REMOTE ASSESSMENT OF FACTORS OF SPATIAL DIFFERENTIATION OF THE VOLGA DELTA SOIL COVER

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ABSTRACT
The results of mapping of the soil cover according to data provided by remote sensing of Earth in the area of the steppe bordering ilmens, located westward of the Volga delta are presented in the article. The Western Ilmen-hill plain is generally shaped by changing moisture conditions as the main landscape-forming factor. In the process the changes are associated with both natural and anthropogenic processes. The article implements an algorithm that allows automated identification of spatial boundaries of soil contours, which are characterized by indicative signs displayed in various thematic layers. Satellite imagery from LANDSAT 5-8, SENTINEL-2 satellites provided by Earth Explorer data portal were used in the studies. The interpretation of the satellite images to determine the extent of soil salinizationand to calculate the NDSI index was carried out during periods when the surface was devoid of vegetation. The remote assessment of the spatial differentiation of the soil cover was carried out by means of a cross-spectrum analysis of the quantitative parameters of soil, vegetation and terrain obtained in the process of field, analytical and remote studies. The analysis of schematic maps of the halurgic soil degradation showed a sudden increase in the salt concentration and soil halurgationin the western part of the Volga in the period from 2010 to 2019 that was caused by changes in the hydrological conditions of the Volga River and road and rail routes usage.

Keywords: *the Volga delta, geoinformational analysis, soil and vegetation cover structure, salinization, soil degradation.*

1. INTRODUCTION

The Volga Delta is located off the northwest coast of the Caspian Sea. Geologically, the Volga delta is located on the border of the southern regions of the Caspian Depression and tectonic folds of the Karpinsky swell, in the area of the large Astrakhan uplift, consisting of a number of local structures [1].

The Volga Delta is a river delta with a progressively branching system of stream flows, which rate is gradually decreases from the top of the delta to its sea edge. The Lower reaches of the Volga delta cover the lower zone of the supraaquatic delta, the kultuchnaya zone and the Avandelta. Specific soil-forming factors in the Volga Delta led to the formation of a unique complex soil cover [2-3].

The Spatial lithological and morphological heterogeneity of the Volga delta land determines the high variability of the hydrological conditions for the formation of vegetation and soil cover from arid to hydrogenic. The soils of the desert and steppe biomes are the oldest soils that were formed under conditions of extreme lack of moisture, with no access to groundwater and under the effect of climatic conditions.

The following stages can be distinguished in the hydrogenic type of delta soils: the younger alluvium, alluvial and bedded soil, meadow soil, marsh-ilmen soil and saline soil. Strong linkage to groundwater and flood water is one of the characteristic features of hydrogenic soils. These soils occupy a certain part of the accumulative deltaic plain [4-6].

To understand the actual ecological situation in the soil cover of the Volga delta, new approaches are required, which should be based on both traditional geo- and soil information, taking into account spatial variability of soil properties, and also the use of geoinformational technologies in combination with remote sensing data [7-9].

The soil map, surface contour map and satellite imagery serve as the basis for the work with geographic information systems. For cooperative processing and visualization of data, it is better to present it in a single scale.

The article presents methods and conditions for the use of remote sensing data based on qualitative and quantitative characteristics of soils, vegetation and terrain in the area of the western steppe bordering ilmens of the Volga delta.

2. MATERIALS AND METHODS OF RESEARCH

The area of the western steppe bordering ilmens (WSBI) is located in the North-western part of the Caspian Sea coast, which is to the west of the delta itself and is a part of the Pre-Caspian closed basin. The internal mesoforms of the basin bottom are complicated by multiple fluctuations of the Caspian Sea level caused by the advance of the sea [10].

The modern process of soil formation in the area of the western steppe bordering ilmens is determined by the water regime, which is strongly dependent on the Volga flood. Flood water is the main groundwater source. Chemically groundwater can be nearly fresh and salty. The salt concentration in groundwater decreases under the influence of the spring flood [11].

A characteristic feature of the Western part of the delta and the area of the steppe bordering ilmens is the existence of a large number of hillocks, which were called the Baer Knolls after academician K. M. Baer, who first described them in 1856. The transitions of the hillocks to the ilmen depressions are made through a talus apron encircling the hillocks. The Baer Knolls and ilmens between hillocks are adjacent to the semidesertic steppe. The transition occurs gradually, as it moves from east to west, from the Volga river-bed to the Kalmyk steppe.

Thus, a large number of the Baer Knolls separated by depressions, cut with mazes of eriks, ilmens and distributaries explain the peculiar nature of the terrain in the region.

Meadow vegetation that occurs on territories of extinct bodies of water and flat tracts of land between hillocks that were affected by spring freshets, occupies a large portion of the vegetative cover head of the WSBI. Meadow vegetation is represented by both cereals and forbs. Cereals of meadow vegetation occupy small areas of land and have poor range of species. These include: the couch grass – *Elytrigia repens*, the reed grass – *Calamagra stisepigeios*, the rough bluegrass - *Poatrivialis* and some others [12].

The botanical composition of forbs is more diverse than that of cereals, although its species range is the same. The most prevalent are: the purple loosestrife - *Lythrum salicaria*, the field milk thistle - *Sonchus arvensis*, the skullcap - *Scutillaria galericulata L.*, liquorice – *Glycyrrhiza glabra L.*, the marsh spurge - *Euphorbia palustris L.*

In low meadows with marsh-ilmen soil, meadow plants are mixed with marsh plants - arrowhead, flowering rush.

The steppe flora is represented by forbs and cereal plants: sagebrush - *Artemisia lercheana*, common oats - *Avena sativa*, sweet grass – *Hierochloe odorata*.

The steppe flora in the western part of WSBI is replaced by desert vegetation, which is mainly represented by saline plants consisting of different kinds of saltwart.

The soil cover of the WSBI consists of slightly humic and brown desert-steppe, alluvial meadow and meadow-ilmen soils and saline soils.

The sod-forming process is the first step in the development of the soil-forming process in the western steppe bordering ilmens. It is represented here by both the marshy and meadow stages of soil development. Marshy soils are formed as a result of the gradual overgrowing of kultuks, ilmens, eriks and other bodies of water. The process of overgrowing of lakes is followed and accelerated by continuous and intensive spreading of dryland in the territory of the Volga River. As a result of drying of ilmens, siltation and overgrowth of water-coastal vegetation, ilmen-marsh soils are formed on heavy loamy ilmen beaching. As a result of drying of ilmens, silting-up and overgrowing of water and littoral vegetation, ilmen-marsh soils are formed on heavy loamy ilmen beaching. The development of marsh-ilmen soils has continued mainly in conditions of excessive moisture. Only one or more well-marked fen clays of a specific cyan color exist in the soil cross section.

Besides the marsh-ilmen soils, meadow-ilmen soils that occupy straightened surface depressions and hardly elevated zones also exist in the western delta region. They are not widely spread in the near steppe part of the ilmens. Morphologically, meadow-ilmen soils differ from marsh-ilmen soils by a lower depth of the humic and accumulative horizon, a huge differentiation of the soil cross section and lower moisture degree. Among the meadow-ilmen soils exist types with a distinct salinization of the soil horizon.

Drying out of the territory, changing hydrological conditions and plant succession in meadow-ilmen soils result in substituting of the boggy pedogenesis with the meadow pedogenesis, which leads to the formation of meadow soils. Meadow soils are formed on sediments of the kultuk-ilmen type. The granulometric composition of these soils is heterogeneous. All meadow soils of the WSBI are more or less saline. The degree of salinity in these soils is determined by the level of groundwater occurrence.

Meadow soils becoming increasingly exposed to salinization evolve into solonchak soils. Most meadow strongly-saline soils show signs of solonetzicity, which is characterized by strong pressure pan with vertical cracks and rough and cloddy structure of soil and heavy texture. Such soils have very rare vegetation, which include shore weed - *Aeluropus*, sea-lavender – *Limonium gmelini* and Tamarix plants – *Tamarix ramosissima Ledeb*. The soil surface is bare.

The soil surface is bare. Solonchak soils are located mainly in the western steppe bordering part of the region, where the most of ilmens are filled with salt water. These soils are devoid of vegetation and located at the bottoms of salt lakes that once existed. Solonchak soils stand in stark contrast to the surrounding desert areas because of huge snow-white spots that strictly preserve the shape of the former lake.

Hydrological changes that led to a decrease in the groundwater level and to reducing the role of floods increase the influence of zonal climatic factors. As a result of these factors that are inherent in near desert areas, brown soil is formed and spread across the western steppe bordering part of the region, where it occupies not only high ground but also the space between hillocks with no ilmens around. Brown soil in the western steppe bordering ilmens is formed on the ancient Caspian sediments that make up the Baer Knolls, as well as on eolian sandy and sandy-loam deposits [13-14].

The brown soil is characterized by the absence of salinity in the topmost part of the profile. Salt is found on the depth of 20-40 cm. At this stage these soils become the final link in the process of evolution of the WSBI soil cover and soils of the Volga delta that are situated near the river channel.

Fixed and weakly-fixed sands determine the extent of soil deflation in the area. There are also tracts of land that have deflated drifted sands in their structure. Occasionally, deflated soils with no vegetation can also be found in the area. At the same time, the constant drifting of sands prevents the formation of a differentiated soil profile [15].

Satellite imagery provided by SENTINEL – 2 and LANDSAT 5-8 satellites was used as remote sensing data (RSD). These satellites have access to multiple survey channels and are connected to the Earth Explorer data portal [16].

The LANDSAT space program is one of the most successful programs on the world market of RSD. The global LANDSAT data history contains images of almost the entire surface of the Earth, including the territory of Russia, which was captured multiple times [17].

The Normalized Difference Vegetation Index (NDVI) was calculated for each pixel of the image as the ratio of the difference of the survey channels to their sum, using the spectral differences of chlorophyll in the visible red and near infrared ranges [18].

The interpretation of satellite images to determine the degree of soil salinity and for calculating the NDSI (Normalized Differential Salinity Index) for 2010, 2016 and 2018 was carried out during periods, when the surface area had been devoid of vegetation.

To obtain the image, geocorrection was performed using a transverse Mercator (UTM-38 zone) and World Geodetic System (WGS-84).

3. RESULTS AND DISCUSSIONS

To assess internal differences in the geomorphological structure and determine the state of the soil cover of the WSBI, a detailed ground morphometric analysis of the territory was carried out. The analysis was performed through diachronous comparison of the satellite images, topographic maps and field data.

The fieldwork was carried out in the period from 2017 to 2020 as part of joint field scientific expeditions of the Centre for Spatial Analytics of the Astrakhan Region and the Department of Soil Science, Land Management & Cadasters of Astrakhan State University. The results of work were used in the formation of a database in order to obtain detailed characteristics of soil types.

The calculation of the NDVI data showed that the values of the vegetation index (the brightness ratio in the two ranges of the image red and infrared) correlate with the values of the amount of steppe and semi-desertic vegetation biomass. With the help of the data of the polyzonal image SPOT 4, histrograms of spatial fluctuations of NDVI values were created for each plant formation. A gross coefficient was further calculated for converting NDVI values into the values of aboveground phytomass reserves (Fig. 1).

Figure 1 shows images that demonstrate the processes of desertification on the territory of the northwest coast of the Caspian Sea, in view of the impact of the climate factor on the processes of reducing vegetation productivity and increasing saline soils.

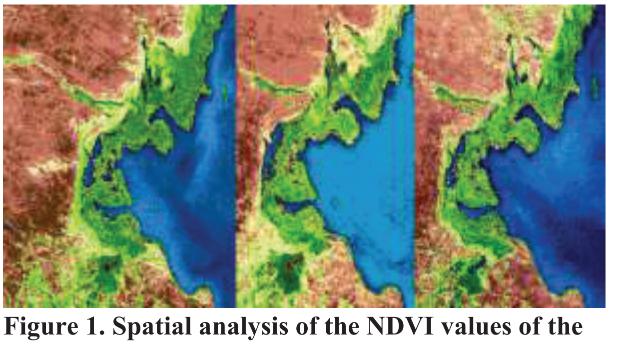

Figure 1. Spatial analysis of the NDVI values of the north-west coast of the Caspian Sea.

The studies showed that the correlation dependence of phytomass reserves exists within the area of vegetation communities.

The ArcMap 10.4 software package was the main tool for identifying the areas of saline soils on the territory of the western steppe bordering ilmens.

The radiometric correction for LANDSAT 5 images was applied by using the pre-processing method, when corrections for atmospheric and radiometric parameters had been made.

At the second stage, atmospheric correlation was carried out to reduce the impact of the atmospheric layer on the final result of the study.

This stage was of particular importance during the verification of reliability of the field data and satellite images obtained.

The NDSI was further calculated (Normalized Difference Salinity Index), "Equation (1)".

$$NDSI = (R - NIR)/(R + NIR) \quad (1)$$

in which R – Red, reflection in the red part of the spectrum (channel 4), which contains the information about the vegetation slopes;

NIR – reflection in the near infrared part of the spectrum (channel 8), responsible for the biomass data output.

The Red spectrum reflection is necessary to distinguish many varieties of plants, since it is the spectrum that can identify the degree of chlorophyll absorption.

The NIR layer is sensitive to the amount of vegetative biomass. It is widely used for studying agricultural soils and crops, as well as for analyzing its productivity and determination of the coast lines of water bodies [19].

The normalized difference salinity index NDSI (not taking into account the vegetation cover) was calculated by using the "Raster Calculator" tool. The schematic maps of the salt soil degradation for 2010, 2016 and 2018 were created (Fig. 2-4).

Transformation tracking of the soil cover based on the salt concentration made it possible to conclude that changing hydrological conditions of the Volga River, as well as road and rail routes usage led to an increase in the salt concentration. This was due to the persistent low-flow period that lasted from 2007 to 2015. Under such hydrological conditions, depleted and shallow groundwater surface could not provide enough soil moisture to lower the concentration of soil solutes.

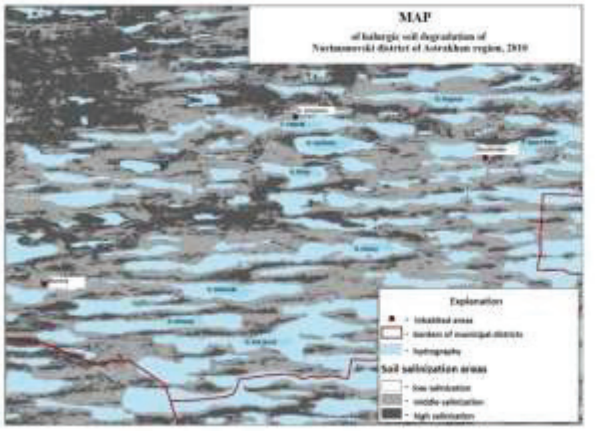

Figure 2. A schematic map of the salt soil degradation for 2010.

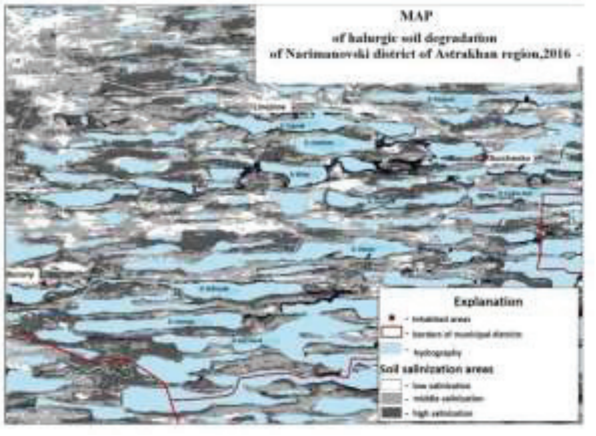

Figure 3. A schematic map of the salt soil degradation for 2016.

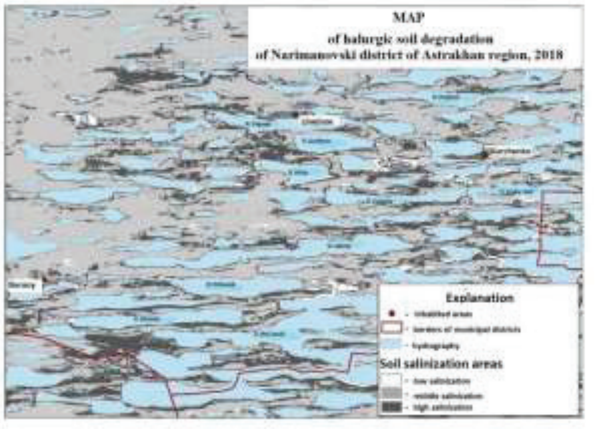

Figure 4. A schematic map of the salt soil degradation in 2018.

The second important conclusion is that in the period from 2010 to 2016, there were ecologically negative changes happening during the process of formation of strongly-saline areas. This resulted from natural flow that occurs during hypertonization of water coming down the soil capillaries and filling ilmens with only salt water that at high temperatures promotes the formation of pellicular salts.

The low-water period of 2019-2020 is a result of abnormally high temperatures in spring and the water pass for the local agricultural and fisheries needs.

The analysis of the RSD obtained by the multi-temporal imagery of the optical spectrum showed that the spatial differentiation of the soil cover depends on geological and geomorphological structure of the territory and the intensity of the soil salinization process development.

To assess the natural and human-caused soil salinization and create schematic maps by using the ERSD methods, the degree of vegetation degradation in solonchak and solonetz soils was taken into account. These studies were confirmed by ground observation methods and determining the amount of salt toxicity in soils.

CONCLUSION

As a result of this work, on the basis of ERS data using GIS-technologies, the following conclusions were drawn.

1. The research showed that in 2010 there were no weakly-saline soils in the soil cover of the western steppe bordering ilmens. Moderately and strongly saline soils prevailed. But the area with moderate salinization was larger than that with severe.
2. In 2016, the coverage area of weakly-saline soils increased and the coverage area of moderately-saline soils reduced. There was also an increase in salt concentration on the banks of ilmens and the stream flows connecting them.
3. The 2018 was characterized by an increase in parts of the area of the western steppe bordering ilmens with moderate salinization and a decrease in parts with weak soil salinization. Moreover, the amount of salt masses along the ilmen banks and the stream flows connecting them had been reduced.
4. A correlation between the NDVI and NDSI was revealed within the borders with the same characteristics.

Thus, in the period from 2010 to 2016, the rewas a positive dynamics in the formation of areas with weak salinization and a decrease in strongly-saline soils. Since 2018, there has been an increase in the accumulation of salt masses near the stream flows connecting the ilmens and along the borders of their banks. This indicates the activation of ground water transport of saliferoussoil elements.

AUTHOR'S CONTRIBUTIONS

The authors of the article directly participated in conducting the field and laboratory studies, as well as in analytical data interpretation, generalization and discussion of the results obtained.

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