Original Research Paper

A Study of the Effects of Soil Salinity on the Growth and Development of Maize (*Zea Mays L.*) by using Sentinel-2 Imagery

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Abstract: Salinization of soil cover and the constant increase in their area have become one of the most pressing problems year after year for irrigated agriculture regions. The degradation processes caused by the salinity of soils negatively affect the growth and development of food crops. Therefore, this study focused on the effects of soil salinity in the midstream of the Syrdarya on the growth and development of maize where the climate is continental and mostly arid, and the cultivation of crops is possible under irrigation conditions. The study made harmonious use of remote sensing and field survey methods based on modern and traditional approaches in terms of time and space. Based on Sentinel-2 satellite images, regression analysis was carried out to determine the dependency of vegetation indices on soil electronegativity and maize biomass from 73 sampling points in the representative area. As a result, in the study of the growth and development of maize, it was found that the dependence of the Normalized Difference Vegetation Index (NDVI) on maize biomass within 18 vegetation indices was "high" (R2 = 0.76) in spring. The dynamics of maize biomass grown on soils of different salinity levels were developed. NDVI dynamics, which covers the entire growth phases of corn, showed that compared to corn grown in unsalted soils, it slows down the growth of corn in slightly saline soils-up to 11 days, in moderately saline soils - 35 days, and in heavily (highly) saline soils - 45 days. Characterization of soil salinity and other factors having a positive and negative influence on the growth and development of maize yield in the studied object is also given.

Keywords: Soil Salinity, Maize Growth and Development, Sentinel-2, Shauldir Irrigated Massif, Regression Analysis, NDVI Dynamics

Introduction

The study of the influence of saline soils on the growth and development of crops is important for understanding the nature of salinization, forecasting yields, and determining the production potential of agricultural lands that have undergone salinization. Soil salinity inhibits the growth and productivity of many crops in desert and semi-desert areas of the world and creates an environmentally hazardous environment (Kotuby-Amacher *et al*., 2000). When studying this problem, distance learning methods are becoming increasingly relevant. After all, it differs from the traditional ground-based research method, of which it is an analog, in its breadth, length, efficiency, and relative cheapness of the spatial coverage range (Chen *et al*., 2008). The compatible use of soil Electrical Conductivity (EC) with remote sensing data has shown promising results (Wiegand *et al*., 1996). Multifunctional satellite sensors (Multi-Scanner Sensor Landsat (MSS), TM, ETM, Thermal Infrared Distance (TIR), Operational Land Visualizer (OLI) - can cover all growing seasons of crops and allow you to explore vast territories (Chen *et al*., 2008; Satir and Berberoglu, 2016). Space data from the Sentinel-2 satellite contributed to medium and large-scale research (Mamatkulov *et al*., 2021). Also, SPOTHRV (Wiegand *et al*., 1996), Indian Remote Sensing Satellites

(IRS), Linear Imaging Self-Scanning System III (ÇULLU, 2003), Earth-Observing One (EO-1), Hyperion (Hamzeh *et al*., 2013) performed works with the use of information is encountered. In all these works, the data on the electronegativity of the soil, crop yield, videography, water quality, etc., obtained by field studies, was used to determine the decoding features of satellite images.

It is known that the reaction of crops to soil salinity varies from season to season and from crop to crop. Several papers have been published in this direction. Soil salinity can be determined using remote sensing data (ÇULLU, 2003; Satir and Berberoglu, 2016; Mamatkulov *et al*., 2021) on wheat (ÇULLU, 2003; Zahra, 2012; Yousfi *et al*., 2016; Satir and Berberoglu, 2016), maize (Satir and Berberoglu, 2016; Feng *et al*., 2017; Bose *et al*., 2018), cane (Wiegand *et al*., 1996; Hamzeh *et al*., 2013), clover (Tian *et al*., 2020). Also, their impact has been conducted. There are papers in the databases that the effects of soil salinity by remote sensing on maize growth and yield have been studied on the Mediterranean coast (Satir and Berberoglu, 2016). East and South-East Asia region are characterized by humid or favorable climates (Feng *et al*., 2017; Bose *et al*., 2018). No such studies have been conducted in the Central Asian region, including Kazakhstan, where the climate is dry and harsh and there is a constant scarcity of water resources.

The Republic of Kazakhstan is the largest state in Central Asia in terms of territory, areas of desert, and saline lands. Of the 272.5 hectares, 66% are occupied by desert and semi-desert lands (Zhumabaev, 2015). The volume of saline and saline soils amounted to 116 million hectares (42.5% of the total land area), indicating that salinization, including secondary salinization, is the primary degradation process leading to desertification (Otarov *et al*., 2008; Laiskhanov *et al*., 2021). Especially the proportion of weedy soils in the soil structure of the river basins such as the Syr Darya, Ili (Otarov *et al*., 2008; Laiskhanov *et al*., 2016, 2021) is increasing year by year.

Maize is one of the economically viable crops for many regions, including Asian countries where saline soils are prevalent. Although maize belongs to the group of moderately sensitive crops, it gives a faster reaction to salinity than wheat and cotton in this group (Irshad *et al*., 2002; Satir and Berberoglu, 2016; Poshanov *et al*., 2022). This biological characteristic of maize can positively influence the understanding of the effects of salinity stress on yield. It is possible to judge the condition and outcome of the crop by studying its growth, creating growth dynamics, and taking into account the greenest period (Yousfi *et al*., 2016; Satir and Berberoglu, 2016).

Our study aims to investigate the effect of soil salinity on maize growth and its development in a region where the climate is continental, mostly arid and farming is done only by irrigation. The object of the study was the Shauldir irrigated massif in the middle mouth of the Syr Darya River, where maize fields are widely spread.

Materials and Methods

The study of the effects of soil salinity on the growth and development of maize was conducted in 2021 in the maize fields of the Otrar district located along the Syrdarya River. Field studies were carried out in May, July, and September during corn growth phases.

Research Area

Otrar oasis-one of the fields where the desert zone fully occupies the territory; agriculture is carried out only by irrigation. The natural state and economic system were formed under the influence of the Syrdarya River and one of its main tributaries-the Arys River. The scientific literature (Otarov *et al*., 2018; Laiskhanov *et al*., 2016) is also known as the "Shauldyr irrigated massif." This massif was one of the oldest farming areas and the ancient city of Otrar, located in the massif, was one of the centers of science and culture along the Silk Road before its conquest and destruction by Genghis Khan (Dawkes *et al*., 2019).

The study site is located in the Turan Depression in Central Asia. This enclosed region has neither an outlet to the world's oceans nor rivers flowing into it. The Shaulder irrigated massif occupies the Otrar district of Turkestan province in Kazakhstan. The primary water supply sources for these irrigated lands are the rivers Syrdarya and Arys, flowing through the Otrar district. Our field research work was carried out at our selected representative area in the Kogam and Kargaly rural districts in the Otrar district (Fig. 1).

The earth crust of the Shauldir irrigated massif is formed by the epiphany structure of the Turan plate (Syrdarya depression). Meadow-grey, meadow-light-grey soils of different degrees of salinity are widely spread in the massif, located on accumulative ancient alluvial plains of the Syrdarya River. According to Pachikin *et al*. (2014) classification, the soil cover corresponds to the subzones of light and ordinary grey soils and grey-brown desert soils. It is possible to encounter meadow-boggy soils in the groundwaters and low-lying areas close to the surface (up to 3 m). Solonchaks and solonchak-like soils have been formed under the influence of solid mineralization of the groundwaters over the mother rocks with heavy texture and saline soils. Contours of soils belonging to this type of soil are widespread in this region. (Faizov, 1983).

The climate is dry and sharply continental. The system of agro-climatic zoning (Belousova *et al*., 1979) refers to a very hot and dry agro-climatic region. Annual precipitation falls in the range of 170-200 mm. Most of it falls in the winter month and early spring. Winter is short, mild, and snowless while summer is characterized by dry and hot air. The number of days when the average temperature in summer exceeds +35°C is 30-40. The driest month of the year is August and this month, there is an annual rainfall of 1-2 mm or 0.2 -0.9% of the annual precipitation rate. Therefore, in the summer months, the surface of the air and soil becomes dry.

Compared to other agrarian areas of the region, Otrar is well supplied with water resources. Nevertheless, due to the inefficient use of water resources, groundwater rises, which leads to soil salinization (Laiskhanov, 2013).

Maize among crops plays a massive role in the economy of the Otrar district. According to statistical data (DBNSASPRRKTR, 2020), there is 33252 ha of arable land in the community, of which 34% (11134 ha) are maize crops. The presence of large areas of maize crops within agriculture and the accumulated experience in studying this region have positively influenced the successful research and the identification of the representative areas.

Methods

The project extensively uses field research methods (reconnaissance surveys, salinity surveys, crop biomass measurement methods) and desktop studies (literature review, high-tech space, geo-information, statistics, mapping) to study the ecological condition of soils and vegetation cover comprehensively.

For conducting field (ground) studies and remote studies in time and spatial interaction, the phases of maize growth during the growing season and representative areas were selected.

Twenty images of Sentinel-2 satellites covering all phases of corn crop growth in the study area (recorded from May 19 to September 11) have been downloaded from open sites (https://glovis.usgs.gov/).

The first stage of field studies included the spring period, characterized by the emergence of seedlings and the full development of seedlings. The second stage is the summer period, in which the beginning and completeness of the emergence of seedlings and the beginning of flowering cobs coincide. Soil salinity and maize biomass were measured in a two-stage field study.

According to Chernyshev (2006) instructions, soil salinity was measured using the progress of its device. Then, saline soils were grouped according to the degree of salinity following the FAO classification (Abrol *et al*., 1988). Corn biomass was calculated using the biomass measurement method for plants in the interline space (Ruleva and Ovechko, 2016). Space images downloaded from an open site by the stages of the study were used to calculate vegetation indices (Cherepanov, 2011). All the data obtained were used when embedded in a Geographic Information System (GIS) GPS receiver "Garmin 65s" and ArcGIS 10.7 GIS software.

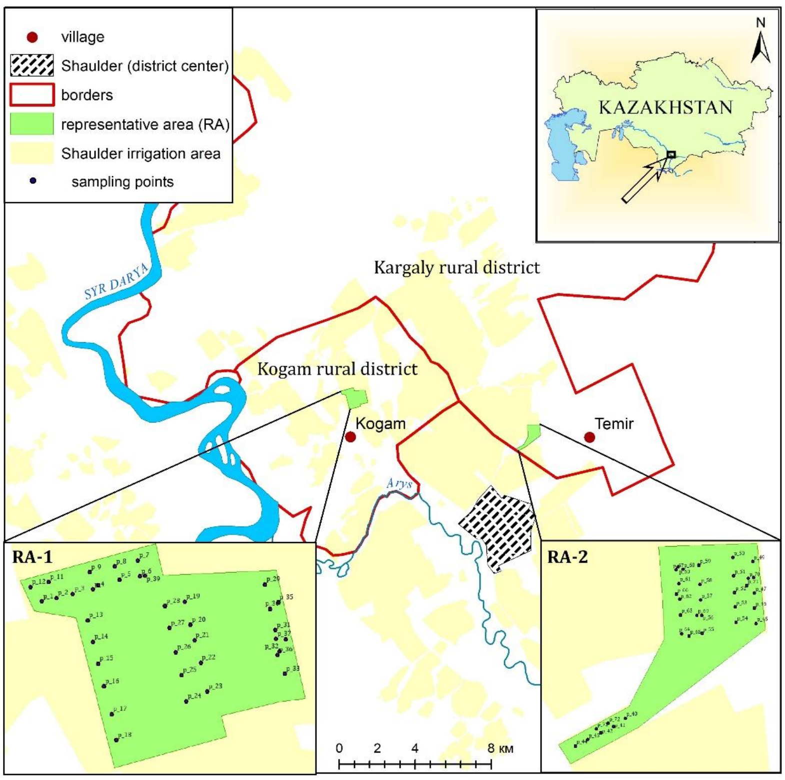

Fig. 1: Research area

The basis of desk research work was a review of the literature on the research topic, the creation of a geographic information system of the object of study in GIS technologies (programs ILWIS v.3.8.5 and ArcGIS 10.4.1), the determination of the spectral characteristics of space images, regression analysis and the compilation of thematic maps.

In the Statistica 12.5 program, a regression analysis was carried out to determine the dependence of space survey data (vegetation indices) on data identified as a result of field studies (soil salt survey, crop biomass). The regression analysis made it possible to reveal the relationship between the research data and reveal signs of interpretation of space images (Salin and Churilova, 2002).

In representative areas, in the form of a survey, farmers carried out the following agrotechnical activities:

- Tillage: Autumn plowing, early-ripening harrowing, pre-harvest pinching and chiseling, inter-row cultivation before irrigation, and inter-row furrow for irrigation
- Seeds of corn were sown from 5 to 8 May. Sowed seed variety: Pioneer PR 31G98. Growing season - FAO 700 (130-140 days) (https://alemagro.com/catalog/kg/semena/product/pr31g98)
- 3 systematic irrigations were carried out using the waters of the Syrdarya and Arys rivers

In May and June, the crops were cleared of weeds two times by mechanical and manual methods (manual).

These measures can characterize the agrotechnical activities carried out in the fields of corn in the irrigated fields of Shaulder. Depending on their financial situation, most of the peasant farms in the fields do not use agrochemical measures (pesticides and herbicides) or mineral and organic fertilizers.

Results

Dependence of Vegetation Indices on Biomass

At present, the development of remote study technologies contributes to the widespread use of vegetative indices in the study of vegetation cover and its condition (Cherepanov, 2011). The number of vegetation indices developed by scientists is very large and among them, some are widely used in research work. We used such standard indices to determine the dependence of vegetation indices on biomass.

Infield studies in the spring and summer periods, a regression analysis was carried out to determine the relationship between corn biomass per 1 sq. km. and vegetation indices taken from 73 sampling points. The indices NDVI (normalized difference vegetation index), IR_R, VEGI, TNDVII, GNDVI, NDGR, IPVI, RVI, OSAVI, SAVI, SI 1, SI 2, SI 3, SI 4, SI 5, SI 6, SI 7 and SI 8 were used as a vegetation index, used in the study of plant biomass and its growth dynamics. As a result, during 18 vegetation indices, the dependence of the NDVI index on corn biomass was "high" in both seasons (Fig. 2).

As shown in Fig. 2, as a result of the regression analysis of plant biomass for the object of study, the coefficient of determination for the vegetation index NDVI (R2) was: For the spring (June) survey -0.74; according to the summer (July) survey -071.

Soil Salinity and its Impact on Maize Growth and Development

Infield studies, the electronegativity of 0-20 cm of the soil layer was measured at sampling points and grouped by degrees of salinity by the FAO classification (Abrol *et al*., 1988). As a result, out of 73 sampling points, 22 were unsalted (interval 0.5-1.9 Ds/cm), 21 were slightly salty (interval 2.2-3.9 Ds/cm), 19 were moderately salty (interval 4.1-7.7 Ds/cm) and 12 were strongly salty (interval 9.4-18.2 DS/cm), consisting of soils.

At the Sentinel-2 satellite research facility, 20 images covered all phases of corn growth (filmed from May 19 to September 11). These images calculated NDVI indices for every 5-10 days of the corn harvest. The dynamics of corn biomass development (NDVI) on soils saline to varying degrees were developed (Fig. 3 and 4). The 3rd and 4th figures give a clear picture of the effect of soil salinization on the growth and development of maize. As the soil becomes saline, its NDVI (biomass) is formed. The highest NDVI was recorded in July on unsalted and slightly saline soils. The NDVI value in saline soils reached 0.60 in RA-1 to 0.56 in RA-2, a slight decrease in slightly saline soils, i.e., 0.57 in RA-1 and 0.55 in RA-1. On moderately saline and highly saline soils, the maximum NDVI falls in September. On moderately saline soils in two Representative Sites (RA), the maximum NDVI does not exceed 0.49 and on highly saline soils, -0.43.

In the course of the study, we were convinced that soil salinization is a limiting factor for the growth and development of corn by determining the fixed time of the greenest harvest period (maximum NDVI). On unsalted soils, the maximum NDVI falls on July 28. While on slightly saline soils, RA1 was registered on August 7 and RA2 on July 28. It was found that the maximum NDVI value of corn grown on moderately saline soils corresponds to September 1 for both RA, while the greenest period of corn grown on highly saline soils (maximum NDVI) is recorded very late. For both, the RA was registered on September 11 and corresponded to the harvesting campaign. After all, since September 12, a campaign for harvesting and harvesting corn has begun at the research facility.

July irrigation greatly impacted the dynamics of NDVI of maize grown on soils with different degrees of salinity. A strong influence of 1st irrigation on NDVI dynamics at the beginning of July can be observed in Fig. 3 and 4. In RA-1 from 8 July and RA-2 from 3 July, maize biomass increased sharply. The study results showed that irrigation activities promoted salt migration in the upper soil layer downwards, creating favorable conditions for maize growth.

Using satellite imagery at the time of registration of the maximum value of the NDVI index of corn crops at the research object (July 28), we have compiled a map of the NDVI of the research object. NDVI allowed for visual analysis of the relationship between salinity and maize biomass by superimposing point layers on the map's surface, showing the degree of salinity of soils obtained by electronegativity (Fig. 5).

It can be seen from Fig. 5 that the predominant part of unsalted (green) dots has a higher NDVI (biomass) value and most of the saline (red) dots correspond to contours with a lower NDVI (biomass) value. Note that slightly saline (yellow) and moderately saline (brown) dots correspond to the average outline of the NDVI value. However, there are no contradictions either. In the course of a field study, the causes of these contradictions were identified. The low NDVI value of some unsalted points is because there is no total amount of sprouted corn at these points. During the spring sowing of grain, the same moisture in the soil is not observed everywhere; due to gaps in the technique of sowing grain, the harvest may rarely come out. The fact that saline points, in some cases, have a higher NDVI value is directly related to the growth of weeds at these points (Fig. 6).

Discussion

According to a study by V. A. Kovda (1949), soils are saline soils if their content exceeds 0.1% of the mass of salts harmful to plants or is more than 0.25% of the total mass of lithogenic rock (dense residue). The degree of salinity of soils depends on the number of salts contained. The degrees of their salinity is also determined by the indicators of electronegativity (Abrol *et al*., 1988). The concentration of salt in the soil, depending on the amount, causes vegetative stress. Salinity negatively affects the plant's growth and the soil's microbiological activity (Laiskhanov *et al*., 2018).

When studying the effect of soil salinity on plant growth and development, space imagery is applied by calculating vegetation indices. As shown above, the results of the regression analysis showed that the dependence of the vegetation index NDVI on maize biomass measured in the field survey was "high (R2 = 0.76 and 0.59)". The NDVI index is also the most commonly used vegetation index to study biomass and plant conditions and predict yield. Numerous studies (Yousfi *et al*., 2016; Satir and Berberoglu, 2016) show that it is essential to consider the greenest period of the crop through NDVI. Accounting for biomass (NDVI) in the greenest period of the maize contributes to estimating or predicting maize productivity (Yousfi *et al*., 2016). Therefore, a study of the effect of soil salinity on maize growth and development was carried out by calculating NDVI indices.

These figures show the dependence of maize biomass (NDVI) on salinity conditions. Salt accumulation in the soil slows plant uptake of water and nutrients, creating osmotic pressure around the plant's root system. Salt causes ionic stress. Salts in the soil damage leaf transpiration cells in the plant and inhibit plant growth (Munns *et al*., 2006). Depending on the degree of soil salinity, plant growth is stunted and plant cover (Canopy cover) is also reduced (Tian *et al*., 2020). Salinity negatively affects maize's growth rate of vegetative organs (Zahra, 2012; Bose *et al*., 2018; Poshanov *et al*., 2022). Moreover, the effect of salinity also depends on the cultivar (Bose *et al*., 2018). Consequently, salinity inhibits maize growth and development and negatively affects its timely ripening and yield. Soil salinity on maize crops, according to Doorenbos and Kassam (1979), is reduced by 0% at EC 1.7 Ds m-1, by 10% at EC 2.5 Ds m-1, by 25% at EC 3.8 Ds m-1, by 50% at EC 5.9 Ds m-1 and by 100% at EC 10 Ds m-1. The water quality used in irrigation also contributes to decreased outcomes (Wang *et al*., 2015; Feng *et al*., 2017). The water quality of the Syrdarya and Arys rivers used for irrigation is not good. According to the Department of Ecological Monitoring of Kazhydromet Agency (UEIRMEGNRRK, 2020), the water quality of the Syrdarya River is "very poor" (>5 class) and that of the Arys River is "poor" (4 class). According to S.I. Koshkarov *et al.* (2008), the mineralization of the Syrdarya River water has increased to 0.7-1.2 g/L in the lands of Uzbekistan; in the lands of Kazakhstan, it reaches on average 1.5-2 g/L. A study by Wang *et al*. (2015) showed that if the salt concentration in the water is up to 3 g/l, it reduces the productivity of any crop by up to 10%. Although the salt concentration is low, prolonged irrigation with saline water significantly reduces yields and contributes to land salinization.

The study of the influence of soil salinization on corn growth, especially in summer, by the cosmic method (using vegetative Indochina) is negatively influenced by such factors as the complete lack of crop roots and weed contamination of the field. Weed contamination also hinders the growth and development of maize. The most common weeds in the study area are seepweed (Suaeda fruticosa) and common seepweed (Phragmites communis). Those two plants are considered one of the most tolerant plants to salinity (Fig. 6).

They have a well-developed root system (ARKLM, 2001) and weeds compete with crops for water, light, nutrients, and space (Tursun *et al*., 2016). Weeds tend to survive and multiply even under relatively harsh agro-climatic conditions and cause enormous quantitative and qualitative damage to maize crop growth (Maqsood *et al*., 2020).

Several researchers (Tursun *et al*., 2016; Maqsood *et al*., 2020) have established through experiments that weed infestation of maize crops is a factor that negatively affects crop growth and development and reduces yield. In their opinion, to improve yield and quality, it is necessary to control weeds during the critical period of maize growth.

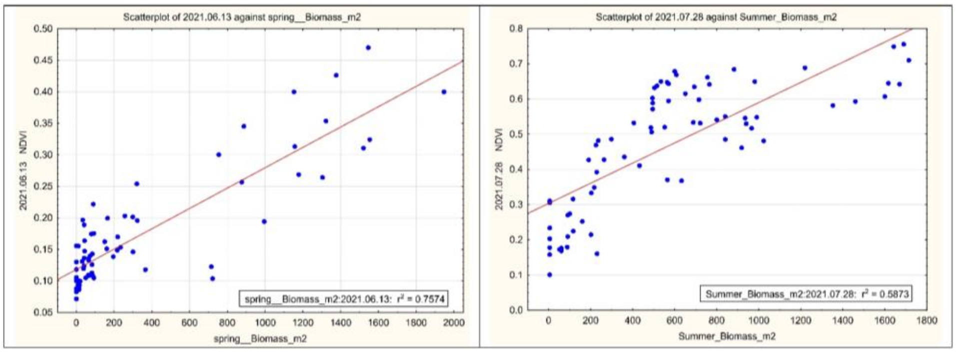

Fig. 2: Linear regression of the NDVI index

Fig. 3: NDVI dynamics of maize grown on soils with different levels of salinity (RA-1)

Fig. 4: The dynamics of NDVI corn grown on soils of varying degrees of salinity (RA2)

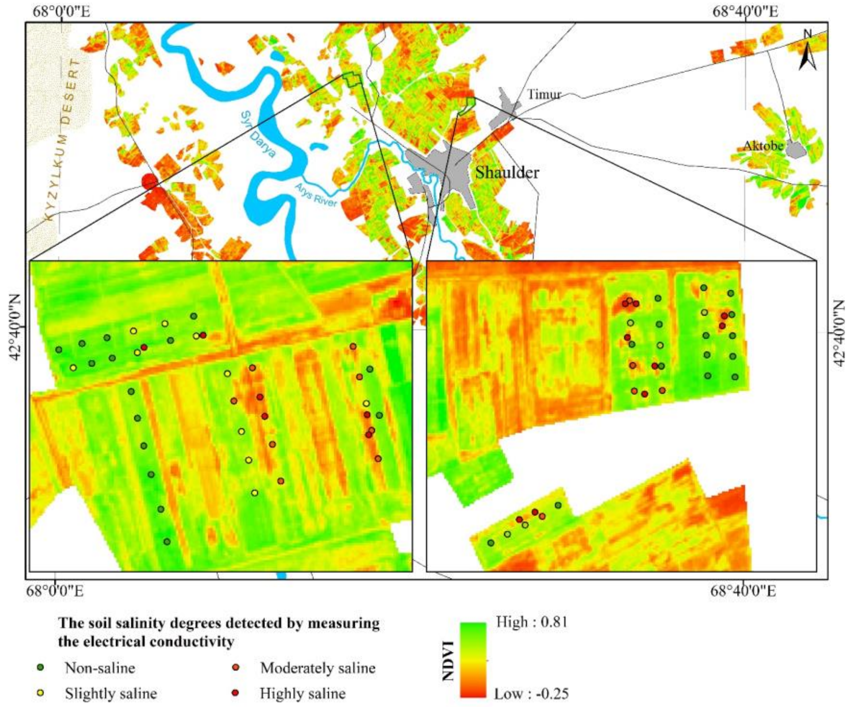

Fig. 5: NDVI map of the research area

Fig. 6: Weeds often grow in saline soils in the study area (left - Suaeda fruticosa; right - common seepweeds (Phragmites communis)

Conclusion

As a result of the flat nature of the relief in the middle mouth of the Syrdarya River, arid climate, availability of water resources, widespread grey soils of medium fertility, and attempts by the local population to use these natural resources, irrigated agriculture was formed. However, due to the inefficient use of water resources and the implementation of appropriate measures to regulate groundwater, the trend of soil salinization has sharply increased and spread to soils of varying degrees of salinity.

To study soil salinity in the study area and its influence on the growth and development of maize in the object of study, maize crops on the area of 95 h in Otyrar rural district and 65 ha in Kargaly rural district were selected as representative areas. In this representative area, 73 sampling points were established and soil salinity and maize biomass per square meter was measured by soil conductivity. A regression analysis was carried out to determine the dependence of vegetation indices calculated from Sentinel-2 satellite imagery on maize biomass. As a result, the reliance of the NDVI index on maize biomass during 18 vegetation indices was found to be "high" in both seasons: The coefficient of determination (R2) was 0.76 for spring surveys; 0.59 for summer surveys. Based on the NDVI index, the development dynamics (NDVI) of maize biomass grown on soils with different degrees of salinity were developed.

Works on comparative analysis of data on dynamics of maize NDVI and soil salinity in the studied object helped to obtain the following results:

1. It was found that on soils with varying degrees of salinity, the growth and development of maize slows down compared to maize grown on unsalted soils: On slightly saline soils-up to 11 days, on moderately saline soils-up to 35 days, and highly saline soils-up to 45 days
2. The dynamics of NDVI of maize grown on soils with different degrees of salinity were greatly influenced by July irrigation. NDVI value for all crops started to grow after irrigation works in the first half of July. Mineralization of the waters of Syrdarya and Ary's rivers and the permanent use of these rivers' waters for Shaulder irrigated lands negatively influence soil salinity and corn yields
3. The assessment of the growth and development of corn through NDVI dynamics is negatively affected by the inferiority of corn crops and weed infestation of crops

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Author’s Contributions

All authors contributed equally to this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and that no ethical issues are involved.

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