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Mapping of Cornfield Soil Salinity in Arid and Semi-Arid Regions

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ABSTRACT

Soil salinization and their annual increase in volume is not only one of the main problems of arid and subarid regions, but it is becoming global. Studying the problem of salinization and its spatial distribution using operational remote sensing methods is very important for Kazakhstan, where almost half of the agricultural land is exposed to salinization, but it is at the initial stage of development in the use of space technologies of research. The main goal of this study is to conduct a field study of soil salinity in corn fields, one of the most common crops in the arid region of the country, located in the Shaulder irrigated massif, using space-based methods, and to create algorithms for compiling a salinity map based on remote sensing data. For this purpose, firstly, using Sentinel-2 images, the method of separating corn from other dominant crops in the region by creating NDVI dynamics covering all phases of growth of agricultural crops was shown. Then, a regression analysis was performed on soil and vegetation indices calculated using satellite images and data on soil salinity obtained through field studies. As a result of the analysis, the main predictor of deciphering salinized soils was determined. By dividing the predictive image into quartiles, contours of salinized soils were determined and a soil salinity map was created. With the help of the soil salinity map, it was found that, non-saline soils – 2912.2 ha; slightly saline soils – 3288.4 ha, moderately saline soils – 2615.2 ha, and strongly saline soils – 1284.3 ha in the study area.

Keywords: soil salinization; satellite images; vegetation indices; regression analysis; mapping of soil salinity.

INTRODUCTION

The most common form and a major process of soil degradation in arid and semi-arid areas is soil salinization, which has social, and economic consequences due to its adverse effects on environmental and land productivity [Shrivastava and Kumar, 2015; Ding and Yu, 2014]. Soil salinization can occur naturally or from poor management practices due to human influence, and its spatial variability depends on several factors: soil characteristics, irrigation and groundwater quality, local terrain, and harsh climatic conditions [Wu et al., 2008; Singh, 2021; Akramkhanov et al., 2011]. It has been repeatedly documented that this process is becoming a serious problem in different regions of the world including Republic of Kazakhstan, because of enhanced primarly and secondary soil salinization in agriculture in irrigated areas. And according to estimated that 43% of the total agricultural land area of the country is affected by salinity [Shahid et al., 2021; Tokbergenova et al., 2018].

In the Republic of Kazakhstan most of the irrigated lands is located in the southern part, in the large deltas and ancient alluvial plains of the Syr Darya river basin (SRB). With the rapidly population density growth has increased anthropogenic impact, and a combination of climatic features leads to increased salinity and pollution of irrigated soils in this region, resulting soil salinization has become the main restraint for a crop production and regional ecosystems [Suska-Malawska et al., 2022]. The Shaulder irrigated massif in the middle reaches of the Syr Darya river, where irrigated lands are most widely used for cornfields, the degree of soil salinity is different and it has been determined that they increase with depth [Laiskhanov et al., 2022]. In determining of the soil salinity in the cornfields, first carried out the division of cornfields, for this, vegetation phenological dynamics were characterized using a time series of vegetation indices derived obtained from satellite data, mainly the Normalized Difference Vegetation Index (NDVI), as a result, the difference in the growth phase of corn and other crops was determined [Jin and Xu, 2013; Segarra et al., 2020]. The soil reclamation hypothesis manifested a close relationship between the concentration level of salts amassed within the soil and the condition of the current crop [Laiskhanov et al., 2022]. Based on local research, although there is information about the development and main sources of irrigation soil salinity, there is lacking a quantifying the magnitude and mapping its spatial distributions. The use and development of modern methods of digital mapping of soils is becoming increasingly important in soil study [Duisekov et al., 2015].

Mapping of soil salinity distribution are even more of a challenge in the case of the terrain of agrolandsapes and crop growth phase heterogeneity, such as the timing of sowing, irrigation and post planting tillage in addition to natural factors, which need to consider the heterogeneity of land development by farmers [Zhang et al., 2020]. The absence of studies in the study area based on these conditions leads to the complexity, when it comes to mapping the distribution of irrigation soil salinity and assessment [Ivushkin et al., 2019; Gebremeskel et al., 2018]. Large scales mapping spatial, temporal, and depth variability of soil salinity is one of the fundamental steps in salinity management at irrigation in arid and semi-arid areas [Li et al., 2020]. Usually, soil salinity monitoring is often carried out with intensive sampling from observation points and an appropriate interpolation method to estimate salinity values for unsampled locations [Laiskhanov et al., 2021].

In world practice, the use of the space method for studying soil salinity is currently one of the most important new areas of soil science. And it is fundamentally different from its analogue - the ground-based method of studying soil salinity by its method of conducting (Remote Sensing), it allows effective use of the cost and time spent on field research, as well as increasing the reliability and completeness of the information obtained by optimizing the surveying period [Laiskhanov et al., 2021]. A review of recent scientific publications shows that the problem of soil salinity over large areas has not yet been solved [Masoud and Koike, 2006; Ajay, 2021]. There are a large number of publications devoted to the study of the possibilities of deciphering soil salinity from satellite data, which are considered as one of the main sources of information for the analysis of soil salinity [Abbas et al., 2013; Ghazali, 2020; Duisekov et al., 2015].

The main feature of remote sensing is that it allows to assess the salinity of irrigated soils over large areas using satellite imagery, which is impractical for terrestrial surveys [Abbas et al., 2013]. However, knowledge of characterizing and monitoring soil primary and secondary salinity, as well as the correlation between of the soil quality and index values of satellite imagery involves the collection of soil samples for chemical analyses and electrical conductivity (EC) under field work [Laiskhanov et al., 2021]. Most researchers in recent years have been actively using Sentinel 2A and 2B satellite data for such studies, which can provide higher resolution up to 10 m [Segarra et al., 2020; Taghadosi et al., 2019; Laiskhanov et al., 2022].

Analytical determination of characteristics such as soil salinity is estimated the concentration, that predominantly consists of the cations Na^+, K^+, Mg^{2+}, and Ca^+ and the anions Cl^-, HCO_3^{2-}, and SO_4^{2-}. These have been accompanied by effects of sodium on soil properties, the threshold of toxicity of specific ions and indices the Sodium Adsorption Ratio (SAR) [Rhoades et al., 1999; Allison, 1954].

The review of scientific publications showed that at the moment there is no unified methodology for monitoring soil salinity in the world. And in Kazakhstan, this direction is at an early stage and not a single operational system for remote monitoring of soil salinity has been identified. Studies of soil salinity, their mapping and monitoring are traditionally carried out on the basis of field surveys [Malawska et al., 2022]. These methods are time-consuming, costly and do not allow real-time monitoring of large areas.

Therefore, we consider that in connection with the development of the space method of soil research (RS) and geographic information systems (GIS), monitoring of soil salinity in irrigated lands can be established at a new modern digital level. This will provide an opportunity to obtain operational information for making management decisions, such as carrying out land reclamation activities, reconstructing irrigation systems, diversifying crops, choosing methods for sustainable management of irrigated lands, and others.

STUDY AREA

The Shaulder irrigation massif is located in the South part of Kazakhstan (right-bank part of the middle reaches of the river). The actual study area is bounded between 68° 01' 17" E ~ 68° 30' 41 " E longitude, and 42° 41' 06" N ~ 42° 54' 06 " N latitude (Figure 1).

This massif is also known as the ancient Otrar oasis located on the Silk Road, and agriculture has been developed here since ancient times. The region is characterized by a sharply continental climate, arid. In summer low clouds, scanty atmospheric precipitation, rapid heating of the air during the day, the absolute maximum can reach +40 °C daytime, about +20 °C at night, and minimum temperature in winter dropped to -25 °C, and rapid cooling at night, large temperature drops, little snow, deep freezing of the ground. The rivers usually freeze in early December, the ice stays until March and often in the spring, the Syr Darya and Arys overflow their banks, flooding a large area. The relief of the territory is represented by a slightly wavy horizontal surface. Vegetation cover is characterized by poor and monotonous flora [OTYRAR, 2005].

The corn for grain, alfalfa are leading crops cultivated in irrigated area, and cotton has been practically uncultivated in recent years [DBN-SASPRRKTR, 2020]. The main sources of irrigation water are the Syr Darya, Arys and partly the ends of the Shayan and Bugun rivers. The irrigation system consists of a main canal with a head water intake from the Arys River and smaller canals that take water from the Syr Darya river using pumping units. The irrigation system is represented by open-type irrigators of various orders, laid in natural soil [OTYRAR, 2005]. The soil cover corresponds to the subzones of light and ordinary grey soils and grey-brown desert soils [Pachikin et al., 2014].

MATERIALS AND METHODS

We selected Shaulder irrigation massif as the study area due to its varying degrees of soil salinization and the transition to homogeneous

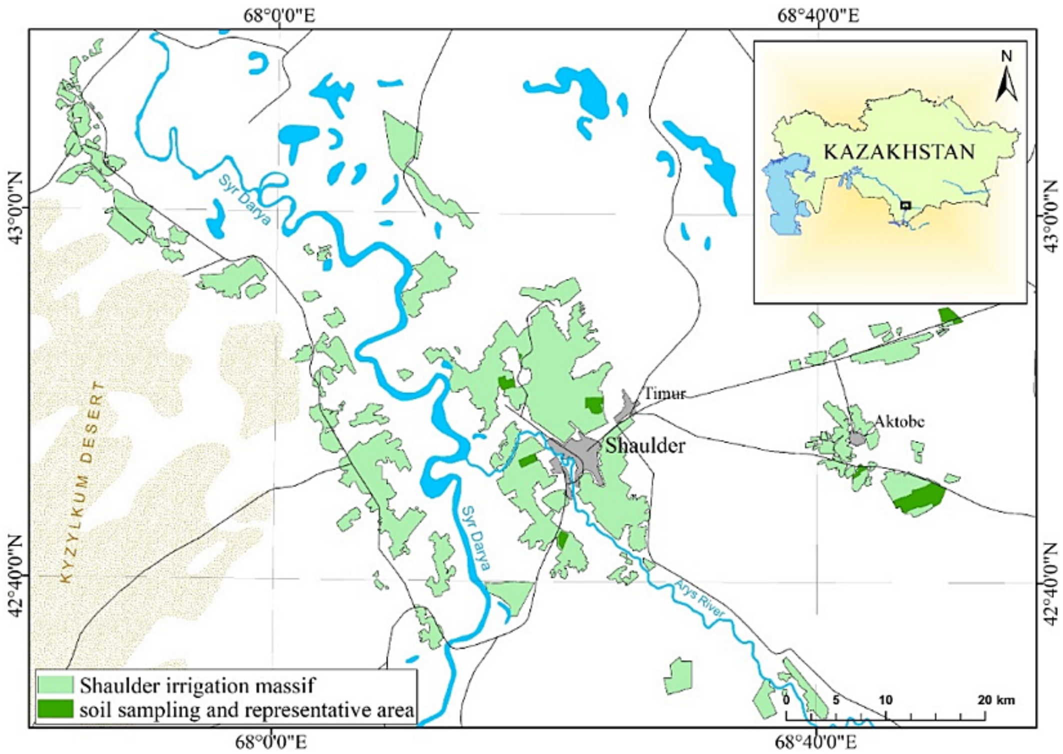

Figure 1. Location of study area and distribution of sampling sites

agricultural crops in recent years. The times of corn growth phases in 2021 were chosen as study period, because excess soil salinity causes poor and uneven growth of crops also poor yields on the degree of salinity, providing an interesting test ground for assessing and soil salinity mapping under one type crop. To date, there is no publicly available spatial information on the distribution of the soil salinity degree in the Shaulder irrigation massif. To gain insights into the evaluation and importance of remote sensing data products used to estimate soil salinity, we compared them with ground surveys data.

The data and research methods

The research was carried out using both traditional ground-based (to a lesser extent) and high-tech methods of satellite and geoinformation technologies. Research work using these methods can be divided into 5 stages:

1. Field soil observation was made during corn growth phases in May, July and September 2021, and during monitoring, electrical conductivity and soil temperature were collected from 245 sampling points in May, July and September, and in order to quality mapping and validate the soil salinity situation in the Shaulder irrigation massif, additional 50 soil samples were collected from selected points in May according to the classic instructions [Varennikov et al., 1995]. The acquisition of these required soil data was carried out in accordance with the stages of the growing phase of corn and for this we used a recording route as shown in Figure 2. Our current study in the field, Garmin 64s hand-held global positioning system (GPS) was used to record longitude and latitude, the T-1 is a widely used electrical conductivity and soil temperature instrument for soil sensing. During the measurement using Progress T-1 it is allows to the 0–100 cm depth, and measuring parameters from the observation points are obtained by layers of 0–20 cm, 20–50 cm and 50–100 cm. And soil samples were taken with a soil auger for chemical analysis from a depth 0–20 cm, at each point of the topsoil.
2. Chemical analysis of soil samples were carried out in the laboratory of U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry in accordance with standard analytical procedures recommended by the Ministry of Environment of Kazakhstan. Salinity indicator parameters, including EC, contents of Na^+, K^+, Mg^{2+}, and Ca^+ cations, and of Cl^-, HCO_3^{2-}, and SO_4^{2-} anions for collected soil samples, were analyzed in the laboratory [Aleksandrova and

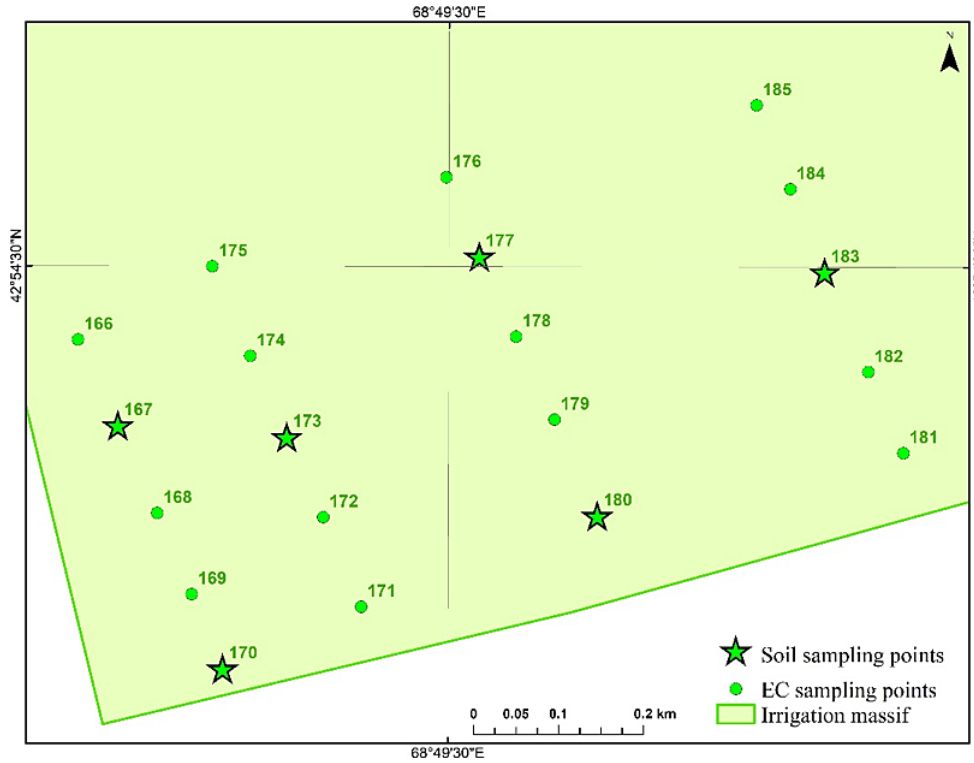

Figure 2. The sampling points in observation site

Naidenova, 1976]. Measurements of these parameters can sufficiently indicate the salinity of irrigated agriculture. The laboratory analysis procedures were applied to analyses these parameters. The SAR was calculated by computing Na^{+}, Ca^{2+} and Mg^{2+} concentrations expressed in mEq/L, and using the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+} + Ma^{2+})}} \quad (1)$$

3. Regression analysis was carried out in the Statistica 12 software environment. The vegetation indices describing the state of vegetation and soil indices were used as predictors. Regression analysis was carried out separately for each studied soil layer (0–20 cm, 20–50 cm, 50–100 cm). The review found that methods such as partial least squares regression (among regression methods) and principal component analysis give the best results and high accuracy. It should be noted that when using regression approaches, it is also recommended to use the likelihood ratio test, the Lagrange multiplier, and the adjusted Akaike information criterion [Darwish et al., 2007; Shrestha and Farshad, 2009].
4. There were types of crops to divide cornfields using NDVI time series values using remote sensing...It should be noted that the interpretation of saline soils can be carried out by the nature of the open soil surface for surface horizons, as well as by the nature of the image of vegetation for salinization of the root layer of soils. At the same time, the decoding methods used may be the same, but when deciphering soil salinity by the nature of the vegetation image, it becomes necessary to include a block for identifying the type of cultivated crops in each specific growing season in the satellite monitoring system. In addition, it is necessary to pay attention to the fact that hyperspectral and radar satellite data can also be used to study saline soils [Weng et al., 2008]. However, methods for their use have not yet been sufficiently developed.

Table 1. Time of Sentinel-2 satellite images used in the analysis

No.	The name of the satellites	Acquisition date	Deciphering the types of agricultural crops	Regression analysis	Soil salinity mapping
1	Sentinel-2A	2021/03/05	+		
2	Sentinel-2A	2021/04/14	+		
3	Sentinel-2B	2021/04/19	+		
4	Sentinel-2B	2021/04/29	+		
5	Sentinel-2A	2021/05/14	+		
6	Sentinel-2B	2021/05/19	+		
7	Sentinel-2A	2021/05/24	+		
8	Sentinel-2B	2021/05/29	+		
9	Sentinel-2A	2021/06/03	+	+	
10	Sentinel-2B	2021/06/08	+	+	
11	Sentinel-2A	2021/06/13	+	+	
12	Sentinel-2B	2021/06/18	+	+	
13	Sentinel-2A	2021/06/23	+	+	
14	Sentinel-2B	2021/06/28	+	+	
15	Sentinel-2A	2021/07/03	+	+	
16	Sentinel-2B	2021/07/08	+	+	
17	Sentinel-2B	2021/07/18	+	+	
18	Sentinel-2A	2021/07/23	+	+	
19	Sentinel-2B	2021/07/28	+	+	+
20	Sentinel-2B	2021/08/07	+	+	
21	Sentinel-2A	2021/08/22	+	+	
22	Sentinel-2B	2021/08/27	+	+	
23	Sentinel-2A	2021/09/01	+	+	
24	Sentinel-2B	2021/09/06	+	+	
25	Sentinel-2A	2021/09/11	+	+	

5. Mapping of cornfield were carried out in the ArcGIS 10.4 software package based on specially developed original algorithms. To interpret satellite images, we used a regression analysis of the relationship between the soil salinization (electrical conductivity and ion-salt composition of soils and satellite imagery data.

Sentinel-2 satellite images taken during the growing season of corn were used in the deciphering of agricultural crops, regression analysis and soil salinity mapping (Table 1).

The regression analysis was performed using satellite data (vegetation soil indices describing the state of vegetation and soil indices) and field research data (electronegativity of the soil and the result of chemical analysis of the soil) synchronously in space and time.

RESULTS AND DISCUSSION

At the first stage of the work, the structure was developed and the soil information system of the object of study with the corresponding spatially coordinated database was created. At the second stage, work was continued to replenish this database of soil salinity. Due to the rather large area of the irrigation array and the high variation of natural conditions, using the references of previous research works and archival satellite images for ground and satellite surveys, contrasting soil salinity and land under different management test sub-satellite territories were selected (Figure 1 - The layout of the sub-satellite territories is indicated by a representative area at the study object).

Separation of crop type to identify saline soils in corn fields

In this study, based on the phenological growth and development of corn crops at different degrees of salinity, it was used to determine and evaluate the spatial distribution of salinity in irrigated soils based on remote sensing data. For this, first, using the values of NDVI time series, the differences in the phase periods of crop types were determined and abandonedlands, corn and alfalfa fields are separated (Figure 3a).

As a result, significant differences of indicators were observed in the biomass of the above-mentioned three crop field from the beginning of the vegetation period. According to the values of NDVI time series, the biomass of alfalfa field starts from March and reaches a high value until September, and it is slightly decreased during haying (Figure 3b), and due to the soil tillage before sowing in the corn fields, the NDVI value in spring showed a completely bare soil value and from June the NDVI value increases steadily until the end of July (Figure 3c), reaches maturity in August and September, and the NDVI value continues to decrease until the corn is harvested.

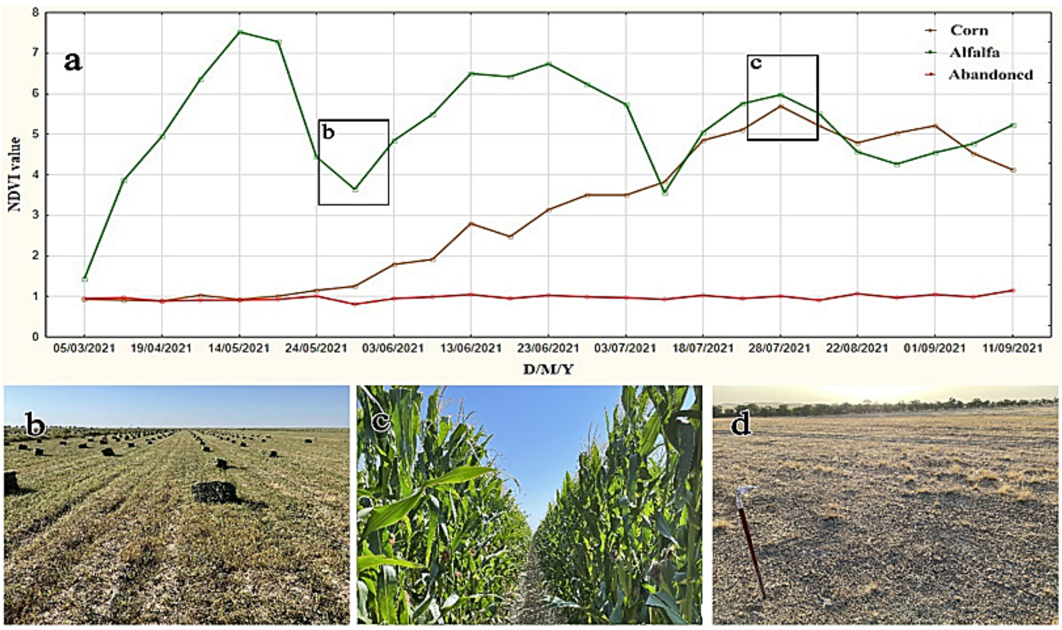

Figure 3. NDVI time series of crop types (a), photo of after haying (b), high vegetation period of corn (c), open soil of abandoned areas (d)

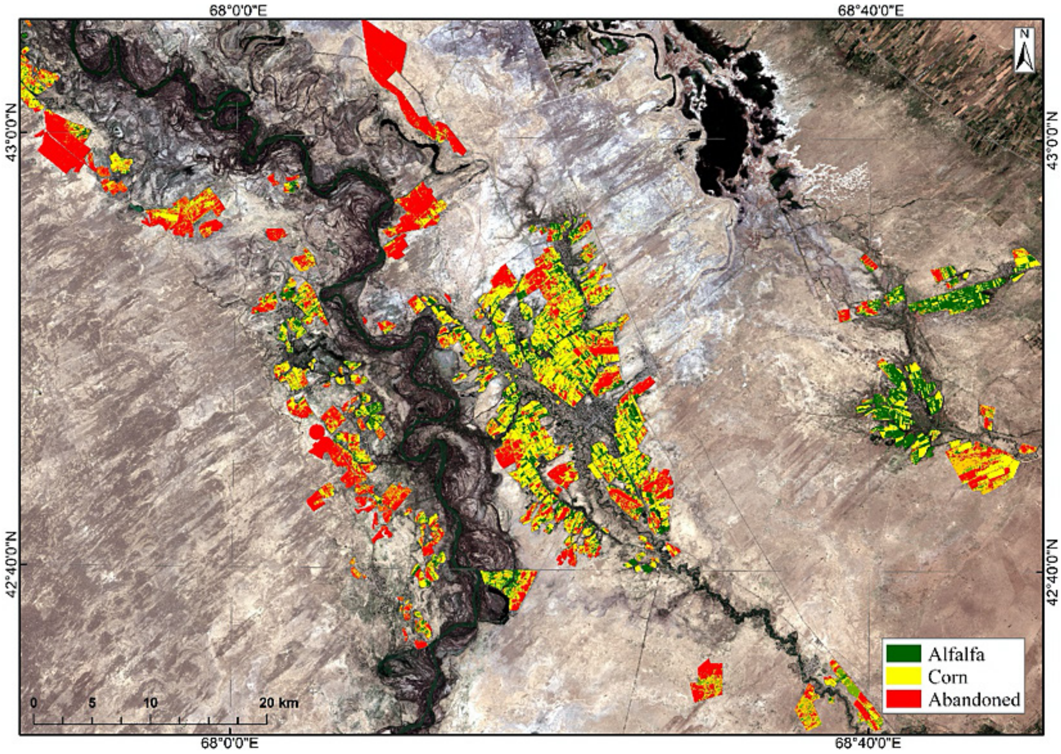

Figure 4. Map of crop types of the Shaulder irrigation massif

Abandoned areas are formed mainly due to high degree of soil degradation, and the main reason is that anionic salts exceed the toxicity threshold. As you can see in Figure 3a and 3d, the biomass of the plant is not visible.

Land cover change refers to changes in certain land characteristics, such as vegetation type and soil properties [Lambin, 1996]. In our example, after determining the vegetation periods of the crop types, we distinguished abandoned areas, corn and alfalfa fields by time change of vegetation cover (Figure 4).

According to statistics, Shaulder irrigation massif is 45,000 ha, and as a result of remote sensing, 10,100 ha of corn, 6,600 ha of alfalfa and 13,000 ha of abandoned land were found in the irrigated area. The total area of these three types of fields was 29,700 ha, and it was not possible to distinguish whether the remaining 15,300 ha belonged to horticulture or other types of crops. And we conducted our research on the aforementioned 10,100 ha cornfield.

Seasonal characteristics of soil salinity

The high concentration of salts in the arable layer of the soil increases due to harsh climatic conditions and other natural factors, as well as the inefficient and improper human use of land. And this process has a negative influence on the soil quality, which ultimately leads to limited growth and yield of agricultural crops, because corn takes the salts accumulation in the root zone as nutrients [Mmolawa and Or, 2000; Bernstein, 1974]. Accumulation of salts in the soil of our irrigated massif may occur due to high evaporation during periods of insufficient irrigation, as well after prolonged cultivation. However, the uneven distribution of salts in the soil is due to the different quality of irrigation water. The main sources of irrigation water are the Syr Darya, Arys and partly the ends of the Bugun rivers and they have different water quality [Zhang et al., 2019].

Statistical analysis of the results (Table 2) reveals that the maximum deviation of the EC value in June varies between 0.65 mS/cm to 22.72 mS/cm in the layers of 50–100 cm. And a coefficient of variation of 106 in the layers of 20–50 cm. In July, in all layers, the value of the EC is higher than in June, and again the lower layer shows a high deviation, varies between 0.39 mS/cm to 38.57 mS/cm, and with a coefficient of variation of 107, and the SAR value varies from 0.24 to 2.25 with a coefficient of variation of 60 in the arable layers. In September, the EC value varies between 0.88 mS/cm to 36.34 mS/cm with a coefficient of variation of 113 in the 0–20 cm layers. The coefficient of variation (CV) can portray the degree of dispersion of random variables by classifying them from weak to strong variability [Alharbi, 2019]. There is a strong variation in this study area at all depths and seasonal conditions. The SAR value is moderate and the Sum of salts value shows strong variability, while the Standard Deviation and CV have moderate to strong variability with season and depth, indicating that there are more differences in the location of the sampling points.

As a result of the analysis of samples obtained during the field observation, it was shown that the percentage of salinized soils varies over time and depth (Table 3). The percentage of non-saline soils is 74.57% in the arable layer of the soil in June, it decreases to 28.66% in July, and in September the amount of non-saline soils increases somewhat and makes 48.34%. And the share of slightly and moderately salinized soils increases by July and September, approximately 20.53%, 15.89% and reaches 38.85%, 19.75%. Strongly saline and very strongly saline soil has a high indicator in the middle and lower layers in all periods, and the volume of soil salinization increases several times from spring to autumn. In the 20–50 cm soil layer, very saline soil amounted to 5.78% in June, 17.20% in July, and 24.10% in September. And the amount of extremely saline soil in the arable and lowest soil layer in June ranges from 0% to 1.73%, in July it exceeds 5.73%, 7.64% and 13.38%, and in September reached 16% in the middle layer and 23% in the lower layer. In addition, this analysis shows that even when using the same soil sampling points, significant differences in salinity were observed due to consumption of irrigation water of different quality and crop area placement in heterogeneous Irrigation systems. The decrease in the volume of non-saline soils in the arable layer of the soil from spring to autumn and the increase in the 20–50 cm and 50–100 cm

Table 2. Average values and statistics of soil properties during seasonal sampling periods: June, July and September

Month	Parameter	EC (mS/sm)			Sum of salts (%)	SAR
	Depth	0–20 cm	20–50 cm	50–100 cm	0–20 cm	0–20 cm
June	Mean	1.85	2.92	4.16	-	-
	Max	10.70	16.94	22.72	-	-
	Min	0.35	0.39	0.65	-	-
	St.dev	1.80	3.09	3.66	-	-
	CV (%)	0.97	106	88	-	-
	Skewness	2.59	2.57	2.16	-	-
	Kurtosis	7.42	7.00	5.53	-	-
	Variance	3.22	9.52	13.43	-	-
	Median	1.18	1.70	3.14	-	-
July	Mean	4.57	6.14	7.98	0.23	0.79
	Max	34.98	35.24	38.57	1.32	2.25
	Min	0.57	0.37	0.39	0.07	0.24
	St.dev	4.87	5.68	7.41	0.24	0.48
	CV (%)	107	92	93	102	60
	Skewness	3.02	2.18	2.00	3.12	2.25
	Kurtosis	12.13	6.01	4.16	10.97	5.79
	Variance	23.73	32.21	54.97	0.06	0.23
	Median	2.68	3.96	4.94	0.15	0.64
September	Mean	4.14	8.67	10.75	-	-
	Max	30.40	31.10	36.34	-	-
	Min	0.58	0.99	0.88	-	-
	St.dev	4.68	6.83	7.56	-	-
	CV (%)	113	79	70	-	-
	Skewness	2.40	1.10	1.03	-	-
	Kurtosis	7.26	0.63	0.71	-	-
	Variance	21.90	46.69	57.18	-	-
	Median	2.08	6.53	8.21	-	-

Table 3. Classification of seasonal (and depth) soil samples by electrical conductivity (EC) is given as a percentage

Sampling seasons	EC (mS/sm)	Salinity classes	Depth		
			0–20 cm	20–50 cm	50–100 cm
June	0–2	Non-saline soil	74.57	58.38	35.26
	2–4	Slightly saline soil	15.61	22.54	32.95
	4–8	Moderately saline soil	7.51	12.14	20.81
	8–16	Strongly saline soils	2.31	5.78	9.25
	>16	Very strongly saline soils	0.00	1.16	1.73
July	0–2	Non-saline soil	28.66	15.29	8.28
	2–4	Slightly saline soil	38.85	36.31	28.03
	4–8	Moderately saline soil	19.75	23.57	33.12
	8–16	Strongly saline soils	7.01	17.20	17.20
	>16	Very strongly saline soils	5.73	7.64	13.38
September	0–2	Non-saline soil	48.34	10.84	3.90
	2–4	Slightly saline soil	20.53	21.69	14.29
	4–8	Moderately saline soil	15.89	26.51	29.87
	8–16	Strongly saline soils	11.26	24.10	28.57
	>16	Very strongly saline soils	3.97	16.87	23.38

layers of medium, highly salinized or strongly salinized soils, due to seasonal periods [Poshanov, et al., 2022; Das, et al., 2020], revealed that salts in irrigated soils are constantly in motion, and this situation showed that there is a direct connection between irrigation periods and flood irrigation. Determining the spatial distribution of soil salts and areas prone to secondary salinization is important for effective agricultural land management and productivity improvement.

Regression analysis of data

A regression analysis was conducted to determine the relationship between the space survey data and the field survey data. The vegetation indexes calculated on the basis of spectral channels of the Sentinel-2 (17 images taken between June 3 and September 11) were used as space survey data, and soil conductivity data (June, July, September) were used as field survey data. The vegetation index here is NDVI, SAVI, OSAVI, TND, GNDVI, NDGR, IPVI, VEGI, SQRT, RVI, SI_1, SI_2, SI_3, SI_4, SI_5, SI_6, SI_7, which very important in the study of soil salinity and condition of plants growing on them [Liu et al., 1995; Huete 1988; Khan and Abbas, 2007].

As a result of the analysis, we built significant regression models for all layers with the coefficients of determination (R2) from 0.64 to 0.76. (Figure 5.). Here, the index SI_7 for the all layers of soils of cornfield turned out to be the best predictors. Also, the “”higher “ (R ≥ 0,7) dependence SI_1 index and the IPVI vegetation index on the soil layers of 20–50 cm and 0–20 cm were fixed.

This analysis was similar for all other 14 training datasets in the 0–20 cm, 20–50 cm, and 50–100 cm layers obtained in June, and was relatively low for the rest of July and September, so we did not show them in this paper. It has been shown that there is a good relationship between the electrical conductivity of the soil in the corn field in June and the vegetation indexes in the third decade of July.

Mapping of soil salinity using remote sensing – the case of cornfield

To map salinity, we used the best predictor - the soil index SI_7, identified as a result of regression analysis. The spectral channels of the Sentinel-2 satellite, taken on July 28, were used to calculate this index. In previous studies [Laiskhanov et al., 2022], it was found that the greenest period of corn grown on non-saline soils corresponds to July 28, and it is much later on saline soils. Salinity slows down the growth and development of corn during the growing season. Therefore, it is possible to use the space images taken at this time and the calculated indices to separate salinized soils from non-saline soils.

Then, the images of the soil index SI_7 were divided into 4 classes corresponding to unsalted,

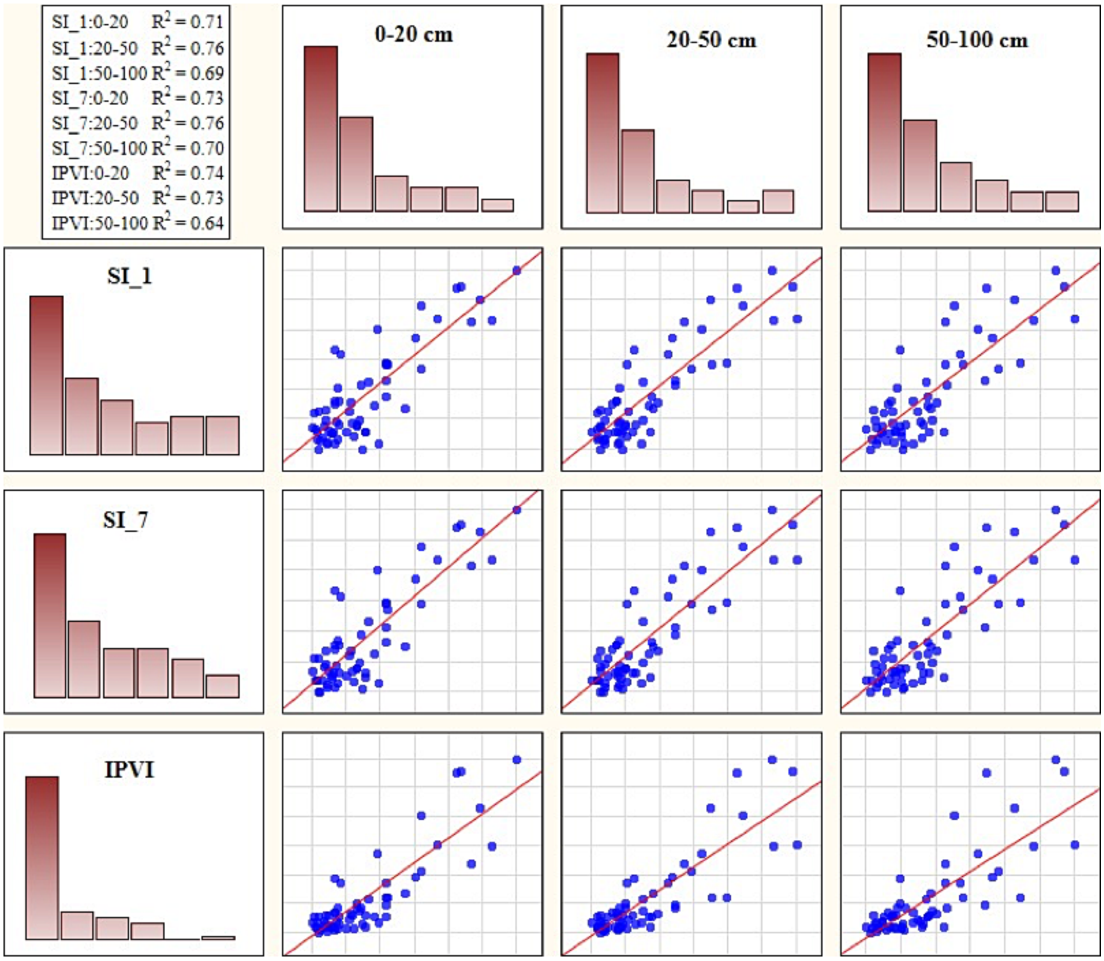

Figure 5. Correlation matrix between indices and soil electrical conductivity

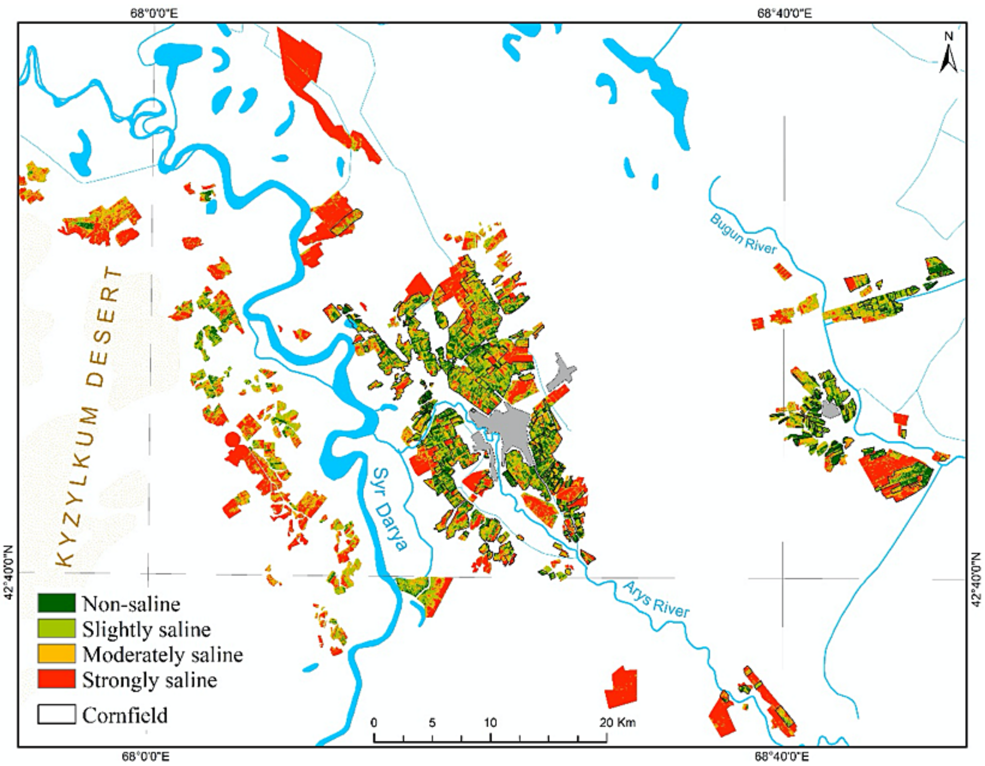

Figure 6. Soil salinity map of cornfield

slightly saline, medium saline and strongly saline soils (Figure 6). The quantiles calculated in the Statistica 12 program were used as class boundaries. As a result, 2912.2 hectares of 10100 hectares of corn fields in irrigated fields are non-saline, 3288.4 hectares are moderately saline soils, 2615.2 hectares are moderately saline soils, and 1284.3 hectares are strongly saline soils. The spatial distribution of salinized soils of different degrees determined during mapping is not uniform, the areas located near the Syrdarya and Arys rivers, receiving irrigation water from these rivers, are dominated by slightly salinized, moderately salinized, and highly salinized soils. And in the valleys located near the Bogen river, the source of irrigation is this river, the soils are not significantly saline, slightly saline and moderately saline soils are less common.

CONCLUSIONS

One of the most urgent problems in agriculture in the world, including arid and subarid regions, is the increase in the volume of saline soils. Currently, it is very important to use time- and money-saving technologies in mapping and determining the development trend of this negative process in the context of different large fields. Therefore, this study was devoted to the development of algorithms for the construction of soil salinity maps in the cornfields of the Shaulder irrigated massif, located in the arid region, based on the data of field research and remote sensing. Research work on the topic consisted of 4 stages. They are: Separation of crop type to identify saline soils in corn fields, Determination of soil salinization characteristics, Regression analysis of data, Mapping of soil salinity using remote sensing: The case of cornfield. The works performed on these stages can be algorithms for deciphering saline soils in the fields. Using these algorithms, the condition of soil salinity in the cornfields of the Shaulder irrigated massif was studied, a map was made, and the spatial distribution of saline soils was shown. The above algorithms can be used to map soil salinity in fields in other regions of the world. However, in the future, their improvement may increase the accuracy of decryption.

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