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Soil mapping using geo-information technologies

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***Abstract*—This paper presents the review of the current state of agricultural land based on GIS technologies using materials of Earth remote sensing on the example of the forest-steppe zone of Western Siberia which is the most developed and populated territory of this region. We used multispectral images of the Landsat 8 spacecraft (SC) (USA) with a resolution of 30 m per pixel. These images allow monitoring of the Earth’s surface every 16th day with a flying-by width of 185 km in nadir. Computer processing of the series of multispectral satellite images (MSI) using the method of synthesizing (superposition of the long and short wavelengths of solar radiation spectrum) was carried out using the licensed software package ENVI 5.0. (produced by ESRI company). During creating electronic cartographic material of the studied area (based on satellite data), a digital basis for agricultural lands was made at first. Digitalization of outdated material was performed using QGis software package (desktop GIS for creating, editing, visualizing, analyzing and publishing geospatial information. It is QGIS Desktop that is often meant by QGIS). For the first time, a spatial-temporal change in the structure of agricultural land of this region over the past twenty-five years was revealed using multi-temporal images made by Landsat 8 SC. Areas were found that have moved from the category of arable land to the fallow one, and were susceptible to flooding. A partial soil survey was conducted in the study area (with sampling for chemical analysis) to establish soil type according to modern classification in order to update soil maps and to create an electronic cartogram showing soil suitability based on their agricultural type. Cost-effectiveness of the cluster method for soil and agrochemical survey of agricultural land was calculated.**

Keywords*—— *soil cover, Earth remote sensing (ERS), soil mapping, GIS technologies, cost-effectiveness of soil survey.

I. Introduction

Using of geo-information technologies for the management of agricultural land attracts interest of researchers all over the world. It is an effective tool that allows farmers to use land resources on a sustainable basis, several times reducing the time and money required for surveys [9]. In addition, studying of GIS benefits in order to fight the negative consequences of soil use (erosion, littering, flooding, etc.) will more effectively predict and prevent such phenomena thus contributing to rational land use [4, 6].

One of the most difficult problems of farming in Russia, as in many other countries, is the process of adoption of lands suitable for efficient agricultural production [8]. However, it should be recognized that due to the unusually high rate of works and in the absence of large-scale soil maps and competent specialists who knew specific local conditions, in many farms certainly inarable soils were added to arable land, and later were again taken out of circulation [1, 2].

From the point of the realization of state priorities in the sphere of restoration of previously used arable land, it is most reasonable to focus on fallow lands [5, 7]. Let us consider this process on the example of the forest-steppe zone of Western Siberia – the territory with the most favorable factors for crops cultivation in the most developed and populated part of the region.

Goal of research: to study the current state of agricultural land and fallow land based on GIS technologies (using the example of the forest-steppe zone of Western Siberia).

Tasks:

• To carry out a thematic processing of material from satellite images made by Landsat 8 (USA);

• To find spatial and temporal changes in the structure of agricultural land based on clusterization method using QGIS software package;

• To evaluate cost-effectiveness of remote sensing data for the soil survey of agricultural land.

II. Literature review

The topic of Earth remote sensing development was covered in the works of P.Ya. Raiser (1933, 1963), P.D. Duz (1944, 1981), A.I. Shershen (1958), V.P. Glushko (1981), S.S. Schulz (1984) et al. Works with specific parts devoted to the development and establishment of geo-information systems were published, and the review was made, i.e. the review of aerospace studies of the use of such images for studying the anthropogenic impact on the environment and solving ecological and geographical problems (Tikunova, 1991; Berlyant, 1996; Knizhnikov, 1997; Makarov, Novakovsky, Chumachenko 2002; Knizhnikova, V.I. Kravtsova, O.V. Tutubalina 2004; K. Dogherty, 2006), the periodization of geo-information systems development was shown (Dmitrieva, Shitova, 2001) [11]. Over the past dozen years, the study of the possibilities of environmental monitoring using satellites has been very actively conducted by scientific organizations and groups in different countries (NASA, Roskosmos, OOO SovZond, etc.). An important line of research is the development of agricultural land monitoring systems, as described in the works of Russian and foreign scientists (Gaveman, 1933, 1937; Garelik, Grin, Tsvetkova, 1932; Glushkova, 2003; Gonikberg, 1983; Gonina, Zubova, 1980, 1982, 1987; Gospodinov, 1958; Gryshchenko, 1958). Over the past 20 years, geo-information technologies have invaded all spheres of human life, and agriculture is no exception. In Russia and in European countries, technologies are being actively developed that allow minimizing costs for updating cartographic material and obtaining the maximum yield of agricultural crops [12].

III. RESEARCH METHODOLOGY

The object of this study was soil cover of agricultural land in the forest-steppe zone of Western Siberia. The subject of the study was the regularities of visualization of the state of agricultural land on satellite images depending on the characteristics of their use.

Multispectral images made by US spacecraft Landsat 8 were used for this work. Computer processing of the series of multispectral satellite images (MSI) was performed using the method of synthesizing using licensed software systems ENVI 5.0 and QGis. The possibility of combining imaging ranges by the elements of solar radiation spectrum from 0.4 to 0.9 nm with color channels in RGB (red-green-blue) system was taken into account. When combining diapason with channel, a synthesized color image was obtained which helped to establish objectively existing differences in studied objects.

Outdated cartographic materials dated 1984 were used for this work. During creating electronic cartographic material of the studied area (based on satellite data), a digital basis for agricultural lands was made at first. Digitalization of outdated material was performed using QGis software package (desktop GIS for creating, editing, visualizing, analyzing and publishing geospatial information. It is QGIS Desktop that is often meant by QGIS).

Analysis of multispectral space images using ENVI software package goes through a series of stages: geolocation of the image with source material (outdated soil map) and classification of multispectral images to identify the complexity of the Earth's surface.

IV. EXPERIMENTAL RESULTS

For the first time, the study of soil cover was conducted for the studied area with the establishment of soil quality characteristics based on the materials of Earth remote sensing using high-resolution multispectral data.

6 soil opencuts were made within the studied area (the object was Novotroitsk rural settlement of the Omsk Region). Three sections were made to the south-east of Sterkhovo Lake: section No. 1 – gray forest medium-deep medium-humic medium loam soil, section No. 2 – gray forest medium-deep medium-humic medium loam soil, section No. 3 – meadow chernozem soil solonized medium-deep low-humic medium loam soil. To the west of the village of Galitsyno, 3 soil opencuts were made on the deposit: section No. 4 – chernozem-meadow carbonate small columnar heavy loam solonets; section No. 5 – meadow carbonate medium-deep medium-humic medium loam soil, section No. 6 – chernozem-meadow solonized, medium-deep, low-humic medium loam soil. To describe the morphological features, let us consider one of the most typical sections of meadow-chernozem solonized medium-deep low-humic medium loam soil in a fallow soil body.

Section 3. MT 255. Positioning coordinates: N 55.51384 °, E 72.58101 °, h 124 m.

No soil effervescence with HCl found to a depth of 65 cm. No gleying found to a depth of 65 cm.

Soil name: meadow-chernozem solonized medium-deep low-humic medium loam soil. (Quasigley solonized medium-deep low-humic medium loam chernozem, "Soil Guide of Russia", 2008).

This soil which is formed on the northwestern slope of the ridge has a deeper humus layer and a deeper carbonate bedding compared to the meadow-chernozem soils in the central part of the region. Another distinctive feature is its alkalinity.

The profile of meadow-chernozem soil is characterized by medium aggregation, with the exception of AB horizon – the structure here is not aggregated what is most likely associated with a soil type characteristic, repacking begins in the horizon. The content of blocky fraction across the horizons is distributed inhomogeneously, large number of blocks, about 90%, is observed in AB horizon, the content of silt fraction does not exceed 15% (Figure 1).

The soil is low-humic, humus content in horizons A and AB on average amounts to 2%. pH reaction is neutral for the whole profile. Soil aggregates of humic horizons have good water resistance.

When applying the spatial-temporal analysis of these Earth remote sensing data, it was found that in the studied area of the Novotroitsk rural settlement at the moment there are about 17 thousand hectares of fallow soil bodies which should be in turn involved in agricultural circulation, some soil bodies (according to soil suitability cartogram and soil maps) should be used for moving and grazing in order to use land resources rationally.

With the help of QGIS software, the soil map of Novotroitsk rural settlement dated 1984 was digitized (Figure 1), during the study of this area it was established that the cartographic materials dated 1985 are relevant as the soil cover has not changed.

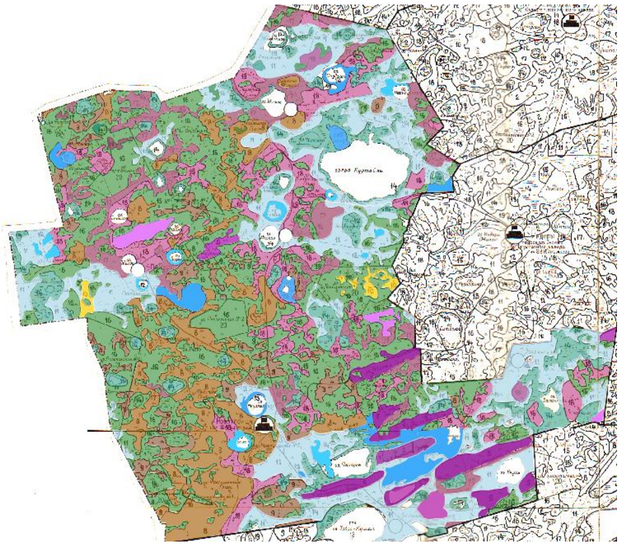

Fig. 1. Soil map of studied areas made with the help of QGIS software

In the studied area, standard meadow-chernozem soils, solonized soils and their combinations with solonetz and solonchak, meadow solonchak and solonetz soils are predominating. In the figure they are highlighted in light brown. On the ridges there are standard chernozems and their combinations with fuchsia-colored soloths. Around the lakes there are marsh high and lowland soils and also meadow-marsh humic and slimy (light blue color) soils. In the vicinity of the settlement, meadow chernozem soils are predominating (brown), towards the lake Tobol Kushly, there are meadow solonized and solonetz soils (blue).

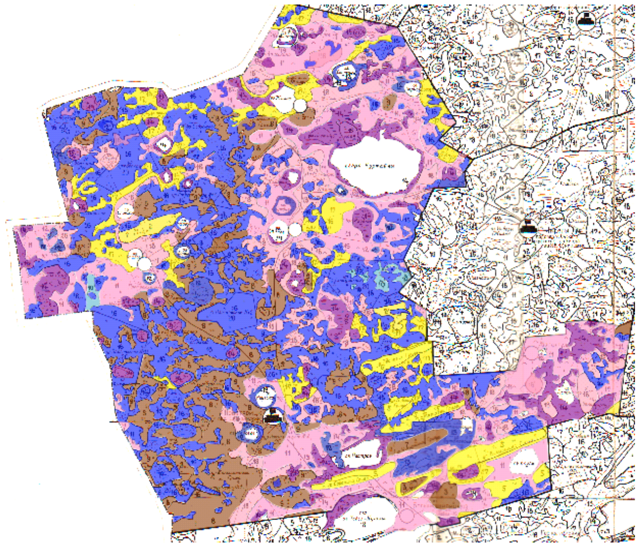

Fig. 2. Cartogram of the suitability classification of the studied soils made using QGIS software

According to the soil map (Figure 2), a map of the suitability classification of soils by their agricultural type was created using specialized software (Table 1). It was established that hayfields and pastures of different quality predominate in the studied area, as well as arable soils of good and medium quality, mainly chernozem, meadow chernozem and chernozem meadow soils. As a result, recommendations were made for improving the efficiency of soil use and soil fertility.

TABLE I. SUITABILITY CLASSIFICATION OF STUDIED SOILS

Color	Soil type	Rational use and fertility increase
II (good arable soil)		
	Chernozems and meadow chernozem soils, dark gray forest soils	For the cultivation of all recognized crops. Conducting crop rotations. Application of organic fertilizers once per crop rotation.
III (arable soil of average quality)		
	Gray forest, medium and deep solonetz, chernozems in combination with solonetz and solods	For a limited number of crops, mainly fodder grains, except root crops. Tillage depth should be less than the depth of the solonetz or solod layer.
IV (The best soils of pastures and hayfields)		
	Standard meadow, carbonate, solonized	Sowing crops resistant to waterlogging. In case grass stand worsening, treatment with a milling cutter or disc harrow.
V (Salted soils of pastures and hayfields)		
	Meadow, small solonetz.	Sowing crops resistant to alkalinity and salinity. In case grass stand worsening, treatment with a milling cutter or disc harrow.
VI (Overmoistened hayfields)		
	Meadow and marsh solods; meadow-marsh.	Using as natural pastures and hayfields. Rational cattle grazing.
VIII (soils of reclamation fond)		
	Marsh soils.	Carrying out land reclamation on individual projects for each contour.

It should be noted that many producers have a great interest in obtaining such information. Let us consider the effect of using the proposed methods of carrying out land surveys with the use of new technologies and without it.

Currently, the process of making soil maps has the following stages: field visit, making soil section, sampling for analysis. As a result, it is possible to obtain soil maps of 1:25000 scale. For the conditions of the region under consideration (3rd category of land complexity), 1 soil section, 4 half-pits and 5 by-pits are made on 50 hectares of land. In the section, structure (1 replication), particle size distribution (2 replications), pH (2 replications), water strength (2 replications) are sampled for analysis from 5 layers, and humus (3 replications) and exchange cations (2 replications) are sampled for analysis from 2 layers. Calculation of the costs of work using this method (method 1) was made for 1,000 hectares. The cost of work amounted to 1,133 million rubles.

Let us consider the method proposed in the study – using satellite images for evaluation (characteristics) of agricultural land use [3]. For the conditions of the region under consideration (3 category of land complexity), on average, 1 soil section, 4 half-pits and 5 by-pits are made for 100 hectares of land (or depending on the specific conditions). In the section, structure (1 replication), particle size distribution (2 replications), pH (2 replications), water strength (2 replications) are sampled for analysis from 5 layers, and humus (3 replications) and exchange cations (2 replications) are sampled for analysis from 2 layers.

The work involves the following stages: obtaining space images. Next, we need to carry out image clustering. As a result, we have the following (Figure 3).

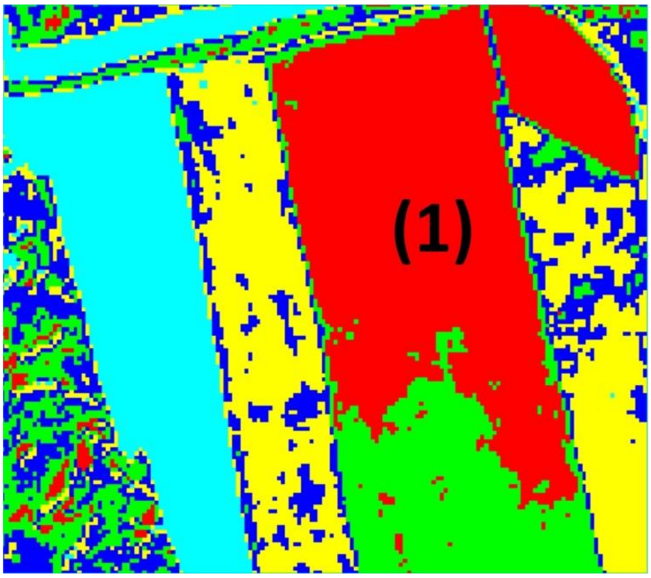

Fig. 3. The example of image clusterization

The results obtained allow us to find land plots with the same characteristics. For example, why should zone (1) be divided into plots of 50 or 100 hectares? It is enough to put points for research in the center of cluster and to conduct as needed. With regard to the conditions of this land, it will be just 5 sections, 20 half-pits and 25 by-pits (calculation according to method 3) (Table 2). Let us consider the costs of work for all methods per 1,000 ha.

TABLE II. COST OF WORKS ON SOIL ANALYSIS

Work type	**Total cost, ths RUR**		
	method 1	method 2	method 3
Soil analysis costs	1,121.9	560.9	280.4
Transportation costs (within 100 km)	5.7	3.8	2.4
Daily costs for researchers	6.0	3.0	1.5
Reimbursement of labor costs of IT specialists		3.0	3.0
Total costs	1,133.6	570.8	287.3

Calculations showed that using methods 2 and 3 leads to cost savings for research in the amount of 562.8 thousand rubles, and under the certain conditions of land – 846.3 thousand rubles. This is almost 2 and 4 times cheaper than the basic version (method 1). In addition to cost saving, there is a saving of time and labor. Results obtained in the course of research make it possible to conclude that it is economically reasonable to improve the process of agricultural land characterization using satellite images.

V. CONCLUSIONS

According to the study results, it was found that the use of spatial-temporal analysis of Earth remote sensing data allows conducting agrochemical survey of land in the shortest time and at minimal cost. The potential of application of geo-information technologies in agriculture is obviously high. GIS technologies are an extremely effective tool that allows conducting complex analysis and monitoring of any territory of the globe, identifying potentially fertile fallow lands, and significantly saving costs on their assessment what is currently an urgent task in the manufacturing of agricultural products.

When applying spatial-temporal analysis of these Earth remote sensing data, it was found that at the moment there are about 17 thousand hectares of fallow soil bodies which should be in turn involved in agricultural circulation, some soil bodies (according to soil suitability cartogram and soil maps) should be used for moving and grazing in order to use land resources rationally. The economic reasonability of using soil maps made with the help of space images for evaluation (characterization) of agricultural land has also been proven.

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