodium sulfates) accumulate in the soils of the province.

Analysis of these provinces by the most common toxicity assessment methods for salt combinations with salinization identified a distinct toxicity in the Caspian plain. In the Lake Balkash region, the possible sodic salinization and boron pose the highest hazard.

CONCLUSIONS

Saline soils are a frequent component of arid landscapes. Salinization indicates soil degradation and significantly reduces soil fertility. The geological development of an area and the composition and structure of the sediments play an important role in the formation of different salt types and their accumulation in the provinces. Based on the generalization and analysis of numerous cartographic materials and in accordance with the halo–geochemical soil structure, four soil accumulation areas or soil–halo–geochemical provinces have been identified in Kazakhstan: (1) the sulfate–chloride and chloride salt accumulation province of the Caspian Sea basin; (2) the chloride–sulfate salt accumulation province of the Aral Sea basin; (3) the soda–sulfate salt accumulation province of the Lake Balkash basin; and (4) the chloride–sulfate salt accumulation province of the Kara Sea basin. Each province features its own soil salinity type and chemical properties, differing by their genesis, composition, and soil transportation patterns.

The geological structure, rock composition, and modern physico-geological processes affect the soil mineralization and salt migration in the soils. The lowlands of the Aral Sea and the Caspian plain are parts of the ancient and modern salt accumulation regions.

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