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https://doi.org/10.5109/6781080

出版情報：Evergreen. 10 (1), pp.300-307, 2023-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Use of Remote Sensing Data for Environmental Monitoring of Desertification

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(Received January 5, 2023; Revised February 17, 2023; accepted March 7, 2023).

Abstract. The relevance of the study is conditioned by importance of problems of desertification of lands, included in system of providing natural resources for individual states and the whole geographical regions, and also efficiency of using modern methods of remote sensing of terrains for the effective solution of problem questions of ecological monitoring of desertification zones. The aim of this study is to investigate the data of remote sensing of terrains to assess the effectiveness of practical use of this methodology for solving the problematic issues of ecological monitoring of terrain desertification in the territories under consideration. The basis of methodological approach in this study is a combination of system analysis of various aspects of remote sensing technology application in various geographical regions with analytical study of problematic issues of ecological monitoring of land desertification, important in terms of their role in implementation of practical tasks faced by agriculture and industrial sector, in whose activities these territories are of significant practical importance. The main results obtained in the course of study are the land surface monitoring data obtained using satellite equipment, demonstrating the sequence of surface desertification stages, and clearly illustrating the possibilities of applying the surface remote sensing technology and the prospects for its subsequent application. The results and conclusions of this study are of considerable applied value from the standpoint of creation of effective methods of application of remote sensing technologies of territories, strategically important for operation of economy and industry of any state. Such technologies are also of considerable interest for employees of design offices and research institutes, engaged in development of modern methods of practical application of remote sensing technologies for assessing the degree of ecological desertification of the above-mentioned territories

Keywords: remote sensing; ecological desertification; ecological monitoring of desertification; system for receiving and processing information; space survey; receiving optical system

1. Introduction

The method of remote sensing of the Earth surface involves obtaining information about the state of its surface through the use of special equipment that allows making changes without direct contact with the terrain. The remote sensing method is used in various branches of science. For example:

- hydrology, including assessment and management of water resources, snowmelt forecasting, flood warnings;
- agricultural fields (weather forecasting and management, control of vegetation type, distribution and condition, etc.);
- oceanography (sea surface temperature measurements, studies of ocean currents and sea wave spectra);
- geology, geomorphology and geodesy (for example, identification of rock types, localization of geological defects and anomalies, measurement of Earth parameters and observation of tectonic) etc.[1)]

Remote sensing of the terrain can be carried out using passive techniques, involving the use of natural objects with reflection of secondary thermal radiation, which is caused by direct rays of the Sun, and active techniques, involving the emission of radio waves and registration of reflected signals[1)].

Identification of specific areas of the terrain considers the differences in the reflection of radio waves from

various objects, such as rocks, water and soil cover, areas of vegetation that absorb and reflect the ranges of magnetic study in different ways. Remote sensing of the terrain using space technology objects (satellites) allows solving problems of studying natural resources, including problems of a meteorological nature, conventionally solved, primarily with the use of radiological and optical equipment. This technology guarantees an advantage in monitoring the surface of open areas of the terrain, regardless of the time of day and current atmospheric conditions.

Environmental monitoring of desertification zones using remote sensing techniques involves monitoring areas of the Earth surface using space satellite equipment to determine the current state of geographic zones characterised by a significant risk of desertification and loss of suitability for practical use of these lands for the needs of agriculture and other economic activities[2]. At the same time, it is necessary to consider the wide possibilities of the technology of remote sensing of the terrain, expressed in the width of the coverage of the investigated territory, the efficiency of the control, the possibility of exercising control over territories of different geographic distance, and the possibility of remote sensing of the terrain in almost any weather and temperature conditions[3]. The latter circumstance determines a significant advantage of the considered method over other methods of terrain monitoring, since the ability to monitor the surface in any weather, regardless of real temperature and atmospheric conditions, allows for almost continuous monitoring, subject to high measurement accuracy and practical continuity. This fact is of significant importance for such sectors of the economy as the oil and gas complex, water management, agriculture and forestry management system of the country, and in studies of the impact on the environment of technogenic and anthropogenic factors that are closely related to each other, but at the same time have significant differences in degree of manifestation[4].

Data obtained from space objects during monitoring by remote sensing methods are widely used to determine patterns of spatial and temporal nature, and in the study of the global properties of the main ecological systems that are closely related to each other and affect one another (water resources, biosphere, atmosphere, cryosphere, etc.). The main technical characteristics of remote sensing data include their availability in digital form, as a result of which it becomes possible to control them using modern computers, use electromagnetic radiation to obtain a wide range of necessary information within the framework of the method under consideration[5]. In this context, an important factor is the possibility of digital processing and modelling of the information received, allows creating multidimensional mathematical models of geographic objects studied using the method under consideration.

The main drawback of studies carried out in this line before was the lack of information on the effectiveness of the application of the method of remote sensing of the terrain to assess the ecological desertification of certain areas. This study sets the task of the practical solution of this problem and the establishment of a full-fledged scientific investigation of the features of the use of remote sensing technology for the study of the problem of ecological desertification of the territory using remote sensing data based on space images.

2. Materials and Methods

The methodology of this study was based on a combination of methods of system analysis of various aspects of the application of remote sensing technology in different geographical regions with an analytical study of problematic issues of environmental monitoring of land desertification, important from the standpoint of their role in the implementation of practical tasks facing agriculture and industrial sector in whose activities these territories are of significant practical importance. Much attention is paid to theoretical studies of the capabilities of remote sensing technologies for areas of the Earth surface to determine the main patterns of ecological desertification in certain geographic regions and to establish an effective procedure for monitoring these areas using the capabilities of satellite technology.

The theoretical basis of this study is numerous research papers by, mainly, foreign researchers, whose activities are aimed at studying the issues of practical application of remote sensing technology to investigate the current state of the Earth landscape as a whole, and to use the study findings to investigate the features environmental monitoring of desertification of certain areas of the Earth. To form the most qualitative and objective picture of scientific research, and to improve the perception of the information provided, all the developments of foreign researchers presented in this paper were translated into English. Thus, the most objective and complete picture of a scientific research is created, corresponding to the whole range of issues presented in its subject matter.

The entire sequence of operations performed in the course of this study assumes a breakdown into several main stages.

At the first stage, a theoretical analysis of the available papers devoted to the problems of the practical application of remote sensing technology for researching various aspects of environmental monitoring of desertification of various parts of the Earth was carried out. In addition, a systematic study of the characteristic features of the practical use of remote sensing technology in geographic regions, which are important from the standpoint of the possibilities of conducting economic activities in them, was carried out.

At the next stage, an analysis of the main problematic issues of environmental monitoring of land desertification was carried out, which are important from the standpoint of their role in the implementation of practical tasks facing agriculture and the industrial sector, in the activities of

which these territories are of significant practical importance. In addition, at this stage of the study, an analytical comparison was made of the preliminary results of the research with the results of related studies by other authors who developed problematic aspects of remote monitoring of various parts of terrain for the purpose of environmental monitoring of their desertification.

At the final stage, based on the results obtained, the final conclusions were formulated, summarising the results of the entire complex of research efforts carried out, and serving as a logical reflection of its results. In general, the results and conclusions of this study are the most objective and complete reflection of the entire complex of investigative work carried out using remote sensing data obtained based on the space and satellite images.

3. Results

Nowadays, many states have mastered systems for remote sensing of the Earth surface, which are orbital based and contribute to the qualitative solution of a wide range of cartographic problems. Under typical conditions, the survey is carried out from a space satellite by an optical electronic system operating in panchromatic and multispectral modes. The first of these shooting modes provides a black-and-white image that covers the entire electromagnetic range, while the second mode assumes the ability to obtain images in a wide spectral range of the infrared and visible radiation spectrum.

Remote sensing of the terrain is carried out using aviation and space technology, which are equipped with a variety of optical and electronic systems, which operate in a strictly defined wavelength range[6]. The technology of remote sensing of terrain using objects of space satellite technology assumes the presence of an optical radiation spectrum in the range (~ 0.4 ÷ 1.2 μm). A schematic representation of the principle of remote sensing of the Earth surface in the optical range of the radiation spectrum is shown in the Figure 1.

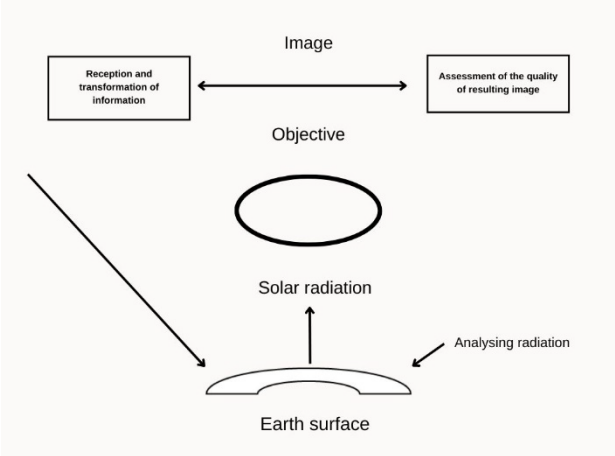

Fig. 1. The principle of remote sensing of the Earth surface in the optical range of the radiation spectrum

The entire visible spectrum of electromagnetic radiation is occupied by panchromatic imaging, carried out in the range (~ 0.6 ÷ 0.8 μm). This provides a full spectrum representation in black and white, with a higher resolution range than multispectral imagery. The study of the technology of remote sensing of the terrain involves the use of modern computer technologies with optical-electrical systems, both during their testing and at the stage of direct operation. This technique allows obtaining images of a higher degree of resolution after carrying out their computer processing (Figure 2).

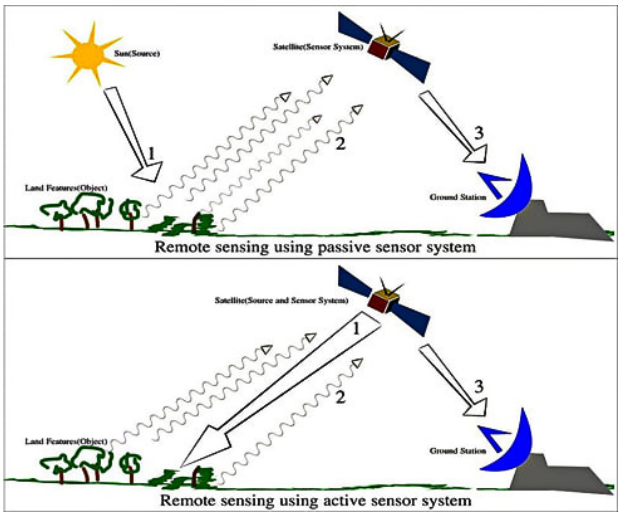

Figure 2. Remote sensing of a terrain section using satellite technology

The use of methods of remote sensing of terrain using satellite technology to study the processes of desertification of its individual sections allows obtaining objective information about the state of objects of almost any scale, even the smallest. The high spatial resolution of the equipment of the used satellite technology allows selecting objects of a smaller scale in the images, provided that there is a small swath and a low frequency of the survey performed.

The use of remote sensing data to conduct high-quality environmental monitoring of desertification of individual sections of the terrain forms a holistic view of the state of these areas, provided that the images are of high quality resolution. In this context, the applied methods of mathematical modelling are of particular importance, which significantly reduces the time and money spent on performing tasks to obtain high-quality images[7]. Notably, investigation of the terrain using remote sensing involves two types of mathematical modelling: analytical and simulation.

The model of optoelectronic systems within the framework of the theory of linear systems can be represented in the form of the following functional dependence:

$$Aoes = \{Batm \times Ssp \times Dob\}, \quad (1)$$

where, the product of the parameters of the superpositions of the optical characteristics of the atmosphere, lens, and environment is presented in curly brackets.

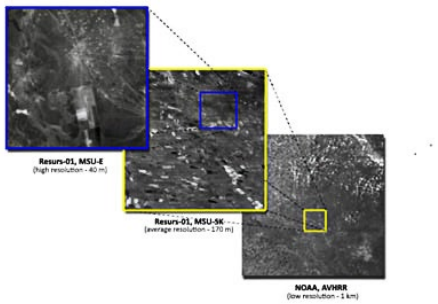

Fig. 3. Images of a site with pronounced signs of desertification, obtained by satellite equipment using the method of remote sensing of the terrain

Figure 3 shows the data of the Earth surface remote sensing system obtained using satellite technology. The images are arranged in ascending order of quality of the image obtained with the use of artificial satellite equipment. Based on the images obtained, digital landscape maps are constructed, which contain information about landscape units, and other parameters characterising the sequence of the desertification process.

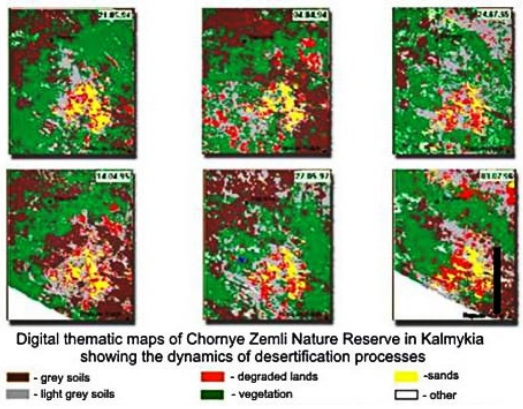

Fig. 4. Analysis of desertification processes based on satellite imagery data

Figure 4 shows the desertification monitoring data obtained using the method of remote sensing of terrain. The presented images clearly show the zones of soils covered with vegetation, degrading, grey, light grey, and sandy zones. The data obtained using the remote sensing technique allow clearly identifying the zones of the spread of degradation processes in the soil cover of the studied territories, which gives grounds to draw conclusions about the trends in the spread of desertification in the area that is the zone of research using satellite equipment. Monitoring areas of the terrain using the remote sensing method allows obtaining the most accurate results, considering the peculiarities of conducting research of this kind and the distinctive characteristics of satellite technology used for such operations[8]. The processes of remote sensing of the terrain allow monitoring the current state of both land plots and water bodies, including the real state of the systems of emergency discharges of toxic substances into water bodies, which is an integral part of the operation of the system of treatment facilities of industrial facilities.

A mandatory requirement for the operation of space systems for remote terrain sensing is a high quality of image resolution created using satellite systems for monitoring the Earth surface. In the event of a loss of quality, the possibility of a qualitative assessment of the real state of the investigated areas of the terrain and the generation of conclusions regarding the prospects for desertification of these areas is lost[9]. At the same time, operational monitoring of land plots from the standpoint of analysing the prospects for their desertification involves conducting research in strictly limited periods of time, to form an objective model for researching the problems of desertification of land plots suitable for agricultural and other activities aimed at improving land use conditions in this specific region. At the same time, the peculiarities of conducting economic activities in a particular region should be considered when assessing the effectiveness of satellite terrain monitoring using remote sensing methods. Thematic processing of remote sensing data of the Earth surface using satellite technology requires the use of modern software systems for data processing, suggesting the possibility of their division into two main complexes:

1. Oriented towards spatial transformations.
2. Thematic decryption and classification.

Modern software tools that make up the first group are distinguished by a developed feature set of geometric transformations of the fixed surface image, considering its binding to a certain coordinate system. At the same time, the resulting programme images, which have undergone the necessary correction and are referenced to a given coordinate system, can be practically used as a raster substrate in geoinformation systems, undergo processing in cartographic systems to obtain topographic maps of the vector type, and intended for solving a number of special tasks of monitoring the state of the terrain. At the same time, the creation of thematic maps is carried out using software systems containing thematic decryption, with developed functionality that allows high-quality texture and topological analysis[10]. As a result, images can be obtained that contain specially selected objects that reflect the essence of the study of ecological monitoring of desertification. Thus, the problem of desertification of territories and the development of methods for detecting such lands using satellite equipment can be effectively and efficiently solved through the development and

implementation of methods for remote sensing of the terrain, which is essential in the context of the timely development of methods for protecting parts of the Earth surface from desertification in the event that if they are of interest for doing business on them. Environmental monitoring allows collecting information in a timely manner, necessary for assessing the current state of ecological systems and monitoring them. This allows timely determining the emergence of new environmental problems and assessing trends that are significant from the standpoint of the establishment of objective criteria for assessing the state of geographic objects subject to research using space satellite technology. The information obtained in the course of the study may turn out to be useful from the standpoint of the prospects for the development of optimal strategies for adaptation to environmental conditions and the qualitative resolution of ecological problems, the origin of which can be detected using modern technologies of remote sensing of terrain[11].

The method of remote sensing of terrain using space satellite technology was developed in the 1960s-1970s. The track equipment of space satellites of that time allowed determining the projection of the measurement area onto the Earth surface, which was a combination of lines and various regular geometric shapes. At the current time, the receiving optical devices accommodate promising scanner arrays created based on charge-coupled devices. They allow obtaining spatial information, both on geographical and man-made processes occurring on the Earth surface in the visible and infrared ranges of electromagnetic radiation[12].

At present, the development of complex space systems is carried out using a variety of methods and means of mathematical modelling, which have significant advantages in terms of resource and time costs compared to full-scale and semi-natural methods of modelling. For this reason, the implementation of mathematical modelling using modern information technologies should be considered an integral part of a modern technological process and one of its constituent parts. Various aspects of this process have long been described in detail in numerous research papers, while such descriptions are based on studies of two main types of processes: physical and economic[13]. At the same time, there are oppositions of simulation and analytical modelling, which implies the compilation of a general functional of a simulation model of the process of remote sensing of an area using one equation or a system of equations. The use of the analytical approach in this context assumes its difference in taking into account the dynamics of the speed system directly during the formation of the functional, instead of implementing it in the form of a given sequence of operations performed[14]. Models of this type facilitate the most complete study only if there are identified analytical regularities of the process that are able to consistently connect as fully as possible the input to the system with the output from it, considering the given initial conditions. This seems to be possible only on condition that limited-type models are used, which are relatively simple in structure. At the same time, complex systems involving a variety of ongoing processes with the use of a large number of variables are mainly used in the case of using space remote sensing systems[15].

4. Discussion

Solving the problems of analytical modelling facilitates the most complete and objective research only in the case when there are pronounced analytical dependencies, reflecting the parameters of entry and exit into the system with equal initial conditions, which is typical for relatively simple systems. At the same time, more complex systems that assume the presence of diverse processes with a large number of parameters, in particular, the processes of remote sensing of the Earth from space, imply the use of simulation systems to describe the monitored processes and phenomena[16]. In this context, the practical application of mathematical simulation techniques allows significantly reducing the risk of inaccuracies in performing numerical modelling operations and to carrying out the procedure for numerical modelling of the actions of the remote sensing system and their sequential coordination, taking into account the influence of disturbing factors of various nature over a given or formed period of time[17]. This means that, in fact, it can be argued that the simulation model is a special apparatus capable of qualitatively linking experiments of the virtual and natural type within the framework of a single software and hardware complex. Subsequently, the combination of various models for conducting research within the framework of remote sensing of terrain provides a qualitative and objective picture of scientific research, using the maximum amount of information provided, taking into account the real possibilities of space satellite technology used in these experiments.

The high efficiency of management of scientific and technological processes that have a direct connection with study aimed at ensuring state and public security, and observing the interests of the national economy, in the context of studying deep and near space using modern spacecraft, involves the use of remote sensing techniques of terrain using the capabilities of astrometry, as one of the main methods of scientific research in this field[18]. Notably, the technology of remote sensing of the terrain in a given optical wavelength range allows collecting information both on the geographic parameters of the terrain, on geophysical parameters, and on all technological processes occurring on the Earth surface. Remote sensing of terrain, considering the main tasks facing the developers of this technique and the persons responsible for its practical application, can be carried out using various techniques for surveying the terrain, such as route, object, stereoscopic, static, dynamic, topographic, and spectrometric. Talking about the optical range of

research, then remote sensing of terrain is carried out using special measuring and fixing equipment, which is located on board of the space satellite. The consistent development of such devices proceeds along the path of the establishment of a certain volume of schematic solutions, and information technologies, which allows forming complexes that are distinguished by a unique combination of information, weight and size, precision and energy parameters[19].

From the standpoint of the effectiveness of the practical application of the technology of remote sensing of terrain, the concept of building the latest complexes based on a strictly verified orbit in outer space presupposes the consistent provision of a number of components, which include: periodic survey of terrain objects, using equipment providing high spatial and energy resolution; collection of information from terrain to describe it qualitatively and create a high-resolution topography; practical solution of astrometric problems with high quality resolution; study of the main astrophysical parameters, with high indicators of accuracy and reliability of the measurements[20]. At the same time, consistent consideration of possible development of modern information technologies, involving remote sensing of the Earth surface using space technology, will contribute to a qualitative search for opportunities to improve these technologies and create optimal opportunities for the development of the entire space research industry as a whole, taking into account real needs of national economy in accurate data on the current state of the terrain and desertification of individual sections of the Earth surface[21]. The development of modern optical systems with a high degree of aperture will only contribute to the establishment of the proper type of resolution, both spatial and energy. In addition, modular optical systems with active control of the wavefront shape allow conducting research and obtaining results with a high degree of reliability, which is of great importance from the standpoint of the effectiveness of researching areas of terrain using modern satellite technology and assessing the degree of desertification of lands that are important in the context of economic development[22].

Assessment of the main parameters of the process of targeted use of the advanced space systems for remote sensing of terrain in the optical range of the radiation spectrum in almost all cases was carried out and is being carried out by practicing organisations-developers. Nevertheless, as the practical experience of using such experimental and design developments shows, based on the results of the tests of the space system, not in all cases the conditional parameters indicated in the terms of reference can be confirmed. In addition to the inevitable production errors, the sequential decrease in quality indicators can also be conditioned by the small depth of research carried out at the design stage (the lack of taking into account one or another influencing factor, and the problems of accuracy of incomplete accounting of the ongoing physical processes[23].

The main problematic aspects of the technology of mathematical modelling of the processes of targeted use of space systems created for remote sensing of terrain should be considered issues related to ensuring the high adequacy of the developed model, and its compliance with the requirements of modern technologies, in terms of ensuring high accuracy of measurements[24]. The significance of scientific and technical tasks performed in this context lies in the actualisation of the high cost of designing and creating means of remote sensing of terrain, and significant requirements for quality parameters and operational reliability, which are objects of a comprehensive theoretical study carried out with the establishment of a calculated estimate at various stages creation of this model[25]. A full-fledged and high-quality solution of all the problems posed requires a full account of all factors that are important from the standpoint of the practical application of space systems for studying the Earth surface by remote sensing methods, using modern space technology and adequate calculation models of mathematical modelling.

The problem of desertification of lands, which have gradually lost their economic importance and negatively affecting the external environment, is the problem of disrupting the full functioning of land areas suitable for conducting economic activities and taking measures to normalise the activities of land holdings and bringing them to a full-fledged state in accordance with regulatory standards and the requirements of business activities[26]. Such lands are distinguished by degradation of the soil cover, problems of the hydrological regime, and establishment of a characteristic relief of the area, which manifests itself due to numerous disturbances in economic activity[27]. The most complete and detailed information on the real state of the land fund, and the identified violations of economic activity and problems of the soil cover in the most affected areas can be obtained using space technology objects when conducting remote sensing of the terrain in specific regions and studying the problems of ecological desertification of specific areas. Carrying out remote sensing of the surface in the most problematic areas allows timely identification of all real problems arising in the field of land use and posing a danger from the standpoint of the subsequent use of these land plots for the needs of the national economy[28].

The data obtained using remote sensing methods using space technology[29, 30]. objects allow timely and efficiently solving many problems, such as tracking the development of soil erosion, the degree of need for an inventory of lands prone to deflation, and identification of areas with signs of waterlogging and desertification. Timely solution of these and a number of other issues in a short time would help to obtain an objective picture of the prospects for the practical application of remote sensing methods for a qualitative solution of the issues of assessing the degree of land desertification.

5. Conclusions

Based on the results of study on problematic issues of using the method of remote sensing of the terrain using images obtained by space satellite technology to monitor ecological desertification, the following conclusions were formulated. The practical application of the technology of remote sensing of the terrain for the purpose of environmental monitoring of desertification facilitates a consistent and high-quality assessment of the real ecological state of areas of the Earth surface that are subject to desertification or have a high degree of potential risk of developing such a scenario. At the same time, it is essential to obtain images with a high degree of resolution for the establishment of the most high-quality and reliable picture of the development of this process, since with a low quality of images made by satellite equipment, obtaining an accurate and complete picture of desertification is problematic.

At the same time, the creation of a model of optoelectric systems within the framework of the theory of linear systems involves the compilation of a functional dependence, considering the characteristics of the lens of the research tool, the atmospheric environment, and also the external environment, which implies the need for a comprehensive study of the relationship of these parameters in a specific time period. The methods of remote sensing of terrain contribute to the achievement of high accuracy of monitoring carried out using modern satellite technology, and allow obtaining high-quality spatial images, without considering the influence of the external environment and under the condition of almost continuous operation of the satellite equipment used in these operations. This determines the significant prospects for the subsequent use of the method of remote sensing of the surface to conduct environmental monitoring of desertification and gives grounds to classify the technology under consideration as one of the most effective methods for tracking the state of the Earth surface using satellite equipment.

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