Using the results of remote sensing of land for programmed agricultural production in arid conditions

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Abstract. The article considers methodological approaches to substantiating the main tasks solved by the developed software package for managing agricultural production in the programmed cultivation of agricultural crops. There are characteristic differences in the reflection spectrum of agricultural plants due to the influence of water vapor absorption. The total reflected radiation in the optical and near-infrared range, recorded by remote sensing, depends on the biological and varietal characteristics of plants, the development of the leaf surface, their growth phases, the chemical composition of the soil, and other factors. The set of vegetation indices NDVI and its modifications is justified. Problems of mathematical modeling of irrigation technologies in arid conditions based on differential equations are revealed. The model takes into account agrochemical features of soils, biological properties of crops, agroclimatic conditions, as well as technological parameters of irrigation regimes. The necessity and expediency of using digital information technologies in agricultural production, including irrigation reclamation, for operational management and control of agrotechnological parameters of crop cultivation are justified. A conceptual and logical database model for programmed crop cultivation has been developed. The developed software package will allow systemically aggregating and accumulating agrophysical and hydrometeorological information to justify land reclamation measures.

1. Introduction

The concept of development of agricultural production, set out in the Federal target program of the Russian Federation «Sustainable development of rural territories for the period up to 2020» [4], notes that it is necessary to widely introduce digital technologies, including the use of remote sensing and monitoring of agricultural land for their reclamation.

The current level of development of remote sensing of the earth methods allows us to obtain spectral information from dozens of spectral channels with different spatial resolution (30-250, 500 and 1000 m), which allows us to evaluate various soil characteristics and parameters of agrocenoses. Available for scientific research is the «VEGA-Science» service developed at the space research Institute of the Russian Academy of Sciences-IKI RAS (http://iki.rssi.ru/). At the same time, specialists of the TUSUR earth space monitoring Center [1] note the lack of methods of mathematical processing and specialized SOFTWARE for analyzing the results of remote sensing of the earth for the level of individual agricultural enterprises.
These programs are not focused on the level of specific agricultural enterprises, which requires the development of specialized intelligent PS that allow adaptation for individual farms, as well as integration with GIS technologies [5, 6].

2. Materials and methods
The creation of specialized databases based on a system approach is based on specific it methods-functional-morphological and autocorrelation analysis. For the purpose of subsequent processing of retrospective yield data, preliminary preparation and transformation of the source information was carried out, which provides computer processing of target information using specialized ML machine learning libraries in Python V. 3.7 [8].

3. Results and discussions
Agricultural plants have different degrees of spectral reflection of solar radiation – relatively low in the visible part of the spectrum (0.3...0.6 microns) and relatively high in the infrared range (0.7...1.0 microns) [9].

In the reflection spectrum of plants, characteristic differences are noted due to the influence of water vapor absorption. Consequently, the total reflected radiation depends on the biological and varietal characteristics of plants, the development of the leaf surface, their growth phases, the chemical composition of the soil, and other factors [7].

The known characteristics of the spectral properties of reflection of various surfaces, shown in Fig. 1, are the basis for calculating the corresponding indices [2].

![Figure 1. Spectral characteristics of reflection of various surfaces.](image)

For tasks remote sensing of the earth agricultural land the most widely used index NDVI, however, for some tasks of land reclamation, may use other vegetation indices - soil adjusted index (Table1), the green chlorophyll index-adjusted vegetation index, normalized red-green index, etc.
Table 1. Basic vegetation indices used in remote assessment of the ameliorative condition of soils.

| Name of the vegetation index | Analytical expression | name of indicators |
|-----------------------------|-----------------------|-------------------|
| Normalized difference vegetation index | $NDVI = \frac{(RED - NIR)}{(RED + NIR)}$, | RED – reflection coefficient in the infrared spectrum; NIR-reflection coefficient in the visible spectrum. |
| Adjusted soil index | $SAVI = \frac{(1 + L)(NIR - RED)}{(L + RED + NIR)}$, | GREEN - reflection coefficient in the green region of the spectrum; BLUE - reflection coefficient in the blue region of the spectrum; |
| Green chlorophyll index | $CIG = \frac{NIR}{GREEN} - 1$, | |
| Vegetation chlorophyll index | $CVI = \frac{(NIR \cdot RED)}{(GREEN^2)}$, | |
| Extended vegetation index | $EVI = 2.5 \cdot \frac{(NIR - RED)}{(NIR + 6 \cdot RED - 7.5 \cdot BLUE + 1)}$, | |
| Adjusted vegetation index | $CTVI = \left(\frac{NDVI+0.5}{NDVI+0.5}\right)^{0.5}$, | |
| Normalized red-green index | $NGRDI = \frac{(GREEN - RED)}{(GREEN + RED)}$, | |

To solve the problems of satellite remote sensing, you can use measurement data from satellite space monitoring devices, which are freely available. Data on radiation reflection in various ranges of radiation spectra can be obtained from open sources [9], some of which allow us to obtain calculated values of vegetation indices at once (Table 2).

Table 2. Technical characteristics of satellite monitoring spectral devices.

| Device name | Permission, m | number of channels | Frequency, days |
|-------------|---------------|--------------------|-----------------|
| ASTER       | 15,30         | 9                  | 16              |
| AVHRR       | 1000          | 6                  | 1               |
| LANDSAT     | 15,30,100     | 11                 | 16              |
| MODIS       | 250,500,1000  | 36                 | 1               |
| VEGETATION  | 300,1000      | 7                  | 10              |

Available to researchers is a multifunctional software package with a web interface «VEGA» [7], the operation of which is based on data from the MODIS satellite sensor, which is designed to calculate the normalized difference vegetation index NDVI with a time resolution of 8 and 16 days [2]. By order of the Ministry of agriculture of the Russian Federation, a «System for remote monitoring of agricultural lands of the agro-industrial complex» is being developed [1].

We are developing a new software system capable of obtaining, storing, preliminary and thematic processing and analysis of processing results with a high degree of automation of processing procedures. the «Internet information system for accumulation, processing and analysis of satellite data MODIS» is adopted as an analog [7]. The algorithmic core of the developed system is the calculation of a set of normalized vegetation indices.

For the effective functioning of an agricultural enterprise of a certain territory throughout the year, it is necessary to formulate the main production tasks, as well as to find a variety of meteorological, soil, and hydrological conditions that affect the implementation of each task. This will allow agricultural enterprises to evaluate the expected benefits of taking into account the results of space monitoring data processing in daily practice, and software developers to formulate the main requirements for the designed systems, including elements of precision farming.
The main tasks of remote sensing of the earth for ameliorative assessment of the state of agricultural land can be divided into the following: pre-sowing treatment, direct sowing, monitoring the development of agrocenoses, harvesting [2]. Some of them can be solved using traditional ground-based measurements, and some are preferred for processing remote sensing data and/or space monitoring.

Note that ground data allows you to calibrate the results of remote sensing of the earth data processing, while reference measurements are performed in separate places of the analyzed territories, and the rest of the land area is surveyed using remote sensing of the earth.

We will highlight the main tasks that are effectively solved using remote sensing and space monitoring data:
1) The qualitative state of land resources and the dynamics of its changes;
2) Detailed distribution of crops (up to 1 ha);
3) Plant development and spatial distribution of phytomass by phases of the growing season;
4) Identification of zones of land degradation (salinization, erosion, et al.) and assessment of overgrowth of trees and shrubs in unused areas;
5) Identification of unused land, as well as facts of unauthorized use of agricultural land;

At the same time, it is possible to accumulate statistical data for the required years of monitoring and research.

The remoteness and mutual location of agricultural fields, including irrigated ones, makes it necessary to create a system of regular monitoring and control over their condition. Data on crop rotations of land use makes it possible not only to optimize their use, but also to make more reasonable forecasts of land productivity and crop yields.

Accumulation of remote sensing and space monitoring data with hydrometeorological data allows us to build an adequate mathematical model verified by the results of ground-based agrophysical measurements, and develop appropriate reclamation measures to preserve and improve soil fertility.

![Figure 2. Working screens of the VEGA satellite monitoring system](image)
a) start window; b) object selection window.

The main tasks that require automation are the procedures for receiving, storing, processing and analyzing remote sensing of the earth data. Among them are: direct receipt from spectral devices and pre-processing of satellite information; filling in relational databases for storing incoming results and their pre-processing; development of software tools for pre-processing and providing information obtained from the results of algorithmic transformations.

The block diagram of the developed software package, the structure of which is based on known systems [2], is shown in Fig. 3. The receiving units of source information provide reception and
subsequent storage (updating) of information RS. The results of calculating the aggregate of vegetation indices are presented in the modeling block.

A separate block provides the construction of spatial and temporal models of changes in the analyzed indices, including determining the trend and seasonal components of the corresponding time series, and comparing the current values with the required reference parameters [5, 11].

![Figure 3. Block-diagram of the ANN of the developed system.](image_url)

In addition, a block is provided for analyzing the obtained parameters based on an artificial neural network (ANN) to support decision-making in case of adverse developments (pest damage, salinization, overgrowth, erosion). Methodological approaches to creating a software package designed for receiving and processing remote sensing data in the visible and infrared parts of the spectrum are considered. The software package is intended for obtaining the results of remote sensing and satellite monitoring with the use of a set of vegetation indices for subsequent analysis. The main tasks solved by the developed software package that determine its structure and logical model of the database are justified and formulated. A set of vegetation indices, including NDVI and its modifications, forming the algorithmic core of data analysis is justified. The developed software package will allow systemically aggregating and accumulating agrophysical and hydrometeorological information to justify land reclamation measures.

4. Conclusion

The analysis revealed the following problems and areas of research. The main problems of mathematical modeling of resource-saving irrigation technologies in arid conditions are identified, including the use of partial differential equations that take into account the agrochemical characteristics of soils, biological properties of crops, agro-climatic conditions, as well as the design and technological parameters of irrigation systems, including irrigation regimes. The necessity and expediency of using modern digital technologies in agricultural production, including irrigation reclamation, for operational management and control of agrotechnological parameters of crop cultivation are justified.

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