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The Operational Method of Conducting Large-Scale Salt Survey and Drawing Salinity Level Maps of Irrigated Lands of the Akdalinsky Array

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Nowadays, the use of satellite images and digital soil mapping techniques become increasingly important in soil studies. In the world practice, the use of space monitoring of soil salinity is currently one of the most topical areas of the soil science. In this regard, the main objective of this work is to develop an operational method for large-scale salt survey and to make the corresponding map of soil salinity based on the research of connection patterns between soil salinity levels and spectral properties of a satellite image, using the methods of space monitoring and digital soil mapping. The object of the study are soils of the southern part of the Akdalinsky irrigation array. The goal of the work is to develop an operational method of large-scale salt survey of soil based on the research of connection patterns between soil salinity levels and spectral properties of satellite images. This work is conducted with the use of both traditional ground-based and space methods of soil research. Based on the study on the connection between spectral properties of satellite images – vegetation indices and the ratio of the different bands QuickBird images and electrical conductivity of soils, we revealed the possibility of using these indicators as interpretive signs of soil salinity levels. At the same time, it was found that the tone of the image in separate bands of a QuickBird image is sufficiently informative to assess soil salinity; the most informative ratios appeared to be the ratios of the tones of individual shooting bands and vegetation indices. Using the ratio values of the image tone in different bands and the values of vegetation indices, we compiled regression equations between the value of electrical conductivity, measured in the field, and the spectral properties of different bands of a QuickBird image. Statistically reliable regression equations were obtained for barley and wheat crops. At the next stage, with the use of the obtained regression equations in the GIS environment, we charted a map of soil salinity under crops of barley and wheat. It should be noted that for alfalfa and rice crops, we failed to obtain statistically reliable regression equations that describe the dependence of the spectral properties of a QuickBird image with soil salinity and this is mainly due to the timing of satellite imagery. More careful selection of the shooting time, which may be the subject of research at the next stages of the works, can correct the situation. The main conclusion is that the success of the developed approach is largely predetermined by the timing of shooting and, accordingly, the timing of the field sample survey.

Key words: Salinization, Satellite images, Vegetation indices, Decoding of satellite images, Soil salinity map.

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Nowadays, the use of satellite images and digital soil mapping techniques become increasingly important in soil studies. The use of similar "space" methods in carrying out soil surveys compared to the traditional ground-based way, allows achieving maximum performance, relative cheapness and accuracy of cartographic material. Space-monitoring techniques in soil and reclamation research is particularly promising in the research on such dynamic properties as secondary salinity and salt regime of soils.

In the world practice, the use of space monitoring of soil salinity is currently one of the most topical areas of the soil science. This is confirmed by the numerous scientific publications devoted to the use of satellite images in large-scale salt surveys and corresponding salt maps (Konyushkova, & Vyshivkin 2009; Konyushkova, 2010; Lebedeva, *et al*., 2009; Gabchenko, 2008). In addition, in 2004, within the framework of the International Society of Soil Scientists, a working group "digital soil mapping" was established, which, along with other issues, engages in the development of remote sensing methods of assessing soil salinization (Lagacherie, *et al*., 2007; Hartemink, *et al*., 2008).

In Kazakhstan, the development areas of space monitoring of soil salinity are rudimentary, similar works are carried out poorly or are of exploratory nature. However, traditional methods of large-scale salt survey and mapping of soil salinity are practically never used mainly due to the high cost. Therefore, currently the main problem of irrigated areas is the lack of reliable and timely data on their soil-reclamation condition and almost universal development of secondary salinization associated with it.

The lack of operational methods of large-scale survey (mapping) of soil salinity makes it impossible to conduct continuous monitoring of soil-reclamation conditions. That is, in these circumstances, it is impossible to detect changes in the transformation direction of the irrigated soils.

In this regard, the main objective of this work is to develop an operational method for large-scale salt survey and to chart the corresponding map of soil salinity based on the research of connection patterns between soil salinity levels and spectral properties of a satellite image, using the methods of space monitoring and digital soil mapping (on the example of the Akdalinsky irrigation array).

METHODS

Area of the research

The object of the research is the soil mantle of the southern part of the Akdalinski irrigation array, which is located at the head of the ancient Akdalinsky river delta of the Ili River. Geomorphologically, in the lower reaches of the Ili river the valley of the Ili River, the modern delta of the Ili River, and the ancient delta (Akdala – Bakanas) and the southern coast of Lake Balhash (Korniyenko, *et al*., 1977) are distinguished. Ancient Akdala – the Bakanas delta, where the research object is situated, occupies a small part of the lower reaches of the Ili River. The Akdala part is the most ancient; it starts from the Tasmurunsk Mountains and passes with a narrow strip, elongated in the north-wet direction, it connects with the head part of the Bakanas Dekta between the sands of Kyzyl-Dzhingil and Sary-Ishik Otrau near the Bakanas village (Figure 1).

Formation of the soil and vegetation mantle of the ancient delta is closely linked with the history of the formation of the river delta. A number of researchers believe that initially the whole Balkhash depression was a sandy desert, and then the Ili River disembogued its waters into it and as a consequence of increased moisture, wetland and meadow landscape formed in the depression (Stegmann, 1946; Dzhurkashev, 1972). The combination of the desert regime and increased humidity created an exceptional contrast and diversity of soil and vegetation cover of the lower reaches.

Here, the leading crop is rice. The crops accompanying its rotation are also cultivated. They are alfalfa, which is an indispensable crop, preceding rice, as well as such nurse crops as spring wheat and barley. On the array, the main source of irrigation is the Ili River. The average long-term annual consumption of the Ili River is 472 m^3/second (Ivanov, *et al*., 1973). The Ili River belongs to a mixed (snow-ice- rain and phreatic) supply type. The water intake of the Ili River is carried out by two separate irrigation systems: Tasmurunsk and Bakanas. Inter-farm irrigation network of the Akdalinsky array is presented by the Tasmurunsk main canal passing into the Akdalinsk and Bakanas canals. The water supply network is represented by different sprinklers of the open type, padded in natural soil (Report on the reclamation state of the irrigated lands of the Akdalinsky irrigation array of the Balkhash district of Almaty region for 2004, 2004). The water drainage network of the inter-farm part of the Akdalinsky system includes two manifolds – the Main waste and the Congregative. Drainage waters are discharged directly from rice fields by various field drain and group wastes.

On the Akdalinsky irrigation array, mainly takyr soils with different salinity and alkalinity have been developed for rice cultivation. Salinization of these soils is of relic nature, inherited from the past hydromorphic soil formation stages. As a result of the long term use for rice cultivation, these soils evolved into irrigated (rice) marsh soils, according to the classification of soil scientists of Kazakhstan. Changes in soil under this crop are associated with the specific conditions of its cultivation – periodic long-term flooding and drying (Borovskyi, *et al*., 1959; Karazhanov, *et al*., 1973; Volkov, 1983).

The predominant type of salinization is chloride-sulphate and sulphate-chloride with the presence of normal soda. All soils of the array are carbonate and characterized by high alkalinity (pH 8-9). Water-physical, physical, physico-chemical properties of soil depend on the degree of salinity and alkalinity (Kornienko, *et al*., 1977). In general, in rice-marsh soils soil formation processes are very intense, as these soils are characterized by a fairly high rate of mobilization and migration processes. In this regard, monitoring of a soil fertility level of rice soils should be conducted regularly and with a wider range of determined properties.

Methods of the research

When carrying out this work, we used both traditional ground-based and space methods of soil research. The work was carried out by means of space and ground survey, which is synchronous by place and time, of soils on the research area. For this purpose, by means of ground reconnaissance survey of the array, we chose subsatellite areas, which are contrasting by soil salinization, and ordered satellite imagery from the QuickBird satellite in the panchromatic mode with a spatial resolution of about 0.6 metres on the ground and in the multispectral mode (4-band recording) with a spatial resolution of about 2.5 metres on the ground.

Ground surveys were conducted according to the “All-union manual on conducting soil surveys and charting large-scale soil maps of land use” (All-union manual on conducting soil surveys and charting large-scale soil maps of land

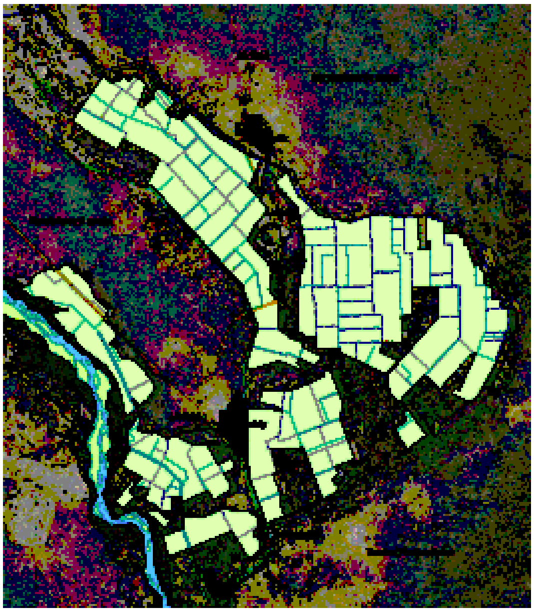

Fig. 1. Scheme of the research object

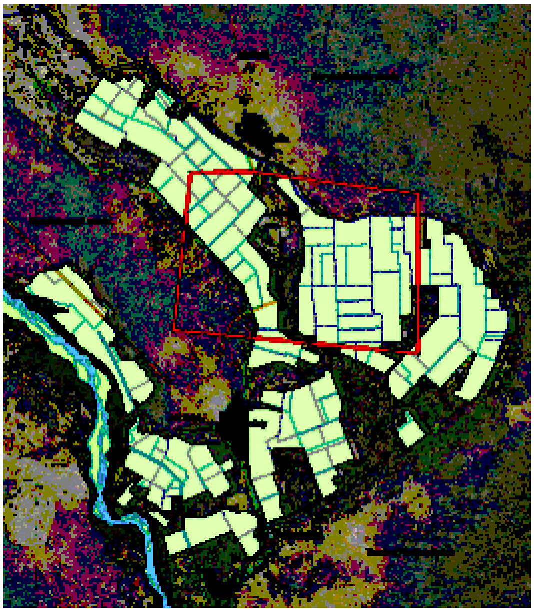

Fig. 2. Allocation scheme of the test subsatellite area

use, 1973) and Guidelines for conducting large-scale soil survey in the Kazakh SSR (Guidelines for conducting large-scale soil survey in the Kazakh SSR, 1979). When using the space method, we took the method of Pankova, Mazikov (Pankova, & Mazikov, 1985) as a basis, and complemented it with the works of her students and Rukhovich D. (Rukhovich, 2009), Konyushkova M. (Konyushkova, 2010).

We would also like to mention the approaches to the choice of methods for decoding images with the purpose of determining the extent of soil salinity. There are direct and indirect methods of decoding images. Many researchers, who had studied the problems of decoding soils, came to the conclusion that the assessment of soil salinity by the images of open soil, not masked by vegetation, is difficult due to the low contrastive reflectivity of both saline and non-saline soils (Pankov, & Rukhovich, 1999; Korolyuk, & Shcherbenko, 1994; Ben -Dor, & Banin, 1995; Dwivedi, 1996; Nield, *et al*., 2007). Therefore, decoding is basically carried out by indirect signs. Decoding of crop vegetation, features of agricultural crops state, that reflects the quality of soil, its fertility, as well the structure of soil mantle, is essential for the recognition of soil properties. Therefore, in our work we also used indirect signs – NDVI values of rice crops and accompanying crops, the ratio of the image tone of satellite images on different bands for decoding the level of soil salinity.

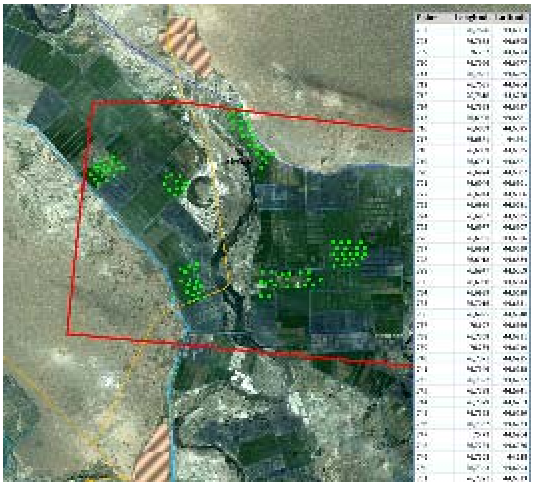

Fig. 3. Measurement points of soil electrical conductivity values and NDVI of crops on the test sites and the database fragment with points' coordinates

To decode the satellite images we used the regression analysis of the connection between the value of electrical conductivity, measured in the field, and the data of space survey. Regression analysis was carried out in the STATISTICA 7.0 programme. We used two sets of predictors as independent variables – vegetation indices, describing the state of the vegetation, and the ratio of bands, not related to vegetation indices. Regression analysis was performed separately by crops for each studied soil layer (0-20 cm, 20-50 cm, 50-100 cm).

In terms of methodology, the work is based on the concept of the modern genetic soil science of soil being a very complex system that has an infinite variety of internal and external functional relations with a very complex multi-level organization structure. The study takes into account the provisions of the hierarchical series of successive levels of the structural soil organization; each level requires specific methods

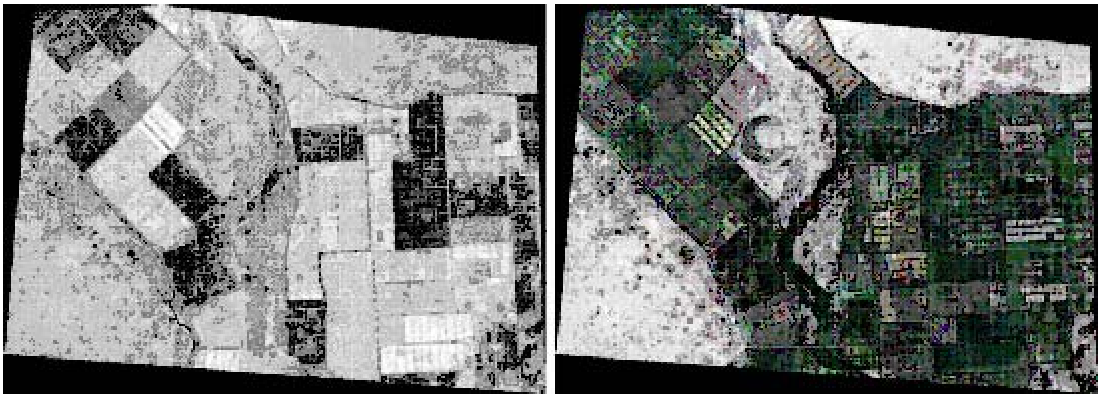

Fig. 4. Panchromatic and synthesized image of the study area on obtained satellite images

and approaches to research, monitoring and control. Any breach of the internal and external functional connections at any level would lead to a breach of the normal processes of soil formation and reduction in its fertility and crop yields. In this case, an increase in soil salinity will undoubtedly affect the level of soil fertility and the yields of rice and accompanying crops. In addition, these indicators will affect the value of the calculated vegetation indices and the spectral properties of satellite images correspondingly. That is by analysing reversed patterns of changes in the spectral properties of satellite images and vegetation indices, we can evaluate a change in the level of soil salinity.

Thus, we can say that in order carry out the work, all available techniques and methodologies of soil research are applied and they

Fig. 5. The result of the crop classification of uniform arable arrays by the colour composite within the grid

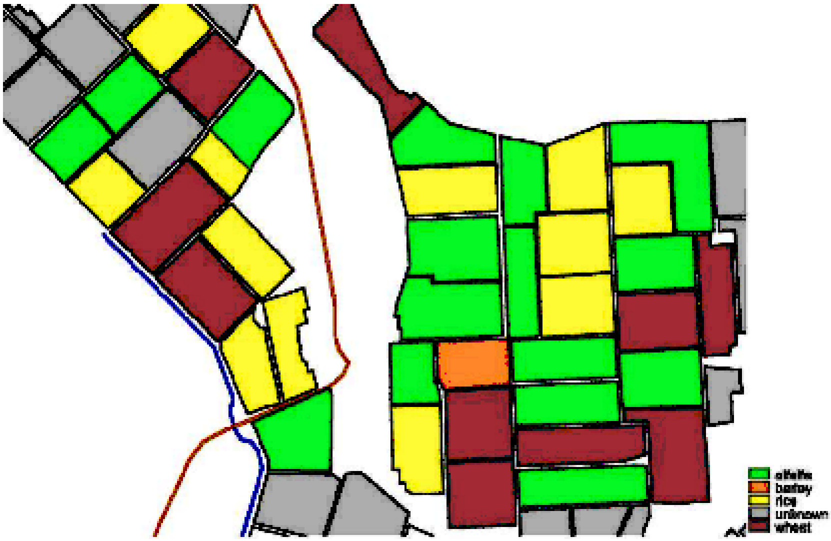

Fig. 6. The map of crops location (see the legend on Figure 3)

will be used to address the issue of establishing an operational method for conducting the large-scale salt survey and charting a map of soil salinity.

RESULTS AND DISCUSSION

Selection of the test site and timing of the terrestrial and satellite imagery of the test sub-satellite area

At the first stage of work, via the ground reconnaissance survey of the array area with the simultaneous use of archival satellite images, archival materials and allocation schemes of crops in 2013, available at the Institute of Soil Science, we chose the test subsatellite area of 100 km^2, which is contrasting by soil salinity and crop composition. The boundaries of the selected area (red lines) are shown in Figure 2.

As we have already noted, the leading crop on the Akdalinsky irrigation array is rice. Alfalfa is also sown as an indispensable crop, preceding rice, as well as spring wheat or spring barley as a nurse crop on the alfalfa crops of 1 year. It is also known that the beginning of the mass sowing of these crops occurs at different times. Spring grain crops and alfalfa are sown early in the first half of April and the massive sowing of rice begins only at the beginning of May. In addition, NDVI of any plant can be measured by both ground and space-based method only when the plant begins to cover the surface of the earth sufficiently. Moreover, in spring time under the conditions of the southern Balkhash region, there are often many overcast cloudy days, which drastically reduces the information content of satellite images. Therefore, the timing of survey is quite important.

Based on the average long-term meteorological data of the Bakanas weather station and prior works of the Institute of Soil Science, last ten days of June were selected as a period of both space and ground surveys. At the same time, it had been assumed that at this time, spring wheat and barley would be in the paniculation phase, alfalfa – at the beginning of the flowering phase (first cut), and rice – at the beginning of tillering, i.e. for crops of all cultures there would be an opportunity to measure NDVI by both ground and space-based techniques. Selection of only one period of space imagery was also dictated by financial capabilities of the project, i.e. the project budget was simply not enough to order satellite images of the second period. Ideally, it would have been necessary to order satellite images for three periods separately for each of the leading crops – wheat, alfalfa and rice.

Table 1. Correlation coefficients between NDVI values of crops and the value of crop soil electrical conductivity at different depths

Crop	Depth of conductivity measurement, cm		
	0-20	20-50	50-100
Alfalfa	-0.21	-0.19	-0.05
Rice	-0.35	-0.32	-0.30

Table 2. Parameters of the multiple regression model for determining the conductivity under barley crops at a depth of 0-20 cm

	0-20 (%) – Param.	0-20 – Std.Err	0-20 (%) – p
Intercept	2890.04	603.9474	0.000113
ndvis	2239.94	455.7152	0.000084
sqrt	-139.69	26.0714	0.00003
tndvii	-3763.96	789.0666	0.000117

Table 3. Parameters of the multiple regression model for determining the conductivity under barley crops at a depth of 20-50 cm

	20-50 (%) – Param.	20-50 – Std.Err	20-50 (%) – p
Intercept	-190.85	44.00412	0.000355
b r	62.561	10.83243	0.000015
qb3	0.926	0.21505	0.00038
irr	-36.578	10.17731	0.001934
sqrt	127.329	38.42224	0.003649

Table 4. Parameters of the multiple regression model for determining the conductivity under barley crops at a depth of 50-100 cm

	50-100 (%) – Param.	50-100 – Std.Err	50-100 (%) – p
Intercept	-730.403	248.2844	0.008372
ndgr	760.396	259.0583	0.008494
sqrt	-64.567	19.783	0.004085
tndvii	326.17	107.5763	0.006858
r_g	553.143	197.0517	0.011248

After defining the period of survey an order to conduct satellite imagery was issued, it was timed to coincide with the dates of the fieldwork – the last decade of June. We ordered satellite images of high resolution from the QuickBird satellite in the panchromatic mode with the spatial resolution of about 0.6 metres on the ground and in the multispectral mode (4-band survey) with the spatial resolution of about 2.5 metres on the ground. The contract with the company "Sovzond" (Russia) was concluded to receive images.

Then, in early June, we started the ground survey of the test site area. Conductivity, soil temperature and the value of NDVI were determined. Measurements of the electrical conductivity and soil temperature at three calculated depths (0-20, 20-50 and 50-100 cm) were carried out by a field portable instrument "Progress T1". NDVI measurements of spring wheat and barley, alfalfa and rice were also carried out with the help of a field portable instrument "Green Seeker". In addition, at each point soil samples were collected from three calculated depths for chemical analysis by drilling wells.

Table 5. Parameters of the multiple regression model for determining the conductivity under wheat crops at a depth of 50-100 cm

	50-100 (%) – Param.	50-100 – Std.Err	50-100 (%) – p
Intercept	12.9617	3.965499	0.004041
qb3	-0.0758	0.015663	0.000114
b_g	-13.9984	5.51408	0.020034

Measurement points of electrical conductivity and soil temperature, NDVI of crops and the database fragment with points' coordinates are shown in Figure 3.

We received satellite images from the QuickBird satellite in the panchromatic mode with the spatial resolution of about 0.6 metres on the ground and in the multispectral mode (4-band survey) with the spatial resolution of about 2.5 metres on the ground.

Quality check of the images showed that they fully comply with the terms of the order – no cloudiness, spatial resolution corresponds to the one ordered, the number of spectral bands also corresponds to the one ordered. Pictures are orthorectified and linked geographically. Images are delivered in the GEOTIF format.

At the next stage, obtained NDVI values of crops were partially used to determine the correspondence between the selected classes of arable soils of the array and the studied crops (crops decoding).

Fig. 7. Soil salinization in the layer of 0-20 cm (nezas – non-saline, slabo – low saline, sredne – medium saline, silno – highly saline, och_silno – very highly saline, by FAO, white – no data)

The correspondence between the class of culture and crops of wheat, the class of culture and crops of alfalfa was determined. The field measurements of soil electrical conductivity at the three depths (0-20, 20-50 and 50-100 cm) was used for determining the connection between distinguished heterogeneity of crops development and heterogeneity in soil salinity of the study area.

Data analysis of satellite imagery and drawing a soil salinity map of the test sites

At the second stage of the work, we carried out the analysis of obtained satellite images. First of all, on the territory of the research a grid of uniform arable arrays was created. Within its boundaries, we carried out supervised classification of pixels by QuickBird satellite data to distinguish the fields occupied by different cultures (decoding of cultures). It should be noted that the satellite survey was conducted at the time of field research. As we have already noted, at the time of the survey, four crops were cultivated on the study area – barley, wheat, rice and alfalfa. During visual analysis of different bands combinations of QuickBird satellite data we

Fig. 8. Soil salinization in the layer of 20-50 cm (see the legend on Figure 5)

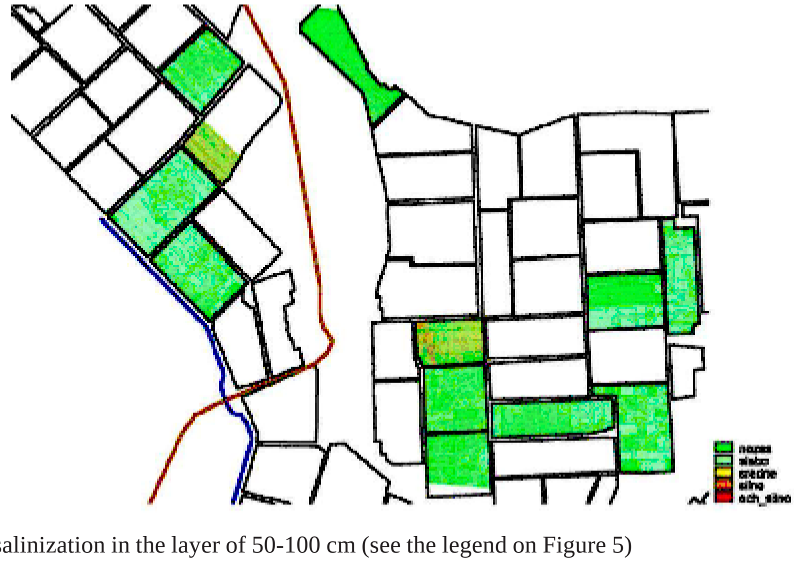

Fig. 9. Soil salinization in the layer of 50-100 cm (see the legend on Figure 5)

revealed that the most distinguished crop among all others was rice The supervised classification allowed isolating arable arrays with this crop from the arrays, occupied by other crops sufficiently well. It proved to be difficult to distinguish between the other crops by the images of the analysed period. Visually, their crops at the time of survey did not differ from each other. The most significant confusion in the classification was observed between alfalfa and wheat (Figure 5).

Due to the fact that the automated crop separation by the satellite data used in the work, proved to be insufficiently reliable, the map of crops location was drawn on the basis of field data (Figure 6).

To some extent, we associate the lack of reliability of automated decoding of crops location by space images with cane weediness of crops, which obscures the vegetation indices of these crops. By the time of satellite imagery, the vegetation indices managed to develop the biomass of aboveground part, which is sufficiently high. Hence the conclusion that the timing of satellite imagery must be selected individually for each crop.

Then separately for fields with the culture of the same type, we conducted analysis on the possibility of charting digital maps of soil salinity based on the regression analysis of the dependence of the soil electrical conductivity value from the NDVI values of crops.

The results of a preliminary analysis of the field survey data on soil salinity showed no significant correlation between the NDVI values of crops measured in the field, and the value of the electrical conductivity at different depths (Table 1).

Therefore, to determine the models that form the basis of salinity maps by the QuickBird satellite data, we used the same approach as for the SPOT satellite data in 2012.

This approach was that we recovered the tone values of the satellite images, obtained in different recording bands, for points with the field studies data on conductivity in the GIS. After that, we additionally calculated the values of the image tone ratio in different bands and several spectral (vegetation) indices. Vegetation index is an index which is calculated as a result of the operations with different spectral ranges (bands) of an image and which is associated with the vegetation parameters in a given pixel of the image. The effectiveness of these indices is determined by reflection characteristics, mainly they are derived empirically.

Then, these data along with the reflection values in certain spectral bands was used to construct a regression between the electrical conductivity value, measured in the field, and space images data.

Predictors used for the regression analysis can be divided into two groups:

1. Vegetation indices, describing the state of the vegetation:

NDVI = (Band4-Band3)/(Band4+Band3);
IR_R = Band4/Band3;
SQRT = *J(Band4/Band3);*
VEGI = Band4-Band3;
TNDVII = *J{{Band4-Band3)/{Band4* + *Band3))* + *0,5*;
GNDVI = (Band4-Band2)/(Band4+Band2);
NDGR = (Band2-Band3)/(Band2+Band3);

2. The ratio of the image bands, not related to vegetation indices:

B_G = Band1/Band2;
R_G = Band3/Band2;
B_Inf = Band1/Band4;
B_R = Band1/Band3;
Inf_G = Band4/Band2.

It should be noted that at this time the GSI index was added to the list of vegetation indices. The GSI index is calculated by the following formula:

GSI = (qb3-qb1)/(qb1+qb2+qb3),

where qb1, qb2, qb3 are corresponding bands of the QuickBird shoot.

Regression analysis was performed separately by crops for each studied soil layer (0-20 cm, 20-50 cm, 50-100 cm).

In the course of regression analysis for fields sown with barley, reliable regression ratios were obtained for all the studied depths. Model parameters are presented in Tables 2, 3 and 4.

In the course of the regression analysis for the fields under alfalfa and rice, we did not obtain reliable regression ratios for none of the depths. As we have already pointed out, this is due mainly to the timing of shooting. For example, at this time the rice had not fully managed to close the water surface, which distorts spectral properties of an image of rice crops. Alfalfa was only in the early regrowth phase at the time of shooting, this also largely distorts the spectral properties of satellite images of alfalfa fields.

At the next stage, obtained regression equations were used in GIS for drawing maps of soil salinity. As a result, soil electrical conductivity maps were charted which were then transformed into the maps of salinity in terms of FAO. Maps were charted separately for wheat fields and barley fields, and then were presented, where possible, in a single map of soil salinity. Results for individual layers of soil are shown in Figures 7-9.

Thus, as a result of the joint analysis of field data and QuickBird satellite information, we charted maps of soil salinity of the study areas in the layers of 0-20, 20-50 and 50-100 cm. It should be noted that the selected survey period did not allow carrying out automatic separation of agricultural crops. We managed to get reliable models, describing soil salinity, only for barley crops (for all the analysed layers) and wheat crops (only for the 50-100 cm layer).

The main conclusion is that the success of the developed approach is largely predetermined by the timing of shooting and, accordingly, the timing of the field sample survey.

CONCLUSIONS

Based on the study on the connection between spectral properties of satellite images – vegetation indices and the ratio of the different bands QuickBird image and electrical conductivity of soils, we revealed the possibility of using these indicators as interpretive signs of soil salinity levels. At the same time, it was found that the tone of the image in separate bands of a QuickBird image is sufficiently informative to assess soil salinity; the most informative ratios appeared to be the ratios of the tones of individual shooting bands and vegetation indices.

Using the ratio values of the image tone in different bands and the values of vegetation indices, we compiled regression equations between the amount of electrical conductivity, measured in the field, and the spectral properties of different bands of a QuickBird image. Statistically reliable regression equations were obtained for barley and wheat crops.

At the next stage, with the use of the obtained regression equations in the GIS environment, we charted a map of soil salinity under the crops of barley and wheat.

It should be noted that for alfalfa and rice crops, we failed to obtain statistically reliable regression equations that describe the dependence of the spectral properties of a QuickBird image with soil salinity and this is mainly due to the timing of satellite imagery. More careful selection of the shooting time, which may be the subject of research at the next stages of the works, can correct the situation.

The main conclusion is that the success of the developed approach is largely predetermined by the timing of shooting and, accordingly, the timing of the field sample survey.

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