Eurasian Journal of Soil Science 2023, 12(4), 290 - 299

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Comprehensive assessment and information database on saline and waterlogged soils in Kazakhstan: Insights from Remote Sensing Technology

Nurgali Bektayev [a], Kamshat Mansurova [a,*], Sagynbay Kaldybayev [a], Konstantin Pachikin [b], Kenzhe Erzhanova [a], Botagoz Absatova [a]

[a] Kazakh National Agrarian Research University, Almaty, Kazakhstan

[b] U.U.Uspanov Kazakh Research Institute of Soil Science and Agrochemistry, Almaty, Kazakhstan

Article Info

Received : 12.11.2022

Accepted : 21.05.2023

Available online : 05.06.2023

Author(s)

N.Bektayev

K.Mansurova *

S.Kaldybayev

K.Pachikin

K.Erzhanova

B.Absatova

* Corresponding author

Abstract

Soil salinity and waterlogging are significant challenges in agricultural regions worldwide, including Kazakhstan. Understanding the characteristics and distribution of saline and waterlogged soils is crucial for developing effective strategies to mitigate their negative impact on crop productivity and environmental sustainability. This study aims to provide a comprehensive assessment of saline and waterlogged soils in various zones of the Republic of Kazakhstan, including the desert, foothill semi-desert (vertical), semi-desert (latitudinal), and dry-steppe areas. By examining the genetic horizons, chemical composition, ionic composition, salt content, and granulometric composition of these soils, this research contributes to the knowledge base necessary for implementing targeted soil management practices and restoration techniques. Fieldwork was conducted at 66 designated base points, where detailed descriptions of the genetic horizons of these soils were made. The data collected from these surveys were utilized to create an extensive information database, encompassing various indicators such as nomenclature, profile structure morphology, chemical composition, ionic composition of water extracts, salt content, absorbed cations, and granulometric composition. The findings reveal that saline soils cover a significant area of 16.7% (35,817.4 thousand hectares) of the agricultural land, while waterlogged soils occupy 0.5% (1,083.4 thousand hectares). The study highlights the poor fertility of saline soils due to high concentrations of water-soluble salts, predominantly sodium chlorides and sulfates, throughout the soil profile. Conversely, waterlogged soils exhibit distinct features such as gleyed horizons and a greenish-grayish color, with variations in fertility. The information presented in this study contributes to the understanding of the characteristics and distribution of saline and waterlogged soils in Kazakhstan, facilitating the development of strategies to restore soil fertility and implement appropriate management practices.

Keywords: Information base, salinity, waterlogging, remote sensing, solonchak soil, peat-bog soil, GIS technology.

Introduction

The classification and understanding of soil salinization play a crucial role in managing agricultural lands and ensuring sustainable productivity. This study focuses on the identification and assessment of saline and swampy soils in Kazakhstan, aiming to provide valuable insights into the distribution, severity, and potential mitigation strategies for these soil types.

Kazakhstan exhibits diverse soil conditions, with varying degrees of salinization (Funakawa et al., 2000; Saparov, 2014; Pachikin et al., 2014; Otarov, 2014; Laiskhanov et al., 2016; Suska-Malawska et al., 2019; Zhang

: https://doi.org/10.18393/ejss.1309746

: http://ejss.fesss.org/10.18393/ejss.1309746

Publisher : Federation of Eurasian Soil Science Societies

e-ISSN : 2147-4249

et al., 2019; Ma et al., 2019; Yertayeva et al., 2019; Kussainova et al., 2020; Liu et al., 2022; Suska-Malawska et al., 2022). Soil salinity is categorized into three gradations based on the level of salinization and solonchak complexes:

i. Slightly saline: This category includes solonchak soils and their complexes with solonchaks up to 10%, covering an area of 11.5 million hectares.
ii. Medium-saline: Encompassing solonchak soils and their complexes with solonchaks ranging from 10% to 30%, this category extends over 7.3 million hectares.
iii. Highly saline: Comprising highly solonchak soils and their complexes with solonchaks exceeding 30% salinity, this category occupies 14.2 million hectares.

These gradations provide insights into the extent of soil salinization and facilitate a comprehensive understanding of the distribution and severity of salinity in specific regions.

Solonchaks, characterized as saline soils, cover approximately 2.8 million hectares of land in Kazakhstan. These saline soils are found in various soil zones, with a significant proportion (more than 58%) occurring in brown and gray-brown soils. Within this group, approximately 64% of the saline soils exhibit medium to strong salinity. The largest concentration of solonchaks, accounting for over 50% of the total area, is observed in the zone of brown and gray-brown soils. Additionally, saline soils are identified on 1.6 million hectares of land in the chernozem (black soil) zone, 6.2 million hectares in the dark-chestnut and chestnut soil zones, and 2.7 million hectares in the light-chestnut soil zone. Furthermore, 2.5 million hectares of saline lands are present within arable land (Funakawa et al., 2000; Saparov, 2014; Pachikin et al., 2014; Otarov, 2014; Laiskhanov et al., 2016; Suska-Malawska et al., 2019; Zhang et al., 2019; Ma et al., 2019; Yertayeva et al., 2019; Kussainova et al., 2020; Liu et al., 2022; Suska-Malawska et al., 2022).

The utilization of saline soils varies depending on their salinity levels and land usage. Weakly saline soils and their complexes (covering 1.8 million hectares) are predominantly utilized in non-irrigated arable land. In irrigated agriculture, slightly saline soils and complexes consisting of unsalted and slightly saline soils with salt marshes up to 30% (covering 190.1 thousand hectares) are utilized. These slightly saline soils require relatively simple desalination and leaching measures, taking into account the presence of a collector-drainage network. On the other hand, medium and highly saline soils with salt marshes reaching up to 30% and salt marshes covering 510.2 thousand hectares necessitate comprehensive reclamation measures. Therefore, it is recommended to exclude them from agricultural use and convert them into grazing land.

Swampy soils cover an area of 1.1 million hectares in Kazakhstan, with 23.9 thousand hectares designated as arable land, including 15.3 thousand hectares of irrigated arable land. These soils are predominantly composed of swamp and meadow-swamp soils, forming in areas with excessive moisture. Although distributed across all regions of Kazakhstan, except for Mangystau, their utilization as part of arable land is impractical due to the need for extensive drainage measures. Furthermore, waterlogged soils cover 2.9 million hectares in the country, with 224.9 thousand hectares used for agriculture. This group primarily consists of hydromorphic and semi-hydromorphic soils, including floodplain lands (1.1 million hectares) and non-floodplain lands (1.8 million hectares). The Karaganda region exhibits the most significant extent of waterlogged lands, covering 0.6 million hectares, while Kostanay, West Kazakhstan, Pavlodar, Aktobe, and Almaty regions have 0.2-0.3 million hectares of waterlogged lands. Excessive meltwater and prolonged flooding pose challenges to planting, maturation, and crop yields in these areas, making it more suitable to utilize these soils for hayfields (Funakawa et al., 2000; Saparov, 2014; Pachikin et al., 2014; Otarov, 2014; Laiskhanov et al., 2016; Suska-Malawska et al., 2019; Zhang et al., 2019; Ma et al., 2019; Yertayeva et al., 2019; Liu et al., 2022; Suska-Malawska et al., 2022).

The primary objective of this research is to utilize remote sensing techniques and conduct comprehensive fieldwork to assess soil properties and vegetation cover in the semi-desert (latitudinal) and dry steppe zones. Furthermore, the study aims to develop a robust database and evaluate the extent of waterlogging and salinization, ultimately facilitating the formulation of effective strategies for mitigation and improvement of these soil conditions.

Material and Methods

Kazakhstan, located in Central Asia, is the world's largest landlocked country, encompassing an area of over 2.7 million square kilometers. Its strategic geographic position places it between Europe and Asia, with Russia to the north, China to the east, and the Caspian Sea and the Caucasus to the west (Figure 1). Most of the country's territory is lowlands and plains, with mountainous areas only in the east and southeast (Pilifosova et al., 1997). The country's diverse geography, climate, and land resources contribute to a wide range of soil covers and altitudes, making it an ideal case study for assessing saline and waterlogged soils.

Kazakhstan's geographic location spans across the northern hemisphere, extending from approximately 40°N to 55°N latitude and 46°E to 88°E longitude. The country's vast territory experiences diverse climatic conditions due to its considerable size. The climate of Kazakhstan is highly continental. In the north of the country, 250–350 mm of precipitation falls annually, and in the southern regions, only 100–120 mm. The average January temperature is −15 °C, while the minimum value reaches −40 °C. The summers are fairly hot, with a maximum mean July temperature of up to 40 °C in low-lying steppes and desert steppes (Salnikov et al., 2015). According to the Koppen–Geiger climate classification, the northern and eastern regions of Kazakhstan belong to cold climates with hot summer (Dfa) and warm summer (Dfb). Areas with dry steppe (BSk) and desert (BWk) climates are located in the southern and western regions (Peel et al., 2007). The arid regions are characterized by low precipitation and high evaporation rates, contributing to the formation of saline and waterlogged soils. Kazakhstan's climate exhibits a diverse range of classifications according to the Köppen-Geiger climate classification system (Figure 2). The country experiences various climate types, including arid (BW) in the southern and central regions, continental (D) in the northern parts, and subarctic (Dfc) in the extreme north. These classifications reflect the variations in precipitation, temperature, and vegetation patterns across different regions of Kazakhstan.

Figure 1. Location map of the study area - Kazakhstan

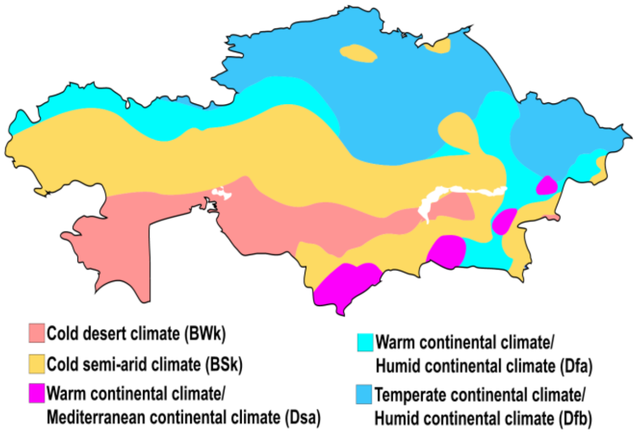

Figure 2. Kazakhstan map of Köppen climate classification

Kazakhstan boasts rich land resources, including vast steppes, deserts, mountains, and forests. Steppes, covering more than two-thirds of the country, are the dominant land cover, consisting of grasslands and shrublands. The desert regions, such as the Betpak-Dala and the Kyzylkum Desert, exhibit specific soil challenges, including salinity and waterlogging, which impact agricultural productivity.

The country's topography varies from low-lying plains to high mountain ranges. The Altai, Tien Shan, and Dzungarian Alatau mountain systems dominate the eastern and southeastern parts of Kazakhstan. These mountain ranges are characterized by high-altitude plateaus, deep valleys, and steep slopes. The altitudes range from below sea level in the Karagiye Depression (-132 meters) to the peak of Khan Tengri in the Tien Shan Mountains (7,010 meters).

Kazakhstan's unique geographic position, diverse climate, vast land resources, and varying altitudes contribute to a wide range of soil covers and challenges, including saline and waterlogged soils. Remote sensing technology provides valuable insights for comprehensive assessment and the development of an information database on these soils. By leveraging this technology, researchers can gain a better understanding of the spatial distribution, extent, and dynamics of saline and waterlogged soils in Kazakhstan, paving the way for effective land management strategies, agricultural planning, and sustainable development in the region.

The digital processing and classification of multispectral space scanning (MSS) data method is a modern and highly effective approach for mapping saline and saline soils (Singh and Dwivedi, 1989; Mulders and Girard, 1993; Dwivedi, 2001). The survey of saline and saline soils consisted of three stages: preparatory, field, and office.

Preparatory Stage

The preparatory stage involved collecting and organizing information on soil and natural conditions, existing soil maps, and digital data related to soil composition. A preliminary list of soil types was developed based on the expected structure of the soil cover. Remote sensing data, such as high-resolution satellite images or aerial photography, were used to create a preliminary map of the soil cover. The primary direct decoding features of saline and saline soils in arid desert, semi-desert, and dry steppe territories were identified, characterized by a relatively light tone across most spectral ranges and a complex contour image pattern. The phytoindication technique, which involves analyzing multispectral space scanning (MSS) data obtained from high and ultra-high spatial resolution satellites, was used as an effective indirect mapping method for identifying saline soils (Murphy, 1986; Dwivedi and Sreenivas, 1998a,b; Dwivedi, 2001). A generally accepted algorithm was employed for the mapping of saline and saline soils, involving systematic, radiometric, atmospheric, and geometric corrections, as well as radiometric calibration, contrast enhancement, spatial filtering, and general statistical analysis to determine the optimal number of classes for image classification. The outcome of the digital processing and classification was a georeferenced hypothetical map representing the spatial arrangement of distinct ranges exhibiting significant variations in optical properties across the Earth's surface.

Field Stage

The field stage of the survey included interpreting a map derived from remote sensing methods to study the Earth's surface. It involved a preliminary survey to determine the relationships between soil and landscape and refine the list of soil types. Soil sections were established based on the boundaries depicted on the soil cover map, and the initial identification of solonetz and solonchak soil complexes was carried out by analyzing the physical structure of the soil profiles, supported by subsequent analysis to determine their genetic status (USDA, 2012; 2015; 2022). For this purpose, 66 monitoring points were selected from the diverse ecological conditions of Kazakhstan, which is the research area (Figure 3).

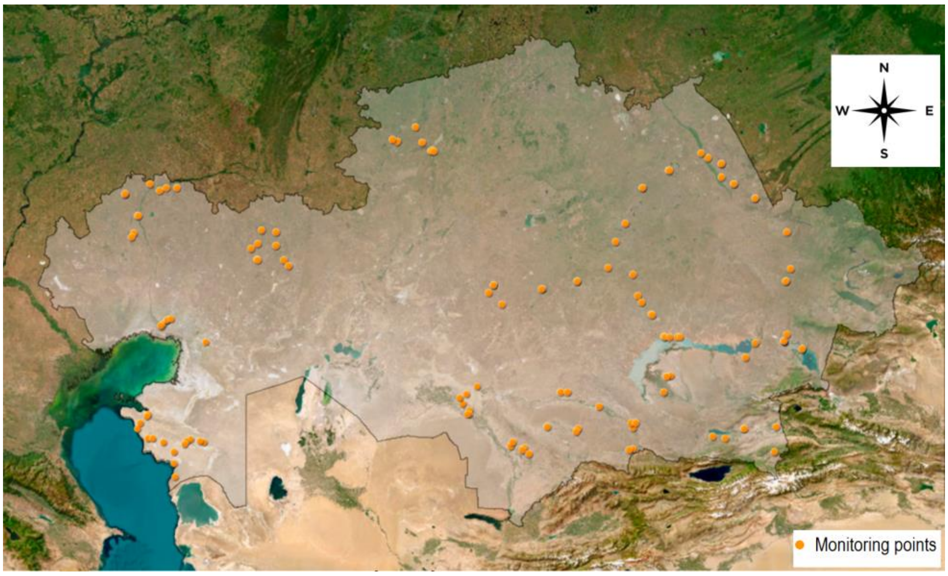

Figure 3. Monitoring points of the study area - Kazakhstan

Laboratory Analysis

Samples of saline and saline soils were collected and analyzed in the laboratory. The analysis focused on determining the humus content, granulometric composition, absorption capacity, amount of absorbed sodium, and cationic-anionic composition of water extracts. Based on the analysis results, specific names of soils were determined, and a final nomenclature list of soils was compiled. Additionally, a soil map, along with its corresponding legend, was prepared as a foundation for future recommendations regarding the reclamation of saline and saline soils (USDA, 2014; 2017; 2022).

Salinity and Waterlogging Determination

The determination of salinity and waterlogging of the soil was carried out using remote sensing data of the Earth. The Geographic Information System (GIS) of the project was created using available soil and geobotanical maps and supplemented with processed satellite images. Medium-resolution satellite data from Landsat 8, Sentinel 2, and Modis TERRA were used for sub-satellite studies, detailed classification of key areas, and verification of ground and space information. Remote sensing data, along with vector data in the form of digitized thematic maps and field survey data recorded using GPS receivers, were utilized. The method of remote sensing of the Earth involved the application of two spectral indices (LDI-NDVI, LDI-TCW) specifically developed to assess soil salinity and waterlogging. These indices considered various parameters, including vegetation cover (NDVI), surface moisture levels (TCW), and the brightness of the satellite image's red channel, where bare soils exhibit the highest brightness properties. Consistent ranges of index values for different satellite data were determined, enabling the identification of areas with saline and waterlogged soil cover in the images, regardless of the acquisition time or year. Seasonal variations in soil cover, such as the drying up of coastal areas, temporary reservoirs, and marshes, were also described using distinct index value ranges.

Methodology for Surface Classification

To determine salinity and waterlogging, special spectral brightness indices were utilized based on the specific wavelengths of the visible and infrared spectra. The primary satellite indices used included NDVI, SAVI, BareSoil Index, Salinity Index, and Top-Soil Grain Size Index. These indices allowed the distinction of various surface types, such as dense, sparse, moderate, bunched, and near-water vegetation, different soil types (clayey, sandy, lkali flat, and solonchaks), battered soils, water, marshes, and shoals.

Results and Discussion

Description of the Soil Profiles

The solonchak profile observed in the study area shows weak differentiation into genetic horizons. It primarily consists of a 10-cm thick humus horizon A, transitional horizons B, and a structureless parent rock. However, a notable feature of this soil profile is the presence of a moist clayey gley horizon with a grayish color. Upon drying, the soil surface and its upper horizon exhibit whitish patches formed by readily soluble salts.

Research Point No.1 - Sasykkol 1: The study site for this research is located adjacent to Sasykkol lake, within the Urzhar district of Abay region in Kazakhstan. The transect was established 200 meters north of the Semey-Almaty highway. The precise coordinates of the transect are N46°40'50.9, E080°35'06.3. The surveyed area is used as pasture land for cattle grazing. The landscape exhibits a greenish aspect. The dominant vegetation community in this area consists of various species of saltwort. These saltwort plants contribute to the formation of saline soils known as solonchaks-solonets. In the following sections, we provide a detailed morphogenetic description of the genetic horizons observed in these saline soils.

The morphogenetic description of the genetic horizons observed in the saline soils of Sasykkol 1 is as follows:

0-10 cm: The topmost layer is light gray in color, dry, loose, and dusty. It has a loamy texture with visible salt deposits on the soil surface. When treated with hydrochloric acid (HCl), it shows boiling, indicating the presence of carbonates. Roots are present in this layer, and the transition to the next horizon is clear.

11-28 cm: This layer is brownish-gray and fresh, with a weakly compacted and medium loam texture. It appears lumpy in structure. Boiling occurs more vigorously when treated with HCl. Small roots are observed, and the transition to the underlying horizon is clear in color.

29-60 cm: The soil in this horizon has a bluish color and is moist. It is weakly compacted and has a clayey texture. The soil structure is unstructured, and brown spots are noted within this layer. Boiling is observed vigorously when treated with HCl. The transition from the previous horizon to this one is gradual.

61-120 cm: This layer is slightly darker than the previous horizon. It is weakly compacted and unstructured, with a moist and clayey texture. Boiling occurs vigorously when treated with HCl. There are few visible spots of carbonates and gypsum within this layer.

These morphogenetic descriptions provide insights into the physical and chemical characteristics of the different soil horizons found in the Sasykkol 1 research site.

Chemical composition analysis of the solonchak - solonetz reveals a relatively low humus content of 0.83%. However, in the lower horizon, this value slightly increases to 1.21% (Table 1). Within the upper 0-10 cm layer, the mobile forms of nitrogen, phosphorus, and potassium exhibit concentrations of 33.6, 83.0, and 750 mg/kg of soil, respectively. As we move deeper into the soil, the nitrogen and potassium content increase to 47.6 and 1000 mg/kg of soil, respectively, while the phosphorus content decreases to 65.0 mg/kg of soil. The concentration of carbonate gradually increases with depth, ranging from 4.61% to 8.72%. It reaches its maximum concentration in the 40-50 cm layer at 11.39%.

Table 1. Chemical Composition of Solonchak-Solonetz Soils

Depth, cm	Humus content, %	Available nutrient contents, mg/kg			Total nitrogen, %	Total carbonates, %
		Nitrogen	Phosphorus	Potassium		
0-10	0.83	33.6	83.0	750	0.098	4.61
10-25	1.21	47.6	65.0	1000	0.098	7.29
25-50	-	-	-	-	-	11.39

The soil being investigated exhibits typical characteristics of saline soils, characterized by the accumulation of neutral salts that result in the formation of salt deposits on the surface. The dominant salt component in the soil composition is the sulfate ion. In the upper layer of the soil, the concentration of sulfate ions reaches its highest level, measuring 52.27 meq 100 g^{-1}. However, as we move deeper into the soil, this concentration sharply decreases to 14.41 meq 100 $g^{-1}$and then gradually increases again to 28.18 meq 100 g^{-1}. Despite these variations, the sulfate ion concentration remains above the threshold of salt toxicity, which is 1.7 meq 100 g^{-1}. In contrast, the chloride ion content increases as we progress deeper into the soil, ranging from 0.95 to 17.1 meq 100 g^{-1} in comparison to the sulfate ion concentration. This elevated chloride ion concentration is known to be toxic to plants. Furthermore, significant amounts of carbonate and bicarbonate ions are present in the salt composition, particularly in the soil's depth of half a meter. The soil composition is characterized by a predominance of sodium as a cation, particularly in the 0-10 cm and 25-50 cm layers, where its content is significantly high at 52.54 and 49.46 meq 100 g-1, respectively. The elevated levels of sodium ions are also reflected in the overall salt content of the soil. In the 0-10 cm and 25-50 cm layers, the salt content reaches its highest levels at 3.871% and 3.436%, respectively. In the other layers, the salt content ranges from 1.3% to 1.5%, classifying them as solonchaks and indicating moderate salinity. Moreover, the soil exhibits remarkably high pH values ranging from 9.5 to 10.46, signifying an extremely alkaline soil environment (Table 2).

Table 2. Ionic Composition of Water Extract from Solonchak-Solonetz

Depth, cm	Total Soluble salt, %	Anions, meq 100 g^{-1}				Cations, meq 100 g^{-1}				pH
		HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	
0-10	3.871	1.20	0.40	0.95	52.27	52.54	0.70	0.69	0.49	9.50
10-25	1.480	2.80	1.68	3.71	14.41	19.75	0.58	0.29	0.29	10.00
25-50	3.436	5.12	4.24	17.1	28.18	49.46	0.55	0.10	0.29	10.36
50-90	1.304	3.84	2.96	14.01	2.30	19.13	0.33	0.20	0.49	10.46

The analysis of absorbed bases data reveals that the proportion of absorbed sodium constitutes a significant portion, ranging from 65.67% to 77.00% of the total cation exchange capacity. This indicates that the soil under investigation is saline. Conversely, the absorbed calcium content is found to be insignificant, accounting for only 8.40% to 11.03% of the total. The soil exhibits a high cation exchange capacity, measuring 29.13 meq 100 g-1 in the 10-25 cm layer. In other soil horizons, the cation exchange capacity is classified as very high (>40 meq 100 g-1) (Table 3).

Table 3. Content of Absorbed Bases in Solonchak-Solonetz

Depth, cm	Cations, meq 100 g^{-1}				CEC, meq 100 g^{-1}	Adsorbed Cations, %			
	Na^+	K^+	Ca^{2+}	Mg^{2+}		Na^+	K^+	Ca^{2+}	Mg^{2+}
0-10	31.68	0.78	4.95	7.43	44.84	70.65	1.74	11.03	16.57
10-25	19.13	1.09	2.97	5.94	29.13	65.67	3.74	10.20	20.40
25-50	31.68	1.21	3.47	4.95	41.31	76.70	2.90	8.40	12.00
50-90	30.84	0.79	3.96	4.46	40.05	77.00	1.97	9.88	11.13

Solonchaks within a half-meter thickness exhibit a granulometric composition primarily consisting of light clay, comprising 52.9% to 58.7% of the soil. This composition is supported by the morphogenetic characteristic descriptions. The mechanical fractions of these solonchaks are predominantly composed of fine sand, with depth-dependent variations ranging from 24.48% to 41.24% (Table 4).

Table 4. Granulometric Composition of Solonchak-Solonets

Depth, cm	Fraction size, mm						
	1,0-0,25	0,25-0,05	0,05-0,01	0,01-0,005	0,005-0,001	<0,001	<0,01
0-10	1.255	41.243	0.810	23.487	19.842	13.363	56.692
10-25	0.795	31.899	8.566	24.883	6.119	27.738	58.740
25-50	0.472	24.482	22.145	7.382	19.684	25.836	52.901
50-90	0.326	35.289	20.375	7.742	15.892	20.375	44.010

Research Point No. 2 - Sasykkol 2. A cutting was established in the Urzhar district of the Abay region, starting from the lowering of the plain of Sasykkol lake, extending 200 meters to the north from the Semey-Almaty highway. The coordinates of the section are N46°43'27.0, E080°33'39.1. The area is characterized by boggy soils covered with reed vegetation and saltwort. The grassland plant community is dominated by reedy vegetation, giving the landscape a dark green appearance. The following are the peculiarities of the morphology of the genetic horizons observed in the studied soils. The morphology of the genetic horizons observed in the studied soils at Research Point No. 2 - Sasykkol 2 are described as follows:

0-15 cm: The horizon appears gray with a greenish tint and has a granular and lumpy structure. It exhibits vigorous boiling when treated with hydrochloric acid (HCl). The presence of roots, both living and decomposed cane roots, can be observed. The soil is dry, loamy, and loose. A noticeable transition is observed.

16-28 cm: This horizon also appears gray with a greenish tint and is fresh in nature. It has a clumpy structure that is weakly compacted. The texture is characterized as light loam. Roots are present, and the soil exhibits vigorous boiling when treated with HCl. A noticeable transition is observed.

29-54 cm: This horizon is characterized by buried humus, giving it a black-brown color. It appears fresh and has a granular-lumpy structure that is weakly compacted. The texture is loamy. Boiling is observed with HCl treatment. Roots, including single larger reed roots, are present. The transition is gradual.

55-100 cm: This horizon is identified as subhumus buried. It is lighter in color compared to the previous horizon and appears fresh. The structure is weakly compacted and clumpy. The texture is loamy. Roots are present, and the boiling response to HCl is weak.

The bog soil profile consists of several distinct horizons that exhibit noticeable variations. The uppermost horizon, known as the organogenic horizon, extends from a depth of 0-15 cm and displays a gray color with a greenish tint. It is characterized by the presence of both living and decomposed reed roots. Similar horizons are also observed at depths of 29-54 cm and 55-100 cm, but they are considered buried horizons compared to the upper organogenic horizon. These buried horizons were once located near the soil surface but became covered by subsequent material accumulation, resulting in their burial.

This interpretation is supported by the distribution of humus content throughout the soil profile, as shown in Table 5. The upper humus horizon has a humus content of 1.38%. The underlying horizons (29-54 cm and 55-100 cm) also contain significant levels of humus, with values of 1.65% and 2.17% respectively.

Table 5. Chemical Composition of Swamp soil

Depth, cm	Humus content, %	Available nutrient contents, mg/kg			Total nitrogen, %	Total carbonates, %
		Nitrogen	Phosphorus	Potassium		
0-15	1.38	33.6	27	400	0.070	3.42
16-28	0.38	16.8	15	160	0.084	2.65
29-54	1.65	-	-	-	-	1.34

The chemical composition of the swamp soil is as follows:

In the upper layer (0-15 cm), the mobile nitrogen content is relatively low, measuring 33.6 mg/kg of soil. Moving deeper into the soil, in the lower layer (16-28 cm), the concentration of mobile nitrogen decreases to 16.8 mg/kg of soil. Regarding mobile phosphorus availability, the soil is considered to have average levels. In the upper horizon, the concentration of mobile phosphorus is 27 mg/kg of soil, while in the lower horizon, it decreases to 15 mg/kg of soil. In terms of carbonate content, the swamp soil exhibits slight levels. In the 0-28 cm layer, the carbonate content ranges from 2.65% to 3.42%. In the deeper layer (29-100 cm), the carbonate content is very slight, ranging from 0.25% to 1.34%. These values indicate the nutrient availability and carbonate content in the studied swamp soil.

The analysis of the ionic composition of the aqueous extract from the marsh soils indicates that they share similarities with solonchak soils. These soils contain soluble salts in concentrations that can potentially hinder plant growth, particularly at depths of 0-15 cm and 29-54 cm. In the latter depth range, the total salt concentrations were measured at 0.789% and 0.440% respectively, as shown in Table 6. The dominant anionic component contributing to the salinity of these soils is sulfate, while the cationic composition reveals a high concentration of sodium. This suggests that the salinity is primarily influenced by the presence of sulfate and sodium ions. Furthermore, the soil solution extracted from these soils displays a strongly alkaline pH, ranging from 8.62 to 8.93. This high alkalinity further contributes to the challenging conditions for plant growth in the marsh soils.

Table 6. Ionic Composition of Water Extract from bog soil

Depth,	Total Soluble	Anions, meq 100 g^{-1}				Cations, meq 100 g^{-1}				pH
cm	salt, %	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	Na^+	K^+	Ca^{2+}	Mg^{2+}	
0-15	0.789	0.68	0.08	1.64	9.10	8.66	0.30	1.57	0.88	8.93
16-28	1.480	0.48	0.00	0.40	1.96	1.07	0.10	0.69	0.98	8.92
29-54	0.192	0.60	0.00	0.95	4.87	4.35	0.11	0.98	0.98	8.62
55-100	1.304	3.84	2.96	14.01	2.30	19.13	0.33	0.20	0.49	8.30

The absorbed bases in the soil column show that calcium is the dominant component, constituting a range of 51.38% to 71.06% of the cation exchange capacity. Following calcium, absorbed magnesium occupies the second position, accounting for a varying share of 26.66% to 44.53% in the soil column, as indicated in Table 7. The substantial presence of magnesium suggests the potential solonetization of the soil, indicating the likelihood of solonetz formation.

Table 7. Content of Absorbed Bases in bog soil

Depth,	Cations, meq 100 g^{-1}				CEC,	Adsorbed Cations, %			
cm	Na^+	K^+	Ca^{2+}	Mg^{2+}	meq 100 g^{-1}	Na^+	K^+	Ca^{2+}	Mg^{2+}
0-15	0.01	0.21	13.37	6.93	20.52	0.04	1.02	65.15	33.77
16-28	0.38	0.21	7.43	6.44	14.46	2.62	1.45	51.38	44.53
29-54	0.44	0.19	19.80	7.43	27.86	1.58	0.68	71.06	26.66
55-100	0.92	0.21	14.85	6.44	22.42	4.10	0.93	66.23	28.72

The granulometric composition of bog soils displays heterogeneity across their profiles. In the depths of 0-10 cm and 35-45 cm, the predominant soil composition is light loam, with a physical clay content ranging from 21.5% to 22.4%. However, between these layers, there exists a distinct sandy horizon (15-25 cm) characterized by a lower physical clay content of 9.26%. It is likely that this sandy horizon originated from sediment deposited by a sandy lake and has gradually been buried over time, as indicated in Table 8.

Table 8. Granulometric Composition of bog soil

Depth,	Fraction size, mm						
cm	1,0-0,25	0,25-0,05	0,05-0,01	0,01-0,005	0,005-0,001	<0,001	<0,01
0-15	1.441	66.903	10.146	3.653	10.552	7.305	21.510
16-28	0.624	85.688	4.428	1.208	4.428	3.623	9.259
29-54	1.610	58.863	17.115	8.965	2.037	11.410	22.412
55-100	0.630	64.026	1.625	4.063	29.250	0.406	33.719

The surveys conducted between 2021 and 2022 in various regions of Kazakhstan, including Almaty, Zhambyl, Turkestan, Karaganda, Ulytau, Pavlodar, Abay, and East Kazakhstan, have yielded a digital information database on saline and waterlogged soils. These regions encompass different zones such as the desert, foothill semi-desert (vertical), semi-desert (latitudinal), and dry-steppe zones. The database incorporates data from both satellite and ground surveys, providing comprehensive information on the characteristics and distribution of saline and waterlogged soils in these areas. Using ArcGIS software, an interactive online map has been developed to visualize the collected data. This map allows users to explore the chemical and granulometric compositions of the 66 monitoring points located across the eight oblasts of Kazakhstan. ArcGIS is a powerful system that enables the creation and analysis of online maps and related geographical information (https://arcg.is/DqXba). The findings obtained from previous studies conducted on saline and waterlogged soils in different regions of Kazakhstan (Laiskhanov et al., 2016; Issanova et al., 2017; Funakawa et al., 2020; Smanov et al., 2023) exhibit significant similarities with the results obtained in this study as well.

By utilizing this interactive map, researchers, land managers, and policymakers can access valuable insights into the properties and distribution of saline and waterlogged soils in the surveyed regions. This information can contribute to informed decision-making, land use planning, and the development of strategies for sustainable soil management in Kazakhstan.

Conclusion

Based on the final findings of this study, the following points can be concluded:

- The study reveals that saline soils cover an extensive area of 35,817.4 thousand hectares in the Republic of Kazakhstan, accounting for approximately 16.7% of the total agricultural land area, which is 214,348.8 thousand hectares. Additionally, waterlogged soils occupy 1,083.4 thousand hectares, representing 0.5% of the agricultural land area.
- The assessment of saline and waterlogged soils encompassed various zones in the republic, including the desert, foothill semi-desert (vertical), semi-desert (latitudinal), and dry-steppe areas. Fieldwork was conducted at 66 designated base points, where thorough descriptions of the genetic horizons of saline and waterlogged soils were made, providing a comprehensive understanding of their nomenclature.
- The collected data on the condition of saline and waterlogged soils in different zones of Kazakhstan allows for a comprehensive assessment of their status in specific areas. This assessment contributes to the development of technologies aimed at restoring soil fertility and implementing appropriate management practices.
- The information database compiled as part of this study includes crucial indicators such as the nomenclature of soils, profile structure morphology, chemical composition (NPK, carbonate content), ionic composition of water extracts, salt content, composition and quantity of absorbed cations, and granulometric composition of soils. This comprehensive database provides valuable insights into the characteristics and properties of saline and waterlogged soils in the desert, foothill semi-desert (vertical), semi-desert (latitudinal), and dry-steppe zones of Kazakhstan.
- Field and camera studies conducted on the soil cover of various zones in the Republic highlight the poor fertility of saline soils, which contain high concentrations of water-soluble salts that are detrimental to plant growth. These salts are present throughout the soil profile, exceeding an average concentration of 1.0%. Sodium chlorides and sulfates are the predominant salt compositions found in most cases. Waterlogged soils, characterized by close proximity to the groundwater and reductive processes, exhibit distinct features such as gleyed horizons with iron oxide rusts and a greenish-grayish color. These soils generally have low fertility, but meadow areas may exhibit differences, showing a sufficient supply of humus compared to peat or turf horizons.

Acknowledgement

The research work presented in this article was conducted as part of the implementation of the program-targeted funding for the scientific and technical program IRN:BR10764865, titled "Scientific and Technological Support of Conservation and Reproduction of Fertility of Agricultural Lands." The specific task number 3 of the program involved the creation of a comprehensive database of marshy and saline lands of Kazakhstan for the period of 2021-2023. We would like to express our gratitude to the funding agency for their support in carrying out this important research.

References

Dwivedi, R.S., 2001. Soil resources mapping: A remote sensing perspective. *Remote Sensing Reviews* 20(2): 89-122.

Dwivedi, R.S., Sreenivas, K., 1998a. Delineation of salt-affected soils and waterlogged areas in the Indo-Gangetic plains using IRS-1C LISS-III data. *International Journal of Remote Sensing* 19(14): 2739-2751.

Dwivedi, R.S., Sreenivas, K., 1998b. Image transforms as a tool for the study of soil salinity and alkalinity dynamics. *International Journal of Remote Sensing* 19(4): 605-619.

Funakawa, S., Suzuki, R., Karbozova, E., Kosaki, T., Ishida, N., 2000. Salt-affected soils under rice-based irrigation agriculture in Southern Kazakhstan. *Geoderma* 97(1-2): 61–85.

Issanova, G.T., Abuduwaili, J., Mamutov, Z.U. Kaldybaev, A.A., Saparov, G.A., Bazarbaeva, T.A., 2017. Saline soils and identification of salt accumulation provinces in Kazakhstan. *Arid Ecosystems* 7: 243–250.

Kussainova, M., Spaeth, K., Zhaparkulova, E., 2020. Efficiency of using the rangeland hydrology and erosion model for assessing the degradation of pastures and forage lands in Aydarly, Kazakhstan. *Eurasian Journal of Soil Science* 9(2): 186 - 193.

Laiskhanov, S.U., Otarov, A., Savin, I.Y., Tanirbergenov, S.I., Mamutov, Z.U., Duisekov, S.N., Zhogolev, A., 2016. Dynamics of soil salinity in irrigation areas in South Kazakhstan. *Polish Journal of Environmental Studies* 25(6): 2469–2476.

Liu, W., Ma, L., Smanov, Z., Samarkhanov, K., Abuduwaili, J., 2022. Clarifying soil texture and salinity using local spatial statistics (Getis-Ord Gi* and Moran's I) in Kazakh–Uzbekistan Border Area, Central Asia. *Agronomy* 12: 332.

Ma, L., Abuduwaili, J., Smanov, Z., Ge, Y., Samarkhanov, K., Saparov, G., Issanova, G., 2019 Spatial and vertical variations and heavy metal enrichments in irrigated soils of the Syr Darya River watershed, Aral Sea Basin, Kazakhstan. *International Journal of Environmental Research and Public Health* 16(22):4398.

Mulders, M.A., Girard, M.C., 1993. Remote sensing of soils in warm arid and semi-arid lands. *Remote Sensing Reviews* 7(3-4): 341-363.

Murphy, J., 1986. LANDSAT MSS sensor and data preprocessing, *Remote Sensing Reviews* 2(1): 27-60.

Otarov, A., 2014. Concentration of heavy metals in irrigated soils in Southern Kazakhstan. In: Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Mueller, L., Saparov, A., Lischeid, G. (Eds.). Environmental Science and Engineering. Springer, Cham. pp 641–652.

Pachikin, K., Erokhina, O., Funakawa, S., 2014. Soils of Kazakhstan, their distribution and mapping. In: Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Mueller, L., Saparov, A., Lischeid, G. (Eds.). Environmental Science and Engineering. Springer, Cham. pp 519–533.

Peel, M.C., Finlayson, B.L., McMahon, T.A., 2007. Updated world map of the Koppen-Geiger Climate classification. *Hydrology and Earth System Sciences* 11(5): 1633–1644.

Pilifosova, O.V., Eserkepova, I.B., Dolgih, S.A., 1997. Regional climate change scenarios under global warming in Kazakhstan. *Climatic Change* 36: 23–40.

Salnikov, V., Turulina, G., Polyakova, S., Petrova, Y., Skakova, A., 2015 Climate change in Kazakhstan during the past 70 years. *Quaternary International* 358: 77–82.

Saparov, A., 2014. Soil resources of the Republic of Kazakhstan: Current status, problems and solutions. In: Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Mueller, L., Saparov, A., Lischeid, G. (Eds.). Environmental Science and Engineering. Springer, Cham. pp 61–73.

Singh, A.N., Dwivedi, R.S., 1989. Delineation of salt-affected soils through digital analysis of Landsat MSS data. *International Journal of Remote Sensing* 10(1): 83-92.

Smanov, Z.M. Laiskhanov, S.U., Poshanov, M.N., Abikbayev, Y.R., Duisekov, S.N., Tulegenov, Y.A., 2023. Mapping of cornfield soil salinity in arid and semi-arid regions. *Journal of Ecological Engineering* 24(1): 146–158.

Suska-Malawska, M., Sulwiński, M., Wilk, M., Otarov, A., Metrak, M., 2019. Potential eolian dust contribution to accumulation of selected heavy metals and rare earth elements in the aboveground biomass of Tamarix spp. from saline soils in Kazakhstan. *Environmental Monitoring and Assessment* 191: 57.

Suska-Malawska, M., Vyrakhamanova, A., Ibraeva, M., Poshanov, M., Sulwiński, M., Toderich, K., Metrak, M., 2022. Spatial and in-depth distribution of soil salinity and heavy metals (Pb, Zn, Cd, Ni, Cu) in arable irrigated soils in Southern Kazakhstan. *Agronomy* 12: 1207.

USDA, 2012. Field Book for Describing and Sampling Soils. Version 3.0. National Soil Survey Center, Natural Resources Conservation Service, United States Department of Agriculture (USDA). 298p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2022-09/field-book.pdf

USDA, 2014. Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2. United States Department of Agriculture (USDA), Natural Resources Conservation Service, Kellogg Soil Survey Laboratory. 457p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2023-01/SSIR51.pdf

USDA, 2015. Illustrated Guide to Soil Taxonomy. Version 2.0. United States Department of Agriculture (USDA), Natural Resources Conservation Service. 680p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2022-06/Illustrated_Guide_to_Soil_Taxonomy.pdf

USDA, 2017. Soil Survey Manual. United States Department of Agriculture Handbook No. 18. 603p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2022-09/The-Soil-Survey-Manual.pdf

USDA, 2022. Kellogg Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No. 42, Version 6.0. Part 1: Current Methods. Kellogg Soil Survey Laboratory, National Soil Survey Center, Natural Resources Conservation Service, United States Department of Agriculture (USDA). 796p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2022-10/SSIR42-v6-pt1.pdf

USDA, 2022. Keys to Soil Taxonomy. United States Department of Agriculture (USDA), Natural Resources Conservation Service, USA. 402p. Available at [Access date: 12.11.2022]: https://www.nrcs.usda.gov/sites/default/files/2022-09/Keys-to-Soil-Taxonomy.pdf

Yertayeva, Z. , Kızılkaya, R., Kaldybayev, S., Seitkali, N., Abdraimova, N., Zhamangarayeva, A., 2019. Changes in biological soil quality indicators under saline soil condition after amelioration with alfalfa (Medicago sativa L.) cultivation in meadow Solonchak. *Eurasian Journal of Soil Science* 8 (3): 189-195.

Zhang, W., Ma, L., Abuduwaili, J., Ge, Y., Issanova, G., Saparov, G., 2019. Hydrochemical characteristics and irrigation suitability of surface water in the Syr Darya River, Kazakhstan. *Environmental Monitoring and Assessment* 191: 572.