

The Use of Remote Sensing Methods to Study the Ecological State of Agricultural Soils

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Abstract—Modern technologies are not used effectively enough in the current structure of the agro-industrial sector. Remote sensing, as a process of collecting information in a non-contact way, allows providing interested users with objective and detailed information. Currently, it is one of the rapidly developing industries of the fifth technological revolution. The use of aircraft- or satellite-based sensors makes it possible to obtain panoramic images of high resolution. Analysis of images allows us to establish the territory of saline soils, assess the condition of crops and conduct environmental monitoring. The soil layer changes its composition and quality through human activities, which leads to negative consequences. The leading place of atmospheric emissions in the Omsk region belongs to motor vehicles, the number of which is only increasing. Salts of heavy metals (lead and cadmium) settle on soil and plants, accumulating in them over time. At the current state we should talk about local pollution of soils that are located near sources of pollution: various industrial enterprises, thermal power stations and automobile and railway transport.

Keywords—remote sensing, satellite images, soil pollution, heavy metals, spectral brightness coefficient, interpretation, discrete NDVI scale.

I. INTRODUCTION

Surrounded by information technology, a modern person cannot imagine his life without them. More recently, mankind could do without mobile communications, the Internet and other interesting technological findings. The levels of technological production taking shape in society largely determine the levels of development of society itself and of a person individually, which is usually called technological paradigm that develops cyclically and in waves. The transition to a new technological structure requires a change in the existing one, but its core remains and affects the formation of a new structure. Currently, methods of remote sensing using various aircraft and satellites are becoming an actively developing industry in the scientific and technological fields. Tasks solved using remote sensing technologies cover new areas of economy and agriculture and are becoming in demand.

Each subsequent way is based on the prevailing resource, which determines the development of the main sectors of the economy and brings to certain achievements, aimed ultimately at a humanitarian breakthrough in the society. The agro-industrial sector in Russia was formed during the fourth technological revolution, on the basis of developed engineering and heavy industry. Developing, society has the right to expect a breakthrough from a new

level of technological structure and a rise in the agricultural economy to a new qualitative level. The fifth technological revolution defines the modern economy, in which the speed of information transfer has increased, and the possibility of remote control of technological processes in all sectors, including the agricultural sector, has appeared. The emerging information technologies made it possible to implement digital farming projects and use remote sensing for the qualitative assessment of agricultural landscapes [1]. The fifth technological revolution is aimed at preparing the stabilization basis of the next stage – the postindustrial one, where nanotechnologies will play a leading role, which are aimed at improving the quality of human life. In this regard, the agro-industrial sector of Russia must make a breakthrough, requiring the use of innovation.

II. METHODS

Empirical research methods were used for developing the subject. Based on the results of field studies of roadside soils and plants located along highways, quantitative indicators of pollution were obtained and the relationship between the accumulation of heavy metals in the soil-plant system was revealed. This connection made it possible to create mathematical models that indicate an established relationship. The obtained informational relationship between soil and plants was used to decode satellite images with the calculation of the normalized difference vegetation index (NDVI). Visualization and quantitative indicators confirm the presence of biomass inhibition in sections of roadside stripes with soils that are subject to active pollution.

III. RESULTS AND PRACTICAL MEANING

Modern technologies are not effectively used in the production process at the current structure of the agro-industrial sector. So, in crop production, the quality of the crop is often largely determined by weather conditions and soil fertility, as was the case in all technological structures. In addition, about 15% of the territory of Russia belongs to zones of extreme agriculture and ecological distress. To identify and control these zones, it is necessary to conduct continuous monitoring of territories.

Despite this, technologies related to development and implementation of artificial intelligence, use and processing of large databases for integration with geographic information systems (GIS) are successfully developing and are widely used as a part of the implementation of national technological initiatives. All breakthrough technologies are

end-to-end technological processes and you only need to find a common ground. GIS of the agro-industrial sector, which is based on remote sensing data of the earth's surface, allows providing interested users with objective and detailed information on land use and, most importantly, making a forecast and reducing the percentage of errors when working with databases.

According to remote sensing data, it is possible to obtain various information [2-3], including predicting crop yields and identifying local damage to crops due to various reasons related to weather conditions, plant diseases or pests, environmental problems and the state of biosystems.

The reflectivity of the soil is characterized by a spectral brightness coefficient in the form of a ratio of the spectral brightness of the soil as an object of study and a standard (values obtained under ideal reflection conditions, taking into account atmospheric errors). Mathematical models of the spectral brightness of the soil, constructed from the values of the coefficients for the corresponding region on the spectrum of electromagnetic waves, make it possible to automatically recognize the properties of objects from images taking into account the spectral brightness in the visible spectrum, in the so-called "atmospheric transparency windows" (0,4-1,3 μm). Among the huge variety of objects on the earth's surface, according to the category of spectral brightness in the visible range, three classes of brightness are distinguished. The upward shift of brightness (in the red zone of the spectrum) is characteristic of rocks and soils composing them due to the presence in their composition of minerals and compounds of iron and humus (class 1). The second class includes vegetation cover, which is characterized by the onset of reflectivity in the green zone of the spectrum, and a sharp increase in reflection in the infrared zone. The maximum brightness in this range is associated with the reflection of rays by chlorophyll [4]. The state of green pigment in plants (chlorophyll) indicates a qualitative and quantitative state of biomass.

Today there is a need to use the results of a systematic continuous survey of the earth's surface with minimal time intervals. Continuous monitoring of the earth's surface can be performed by small second-generation remote sensing spacecraft operating in low Earth orbits. Continuous coverage of the Earth's surface with images allows you to combine the received information with geographic information systems for online monitoring.

Monitoring using satellite navigation systems allows you to monitor the implementation of agricultural activities from the very beginning to the end of the field season.

Remote sensing is considered as a process of collecting information in a non-contact way. Currently, it is one of the rapidly developing industries of the fifth technological revolution [5]. The use of aircraft- or satellite-based remote sensing makes it possible to obtain panoramic images of high

resolution. Analysis of images allows you to: establish the territory of saline soils, assess the condition of crops.

Soil is a biological resource of all life forms on the planet: microorganisms, plants, animals and humans. There are no constant life conditions in the world, they are constantly changing, so it is important to track the trends of change and not to miss the opportunity to take the necessary measures. The soil layer composition and quality changes, due to human activities, and that leads to negative consequences.

According to the currently standards in the Russian Federation, all chemicals entering the soil are divided into three hazard classes: highly hazardous, moderately hazardous, and low hazard. Pollutants are not dangerous as the substances themselves, but their concentrations are, which are defined as heavy metals (HMs), which are capable of settling in the soil, be absorbed by the plants, and accumulate in the human body. Heavy metals include chemical elements with an atomic mass of more than 40. If their number is optimal, then they can be considered as trace elements that are essentially supporting all types of life. If their number exceeds a certain limit – threshold limit value (TLV) of soil content, then such soils are considered contaminated and adverse for growing crops; if the content of HM significantly exceeds TLV, then it is about the environmental risks that can nevertheless be calculated, predicted and managed. The quantitative state of the physicochemical composition of the soil is the most important environmental indicator of the soil, distinguishing it from the other rocks that make up the planet. The quantitative state ultimately determines the quality of fertile soils, plants, and human life in a biogeocenosis.

Arable lands in the Omsk region can be considered environmentally friendly because the actual content of HM in the arable layer for the region as a whole and for its individual areas is within 0.5 TLV, i.e. pollution has not yet become a widespread negative phenomenon, but this does not mean that accumulation trends are completely absent. At present, we should consider local pollution of soils located near pollution sources, which include: various industrial enterprises, thermal power stations and automobile and railway transport. The percentage of atmospheric emissions in the Omsk region, unfortunately, is consistently high and the leading place belongs to motor vehicles, the number of which is only increasing [6]. Salts of heavy metals (lead and cadmium) with dust particles are transported to considerable distances from sources of pollution and settle on soil and plants, accumulating in them over time.

Roadside stripe pollution with lead is associated with gas-powered vehicles: the lead content in the soil near the source of pollution is at maximum, and when removed from the source of pollution, it decreases noticeably and at a distance of more than 100 meters it becomes close to its background content (Table I). The data were obtained according to the results of field monitoring studies [7].

TABLE I. AVERAGE CONTENT OF MOBILE FORMS OF HEAVY METALS IN THE ROADSIDE STRIPES SOIL OF THE MAIN HIGHWAYS IN THE OMSK REGION, MG / KG

Sampling point	HM content in soil (M ± tpm)				
	Cu	Zn	Pb	Cd	Ni
Eastern direction					
Roadside	0.47±0.11	9.63±6.31	4.56±3.16	0.25±0.06	1.57±1.06
100 m distance	0.09±0.08	0.32±0.14	0.71±0.25	0.09±0.03	0.77±0.11
Western direction					
Roadside	0.50±0.19	13.18±3.2	7.56±5.28	0.22±0.06	1.75±0.53
100 m distance	0.15±0.06	0.49±0.39	1.08±0.64	0.20±0.08	0.91±2.52
Northern direction					
Roadside	0.53±0.19	7.27±3.14	7.63±3.14	0.21±0.05	1.43±0.36
100 m distance	0.25±0.19	1.04±0.8	1.26±0.25	0.10±0.05	0.65±0.08
TLV	3.0	23.0	6.0	-	4.0

M – the arithmetic mean, m – the arithmetic mean error, tp – the student's t-test at P = 0.95

The given data inflexibly indicate the excess of lead and cadmium at the roadside, not only their background value, but also the threshold limit value at a distance of 100 m from the roadside.

Lead and cadmium are considered the most environmentally hazardous. Mobile and easily accessible for plants forms of lead make up about 1/3 of their potential soil reserves. In fact, the amount of pollutants near highways is higher than the limit values, which indicates the possibility of significant absorption and accumulation in the plants' root system. Plants growing along roads are able to accumulate HM in much larger quantities, because the absorption of chemical elements occurs not only by the root system, but also through the leaf blades, which leads to a significant deterioration in the quality of crop production. And the question of the direct influence of toxic chemical elements, including HM, in the soil-plant-animal system – on a human's health is still under study.

The researches clearly indicate the existing relationship between the content of mobile forms of heavy metals in soil and plants. Mathematical models of the relationship between the accumulations of pollution in the soil-plant system made it possible to create a graph of their dependence. The graph for a number of plants studied is presented in figure 1.

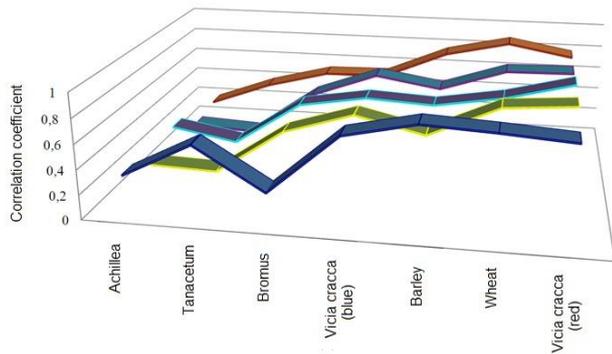


Fig. 1. Dependence of heavy metal content in the soil-plant system

For a comprehensive assessment of the emerging problems of soil and plant pollution and making timely decisions, it is effective to use an electronic map, which is the basis of the geographic information system (GIS). An electronic map allows you to simulate the process and predict the effects of pollution in time and space for management in a biogeocenosis.

In connection with the needs of global trends, actively developing network markets, form the strategic goals of their

development. The leader in the global market for unmanned aerial vehicles and small spacecraft systems – Aeronet, includes segments in the program of the roadmap for its development, including Agriculture, Remote Sensing and Monitoring. Many government and business entities are interested in the development of environmental monitoring and digital agriculture.

A modern way to obtain information about the state of soil and plants is the processing of remote sensing materials to solve a variety of scientific and applied goals [8]. A review of a number of sources showed that there is practically no research on the use of satellite imagery to monitor contaminated soils for the presence of exceeding doses of trace elements (HM) that inhibit plants [9-10].

As a decoding attribute in the analysis of images, in this case, we can use the change in the brightness of the color tone and/or the value of the normalized difference vegetation index at the reflection point, falling in a certain region of the spectrum (figure 2). For plants it is red light (0,6-0,7 μm) and near-infrared NIR light (0,7-1,0 μm). In the scientific literature it is called the normalized difference vegetation index of photosynthetically active biomass NDVI = (NIR – RED) / (RED + NIR). A high value corresponds to a good state of vegetation in the study area; low – corresponds to the state of inhibition. The “normalized” index was developed in 1973, when a group of scientists from the University of Texas began to consider not only the ratio of infrared light to red, but the ratio of their difference to their total. This made it possible to bring all index values to a range from -1 to 1, that is, to “normalize” for easier comparison with each other. NDVI values from -1 to 0 are objects of inanimate nature and infrastructure – snow, water, sand, stones, houses, roads, etc. Values for plants range from 0 to 1.

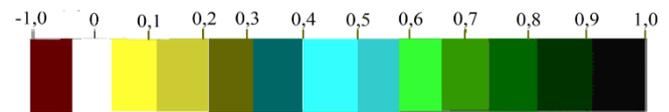


Fig. 2. Discrete ndvi scale

Using indicators of the discrete NDVI scale and data on the relationship between the accumulation of HM in soil and biomass inhibition on contaminated sections of the Omsk Region's roads in three directions from the city, images of the Omsk Region's road – federal highways P-254 and the West Siberian railway branch line 52K-2 (Figure 3). Figures b), c), d), e) and f) show index maps of sections of these roads. The maximum distance from the axis of the road on the presented maps is not more than 500 m. When analyzing the values of the NDVI along the road and the railway, it was found that the value of this index at the same distance from the axis of

the road is not the same. So, it reached a higher favorable value of 0.6-0.7 along the highway only at a distance of at least 100 m, while along the railway this distance is about 30 m.

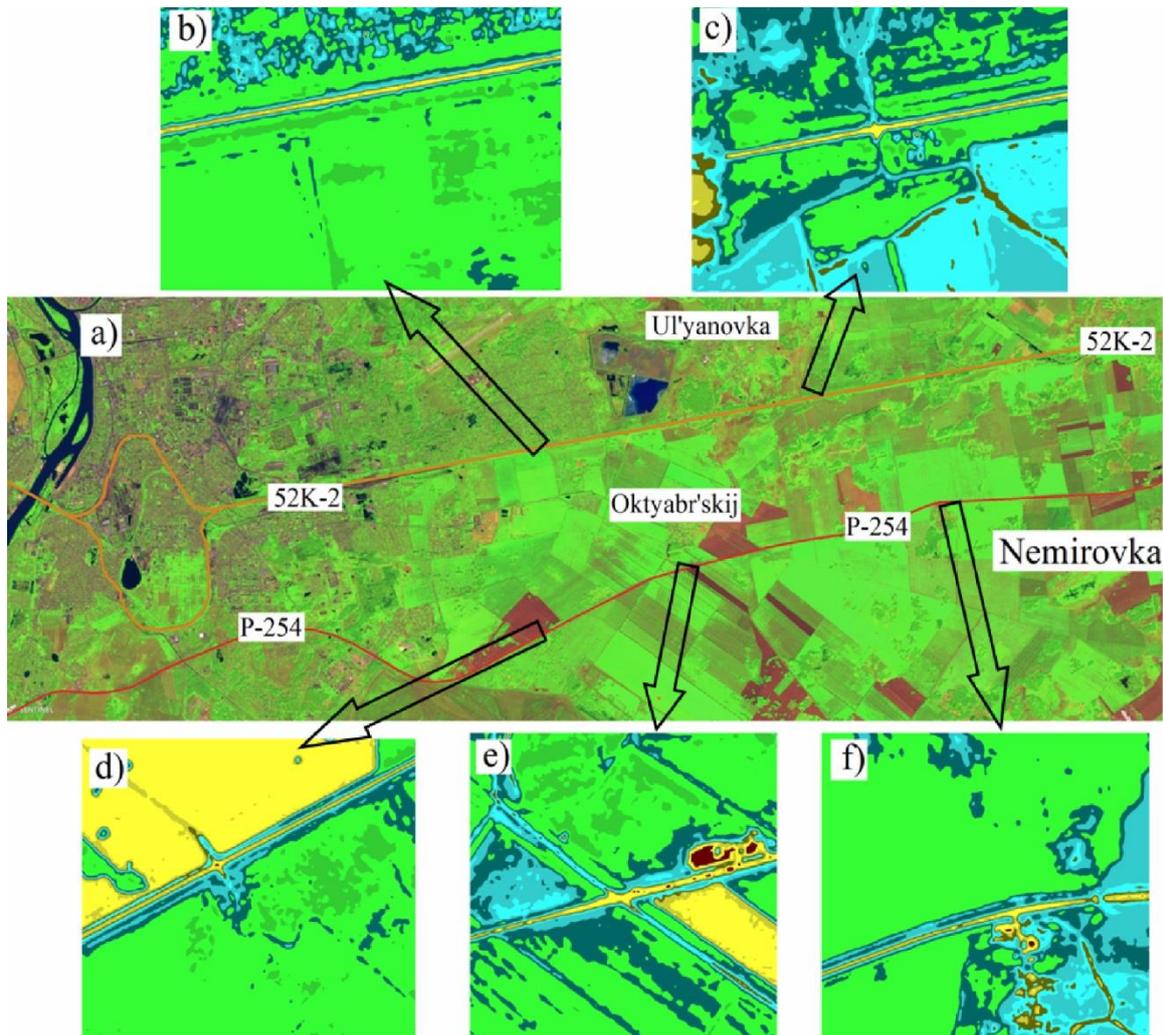


Fig. 3. a) Omsk-Novosibirsk road and railway fragment; b), c), d), e), f) - NDVI maps of local sections scale

IV. DISCUSSION

Analyzing the possibilities of information obtained using satellite images, it can be noted that at the moment it is very diverse, and the possibilities for its use are high. The information obtained from satellite images and used for the development of the agricultural sector is at the stage of its development. But already today, the use of NDVI allows you to monitor the situation of the quality of seedlings and the development of crops, predict the yield and identify the need for fertilizers [10]. Deciphering of satellite images during agroecological monitoring is not only about recognition of objects for outlining the boundaries (contour interpretation), but also gives a possibility to establish the qualitative and/or quantitative content of the structural components of the soil layer (genetic decryption). The main recognizing feature when monitoring images using high-resolution remote sensing data, as many authors indicate, is the brightness and color tone of the soil horizon [11-12]. In addition, by varying

spectral brightness, it is possible to determine the oppression of plant biomass and look for the causes of its appearance, one of which can be significant pollution of the soil and plants with heavy metals, which in large quantities appears in the atmosphere because of vehicles.

V. CONCLUSION

Heavy metals, in large or small quantities are constantly able to accumulate. This leads to uneven seedlings, diseases, general inhibition and, as a result, a decrease in yield and environmental security of plants. Inhibition of biomass growing along highways is possible for various reasons; the correlation coefficient values of lead and cadmium accumulation in plants and soil (Figure 1), as well as the results of the biomass index (Figure 3), persistently indicate the main reason – the excessive content of heavy metals in plants, and as a result, their suppression.

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