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Ryspekov, Tilepbergen
Faculty of Agrobiology, Kazakh National Agrarian Research University

Aizhanat Kustabayeva
Department of Water Resources and Melioration, Kazakh National Agrarian Research University

Anastasia Gubaidullina
Faculty of Agrobiology, Kazakh National Agrarian Research University

Lyazzat Makhmudova
Department of Water Resources, Institute of Geography and Water Security

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Paired Ground-Based and Satellite Observations for Remote Sensing of Saline Soils in Southeastern Kazakhstan

Tilepbergen Ryspekov[1], Aizhanat Kustabayeva[2], Anastasia Gubaidullina[1], Lyazzat Makhmudova[3,*]

[1]Faculty of Agrobiology, Kazakh National Agrarian Research University, Almaty, Republic of Kazakhstan

[2]Department of Water Resources and Melioration, Kazakh National Agrarian Research University, Almaty, Republic of Kazakhstan

[3]Department of Water Resources, Institute of Geography and Water Security, Almaty, Republic of Kazakhstan

*Author to whom correspondence should be addressed:
E-mail: lyazzatmakhmudova3@gmail.com

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Abstract: The aim of the study was to identify and analyse the potential role of the relationship between ground surveys and remote sensing in creating a comprehensive view of changes in the surface state of soil salts under different weather conditions. An experimental method was used in the process of realizing the study. In the course of the study, the possibilities of joint ground and satellite observations for remote sensing of saline soils of south-eastern Kazakhstan were analysed. The experimental method was used to study meadow solonchaks and strongly solonchak meadow-serozems located within Enbekshikazakh district of Almaty region, as well as salt composition of soil under soybean and maize crops on the territory of Limited Liability Partnership (LLP) "Baiserke-Agro" in Talgar district of Almaty region. World tendencies of modern remote sensing of the Earth (RS) are analysed. Satellite information requirements specific to the industry under study have been considered. It is determined that information support of the implementation of the concept of sustainable development is carried out through the organization of remote monitoring of mandatory and specific indicators of territories, and remote sensing of soils is positioned as an integral element of the monitoring system. The peculiarities of the process of joint use of ground and satellite observations are revealed. The prospectivity of the proposed concept on creation of variability of using the potential of joint ground and satellite observations for remote sensing of saline soils of south-eastern Kazakhstan is proved. Innovative conceptualization of the studied strategy is defined, which shows essential efficiency, being positioned at the same time economically expedient. The new vision of formation of an effective system of soil sensing is stated.

Keywords: development strategy; salt composition; geoinformation technologies; salt marsh; monitoring studies; visual decoding

1. Introduction

The actual concept of sustainable use of saline soils in the south-east of Kazakhstan requires fundamentally new approaches to the processes of research, monitoring, analytical processing of informative data and prompt response to discrepancies. In the light of the above problems, a special role is given to modern innovative methods of remote sensing, as the system of remote land monitoring provides an opportunity to carry out instrumental control of reliability of statistical and monitoring information, which is accumulated over a long period of time[1),2)].

Saline and saline soils are one of the most complicated objects of soil survey and mapping. The main method of assessment of salinization processes in soils is soil survey as a source of obtaining operative and long-term information on salinization indicators. At the same time, the peculiarity of spatial heterogeneity of saline soils is accompanied by contrasting differences in tonality of images of both the open surface and covered with vegetation, which allows widely applying remote sensing methods of the earth surface in combination with the traditional method of ground survey[3)]. The method of digital processing and classification of multispectral space scanning data is positioned as a highly effective method of saline soil mapping. The problems of sustainable agricultural development require an integrated approach

to the system of natural processes management. Such a concept requires studying the interaction of natural components and agriculture and their impact on natural systems. The basis for planning of complex land reclamation is the development of a system of simulation models and methods for long-term forecasts of changes in the state of irrigated lands. To achieve the set goal, it is necessary to apply innovative approaches to soil sensing[4].

Recently, scientific interest in the possibilities of combining ground and satellite observations for remote sensing of soils has grown considerably. The issues of possibilities of agrochemical soil survey using remote sensing tools are considered in the studies of S.A. Tulkubayeva et al.[5]. Their work emphasises the integration of ground and satellite observations to enhance the understanding of soil fertility and crop health on a larger scale. The authors have demonstrated how remote sensing can be effectively used to assess soil properties like organic matter content, nutrient levels, and moisture, all of which are critical for sustainable agricultural practices. However, while the study effectively utilises remote sensing tools for various aspects of soil analysis, the low correlation of certain vegetation indices (NDVI and SAVI) and ground-based soil salinity measurements with soil salinity data suggests a potential limitation in their effectiveness for this specific application. Some scientists, in particular, Zh.A. Onglassynov et al.[6] pay special attention to the aspects of implementation of the assessment of the current state of local areas on the basis of satellite data analysis, particularly emphasising the monitoring and assessment of soil salinity in irrigated lands. Authors created a salinity map for the irrigated lands of the Semey area, delineating regions with varying degrees of salinity. This map is a crucial tool for local farmers and land managers in planning and implementing appropriate agricultural practices to mitigate the impact of soil salinity on crop production. Scientists A.B. Myrzakhmetov et al.[7] come to the conviction that for the purpose of comprehensive inventory of resources, ensuring their accounting and effective monitoring, it is necessary to clarify the correctness of information obtained in the process of field studies by remote sensing. At the same time, scientists argue that the proposed method contributes to further optimization of the complex system of indication of the state and dynamics of the land fund.

In spite of significant modern scientific achievements in the studied sector, they minimally represent practical development of algorithms for joint ground-based and remote sensing of saline soils in Southeastern Kazakhstan. The study areas in Enbekshikazakh and Talgar districts of Almaty region were selected as they contain representative saline soil types (meadow solonchaks and strongly solonchak meadow-serozems) that are prevalent in Southeastern Kazakhstan. Additionally, the Talgar site allowed for investigating the influence of agricultural land use and crop residues on soil salt dynamics. These areas were deemed suitable for conducting integrated ground and remote sensing observations to develop a comprehensive understanding of saline soil processes in this region. The question of expediency of partial or full replacement of traditional research methods by innovative digital capabilities remains unexplored. Despite the relevance of the studied issue, today there is a need to optimize the algorithm of correlation of data obtained by ground and remote sensing of certain locations. The aim of the study was to identify and analyse the potential role of the relationship between ground surveys and remote sensing in creating a comprehensive view of changes in the surface state of soil salts under different weather conditions in Southeastern Kazakhstan. It investigated the hypothesis that combining ground-based measurements with satellite remote sensing observations can provide a more holistic understanding of the spatial and temporal dynamics of soil salinity compared to using either method alone. Specifically, the study had two main objectives. Firstly, to experimentally investigate the changes in salt content in the upper soil layers of meadow solonchaks and strongly solonchak meadow-serozems located within Enbekshikazakh district of Almaty region, as well as the salt composition of soil under soybean and maize crops on the territory of “Baiserke-Agro” LLP in Talgar district of Almaty region. This involved studying how weather dynamics, particularly precipitation and temperature, influence the mobility and accumulation of easily soluble salts in these areas. Secondly, to explore the potential for correlating and monitoring the salt content changes in different years by utilising Google Maps satellite imagery, thereby complementing the ground survey data with remote sensing observations.

2. Materials and Methods

In the course of the realization of the research, the method of scientific experiment, as well as elements of general scientific methods of cognition, were involved. System analysis and synthesis were used to study the aspects of interrelation between ground research and remote sensing of saline soils. With the help of the generalization method, typical features and regularities of the studied problems were determined and the most effective solutions were identified. The basic method of research is experiment.

The objects of the study are meadow solonchaks and strongly solonchak meadow-serozems located within Enbekshikazakh district of Almaty region. The salt composition of soil under soybean and maize crops on the territory of “Baiserke-Agro” LLP in Talgar district of Almaty region was investigated. In particular, the presence of salts in the upper layers of soils of this location was determined. A combination of expeditionary, visual, and chemical methods of soil analysis was used in the research (Table 1).

Table 1. Summary of site selection and methods used for remote sensing of saline soils in Southeastern Kazakhstan

Aspect	Details
Study Sites	Meadow solonchaks and strongly solonchak meadow-serozems in Enbekshikazakh district, Almaty region; soybean and maize crops on "Baiserke-Agro" LLP territory, Talgar district, Almaty region.
Sampling Method	Soil samples taken in 5 cm incremental layers from surface crust to 30 cm depth using a soil auger/core sampler. 3-5 replicate samples collected within a 10 m radius and composited to account for small-scale variability.
Sample Preparation	Soil samples air-dried, ground, and passed through a 2 mm sieve before analysis.
Salinity Measurement	Electrical conductivity of a 1:5 soil extract following standard methods.
pH Measurement	Measured potentiometrically in a 1:2.5 soil suspension using a calibrated pH meter.
Salt Analysis	Easily soluble salts analyzed by water extraction method.
Meteorological Data	Daily data including precipitation, air temperature, humidity, wind speed and direction obtained from the national hydrometeorological service of Kazakhstan.
Field Observations	Visual and chemical analysis of soil at “Nurly” and “Lavar” sites. Specificity of color change and analysis of salts in different parts of solonchak soil.
Statistical Analysis	ANOVA to determine significant differences in salt levels between soil depths, sites, and sampling periods. Correlation and regression analyses to relate salt data to weather parameters.
Remote Sensing	Use of Google Earth data for long-term studies on soil surface color dynamics due to presence of easily soluble salts. Automated methods of soil interpretation from satellite data.
Experimental Focus	Study of changes in salt content in upper soil layers, influence of weather dynamics (precipitation and temperature) on salt mobility and accumulation. Correlation and monitoring of salt content changes using Google Maps satellite imagery and ground survey data.

Soil samples were taken in 5 cm incremental layers from the surface crust down to 30 cm depth using a soil auger/core sampler. At each location, 3-5 replicate samples were collected within a 10 m radius and composited to account for small-scale variability. The soil samples were air-dried, ground, and passed through a 2 mm sieve before analysis. Soil salinity was determined by measuring the electrical conductivity of a 1:5 soil:water extract following standard methods. Soil pH was measured potentiometrically in a 1:2.5 soil:water suspension using a calibrated pH meter. Easily soluble salts were analysed by water extraction method. Meteorological observation information was used to fix the salt movement patterns. The process of identification of direct connection between migration of easily soluble salts and drought phenomena, as well as dynamics in salt content of upper soil layers, was made. During the survey of “Nurly” site, where there is a crusty-puffy solonchak with vegetation, the specificity of colour change of solonchak was studied. At the site “Lavar” the analysis of salts in both grey and white parts of the solonchak soil was carried out. Analysis of the difference between the two was also replicated. The dynamics of salt composition in the upper layers of solonchak in spring was experimentally recorded according to weather conditions, in particular with the amount of precipitation and air temperature.

Daily meteorological data including precipitation, air temperature, humidity, wind speed and direction were obtained from the national hydrometeorological service of Kazakhstan. The specific weather station records used were from the Shelek meteorological station located in close proximity to the study sites in the Il-Alatau region. In the foothill region of Almaty oblast, the growing season of 2020 was characterized by dry conditions. It was characterized by a long, multi-month period of exceptionally low precipitation. In May, only 11.7 mm of precipitation fell, and in June – only 2.3 mm. Notably, the maximum temperature in May was 35.9℃ and the average was 21℃, while in June the maximum temperature was 35.9℃ and the average was 23.2℃. These critical months for plant growth were unusually dry. The following three months were also deficient in rainfall: July received 10.3 mm, August received 9.4 mm and September received 5.8 mm. Accordingly, temperatures remained high during this period, with July reaching a maximum temperature of 37.9℃ and an average of 25.1℃. The values for August were 36.5℃ and 24.9℃ respectively, while in September the maximum temperature reached 32.9℃ and the average 19.5℃. These conditions resulted in drying of the soil and lowering of the water table. In 2021, conditions were slightly different but remained dry. Precipitation was higher in May at 26.5 mm, but decreased to only 7.6 mm in June. At the same time, maximum air temperatures of 34.9℃ were recorded in May, with an average of 21.1℃, and 35.7℃ and 23.9℃ in June, respectively. These months were characterized by higher temperatures, with July recording a maximum temperature of 40℃ and an average of 27.8℃. The values for August were 36.6℃ and 24.8℃, respectively, while September had a maximum temperature of 36℃ and an average of 21.4℃ [8)].

Statistical analysis was performed using ANOVA to determine significant differences in salt levels between soil depths, sites and sampling periods. Correlation and regression analyses were applied to relate salt data to weather parameters. In order to study the dynamics of soil surface colour due to the presence of easily soluble salts,

the potential of long-term studies using Google Earth data, whose archive has an extensive number of space images, was used. Site monitoring data during several growing seasons and in different years, obtained using automated methods of soil interpretation from satellite data, were analysed. An integrated systems approach was used to determine the effectiveness, identification of features and benefits of certain solutions in the investigated process. With its help, the work is positioned as research oriented on revealing the integrity of the object. At the same time, attention is paid to the variability of using the potential of joint ground and satellite observations for remote sensing of saline soils in Southeastern Kazakhstan.

3. Results

3.1 Soil salt dynamics in drought conditions

The process of salinization is identified as one of the most large-scale types of soil degradation. In the desert zone of Kazakhstan, saline soils, including salterns and solonchaks, occupy more than 20 million ha[9]. For optimal performance of identification and analyses of the relationship between ground surveys and remote sensing, the necessary stage is the study of pre-conditions and factors influencing the level of soil desiccation and salinization. Prolonged, abnormally dry weather conditions in 2020 had a strong influence on soil processes, and the situation continued in 2021. The drought provoked the process of upward movement of salts into the upper soil layers and the appearance of salts on the surface.

During the survey of the Nurly area, where there is a crusty-puffy solonchak with vegetation, it was noticed that in the summer of 2022, the solonchak changed noticeably in colour. There was no longer a swollen layer of salts on the soil surface, and the crusty-puffy solonchak condition changed to a crusty solonchak condition. On 28 June 2022, this salt marsh had greyish areas with brown patches. At the Lavar site, salt analysis was carried out on both the grey and white parts of the salt marsh soil. The analysis of the difference between the two was replicated. During the summer period, the salt composition in the grey part of the salt marsh was as follows: anions in the grey crust of the salt marsh included CO_3-2.72, HCO_3-2.2, CL-20.2, SO_4-19, and cations included Ca++5.15, Mg++4.10, Na+34.87. Salt composition in the white part of the solonchak was as follows: 0.88, 0.76, 9.5, 18.75, 5.2, 5.15, 19.54 mg/eq per 100 g of air-dry soil. Significant accumulation of salts occurred in the cortical layer on 28 June 2022. The highest amount of anions was 130 mg/eq per 100 g of soil, and sodium cations were 145 mg/eq per 100 g of soil. The dynamics of salt composition in the upper layers of the salt marsh in spring was experimentally recorded according to weather conditions, in particular with the amount of precipitation and air temperature. Thus, the highest salt concentration was observed in the 5-10 cm layer (2.26-3.449%). This salt marsh on 23 May 2022 contained the highest amount of anions and cations in layers up to 10 cm deep. It is noteworthy that the composition of carbonate and hydrocarbonate anions increased significantly, while chlorine ions decreased. At the same time, the pH in the 0-30 cm layer varied from 9 to 9.5. Figures 1 and 2 show the result of salt accumulation on the soil surface of “Lavar” solonchak.



Fig. 1: Surface of the “Lavar” solonchak in the fall (11/28/2021).
Source: compiled by the authors.



Fig. 2: Surface of the “Lavar” solonchak in the spring (05/31/2022).
Source: compiled by the authors.

Under the conditions of the current study, drought provokes the rise of water solutions, leading to active evaporation of water from the soil surface. In addition, it promotes the continuous inflow of new moisture into the upper soil layers, together with easily soluble salts[10]. In this scenario, drought is the cause of soil salinization, which in turn hinders the development of vegetation.

Rainfall in the study location was observed only from October onwards. Chemical and morphological analysis of soil samples collected from the fields of Baiserke-Agro LLP showed that salts penetrated deeper into the soil after rainfall. These fields were irrigated during the growth of cultivated plants and, as a consequence, salts reappeared during the period of plant growth.

During the implementation of the study, soil samples were collected from these fields on 03.11.2021. Aqueous extract analysis was carried out on the soil samples taken from field No. 4 where soybean was grown. The analysis showed that in the soil crust composition, the highest concentration of sulphate ions among the anions was 10.7 mg/eq per 100 g air-dry soil and sodium cations were 9.85 mg/eq. This trend was observed in layers at different depths: 0-5 cm (sulphate ions: 11. 25 mg/eq, sodium cations: 11.17 mg/eq), 5-10 cm (sulfate ions: 12.5 mg/eq, sodium cations: 12.27 mg/eq), 10-20 cm (sulfate ions: 12.8 mg/eq, sodium cations: 12.05 mg/eq) and 20-30 cm (sulfate ions: 13.25 mg/eq, sodium cations: 12.29 mg/eq) per 100 g of soil. After rainfall on 29 October 2021, the movement of easily soluble salts was observed from 5 to 30 cm depth. Aqueous extract analysis was also carried out on soil samples taken from field No. 5 where maize was grown that year. The distance between the soil sampling points in the fields is about 180 m. However, in field No. 5 the soil crust is weakly expressed. In samples from 0-5 cm layer, the concentration of sulphate ions was only 1.35 mg/eq and sodium cations were 0.89 mg/eq per 100 g of soil, which is much lower than that of field No. 4. Field No. 5 showed the highest concentration of sulphate ions among anions in the 5-10 cm layer, which was 8. 1 mg/eq, at the same time sodium cations content reached 7.21 mg/eq. These values increased at depths of 10-20 cm and 20-30 cm, where sulphate ions concentration was 8.7 and 8.5 mg/eq, respectively, and sodium cations concentration was 7.62 and 7.73 mg/eq.

The increase in salt content in the 10-20 cm layer could be observed visually due to its accumulation in the soil. In the field sown with maize, high and dense maize stubble and weeds were left after harvesting. These residues affect the level of accumulation of both soil moisture and precipitation moisture. The residual vegetation retains moisture in the soil by providing shade and reducing wind speed. In essence, the abundance of vegetation in the field during autumn prevents the soil from drying out due to sunlight and wind[11]. Consequently, the retained moisture dissolves salts more effectively, causing them to migrate deeper into the soil. In fields with less crop residue, the rate of evaporation of moisture from the soil is higher, causing salts to rise to the soil surface[12),13]. This difference in moisture retention may explain the different salt content observed in soybean and corn fields.

The amount of precipitation in 2022 changed significantly from previous years[8]. Firstly, March had 2-3 times more rainfall than the previous two years. In addition, May and June had significantly more rainfall, resulting in significant movement of rapidly soluble salts in the soil. The maximum temperature in May was 33.5ºC and the average temperature was 20.4ºC, 0.6ºC and 0.7ºC lower than in 2020 and 2021, respectively. The temperature in June reached 38.3ºC and 25.2ºC, 2.4ºC and 2.7ºC higher than previous years, respectively. Temperatures remained consistently high during these months, with a maximum temperature of 40.2ºC in July and an average temperature of 27ºC. In August, the temperature was 35.1ºC and 23.4ºC, respectively. Generally, the evaporation rate increases with increasing air temperature. However, in 2022, the distribution of salts at the observed points on the soil surface was influenced by rainfall. In particular, significant precipitation fell on 21 and 22 May, effectively moistening the soil to a depth of 15-25 cm and even deeper.

The salt marsh in the “Lavar” river area also had varieties. On 24 November 2021, the salts came to the surface, forming a crusty and puffy salt marsh[14]. However, a few months later at the same site, the salts did not form a continuous cover but appeared as scattered patches, relatively small. Within the limits of the current study in 2022, changes in salt cover were observed on meadow-sierozem solonchak meadows[15]. In this case, winds play a crucial role in the movement of salts in solonchak landscapes. During the stay at the studied sites, different wind speeds characterized different seasons. Interestingly, it was often observed how the eastern wind direction changed to the western wind direction. It is evident that at the Lavar site, the eastern part of the rugged terrain is dried out by the prevailing winds (Fig. 2). This observation suggests that wind-induced drying of the uneven soil surface leads to a more intense accumulation of salts in the eastern part of the microplots. This salt accumulation, clearly visible on the eastern side of the uneven plots, increases after light rainfall. From 22 to 23 May, 11.9 mm of rainfall resulted in the emergence and gradual increase of salts. Within 7-8 days, the site was almost completely covered with salt (Fig. 3).



Fig. 3: Brown and light colours on crusted solonchak (north of the SVH field).
Source: compiled by the authors.

3.2 Impact of precipitation on salt migration

Salt migration in soil occurs under the influence of precipitation. Increased soil moisture leads to dissolution of soil salts, which causes their downward migration. At the same time, precipitation contributes to surface run-off and a rise in the water table. From March to June 2022, significantly more precipitation occurred. The increased rainfall resulted in a marked increase in vegetation density and height. Notably, despite almost identical air temperatures, the amount of precipitation from January to August 2022 was almost twice the amount of precipitation for the same period in 2021 (Table 2).

In autumn, namely 28 November 2021, a thick, crusty, and puffy salt marsh characteristic of the Lavar salt marsh was observed throughout the site. Figure 1 shows the hard salt surface of this salt marsh with numerous small depressions. These depressions, as seen on the salt marsh surface, are a direct consequence of grazing by domestic animals, especially cattle hooves. It is known that salts are ejected from the underlying puffy horizon during the decomposition of soil-salt crust. At that, formation of microfoci as a result of wind erosion, and especially during cattle grazing, can lead to significant displacement of salts from the downy horizon. This phenomenon was observed when studying solonchaks in spring. In addition, loose salt layers persisted predominantly on the leeward side of the microrelief and near plant bushes (Fig. 2).

Table 2. Average air temperature and precipitation in 2020-2022 (based on Meteostation Shelek data).

Amount per months	Years					
	2020		2021		2022	
	Precipitation amount (mm)	Average air temperatures for the period, ℃	Precipitation amount (mm)	Average air temperatures for the period, ℃	Precipitation amount (mm)	Average air temperatures for the period, ℃
15	73.3	8.3	149	6.9	158.9	8.4
3-5	49.7	14.6	66.7	13.3	128.3	14.6
6-9	22	23.1	11.6	24.4	36.3	22.8
18	95.3	14.3	160.6	13.9	195.2	14.1
19	101.1	14.8	161.2	14.7	197.2	14.8

Source: The national hydrometeorological service of Kazakhstan[8)]

Compared to the autumn period of 2021, carbonate and hydrocarbonate anions increased significantly in 2022, while chloride ions decreased. During the spring of 2022, 72.9 mm of precipitation fell. This cumulative amount exceeded 128.3 mm, exceeding the precipitation levels that fell in 2020 and 2021 during the same period. In addition, 20.7 mm of rainfall occurred in June 2022 [8)]. In spring, areas without salt accumulation were observed at Lavar salt marsh, as shown in Fig. 2. The absence of salts was particularly noticeable on the eastern side, where the distribution of salts was probably influenced by wind and wind-borne rainfall. The east wind played a role in salt removal, and if rain accompanied the wind, both salt removal and dissolution occurred. As a result, the salt crust became thinner and harder compared to the winter condition. By analysing Figure 1 and Figure 2, it was observed that the depressions with sharp edges from animal tracks changed into smoother and shallower depressions. These changes in the shape of the depressions are the effect of the synergy of wind and precipitation from 28 November 2021 to 31 May 2022.

Interestingly, the colouration of the salt marsh is a combination of white, crusty puffy areas and brown areas. Notably, the brown areas represent a firm, hard crust (Fig. 3). In the spring, a thin layer of water (about 1 mm) had accumulated on this section of salt marsh due to past rains. This moisture probably influenced soil processes, resulting in a mosaic of white and brown colours in the salt marsh. The movement of salts directly affected the hardness of the salt crust. Therefore, where the salts

appear white, the crust is characterized as puffy and puffy, while brown-coloured areas have a harder crust. Salt availability is influenced by periodic periods of flushing and run-off due to weather conditions, making the assessment of saline soil conditions difficult without space monitoring. Saline conditions on the soil surface were intermediate, as the amount of salts decreased again in June and October (Fig. 4). During this period, there were noticeable changes in vegetation composition. The vegetation became more diverse and larger.



Fig. 4: Surface of the Lavar solonchak (10/27/2022). Source: compiled by the authors.

Changes in the content of water-soluble salts were observed during three years, in the context of seasons. For convenience of comparison, data of salt content changes in solonchak meadow crusty-puffy soil (mg/eq) were grouped into separate tables by ion content (Tables 3-5). Analyses of samples in the upper soil layers show significant differences.

The manifestation of soil surface colour dynamics due to the presence of readily soluble salts highlights the potential for long-term research using Google Earth data. The archive of space images is extensive. The development of automated methods of soil interpretation from satellite data allows monitoring of sites during several growing seasons and in different years[16]. Various aircrafts are used for interpretation of vegetation residues. Visual land cover interpretation involves the extraction of direct features such as colour, image pattern, crop size and shape. Google Earth images allow effective interpretation of saline soils based on their colour. During monitoring studies in a reference plot, the colour of saline soils changes while the image pattern, size, and shape of the plot remain constant[17].

Table 3. Seasonal dynamics of anion Cl^- of meadow crusty-puffy solonchak, mg/eq.

Depth, cm	Date of selection						
	28.04	**26.05**	**24.06**	**26.07**	**20.09**	**29.10.21**	**05/23/22**
0-0.5	24.17	1.69	190.69	256.91	162.15	430	1.9
0.5-1	7.13		38.55	54.94	53.38	198	2.5
1-10	5.61	12.66	6.63	8.69	20.69	255	1.4
10-20	4.19	3.64	6.94	5.99	14.29	6.1	1.4
30-40	2.7	2.31	2.82	3.36	2.59	16	1

Source: compiled by the authors.

Table 4. Seasonal dynamics of SO_4^{2-} anion of meadow crusty-puffed solonchak, mg/eq.

Depth, cm	Date of selection						
	28.04	**26.05**	**24.06**	**26.07**	**20.09**	**29.10.21**	**05/23/22**
0-0.5	1314.61	278.44	699.18	637.78	732.02	16.25	18
0.5-1	1032.89		44.01	38.61	198.72	17.05	18.25
1-10	54.4	41.03	24.83	22.74	37.68	17.55	16.5
10-20	20.81	18.47	22.88	19.44	33.54	18	14.25
30-40	19.68	18.77	17.27	16.82	19	19.25	10.75

Source: compiled by the authors.

Table 5 Seasonal dynamics of Na^+ cation of meadow crusty-puffy solonchak, mg/eq.

Depth, cm	Date of selection						
	28.04	**26.05**	**24.06**	**26.07**	**20.09**	**29.10.21**	**05/23/22**
0-0.5	1307.66	261.8	795.7	789.2	815.3	433	22.29
0.5-1	1021.78		60.87	62.61	208.7	204.6	27
1-10	43.48	39.6	17.3	15.56	37.74	262	21.92
10-20	8.66	6.43	16	10.1	30.7	20.04	17.67
30-40	4.01	3.6	5.04	5.96	5.43	31.13	12.35

Source: compiled by the authors.

3.3 Remote sensing and field observations

Experimental studies in the Ile Alatau region demonstrate the dependence of the upward movement of salt to the soil surface on the level of aridity. Winds and precipitation are the priority influencing factors. Salt rise is especially noticeable in spring. The process is explained by the significant content of easily soluble salts at a depth of 0 to 30 cm[18]. Precipitation and winds also have an influence. The surface of the Lavar salt marsh, as evidenced by Google Maps imagery, had the same salt colouration in both spring and autumn in 2021 (Fig. 5). However, when compared to a photograph taken in June 2022 (Fig. 6), the difference becomes apparent. The once solid white expanse has been transformed into areas devoid of surface salt. Only isolated patches of salt are still visible in this region. It appears that by this time, the white salt that covered the soil surface during the summer and autumn seasons has virtually disappeared (Fig. 6). Interestingly, neighbouring areas also show differences in colour between the 2021 and 2022 Google Maps images. It is reasonable to identify the relationship of this difference with the identified presence of salt accumulation around the Lavar salt marsh. In other words, the white salt plaque areas on the 2021 Google Maps become almost invisible on the 2022 Google Maps photo.



Fig. 5: Surface of "Lavar" solonchak on Google map (05.2021).



Fig. 6: Surface of "Lavar" solonchak on Google map (06.2022).

The results of photo analytics show that the fact that easily soluble salts have moved across the surface soil layer in the foothill part of Il-Alatau is clearly visible on Google Maps images taken in 2021 and 2022. The Google Maps image taken in June 2022 shows that the salt level has decreased again. The qualitative condition of land plots is determined based on information from soil, geobotanical, soil-reclamation and other surveys[19]. According to this classification, soils used as part of arable land and soils with weak salinity are considered satisfactory, and soils with medium and strong salinity belong to the unsatisfactory category. This approach creates conditions for assessing the degree of salinity of soils and their corresponding locations[20]. An analytical comparison of the data obtained with the 2017, 2018 and 2019 maps shows that in previous years even fewer salts were visible on the soil surface in summer and autumn than in June 2022. Thus, the synergy of field expeditions, remote sensing and chemical survey methods provides a comprehensive understanding of the processes occurring in saline soils. The noticeable variability of reflectivity of some solonchaks was observed, which allowed categorizing them as highly saline soils in the areas that were studied. The availability of informative data of remote and ground measurements allows establishing correlation between weather conditions and reflectivity of solonchaks.

4. Discussion

4.1 Integration and optimization of observational methods

The trend of actualization of scientific and practical interest in research on the possibilities of joint ground and satellite observations for remote sensing of soils is related to the global process of transformation towards sustainable development.

Numerous scientific studies confirm the fact of the necessity of convergence of ground and remote sensing of soils[21)-23)]. Modern scientists, in particular, H. Ma et al.[24)] propose in their studies to position such an approach to probing as optimal. According to the researchers' conviction, the proposed concept allows significantly improving the quality of research. This study not only supports but also expands upon the conclusions reached in the second study by demonstrating the practical applications and benefits of remote sensing in understanding and managing soil conditions, specifically salinity. This further validates the critical role of integrating different remote sensing products with ground observations to advance soil science research and its applications in environmental management and policy-making.

4.2 Seasonal and spatial dynamics of saline soils

Integrating disparate findings from various studies is pivotal for a comprehensive understanding of soil dynamics. The scientific search of Y. Deng et al.[25)] indicates that salts appear on salterns most intensively and

almost without admixture in spring at high humidity and moderate air temperature; high summer temperatures bind salterns with a crust, preventing surface accumulation of salts. The scientist at the same time states that rainfall during the warm season favours the movement of salts to the surface. In continuation, Q. Yuan et al.[26] describe the surface of soils covered with a strong salt crust in the wet season, i.e., mainly in spring. At the same time, the sites studied in the current study had salt crust on the soil surface in both autumn and spring. At the same time, it was found that salts on the surface can disappear both due to migration into the soil and as a result of aeolian transport[27),28]. Thus, the results of this study partially contradict the conclusions of earlier experiments, and therefore require further scientific development.

Among modern approaches to soil research and monitoring, D. Radočaj et al.[29] prioritize the combination of ground and remote sensing. The authors emphasize that remote sensing is indispensable for tracking changes in land cover and detecting subtle environmental changes over large areas. They also note the economic advantages of using open data from global satellite missions. This study leverages these technologies to efficiently monitor vast agricultural landscapes in Kazakhstan, which would otherwise be logistically challenging and costly. The researchers' conclusions are identical to the results of the current work; it is only necessary to emphasize the synergy possibilities of both methods in the aspect of high efficiency. Such an idea was partially considered by O. Dubovik et al.[30], who propose to include soil remote sensing programmes into nationwide observation systems. It is necessary to actualize this direction for Kazakhstan. Remote sensing of the Earth (RSE), according to P. Abbaszadeh et al.[31], is the most operative and technological option for soil monitoring. Scientists foresee the potential of long-term studies as particularly important.

The results of the team of scientists led by D.B. Upadhyaya et al.[32] focus on the possibilities of analysing the spatial variability of soil properties using combined ground and satellite observations for remote sensing. The scientists state that it is necessary to take into account a number of aspects that affect the spatial dynamics of soil properties. These include, firstly, peculiarities of geographical location and climatic factors (temperature, precipitation, air humidity)[33),34]. The results of scientific searches by A.F. Feldman et al.[35] testify to the need to study the peculiarities of spatial dynamics and variability of soil properties, which determine the level of their resistance to degradation, while convincing in the effectiveness of geostatistical analysis. The latter, as parried by scientists M. Khaki et al.[36], optimizes the process of prediction and interpolation of soil properties dynamics, which is the basis for the formation of soil variability maps. In the work of the researchers, as in the current study, it is proposed to maximize the use of the available potential of remote sensing methods.

4.3 Emerging technologies in soil monitoring

In order to advance soil monitoring approaches, researchers have increasingly resorted to developing technology to improve geographical resolution and temporal precision. The researchers C. Zheng et al.[37] draw attention to the possibilities of using unmanned aerial vehicles for monitoring. The high spatial resolution of the data, according to the scientists, as well as the unprecedented possibility of imaging at a given time allow effective assessment of soil parameters. They propose to use data from standard drones to solve separate tasks of mapping, soil monitoring and assessment of soil dynamics. The advantage of this approach, according to the researchers, compared to satellite technologies for work at the level of individual locations, is the possibility of obtaining images at the necessary moment when the soil surface is open for observation[38)-40]. It is difficult to disagree with the scientists' conclusions, as soil imagery data from unmanned aerial vehicles can be positioned as a more affordable alternative to expensive satellite observations for effective mapping and implementation of local soil monitoring[41),42]. Many experts, in particular S.L. Ustin and E.M. Middleton[43], as well as S.B. Duan et al.[44], are working on defining an algorithm for the formation of digital soil maps. For instance, the method of using ground-based measurements for calibration, as described by S.L. Ustin and E.M. Middleton[43], mirrors the approach used in the current study to calibrate soil salinity maps with in-situ data. According to the scientists, through the potential of digital mapping, the formation of information bases of soil research, data dynamics processes and interpretations, and risk assessment becomes available. These developments not only make it easier to inventory soil resources in real time, but they also enable well-informed decision-making on land management techniques.

The concept of maximum intensification of interaction between terrestrial and remote sensing methods, proposed in the study, according to the belief of most modern scientists, allows forming accurate multifactor models, as well as an interactive system of land resources management. Despite the effectiveness of theoretical and methodological developments and increased interest in the research topic in scientific circles, there is a deficit of experimental and practical studies of functional capabilities of convergence of ground and satellite observations for remote sensing of saline soils. Thus, deepening of fundamental vector studies and practical development of fundamentally new algorithm for remote sensing of soils is a priority direction of the studied branch in Kazakhstan.

5. Conclusions

In the course of the study, the possibilities of joint ground and satellite observations for remote sensing of saline soils of south-eastern Kazakhstan were analysed. With the help

of implementation of experimental method saline meadow and strongly saline meadow-serozems located within Enbekshikazakh district of Almaty region, as well as salt composition of soil under soybean and maize crops on the territory of "Baiserke-Agro" LLP in Talgar district of Almaty region were studied. In the process of the study, the change of salt content in the upper layers of soil was studied. It was identified that the presence of salts is influenced by periodic periods of washout and run-off caused by weather conditions, which makes the assessment of the state of saline soil difficult without space monitoring. The experiment found that fields with less crop residues have a higher rate of evaporation of moisture from the soil, which causes salts to rise to the soil surface. This difference in moisture retention may explain the different salt content observed in soybean and maize fields. The decisive role of winds as well as increased soil and air temperature in salt transport in saline landscapes was also noted.

In the course of the research, the possibility of correlation of salt content indicators in different years was studied using Google Maps, the world trends of modern remote sensing of the Earth were analysed, as well as the requirements to satellite information specific to the industry under study. It is proved that information support of the sustainable development concept implementation is carried out through the organization of remote monitoring of mandatory and specific indicators of territories, and remote sensing of soils is positioned as an integral component of monitoring. The perspectivity of the proposed concept on creation of variability of use of potential of joint ground and satellite observations for probing saline soils of south-eastern Kazakhstan is determined. For example, development of automated methods of soil interpretation by satellite data allows monitoring of sites during several vegetation periods and in different years. The system of remote land monitoring provides an opportunity to carry out instrumental control of the reliability of statistical and monitoring information that is accumulated over a long period of time. The strategy of remote sensing development in Kazakhstan should be based on the available scientific, technical and production potential with maximum use of international experience.

However, it is critical to recognise certain significant limits that determine the context and bounds of the data and findings. The research concentrated on meadow solonchaks, heavily solonchak meadow-serozems, and agricultural fields in particular regions of the Almaty region in Southeastern Kazakhstan. The findings may not be applicable to other soil types or areas with different climates. Furthermore, the collection of ground truth data was confined to certain places and depths, while soil salinity can vary widely across regions.

The results of the current study indicate the promising innovation conceptualization of the strategy under study, which shows significant efficiency while being positioned as economically viable. For its development, it is necessary to deepen fundamental vector studies, as well as practical development of a fundamentally new algorithm of joint application of ground and satellite observations for remote sensing of saline soils of south-eastern Kazakhstan. The proposed approach maximally corresponds to the goals of sustainable development of the republic.

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