Agro-ecological monitoring of the territory of the Chelyabinsk agriculture research institute

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Abstract. Agroecological monitoring of lands is an important tool in regulating the development of unfavorable processes of lands suitable for agricultural use. It is a component of land use forecasting. The article is devoted to the organization of agroecological monitoring on the territory of the Chelyabinsk Agriculture Research Institute enterprise using methods of Earth remote sensing. This article analyzes the current state of agricultural lands of the Chelyabinsk Agriculture Research Institute with territory classification. The main focus is on monitoring the condition of crops for the growing season of 2023. The analysis of data in GIS systems allows to predict risks and take measures to increase crop yields and resistance to climate change. This direction has its relevance today. Monitoring is one of the tools for forecasting and rational land use.

1 Introduction

Modern agriculture faces significant challenges related to the preservation of soil fertility, rational use and protection of land resources. In this context, agroecological monitoring is an important tool, which makes it possible to systematically monitor the condition of agricultural territories and identify potential problems.

Agroecological monitoring, which is a system of operational, periodic, and basic (initial) observations of changes in the qualitative and quantitative state of agricultural land, using Earth remote sensing materials, provides information on the state of crops, which allows optimizing the use of resources, which in turn leads to increased yields, reduced losses, and reduced costs on production factors.

In the process of organizing agroecological monitoring of the territory of the Chelyabinsk Research Institute for the analysis of the current state of agricultural land, identifying quantitative characteristics of changes in land areas and land plots, types of agricultural land, the classification of the enterprise territory was carried out in the GIS system SAGA GIS (System for Automated Geoscientific Analyses) [18] and the EarthExplorer service (Earth Researcher) - service, providing free access to Landsat satellite images, the images contain data for territory classification, detailed information about the earth's surface [10].

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2 Materials and Methods

The classification is performed in two ways:

Method No. 1 – using satellite images obtained on the Earth Explorer portal (EarthExplorer), satellite system – Landsat.

Method No. 2 – using a bitmap image obtained on a satellite Yandex map.

To implement method No. 1, 3 satellite images of Landsat 8-9 OLI / TIRS C2 L2 were uploaded to the EarthExplorer service, reflecting the state of the territory during the growing season from early May to mid-September 2023. 1 snapshot dated 05/24/2013; 2 snapshot – 07/11/2013; 3 snapshot – 12/28/2013.

To classify the territory, a Landsat 8-9 OLI / TIRS C2 L2 snapshot dated 08.12.23 was uploaded to the SAGA GIS program (Figure 1).

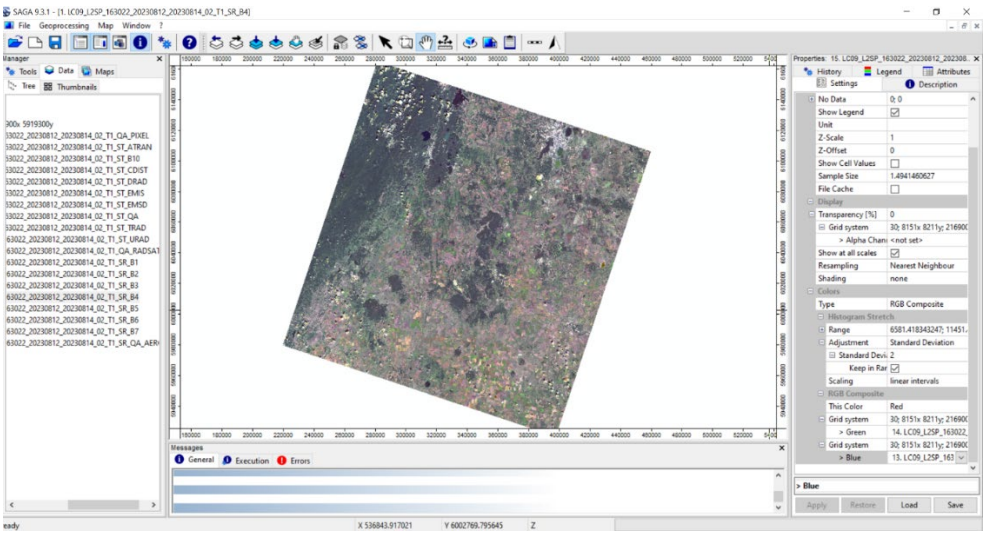

Fig. 1. Landsat 8-9 OLI / TIRS C2 L2 image in RGB Composition.

The Landsat 8-9 series of images has from 8-11 channels and spectral ranges. To display the image in colors familiar to the human eye, a combination of "natural colors" "RGB Composition" was used, which is achieved by superimposing spectral bands in the order of 4, 3, and 2, which correspond to the red, green, and blue parts of the visible spectrum [2].

Having determined the desired range of raster data, using the Clip Grids [interactive] function, a part of the image from the territory of the enterprise is cut out. Despite working with three spectral ranges (band 4, band 3, band 2), all available spectral ranges are subject to the action of the Clip Grids [interactive] tool to achieve the most accurate result.

Having selected the desired area, a satellite image of the territory of the Chelyabinsk Agriculture Research Institute was obtained, from which it is possible to classify the territory (Figure 2).

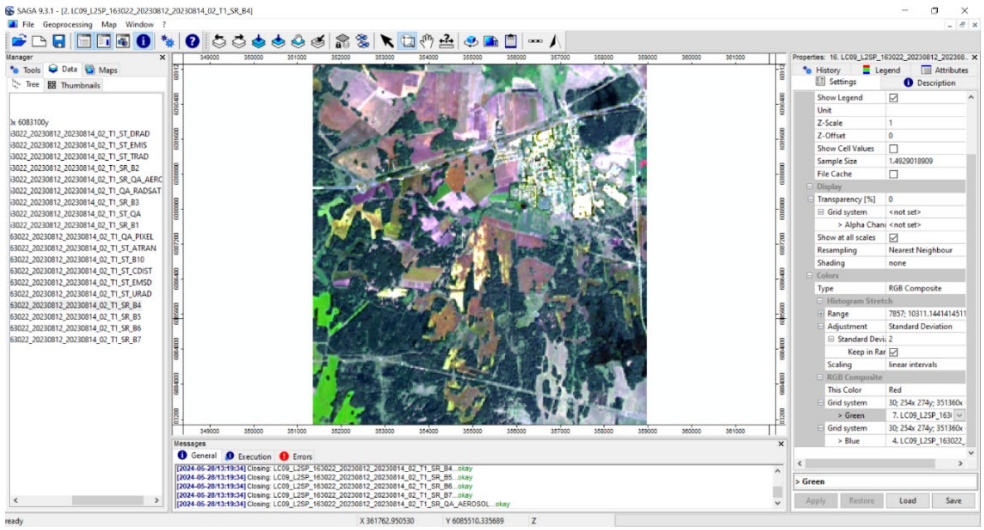

Fig. 2. Processing of a satellite image dated 08/12/23 of the territory of the Chelyabinsk Agriculture Research Institute enterprise in the SAGA GIS program.

The classification process consists in determining the territory classes based on the color pixels in the raster image. The following classes were allocated:

1. Forest areas.
2. Arable land not occupied by vegetation.
3. Arable land occupied by vegetation.
4. Areas of terrain occupied by grassy vegetation.
5. Built-up areas.

With the help of vector polygon data, the corresponding classes were assigned to the program. To do this, using the Create New Shapes Layer function, a Shapes file was created with the name "Classes", which contains 2 attributes: ID – class code; name – class name; and 4 parameters (Figure 3).

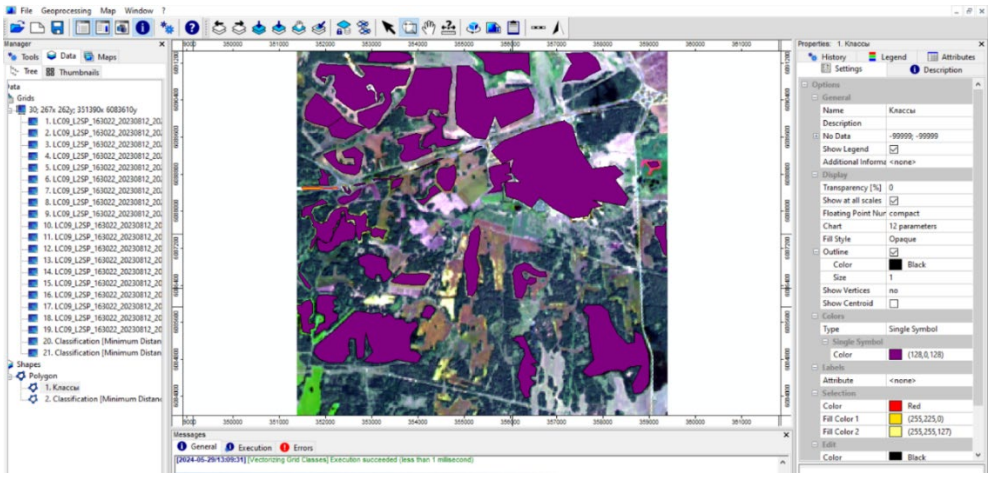

Fig. 3. Vector layer with polygons defining the territory classes of the Chelyabinsk Agriculture Research Institute (method No. 1).

For subsequent spatial calculations, the WGS 84 / UTM zone 41N projection coordinate system is set to the file, in which the satellite Image Grid system is located, using the Set

Coordinate Reference System function. The WGS 84 coordinate system provides an accurate representation of the distances within the zone. The territory of the enterprise corresponds to zone 41N [20].

By activating the Create New Shapes Layer tool and defining the areas in the image that represent each class, 32 polygons were created (Figure 4).

Having prepared the specified parameters in the form of polygons, the Supervised Image Classification function is performed, the trained classifier is applied to the entire image to assign each pixel to a specific class. The image classification method is Minimum Distance.

Thus, the classification of the territory of the Chelyabinsk Agriculture Research Institute is obtained, shown in Figure 4, where 5 classes are displayed.

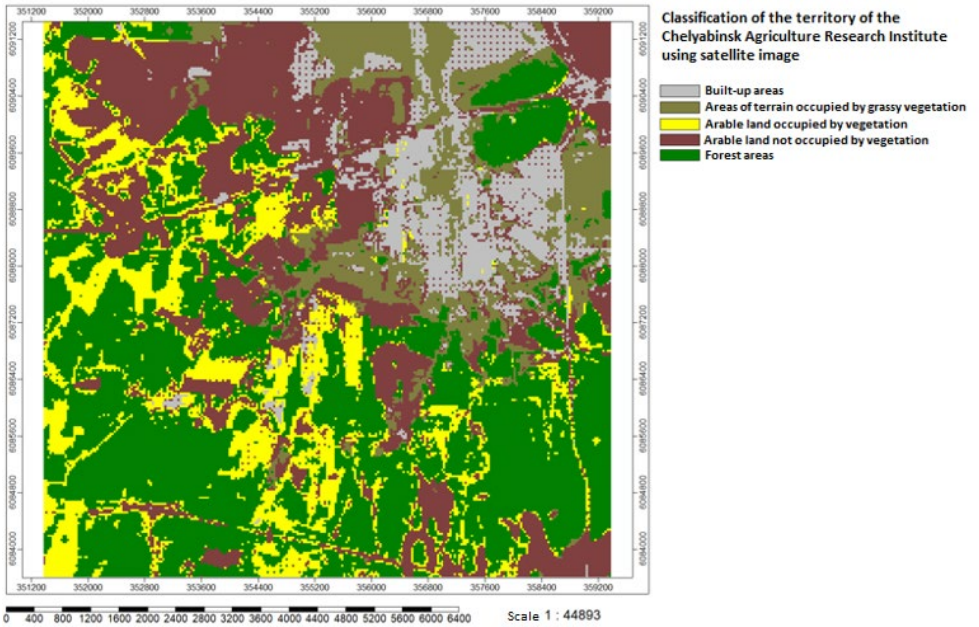

Fig. 4. Classification of the territory of the Chelyabinsk Agriculture Research Institute enterprise (method No. 1).

To determine the area of each class using the Vectorizing Grid Classes function, the Classification layer was vectorized, which was obtained during the classification process.

Using the Polygon Properties tool [6], the area and perimeter of each class were calculated. The data are presented in Table 1.

Table 1. Calculation of spatial characteristics (method No. 1).

Class ID	Class name	Perimeter, m	Area, ha
1	Forest areas	364080	2,419.56
2	Arable land not occupied by vegetation	429720	1,602.63
3	Arable land occupied by vegetation	419580	949.86
4	Areas of terrain occupied by grassy vegetation	223860	728.01
5	Built-up areas	203100	595.89
		TOTAL	6,295.95

According to Table 1, it can be seen that forest areas occupy 2,419.56 hectares of territory, agricultural land is represented by 2,552.49 hectares, of which arable land not occupied by

vegetation is 1,602.63 hectares, arable land occupied by vegetation is 949.86 hectares. The areas occupied by grassy vegetation amounted to 728.01 hectares, and the built-up areas occupy 595.89 hectares. The total area of the cultivated area was 6,295.95 hectares.

The implementation of method No. 2 of classification was performed using a raster image of the territory of the Chelyabinsk Agriculture Research Institute enterprise on a satellite Yandex map [8]. The classification was carried out in the SAGA GIS program [18].

4 reference points at the vertices of the bitmap image were selected using the Create Reference Points [interactive] tool (Figure 5) to carry out the geographic reference.

Fig. 5. Reference points at the vertices of the raster image of the territory of the Chelyabinsk Agriculture Research Institute.

Then, using the Rectify Grid tool, using the Automatic (Nearest Neighbor) method, the coordinates of the enterprise territory were assigned to each reference point, as shown in Table 2 [1].

Table 2. Coordinates of the reference points (WGS 84 / UTM zone 41N projection coordinate system).

No.	East (latitude)	North (longitude)
1	351352	6091455
2	359337	6091455
3	359337	6083622
4	351352	6083622

The WGS 84 / UTM zone 41N projection coordinate system was installed using the Set Coordinate Reference System tool [20].

The main difference between the classification process and method No. 2 is the assignment of geographical coordinates to a raster image. Further, the course of action is similar to method No. 1 of classifying the territory in SAGA GIS.

To carry out the classification, a bitmap image was analyzed and the following classes were determined:

1. Forest areas.
2. Arable land on slightly humic soil.
3. Arable land on medium humic soil.
4. Arable land on high humic soil.
5. Water bodies.
6. Built-up areas.

35 polygons were created using the Create New Shapes Layer tool.

Having prepared the specified parameters for the operation of the program, the Supervised Image Classification function was performed, as a result of which the classification of the territory of the Chelyabinsk Agricultire Research Institute was obtained by method No. 2, shown in Figure 7.

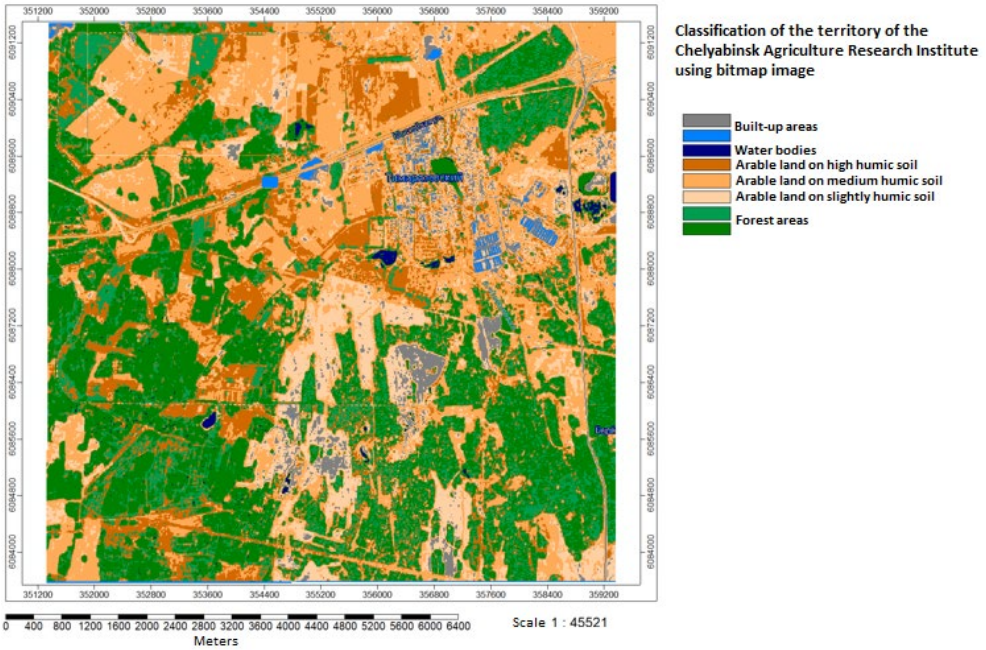

Fig. 6. Classification of the territory of the Chelyabinsk Agriculture Research Institute enterprise (method No. 2).

The resulting classification map shows that the program made a number of mistakes, defining the "road" to the class – "arable land", as well as highlighting part of the arable land as the class "locality".

For subsequent spatial calculations, the vectorization of the layer with image classification was performed using the Vectorizing Grid Classes tool. Using the Polygon Properties tool, the area and perimeter of each class were calculated [6]. The data of the calculations performed are presented in Table 3.

Table 3. Calculation of the spatial characteristics of method No. 2.

Class ID	Class name	Perimeter, m	Area, ha
1	Forest areas	1200670	2,429.61
2	Arable land on slightly humic soil	6547810	654.78
3	Arable land on medium humic soil	18223000	1,822.3
4	Arable land on high humic soil	11315100	1,131.51
5	Water bodies	395086	39.51
6	Built-up areas	2360660	283.58
		TOTAL	6,361.29

According to Table 3, the area of forest plots was 2,429.61 hectares, agricultural land represented 2,953.81 hectares of territory, of which arable land on slightly humic soil is 654.78 hectares, arable land on medium humic soil is 1,822.3 hectares, arable land on high humic soil is 1,131.51 hectares. Water bodies occupy 39.51 hectares, built–up areas - 283.58 hectares.

A comparison of the methods is presented in Table 4.

Table 4. Comparison of methods for classifying the territory of the Chelyabinsk Agriculture Research Institute.

Class name	Method No. 1 – using a satellite image	Method No. 2 – using a bitmap image	Discrepancies between method No. 1 and method No. 2	Average value
	Area, ha			
Forest areas	2,419.56	2,429.61	10.05	2,424.59
Agricultural land	2,552.49	2,953.81	401.32	2,753.15
Built-up areas	595.89	283.58	312.31	439.74
Water bodies	-	39.51	39.51	39.51
Territories occupied by other vegetation	728.01	-	728.01	728.01
TOTAL	6,295.95	6,361.29	65.34	6,328.62

According to Table 4, it can be seen that the area of the "Forest areas" class, obtained in two ways, is determined quite accurately, with a difference of 10.05 hectares. The area of agricultural land obtained by method No. 2 is 401.32 hectares larger. Further, the differences are significant due to the quality of the images: the area of the "Built-up areas" class is determined with a difference of 312.31 hectares. The class "Water bodies" in method No. 1 is not defined, since the satellite image has a lower resolution, but the class "Territories occupied by other vegetation" was defined as 728.01 hectares. The total area of the treated area was obtained with a difference of 65.34 hectares, which is the program error.

Comparing the methods of classification, it can be concluded that method No. 2, based on the use of a bitmap image, demonstrates increased accuracy, which made it possible to identify a larger number of classes (6). Figure 8 shows how the plots and fields are highlighted in detail, despite the errors committed by the program. Classification by method No. 1 allows to work with spectral ranges and also helps to obtain reliable results if a high-quality image of good resolution is used.

3 Results and Discussion

Monitoring of the condition of crops is an important aspect of modern agricultural production, which makes it possible to optimize agrotechnical measures and increase crop

yields. One of the most effective monitoring methods is the use of the NDVI (Normalized Difference Vegetation Index), which evaluates the level of photosynthetic activity of plants based on satellite imagery data [14].

NDVI is calculated using the following formula:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad , \tag{1}$$

Where:

NIR is a reflection in the near infrared region of the spectrum.

RED is a reflection in the red region of the spectrum [15].

According to this formula, the vegetation density (NDVI) at a certain point in the image is equal to the difference in the intensities of reflected light in the red and infrared ranges divided by the sum of their intensities.

NDVI values range from -1 to 1. High NDVI values (close to 1) indicate high photosynthetic activity, usually associated with dense vegetation; low NDVI values (close to -1) indicate the absence of vegetation or its stress state [16].

To calculate the NDVI index, 3 Landsat 8-9 OLI / TIRS C2 L2 satellite images were uploaded to the EarthExplorer service, reflecting the state of crops during the growing season of 2023. 1 snapshot dated 05/24/2013; 2 snapshot – 07/11/2013; 3 snapshot – 12/28/2013.

The index was calculated in the SAGA GIS (System for Automated Geoscientific Analyses) program [18]. The first image of Landsat 8-9 OLI/TIRS C2 L2 dated 05/23/24 has 11 spectral ranges, of which band 4 is the red range, and band 5 is the NIR infrared range [4].

To obtain a raster image with the NDVI indicator, the Vegetation Index (Slope Based) tool was used, as a result of which a snapshot of the territory of the Chelyabinsk Agriculture Research Institute enterprise with the NDVI indicator was obtained, shown in Figure 8.

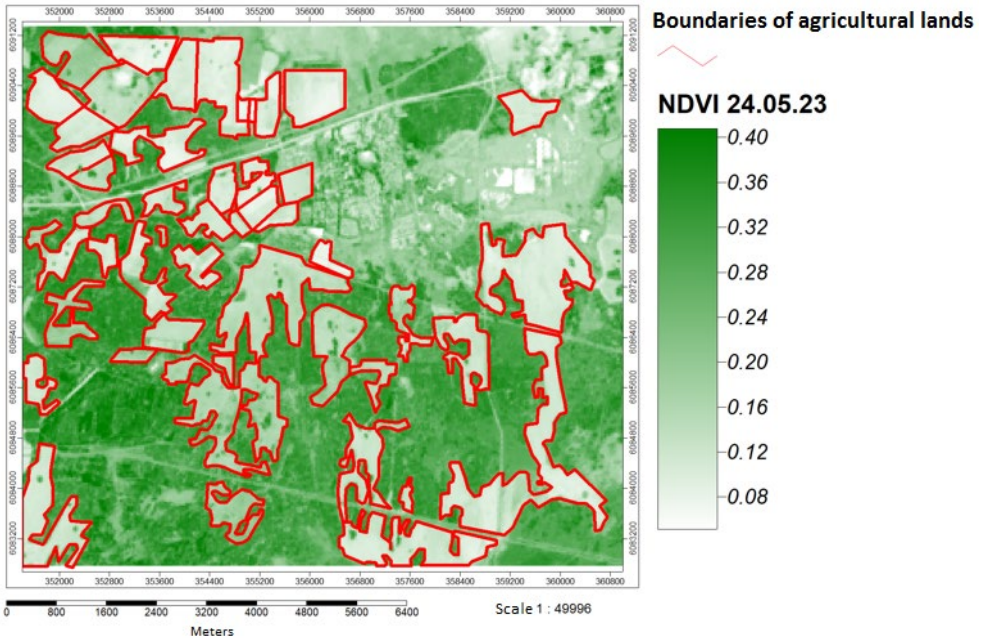

Fig. 7. Snapshot of the territory of the Chelyabinsk Agriculture Research Institute with the NDVI indicator (date of shooting 05/23/24).

Figure 8 shows that green color characterizes the density of vegetation, white color – its absence or the initial stage of growth.

The picture was taken on May 24, 2023, which may indicate the beginning of the season. Thus, we can conclude how the plant overwintered. NDVI ranging from **0.2−0.3** indicates that the plants have managed to enter the tillering phase and resume vegetation. The territory with this index is represented by forest vegetation. The plots of agricultural fields in the raster image contain an index from **0.08-0.16**, which indicates plowed soil without vegetation [3].

The classification of the state of agricultural land is presented in Table 5 [3].

Table 5. Classification of the agricultural land state.

NDVI value	Agricultural land state
0.1 -0.2	Open ground
0.2-0.4	Weak sparse vegetation
0.4-0.6	Moderate vegetation
0.6<	Healthy dense vegetation

To work with the second image of Landsat 8-9 OLI / TIRS C2 L2 dated 07/11/23, the Grid Calculator tool was used, in which NDVI is calculated using the formula (1).

Figure 9 shows the resulting snapshot of the territory of the Chelyabinsk Agriculture Research Institute with the NDVI index dated 07/11/2013.

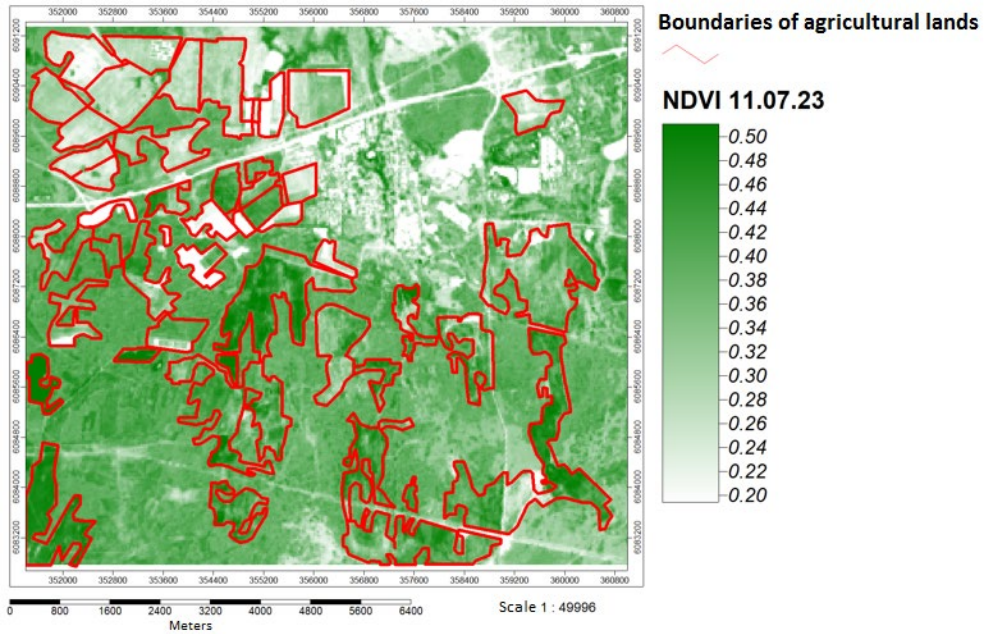

Fig. 8. Snapshot of the territory of the Chelyabinsk Agriculture Research Institute with the NDVI indicator (date of shooting 07/11/23).

According to the obtained image, it can be seen that the vegetation cover in agricultural fields has grown significantly, as evidenced by the NDVI scale, which starts at **0.20** and ends at **0.50**. Probably, crops have already been harvested in fields with NDVI index of **0.20**.

Index of **0.50** is indicated on the arable land, it can be concluded that moderate vegetation is present in these fields [3]. This level of vegetation provides high photosynthetic activity, which leads to an increase in carbon dioxide uptake and biomass production. This picture was taken on July 11, 2023, it is likely that at such a time stage the plants did not reach the most active growth phase.

To analyze the condition of crops at the end of the growing season, a satellite image daetd 12/08/23 was uploaded, the result is shown in Figure 10.

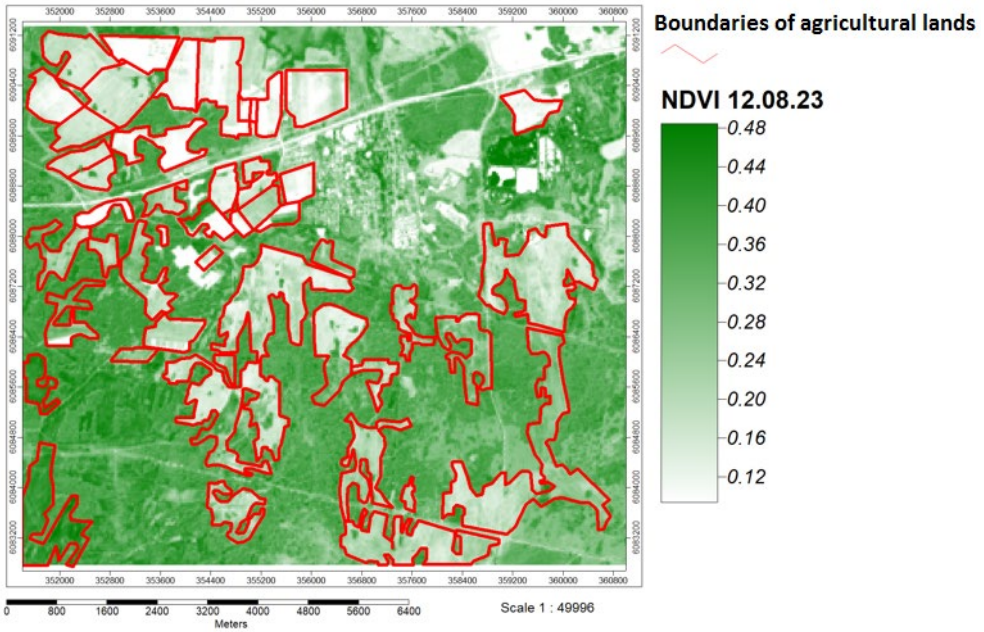

Fig. 9. Snapshot of the territory of the Chelyabinsk Agriculture Research Institute with the NDVI indicator (date of shooting 12/08/23).

On this NDVI map, which shows the spatial distribution of vegetation cover, it can be seen that, in comparison with the map dated 07/11/23, there is a decrease in the density of photosynthetically active biomass. The NDVI scale starts from a value of **0.12**, which indicates the absence of vegetation and characterizes open soil [12].

Most agricultural fields have NDVI from **0.12** to **0.23**, which is due to the end of the growing season for plants and their harvesting, only a few of them contain an index from **0.40** to **0.44**, which may indicate individual varieties of crops with a long growing season. Non-agricultural lands have an NDVI of about **0.34**, and are represented by forest and grassy vegetation.

For a detailed analysis of the NDVI value, a land plot with a cadastral number 74:23:0910001:215 was selected [5], with a total area of 34.67 hectares, of which 7 hectares is the working field for which the analysis was carried out.

Using the Show Cell Values tool, a map of the land plot with the NDVI index was obtained, shown in Figure 11.

Fig. 10. Land plot with cadastral number 74:23:0910001:215 with NDVI display (07/11/2013).

Figure 11 clearly illustrates the distribution of the NDVI indicator on the land plot of the Chelyabinsk Agriculture Research Institute enterprise. Based on this map, the NDVI area occupied by each individual indicator is calculated, the data is presented in the form of a graph (Figure 15).

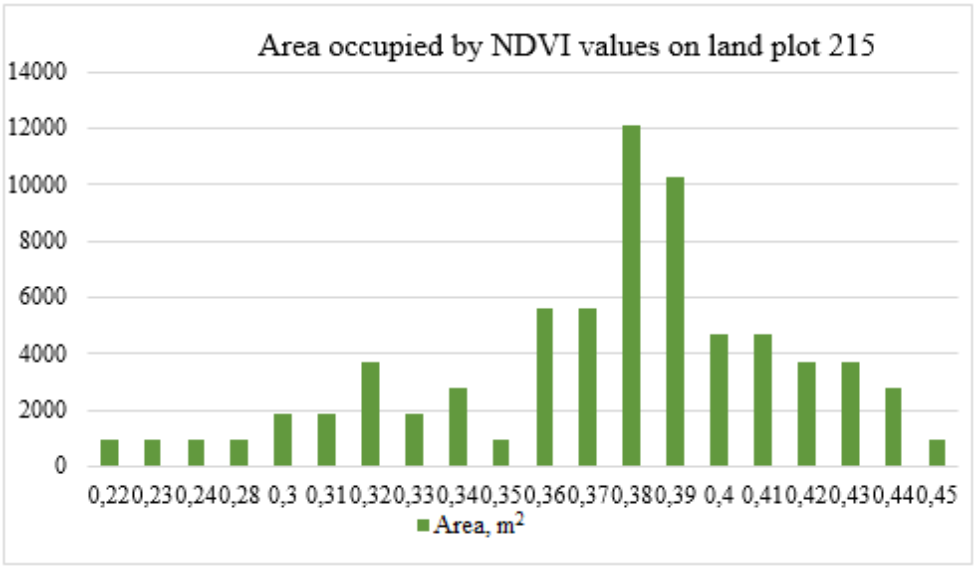

Fig. 11. The area occupied by NDVI values on a land plot with cadastral number 74:23:0910001:215.

The graph (Fig. 12) shows that NDVI equal to 0.38 occupies 12098.84 m^2. This indicator occupies the largest area on the selected land plot. NDVI equal to **0.38** indicates the early stages of crop growth [17]. NDVI values on the site range from 0.23 to 0.45, which usually corresponds to agricultural land, pastures and forests with moderate vegetation cover.

4 Conclusions

Thus, the assessment of crops of the Chelyabinsk Agriculture Research Institute was carried out. Based on the work done, it can be concluded that monitoring the condition of crops at the enterprise according to the NDVI indicator is an effective tool for optimizing agricultural production, but it has its own errors. NDVI can be sensitive to atmospheric conditions such as cloud cover, haze, and aerosols. This can distort its values and make it difficult to accurately interpret the data. The interpretation of the values of the photosynthetically active biomass index may vary depending on the type of crop and soil conditions. The use of NDVI may be limited by the availability and quality of satellite images. Despite these disadvantages, the use of this indicator in conjunction with GIS systems allows to quickly assess the condition of crops in large areas, identify problems and respond to them in a timely manner, which helps to increase crop yields and reduce losses.

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