Applied methods for remote sensing of the Earth in the interests of agriculture of Russian Far East

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Abstract. The paper presents the methods (procedures) of processing data from satellites of the Landsat series, for classification and evaluation of agricultural land used for rice cultivation in the area of Lake Khanka, Primorsky Krai. Opportunities for using various vegetation indices for analysis are described, as well as their complex combinations that ensure most accurate identification of the considered culture during the entire period of active vegetation. The developed procedures provided foundation for analysing the growth dynamics of crops innate to the Far East, where the potential for using satellite data for agricultural needs remains practically untapped.

1. Introduction

The agricultural sector in the Far Eastern region of Russia has undergone significant growth in recent years, mainly due to the implementation of projects in the areas of priority development. This factor cannot but affect large-scale changes in the development of territories and the dynamics of agricultural land. At the same time, rather harsh climatic and landscape conditions disallow the development of a common strategy for land reclamation for agricultural purposes, including the choice of the source of production that is most effective in terms of economic benefits. In any case, the main directions here are the increase in output of already proven agricultural products, such as soy-beans, and reclamation of unused arable land – about 600,000 hectares (circa 1,500,000 acres) according to the web-portal of the Ministry for the Development of the Russian Far East (https://minvr.ru/). Both areas require the organisation of projects to study the land conditions, efficiency of land use, assessment of the impact of negative natural factors, and a number of other indicators.

With the development of multi-spectral satellite imagery, experts increasingly use Earth remote sensing data in conjunction with field research. Today, we know a fairly large number of methods for digital processing of satellite images, adopted in various geographic information systems (GIS) and Web-based services of global satellite monitoring for agriculture [1,2], however, most of tools and analytical materials used therein relate to the European part of Russia and a number of regions Siberia, at most. For the Far East, such information is still at the stage of experimental operation or isolated application [3]. There are several reasons for this: a long period of shortage of industry development trends, entrenched technologies and forms of work within individual farms and enterprises, and most importantly, a low level of informing the farmers and managers about the possibilities and prospects of using archived and near real-time satellite imagery data for tasks that require monitoring of agricultural resources. In most satellite monitoring systems, various vegetation indices are used as the
main criteria for analysis. The key problem is that the consumer is provided with either already calculated maps of index or information that has been analytically processed and presented as graphs and tables, which raises questions regarding its practical use.

The purpose of this work is to provide information on applied methods for solving agricultural monitoring tasks by using the Landsat series satellites data in the Far-Eastern Center of State Research Center for Space Hydrometeorology «Planeta».

2. Satellite imaging data
Depending on the tasks to be solved, satellite data can provide ongoing monitoring of the state of agricultural and other lands or an array of data for analysis of long-term changes. In the first case, the most suitable for analysis are the data of the MODIS instrument installed on the satellites Terra/Aqua [4]. These data provide for daily monitoring for areas that are free from cloud cover; this is used for annual update on the size of arable land and areas under winter crops, and for weekly update on the state of plants. In the case of analysis of long-term changes, availability of the long-term surveying data is the main requirement for choosing the source of satellite information. At the same time, the information obtained at various points in time should be consistent, so as to provide for the plotting and analysis of long-term data series. The most suitable system in this regard is the Landsat series of satellites, which have been surveying the Earth for decades. We use this type of data for methods of processing and interpretation of satellite images that follow.

3. Procedures for identifying image boundaries of different objects
With respect to the analysis of agricultural land used for rice cultivation, the initial task is to detect on images the objects and sites that are characteristic (typical) representatives of rice irrigation systems (RIS). The main difficulty here is their correct identification against the background of non-agricultural objects. Given that the basic information about the feature of objects on the Earth’s surface is contained in their spectral characteristics [5], in work with spectral information, the so-called «index» images are used. Based on a combination of brightness values in certain channels of the satellite device, by calculating the required «spectral index», the operator gets the information necessary for identifying the object. Next, images corresponding to the index value in each pixel are constructed, which allows the operator to separate one object from another and evaluate its condition. Next, we will show how it looks in practice.

After selecting a site on the Earth’s surface to be studied (containing the characteristic RIS elements), operator calculates indices for satellite images, displaying these in the form of a standardised continuous gradient scale in the range from -1 to 1. You can familiarize yourself with the indices in more detail in the work [8]. In our case, the first stage uses:

- NDVI – Normalized Difference Vegetation Index;
- NDWI – Normalized Difference Water Index.

The NDWI index, which has high values for water (close to 1), is the main sign for the allocation of pixels containing water objects. NDVI index is used when selecting pixels containing roads and anthropogenic objects, as it has low values for these (from -0.5 to 0.025). Also, the NDVI index is used to highlight pixels related to fields, as for these objects the index value, depending on the time of the image, is either significantly lower or higher than the surrounding natural objects. However, if one is guided by indices alone, there will be a large number of false positives. To eliminate these, satellite images require additional processing. Most often, this requires the SPEAR LOC tool of the ENVI (Environment for Visualizing Images) software package, with filters based on the use of spectral parameters (MF, SAM, MF/SAM, Red Soil) [9]. For example, image pixels containing water bodies are characterized by high values of the spectral parameter MF, but low SAM values.

The next step is the thematic adjustment of the classification results, which is actually carried out according to the data characteristics of the objects: combining, elimination of small false positives, smoothing the borders, etc. Using the spectral channels obtained at the pre-processing stage, the operator creates several various syntheses for a more detailed assessment of image elements. For
example, the combination of channels 7-5-3 for satellite Landsat 8 provides an image that displays natural colours, yet allows the operator to analyse atmospheric pollution by natural or manufactured aerosols; the combination of channels 6-4-2 shows topographic textures, while 7-3-1 allows the operator to distinguish the geological materials. As a result, on the output the consumer gets categorised images that display the boundaries of the objects with RIS signatures, where the actual fields can be studied (figure 1).

![Figure 1](image)

**Figure 1.** Application of the procedure of identifying the image boundaries with RIS signatures (an example): a – the original image; b – image using categorisation.

4. **Rice field selection procedure**

The unique physical properties of rice fields (during their flooding) and rice itself (during the ripening period) allow us to monitor the dynamics in vegetation indices. Knowing this dynamics, it is possible to identify rice fields with great accuracy against the background of other crops. Knowledge of the relationship between the structure/state of vegetation and its spectral reflectivity provides for the use of satellite imagery to map and identify vegetation types and their stress state.

According to work [7], for rice fields detection, the following can be used in addition to NDVI:

- **EVI** – Enhanced Vegetation Index;
- **LSWI** – Land Surface Water Index.

During the crop season, the underlying surface of the rice fields consists of the following types: flooded fields, a mixture of water and rice seedlings, only rice, post harvest fields. Based on the processing of archived (over a 15-year period) data from Landsat series satellites, the dynamics of indices for various types of vegetation and underlying surface was plotted for the study area. The analysis of the obtained dynamics shows that when fields are flooded, the LSWI value becomes larger than the NDVI or EVI. After the sprouted seedlings are transplanted into the fields, the latter become now a mixture of water and green plants, whereas the NDVI and EVI indices are gradually increasing while the LSWI is falling. After 50-60 days of cultivation, most of the grown rice completely covers the field, and the LSWI value becomes lower than NDVI and EVI. It is important to note that other types of land cover in the study area have lower LSWI values compared to NDVI and EVI, over the entire calendar season of rice growth (figure 2).
Figure 2. Seasonal dynamics of NDVI, EVI and LSWI for the main types of land use, separate sites. Distribution chart of indices calculated: a) for rice; b) for corn; c) for soybeans; d) for the forest; e) for wetlands; f) for water bodies.

Having calculated and plotted such dynamics of vegetation indices for any region of interest, one can obtain preliminary data on the state of land and crops during the crop season. However, the data inherit some errors as it represents average perennial values. Often, the farmers change the set of crops cultivated in the study area, there are periods of weediness of crops, different climatic conditions, etc. Thus, for a more detailed analysis of a particular culture, the use of more complex combinations of indices and their analysis throughout the growing season is necessary.

Rice during flooding and transplantation has a unique spectral characteristic $\text{LSWI} – \text{EVI} \geq 0 \text{ or } \text{LSWI} – \text{NDVI} \geq 0$. As an example, let’s consider the spatial distribution of EVI, NDVI, LSWI – EVI, LSWI – NDVI for the study area for the period when the rice has already been planted and flooded with water (figure 3).

Figure 3. Spatial distribution of indices and their differences: a) EVI index; b) NDVI index; c) the LSWI – EVI index difference; d) the LSWI – NDVI index difference.

The figure shows that the rice fields are not yet covered with vegetation, as evidenced by the NDVI index, which does not exceed 0.2 – 0.4 units, and EVI index, which lies in the range of 0 – 0.2 units (for sparse vegetation, the values should exceed 0.5 and 0.4 units, respectively). On the other hand, the difference between LSWI – EVI and LSWI – NDVI clearly identifies the flooded areas of agricultural land. The main types of vegetation represented by the NDVI index in figure 3b are quite identifiable, as shown by the graphs in figure 4.
Floated rice fields have low values of EVI (0 – 0.2) and NDVI (0.2 – 0.4). Water bodies (lakes, reservoirs) are also easy to identify; they have negative EVI and NDVI values. Other fields that also have low EVI and NDVI values, in turn, have negative LSWI – EVI and LSWI – NDVI values. Forests and shrubs have high EVI and NDVI and low LSWI. Thus, by analysing the EVI, NDVI, and LSWI indices, one can trace the dynamics of the use of rice fields from the time the land was prepared and flooded, up to the rice planting period.

Rice fields also have unique spectral characteristics during ripening season. From late August to late September, the NDVI index for rice drops to 0.6 (figure 2a), while for the forest it remains quite high, on the level of 0.8 (figure 2d), the same applies to soy-bean and corn (figure 2b and 2c). The wetland by this time is overgrown with lush vegetation and its LSWI index tends to zero, while staying at 0.2 for rice. Thus, by analysing the EVI, NDVI, and LSWI indices, rice fields can be detected during ripening season, too. Rice fields have a pronounced difference between NDVI (EVI) and LSWI compared to other crops. According to [6], RGB synthesis was obtained from a combination of the indices $R = (\text{LSWI})$, $G = (\text{NDVI})$, $B = ((\text{NDVI} + \text{EVI}) / 2 - \text{LSWI})$ (figure 5b).

Analysing figure 2, it can be noted that in late August / early September the change in the NDVI index for rice is greater than in the EVI index, which is confirmed in figures 5c and 5d, where this difference is clearly visible. Comparing figures 3c, 3d and 5b, 5c, we can conclude that the areas of rice fields calculated for the spring and autumn period coincide.

Thus, the difference LSWI – NDVI allows the operator to accurately determine the rice fields, while the synthesis from the combination of indices (as presented in figure 5b), provides for qualitative display of the fields, for further calculation of the field area used for rice cultivation. The figure clearly shows the rice fields, which during RGB synthesis from a combination of the indices $R = (\text{LSWI})$, $G = (\text{NDVI})$, $B = ((\text{NDVI} + \text{EVI}) / 2 - \text{LSWI})$ are coloured in shades of light brown and orange tones.

Notably, the results of such monitoring provide more reliable and accurate information when combined with relevant and fairly accurate data from field studies. But in any case, if using remote sensing data, monitoring tasks are solved more efficiently and at significantly lower cost, since there is no need to use in situ data for identifying field boundaries, provision of constant crops monitoring, etc. The above methods of mapping and analysis of index images are not fully automated and require involvement of interpreter specialist at certain stages. However, once performed for a given region, the evaluation can be used for quite a long time as auxiliary or primary information in research, without the need of regular repetition.
Figure 5. Synthesized images and index differences: a) R / G / B synthesis = SWIR / NIR / Red; b) synthesis of R / G / B = LSWI / NDVI / ((NDVI + EVI) / 2 - LSWI); c) the LSWI – NDVI index difference; d) the LSWI – EVI index difference.

5. Conclusion
The presented paper uses an example of one crop to describe the potential of satellite data in solving the tasks of ongoing monitoring of agricultural lands. This potential is practically untapped in relation to the regions of the Far East. To change the situation, additional practical research and experiments are needed, to combine in situ and remote sensing data both for territories limited to one or several fields, and for large-scale areas. Provision of the results of such studies through GIS and Web resources will significantly improve the efficiency of informing the interested consumers.

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