Дистанционные методы исследования Земли
Remote methods in Earth research

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THE SYSTEM OF GLOBAL SPACE MONITORING OF THE PROCESSES OF LITTERING OF THE PLANET EARTH (A JOINT RUSSIAN-CHINESE PROJECT)

ABSTRACT

Currently, geoinformation systems using Earth remote sensing data from space have taken strong positions in the field of economics, politics, and, practically, all spheres of human activity. As a consequence of human activity in urbanized areas, this is the emergence and further spread of unauthorized landfills and industrial waste. The littering of the planet is becoming an increasingly serious problem that we face in the modern world. Plastic waste, air and water pollution, improper waste disposal — all this damages the environment and can have long-term consequences for the planet and life on it. A variety of human diseases, such as chronic lung diseases, malignant tumors, and oncological diseases is directly related to atmospheric pollution, namely the gas component — landfill gas. In order to intervene in time and stop the spread of infection and changes in the soil composition of territories, etc., it is necessary to have a global automatic monitoring system for landfills and industrial waste. The purpose of the work is to design a model of a global automatic monitoring system for waste disposal facilities, including industrial ones, using Earth remote sensing technologies from space. Scientific novelty: a model of a global automatic space monitoring system for the processes of littering of the planet Earth is proposed. A general methodology is given for constructing a geoinformation model that monitors territories for the presence of waste disposal facilities. The analysis of modern prospects in the creation and operation of such automatic geoinformation systems using certain knowledge in the field of ultra-large, distributed and open data archives, as well as modern methods for improving color images, is presented.

KEYWORDS: remote sensing of the Earth, satellite monitoring, waste disposal facilities, spatial data processing, global monitoring system for landfills and industrial waste

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INTRODUCTION

Currently, the planet Earth is experiencing a triple crisis: climate change, loss of biodiversity and environmental pollution. This was stated by UN Secretary-General Antonio Guterres, addressing the participants of the One Ocean Summit, which took place in France on February 9–11, 2022.

The littering of the planet is becoming an increasingly serious problem that we face in the modern world. Plastic waste, air and water pollution, improper waste disposal — all this damages the environment and can have long-term consequences for the planet and life on it.

Threat to biodiversity. Pollution and littering of the planet cause serious damage to biodiversity. Waste, especially plastic, ends up in the seas and oceans, threatening marine organisms and ecosystems. Many animals and plants are at risk of extinction due to the impact of debris on their natural habitats. In the long term, this can lead to disruption of ecosystems and loss of unique species.

Consequences for human health. Environmental pollution, including water and air, has a negative impact on human health. Harmful substances contained in waste and emissions can lead to various diseases, including respiratory and food infections, cancer and problems with the immune system. Long-term exposure to a polluted environment can have serious health consequences for future generations.

Climate change. Garbage and waste play a role in climate change. Uncontrolled waste incineration and greenhouse gas emissions lead to an increased greenhouse effect and global warming. In the long term, this can lead to rising temperatures, changing climatic conditions, changing seasons, rising sea levels and other climatic disasters that have a negative impact on life on Earth.

Threat to ecosystems and natural resources. Littering the planet can lead to the destruction of ecosystems and depletion of natural resources. Damaged ecosystems cannot perform their functions, such as purifying air and water, ensuring soil fertility and maintaining biological balance. The depletion of natural resources, such as forests and water reserves, creates unpredictable consequences for living organisms and economic development.

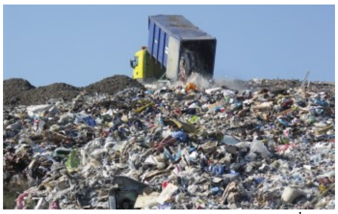
Global responsibility and challenges. The littering of the planet is a global problem that requires urgent and coordinated action by the entire world community. This calls for changes in consumer behavior, the development of environmentally sustainable technologies, waste reduction and improvement of the waste management system. The long-term prospects for littering the planet require awareness and action on the part of governments, businesses, and each individual.

To combat such a global phenomenon as the littering of the planet Earth, it is necessary to fully utilize the capabilities of modern technologies, in particular, technologies for creating a digital image of the planet Earth, coupled with technologies for remote sensing of the Earth from space. The problem of littering can be considered as the creation of a new layer on the Earth's surface (on land and in water areas) with an uneven thickness (where there are more accumulations of debris, there is a thicker layer). In order to prevent an increase in the thickness of this layer, it is necessary to have a system for global monitoring of the processes of littering planet Earth using geoinformation technologies and technologies for remote sensing of the Earth from space, which could provide the world community with objective information about the processes of littering and their impact on the environment in real time to make effective management decisions both at the level of individual states and at the level of the global community.

The proposed article is based on the works of an outstanding Russian scientist in the field of creation and practical application of space environmental monitoring systems, Academician of the Russian Academy of Sciences Bondur [*Bondur*, *Savin*, 1992, 1995; *Bondur*, 2000, 2004, 2006, 2011, 2014; *Bondur* et al., 2003, 2009; *Keeler*, *Bondur*, 2005].

Background

Human activity on a global scale is determined by the presence of a large number of WDF and IW, which have an extremely negative impact on nature and the life of living organisms and people (Fig. 1). This is especially true for Asian and African countries. For example, everyone knows plastic islands floating in the Pacific Ocean that destroy biological species living in the water. Preventing the occurrence of spontaneous unauthorized WDF is the primary task of all countries of the world.



Littering of the Earth's surface[1]

A huge amount of waste falls into the aquatic ecosystem[2]

Now there exist real "Garbage islands" occupying vast territories in the world ocean[3]

The ocean inhabitants often become the victims of the environment littering[4]

Birds and fish often take garbage for food, swallow it and die[5]

Victims of the garbage disaster influence[6]

Death by garbage[7]

Plastic and waste[8]

Furnaces of hell[9]

Fig. 1. Impact of WDF and IW on the environment

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1 Web resource: https://global-tomsk.ru/news/id/3164 (accessed 09.30.24)

2 Web resource: http://interesno.cc/article/15443/20-letnijj-junosha-reshil-globalnuju-problemu-musora-v-okeanah (accessed 09.30.24)

3 Web resource: https://ria.ru/20160914/1476976058.html (accessed 09.30.24)

4 Web resource: https://zen.yandex.ru/media/id/5d2ae9a9998ed600acf9ad6a/issledovaniia-pokazyvaiut-chto-sotni-a
kul-i-skatov-zaputalis-v-plastikovyh-othodah-5d2af2af14f98000ac62201c (accessed 09.30.24)

5 Web resource: https://plasticchange.dk/videnscenter/fakta-om-plastik-i-havet/ (accessed 09.30.24)

6 Web resource: https://prostolike.net/life/fotofakty-zhestokaya-pravda-o-posledstviyah-zagryazneniya-okruzhayush
hej-sredy.html (accessed 09.30.24)

7 Web resource: https://lenta.ru/articles/2019/03/24/trash/ (accessed 09.30.24)

8 Web resource: https://lenta.ru/articles/2019/03/24/trash/ (accessed 09.30.24)

9 Web resource: https://lenta.ru/articles/2019/03/24/trash/ (accessed 09.30.24)

In the work, research is being conducted in the field of waste disposal facilities (WDF), which will be considered when creating a global remote monitoring system. WDF are a source of danger associated with atmospheric air and soil pollution, and pose a real threat to humans and the environment [*Richter*, 2018; *Kazaryan* et al., 2019; *Kazaryan*, *Voronin*, 2020]. WDF is a concept that includes the following facilities: landfills of solid household and industrial waste (SHW and IW) (Fig. 2a), municipal urban landfills (Fig. 2b), landfills (Fig. 2c), unauthorized landfills (Fig. 2g), recultivated quarries (Fig. 2d), recultivated landfills (Fig. 2e), cluttering of the territory (Fig. 2g), typical landfills (Fig. 2h), industrial landfills (Fig. 2i).

Let's now consider the ideology of creating a global system for remote monitoring of waste disposal facilities (WDF), including industrial (IW) — (GSDM_WDF and IW).

It should be noted that similar studies on remote monitoring are actively conducted all over the world [*Lavrova* et al., 2015; *Loupian* et al., 2016], as well as in the leading specialized research institutes of our country [*Putilina*, 2015; *Aristov*, 2019] and the same topic is the object of mass media quite often published on the Internet. The relevance of research in the field of application of Earth remote sensing technologies is obvious. This is due to the range of problems created by the appearance of unauthorized WDF and IW, as well as the resulting consequences in all spheres of human activity.

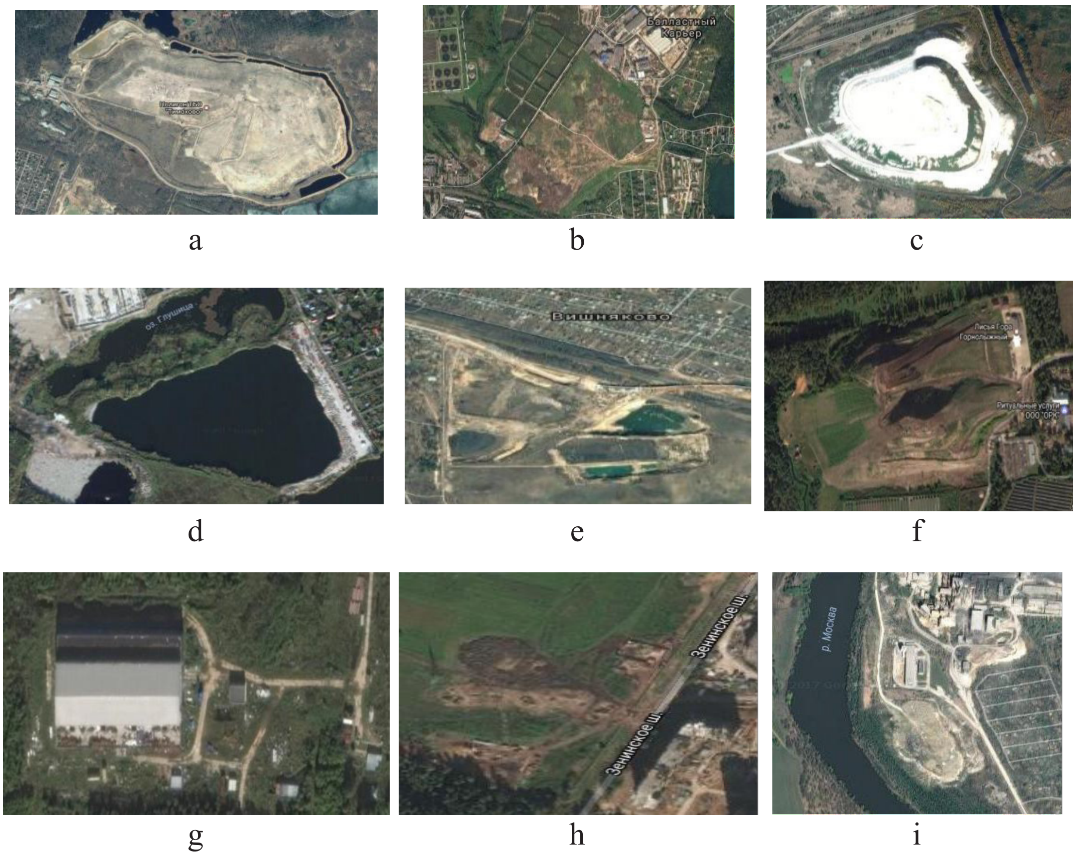

Fig. 2. A variety of WDF presented in satellite images:[1]
a) SHW — landfill; b) urban municipal landfill; c) Belaya Gora — landfill;
d) landfill — unauthorized; e) quarry — recultivated; f) landfill — recultivated;
g) territory with clutter; h) landfill — construction; i) landfill — industrial

[1] Moscow Region. Map data by Google

RESEARCH MATERIALS AND METHODS

Learn more about monitoring territories for the presence of WDF.

Ground-based methods for detecting and conducting research are quite well developed. There are a sufficient number of publications on this topic [*Putilina*, 2015; *Aristov*, 2019]. The works analyze issues related to:

- methods of reclamation, operation and design of WDF landfills;
- chemical composition and associated landfill processes;
- the use of ground-based monitoring methods to study the impact of landfills on the environment;
- studies of water, air, and soil located at a certain distance from specific polygons.

The literary analysis of terrestrial methods of environmental monitoring of the WDF according to some sources has demonstrated:

- morphological composition of the landfill, frequently encountered fractions;
- a scheme of the degradation process of waste consisting of anaerobic, aerobic phases and humification with appropriate properties;
- the production of filtrate and the movement of heavy metals with laboratory studies;
- landfill gas production and its infiltration;
- production of humus and formation of organic substances;
- production of microbial fermentation and trophic groups.

The research is of a laboratory nature, and the analysis allows us to draw the following conclusions:

- WDF ground monitoring technologies in almost all countries have good scientific justification and elaboration;
- there are a large number of scientific publications on the problems of WDF and ground-based research;
- scientists conducted [*Kazaryan* et al., 2019] a fairly in-depth analysis of the landfill in terms of its chemical composition and the processes taking place in its body.

Let's turn now to the remote method of monitoring territories for the presence of WDF. It was only in 2007 that scientific research on WDF began. Active work is being carried out in Ukraine. These are researchers M. V. Aristov, V. S. Gotynyan, O. V. Tomchenko, and Miko-lenko. This issue is being dealt with in the NC "Nature", as well as in the "Institute of Applied Geography" [*Aristov*, 2019]; in Russia, similar studies are being conducted in the Krasnodar Territory, in the Irkutsk Region, etc.; in Japan, the works of researchers S. Oshi, Ya. Yatsuoka, M. Tamura are known [*Moore, Hansen*, 2017].

A literary analysis of WDF remote environmental monitoring methods according to some sources [*Kazaryan* et al., 2022, 2023] demonstrated:

- necessary conditions for detecting household and construction waste by threshold values of spectral brightness coefficients (SBC) when conducting experiments with satellite images (SI) of the QuickBird, Ikonos, IRS-1C/1D series (given the specifics of the WDF texture, it is necessary to use the WDF surface texture parameters in addition to threshold filtering);
- necessary conditions for the use of controlled classification methods and iterative methods of uncontrolled ISODATA classification — (to divide objects into classes, it is necessary to use not the ISODATA method, but to "try on" masks of standards on the image);

- decryption algorithms and the impact of landfills on the natural environment, human health, assessment of soil, vegetation, and surface water pollution;
- analysis of the environmental impact on landfills;
- dynamics of the WDF area change;
- the presence of spontaneous combustion of debris and the detection of this factor on the thermal channel by SBC and the presence of a plume of fire, smoldering.

The accuracy of SI decoding varies from 88.76 % to 98.9 % when using various processing methods.

Techniques for processing aerospace images

When conducting aerospace monitoring based on aerospace images, it is necessary to use methods for detecting WDF and IW [*Kazaryan* et al., 2019].

The following are used WDF detection techniques:

1) Vegetation Reaction Index Technique;
2) The technique of information feature matrices;
3) Visual technique;
4) Textural technique;
5) The methodology of the standard;
6) The methodology of the normalized vegetation index;
7) Interactive methodology;
8) Radar technique.

These techniques have a certain complexity and accuracy. They are free, but their use depends on the size of the WDF. For example, large WDF can be detected using method 1, but with less accuracy. If you use method 2, you can increase the accuracy, and small WDF can also be detected using method 2, etc.

Analyzing the work of scientists on remote monitoring, it can be concluded that there are serious developments in the processing of satellite images.

The task set for the researchers is to further develop a methodology for automated (automatic) monitoring using RSE methods and technologies, taking into account the specifics of WDF on a global scale. Further research will be devoted to this problem.

Now the whole world is faced with the emergence of the coronavirus or COVID disease. Of course, one of the factors of its appearance is the deterioration of the environmental situation around the world, which can also be facilitated by unauthorized WDF.

Developed civilized countries around the world invest large amounts of money to carry out measures to prevent the spread of landfills and sanitary and epidemiological work to prevent the spread of infectious diseases and other consequences of WDF at the state level. To work in this direction, it is necessary to have a spatial data infrastructure at the global level for effective use of them.

Spatial data (SD) here refers to some digital information (shape, location, properties) about WDF and IW, defined in a coordinate-time frame of reference. By basic spatial data, we will understand spatial data that is allowed for open publication in print and on the Internet, they have a stable spatial position in the coordinate-time frame of reference. This makes it possible to orient other spatial objects to them. Metadata is information describing the characteristics of spatial data, such as volume, content, etc.

At the moment, there is no unified system for identifying spatial data on a global scale, which makes it impossible to build a single global information space.

It is necessary to develop an SD infrastructure that will provide:

- improving the efficiency and quality of management on the scale of interested states by attracting open SD information resources to make optimal management decisions and monitor their implementation;
- obtaining reliable and up-to-date information from the SD database for consumers according to common international standards;
- reduction of SD development costs, elimination of duplication and redundancy of data;
- the need to involve budgetary funds to carry out the necessary work, as well as the involvement of information elements.

The emergence of the Internet, the widespread use of information technology, the open use by users of desktop GIS, navigators, for example (the so-called LBS) working in direct connection with satellite navigation systems have made SD a common attribute of a user working in a wide variety of fields.

More recently, it was necessary to perform a topographic survey in order to obtain an SD. Now there is no need for this, it is enough to have a satellite image, laser scanning, aerial photography, etc.

Due to the active implementation and mass character of SD, any organization and active user can have maps and a variety of applications. This facilitates the processing, analysis and visualization of information on a range of tasks to be solved using SD.

The following conclusion can be drawn — on a global scale, it is necessary to have an SD with a developed information infrastructure, which is the basis for the development of the digital economy of civilized countries.

It is very important within the framework of SD application to solve the problem of detecting unauthorized storage and proper operation of authorized SHW and SD landfills in accordance with current legislation, to assess the impact on nature. When working with SD, it is necessary to have an environmental management system based on RSE technologies from space.

To solve the problems associated with the detection of unauthorized waste disposal facilities (WDF) and industrial waste (IW), it is necessary to conduct remote methods and then field studies confirming the results.

There is also an obvious interest of the authorities responsible for the timely prevention of accumulations of solid household waste (SHW), which entail irreversible consequences both in the field of sanitary and epidemiological, and in other areas of the socio-economic and medico-biological condition of the studied region.

It should be noted that in recent years the number of spacecraft (SE) has increased in the world. This contributes to an increase in the frequency and volume of information needed for further processing.

For our task, namely, global environmental monitoring for the presence of WDF and IW, this means the possibility of detecting some negative consequences already at the early stages of the appearance of unauthorized landfills, and this is essential.

On the Internet, it is possible to obtain satellite images (SI) in open access quite simply, using various technologies.

The level of accessibility of information has also increased, respectively, on the topic of research — WDF and IW, which contributes to the use of satellite information without creating specialized additional centers for the accumulation of primary information and this is additional cost savings, increasing the profitability of the system. This fact may lead to the creation of our own super-large archives of satellite information on the topic of WDF and IW.

Simulation of the global space monitoring system WDF

The creation of a global monitoring system for waste disposal facilities, as well as industrial waste, requires the fulfillment of certain requirements that have already become classic — these are the basic elements of the global monitoring system (GSM). Regardless of the type of GSM, these elements are represented in performing certain actions with space information.

The initial project is characterized by the development of the launch complex (core) of the system, which includes the ground and space segments.

The global environmental monitoring system necessarily includes a space-based part[1,2,3,4], which consists of spacecraft in circular sun-synchronous orbits. On board the spacecraft there are devices for active and passive sensing with certain technical characteristics, i. e. spatial resolution in the widest possible range of the electromagnetic spectrum.

The functions of the system under development include the procedure of regular survey of the studied territory in any corner of the Earth. It is advisable at the initial stage to use the existing grouping of Russian and Chinese Earth remote sensing satellites of various spatial and spectral resolutions. In the future, spacecraft from other countries may also be involved.

Let's consider the structure of the ground-based GASCOM WDF. It is based on a certain infrastructure that forms a certain system for receiving information in the process of remote sensing. It is logical to imagine it as a distributed network for processing satellite images, and there is also a need to create duplicate universal stations for receiving satellite images.

Development of integrated automated (automatic) global space monitoring systems WDF, which combine into a single structure control and information modeling systems, equipment for collecting and transmitting information through local and global computer networks, and software complexes created for these purposes. The creation of algorithms and promising models for predicting the foci of unauthorized WDF — all this is an urgent problem of the digital economy at this level of development of human civilization.

Let's introduce a number of designations. When developing a global system for automatic space monitoring of environmental emergencies associated with unauthorized environmental littering, methods are introduced (12), namely: the global integrated methodology (GCM) (see Fig. 3), which consists of three blocks (components of the methodology) — A, B, C; the global methodology for the detection of territories (GSM1) is block A (see Fig. 4); the global methodology for estimating the parameters of WDF and IW (GSM2) is block B (see Fig. 5); global methodology for assessing the impact of WDF on nature (GCM3) — block C (see Fig. 6). The main blocks are A, B, and an additional block C. When conducting global monitoring of territories, the WDF detection process is initially carried out using the original satellite images, then the characteristics, parameters, and condition of vegetation in the studied territory are evaluated using the same information or additionally using other satellite images. This algorithm is embedded in this technique, it is quite easy to use, and does not require additional information.

Let's look at the general characteristics of blocks A–C. Let's consider the operation of block A (see Fig. 4).

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1 Web resource: http://www.ntsomz.ru/dzz_info/articles_dzz/dzz (accessed 9.30.24)
2 Web resource: http://geomatica.ru/clauses/262/ (accessed 9.30.24)
3 Web resource: http://www.iki.rssi.ru/earth/tes.pdf (accessed 9.30.24)
4 Web resource: https://books.google.ru/books?isbn=5457966909 (accessed 9.30.24)

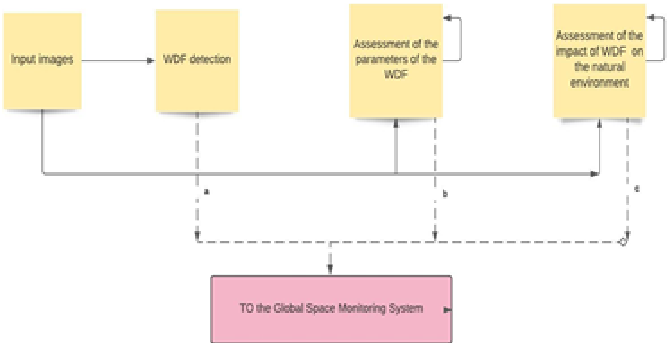

Fig. 3. General scheme of GIM: a — locations of objects, selection of objects and their components; b — parameters and characteristics of objects; c — state of vegetation on objects and in the vicinity

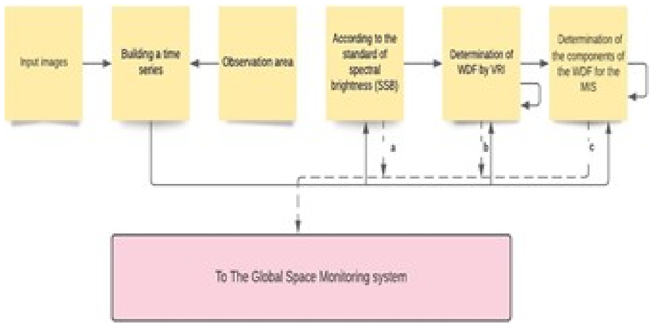

Fig. 4. General scheme of GIM1: a — locations of WDF; b — area of WDF; c — WDF components

The WDF detection process [*Richter*, 2018] consists of three stages:

1) WDF is determined by the standard of spectral brightness (ESIA);
2) according to the vegetation reaction index (IRR), the detected WDF is isolated;
3) according to the matrix of information features (MIP), the WDF components are isolated.

GCM1, as a result of functioning, determines the following areas or shapes:

- the location of the WDF or footprint;
- at the moment of shooting, it determines the area or territory of the WDF coverage;
- at different points in time of filming, a series of (temporary) WDF areas is formed;
- at each moment of the survey, the maximum degradation of the soil cover of the territory under consideration is determined, forming a focus of WDF;
- isolation from satellite images of the early state of the landfill, the concept of a pre-dump is being formed;
- the allocation of the coverage area of a certain surface class or component, the area of the WDF component is formed;
- combining different landfill territories and classifying them to a certain surface class, forming the WDF surface classification.

So, the work of the WDF detection stage is formed according to the following algorithm:

1) determining the location of the WDF — (1);
2) setting the WDF area — (2)–(5);
3) The establishment of the WDF components is (6)–(7).

Let us proceed to the consideration of the operation of block B (Fig. 5). As is known [*Richter*, 2018], the main parameters or characteristics of WDF that are obtained as a result of the operation of remote sensing technologies and satellite image processing include:

- thermal characteristics — WDF surface temperature (minimum, average and maximum temperature);
- geometric characteristics on the plane — perimeter, concentration of debris, area, etc.;
- geometric characteristics in space — height, volume, slope angle, etc.

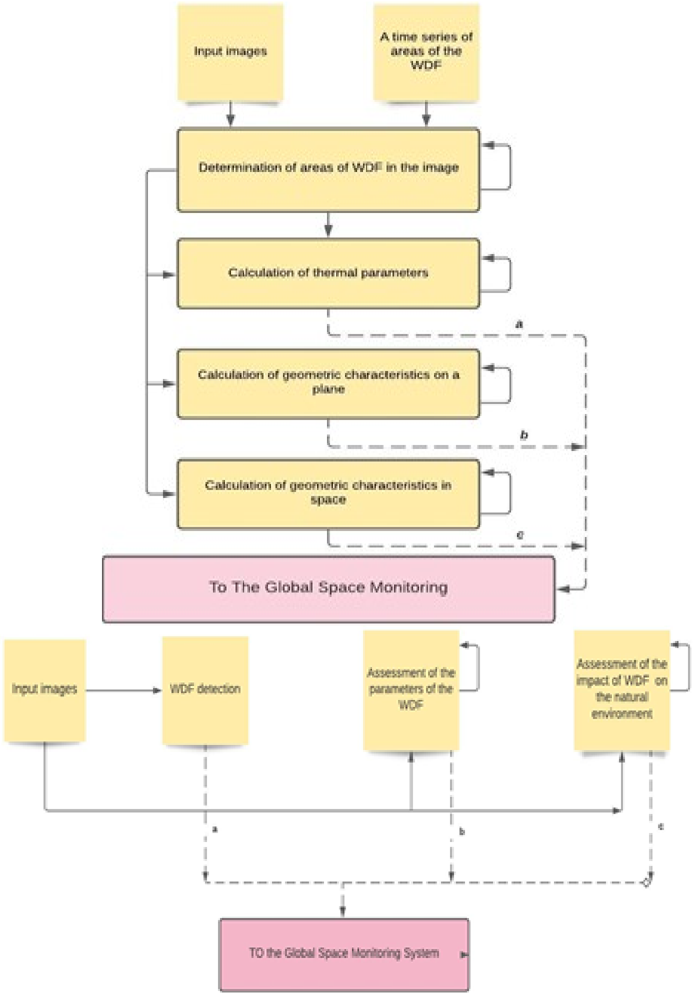

Fig. 5. General block diagram of GIM2: a — seasonal chronological changes in temperatures, characteristic surface temperatures, etc.; b — perimeter, area, concentration of litter, change of litter in the direction, etc.; c — volume, slope angle, characteristic values of height, surface area, etc.

Let's move on to the work of block C (Fig. 6).

The algorithm of the block C operation:

- at the input of the algorithm we have satellite images. (Landsat-4–8) — time series, i. e. multispectral SI of medium or high resolution — geo-linked, shooting conditions — warm season, which provides good conditions for detecting plants;
- according to the data of sub satellite monitoring, the image metadata is used to calculate the values of the XIA, which determines the factor for a fixed observation area;

- the surface temperature is determined using the SI thermal channel, which is later used as a factor for calculating the IRR;
- the NDVI index is determined using the red and infrared channels as a reaction calculated for fixed areas of the observation area;
- according to the normalized values of the factor, the IRR index is determined in accordance with the reaction at any time of the shooting.

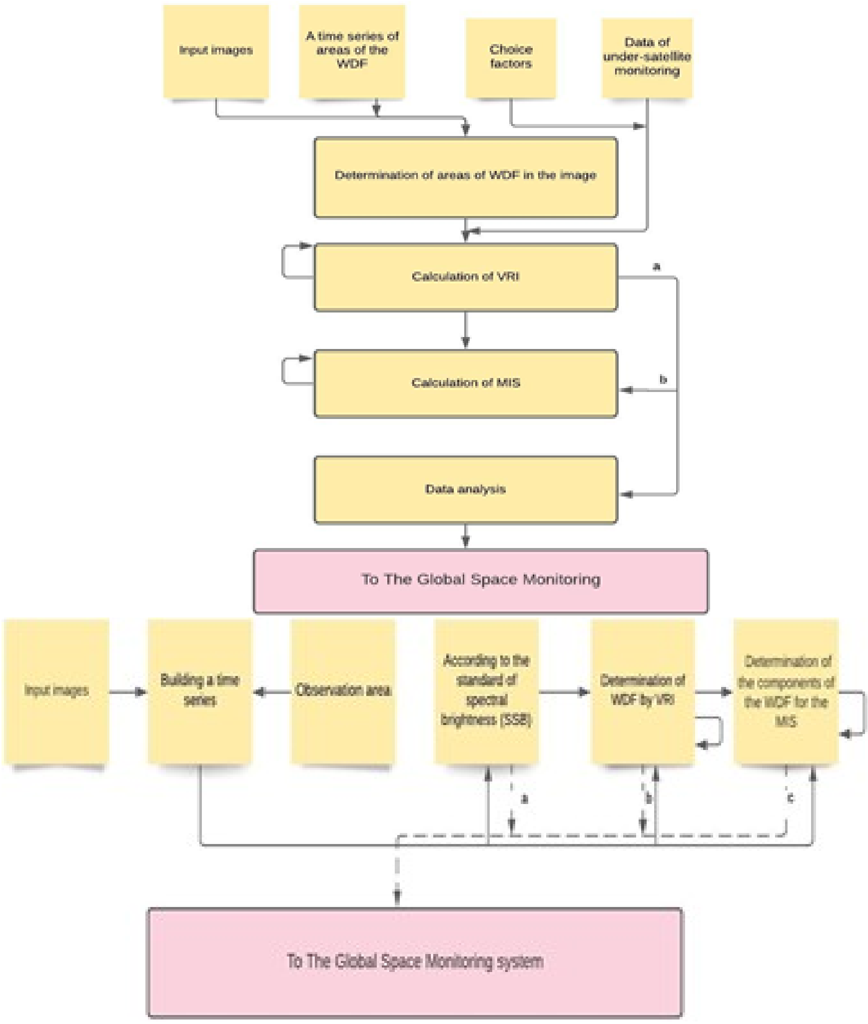

Fig. 6. General block diagram of GIM3: a — matrix of VRI values; b — matrix of MIS values

Let's consider the general scheme of the WDF global monitoring system, highlighting the work of GCM. The Global Space Monitoring System WDF consists of the following interconnected blocks:

- **Block I** is a data warehouse for existing WDF polygons. They are in the state register of municipal solid waste landfills (SHW) at this point in time;
- **Block II** is a subsystem for determining unauthorized WDF at a given time;
- **Block III** is a control subsystem for compliance with the rules of design, operation and reclamation (PEER) of existing SHW landfills;
- **Block IV** is a subsystem for developing an assessment of WDF parameters and their impact on the natural environment;

- **Block V** is a subsystem for predicting possible places of occurrence of WDF, with appropriate WDF parameters, as well as the impact of WDF on nature and human health;
- **Block VI** is a subsystem for satellite monitoring;
- **Block VII** is a subsystem for additional processing and appropriate analysis of the results of global space monitoring.

In the WDF global space monitoring system, information is transmitted according to the following principle. In block II, space images are processed using automation of space image processing in conjunction with WDF detection. The WDF detection area is compared with the information in the SHW polygon database in block I, unauthorized WDF are located, which are then recorded in block II. In block IV, the WDF parameters are evaluated for both WDF polygons located in block I and unauthorized WDF located in block II. Block V collects information when performing appropriate space monitoring technologies and methods to perform forecasting. Combining this information in block III with information from blocks I and IV, the analysis and collection of incoming data are carried out, violations of the necessary rules are determined during the operation of existing SHW landfills and the necessary environmental measures are applied. In block VII, information is collected from all blocks to perform processing and analysis of the collected information. In performing all of the above tasks, software complexes with a high level of automation, the possibility of using distributed network technologies, etc. are used.

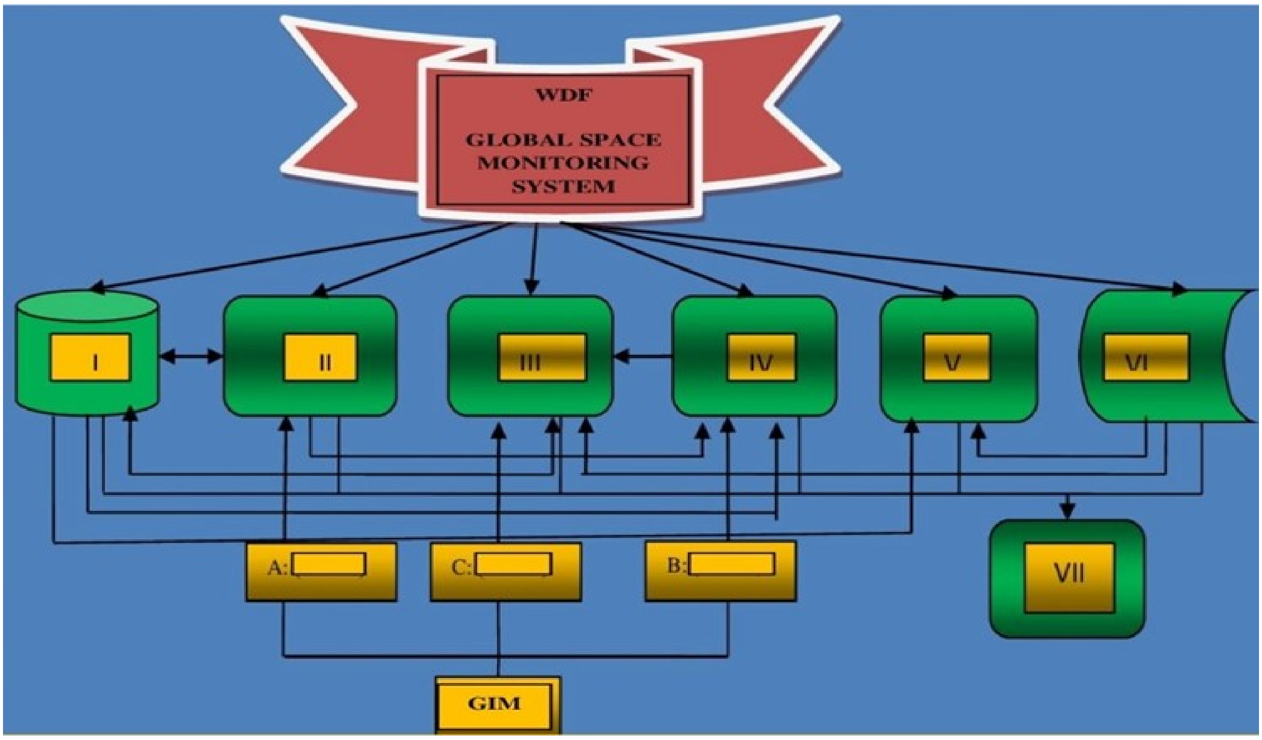

Fig. 7. Block diagram of the GMS for WDF: I — Database of municipal solid waste; II — Subsystem for detecting unauthorized WDF; III — Subsystem for monitoring the rules of solid waste landfills; IV — Subsystem for evaluating the parameters of WDF; V — Forecasting subsystem; VI — Subsystem of sub-satellite monitoring; VII — Subsystem of data analysis and processing; A — GIM1, B — GIM2, C — GIM3

Designing a global remote monitoring system (GSDM) WDF-IW

Let's look at the questions which are about organization of software development of automated reception and collection of satellite data.

We are investigating the task of creating software for the WDF and IW monitoring system according to RSE data. First of all, the situation of collecting and receiving space information is being investigated. Based on modern realities, namely, open (relatively) access to SI storage databases via the Internet, makes it possible to create specialized centers for receiving and processing SI. All information on SI from everywhere, including various funds of scientific projects, will be sent to these centers. To solve such a problem, it is necessary to have multifunctional utilities and programs for processing all kinds of SI and obtaining information for processing and monitoring territories for the presence of WDF and IW.

Let's consider the task of creating an automatic satellite data archiving system. Any system of this type should have a unit for maintaining satellite data archives, the main purpose of which is to store and provide CS to users in local and remote operation mode.

To automate this block of the monitoring system, it is necessary to use a DBMS with a built-in SQL language that allows you to work in program mode, having a friendly computer program interface, or using a SQL query system to implement a range of tasks related to the search and extraction of the necessary SI series. The information storage unit must have the following properties:

- adaptability to all types of satellite information, which can be modified over time;
- user operation in remote access mode;
- maximum automation of the preliminary stages of SI storage is annotations, archiving, and the storage process itself in the database;
- this system should be open in terms of replenishment with new SI and, accordingly, modification of technical means (servers, etc.) allocated for archives;
- and, as a rule, there should be separate geographically distributed centers in the country as information repositories and, accordingly, certain nodes of the open Internet system, physical media (CD, etc.).

Fig. 8 shows the architecture model of the automated SI archive.

Let's give some comments on each block of this model.

The first block of the archive management system includes databases for all types of information, i. e. data catalog, file storage, and long-term file storage. The archives of space data of the OZONE and software are presented in the form of a software package, which is updated depending on the tasks of users and, accordingly, researchers.

The second block, the archive administration system, includes archiving utilities, working with data, as well as sampling the necessary information for processing and supporting user orders. In the control plan of the unit, a group of operators responsible for this front of the system is attached.

The third block is the availability of archiving systems via the Internet, i. e. the corresponding web sites. This system includes user web interfaces, as well as service web interfaces. The work on managing this block is performed by operators and users who are literate in terms of information culture.

The fourth block is the system control. It includes checking web interfaces, e-mail notification of various emergency situations, checking the technical condition of computers and automatically launching special utilities — tests for checking the SI storage system as a whole. This system is open, i. e. the utilities are replenished with a variety of application programs that improve the quality of SI and modify the methods of storing them in information repositories.

So, we have a description of the WDF and IW remote monitoring model using information systems that provide work with ultra-large, distributed and replenished satellite image repositories.

We are investigating the issue related to the space information processing system. The processing of space information is presented in the form of primary and thematic processing of data. This work is carried out in two modes — automatic and automated.

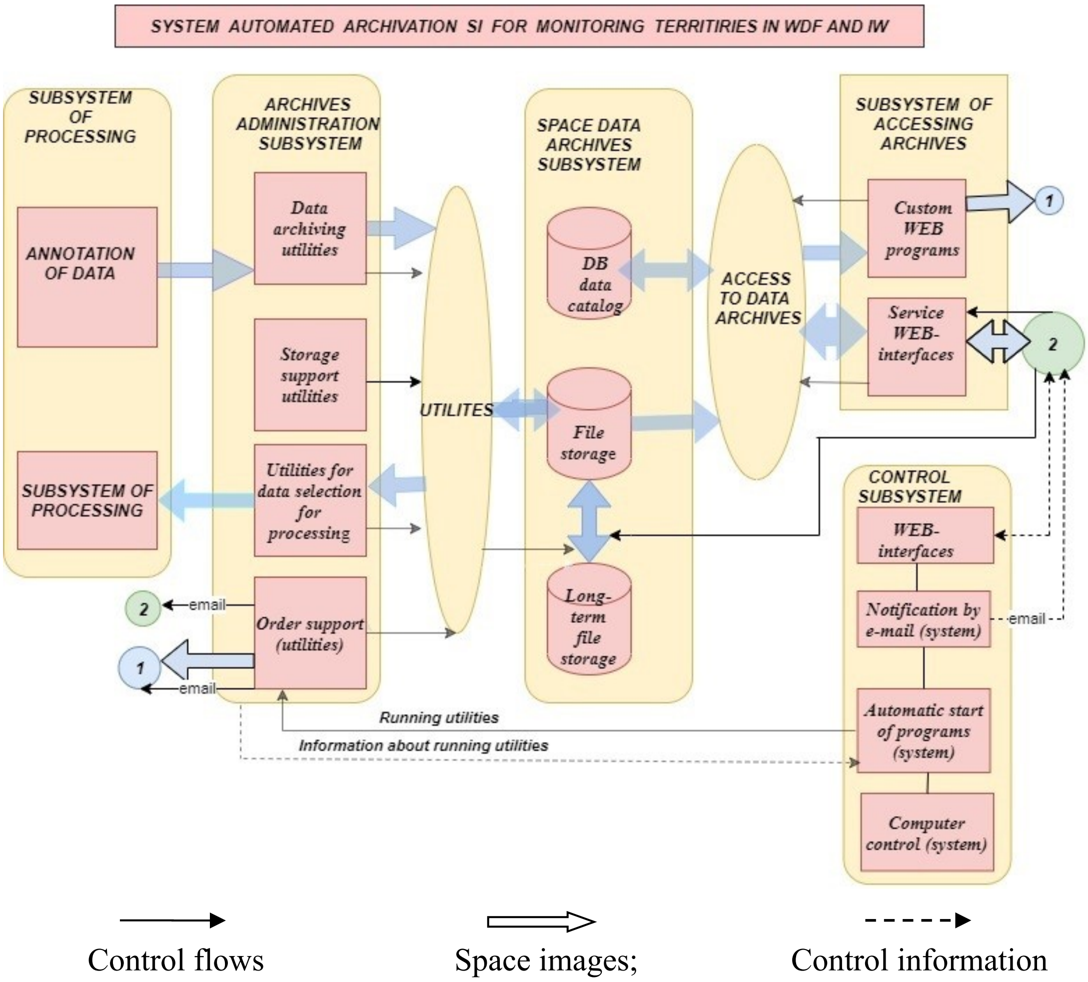

Fig. 8. Model of the architecture of the automated archive of the SI:
1 — archive operators; 2 — users

In the first case, a software package is being developed, a system of macros is used, for writing which, its own interface is provided. It provides a mode of remote access to information.

In the second case (automated), a sequential chain of information processing is created, forming data streams and parallelizing the process of processing space data. At the same time, tasks are created for workstations, their operation is monitored, which leads to an increase in production capacity. You can increase the number of workstations at any time, etc.

We are investigating the issue related to the integration of the results of space data processing with the diverse information used in the WDF and IW monitoring system.

To accomplish this task, SI data and processed results must be integrated into GIS. There are two approaches to the implementation of the task.

The first is the creation of two archives within the framework of a specialized monitoring system (SMS) WDF and IW. One ensures the collection, storage and processing of CS, the second ensures the operation of GIS. This work option requires additional resource costs. This method is used when the monitoring system is not created from scratch. An additional unit with satellite information is inserted into the system. Therefore, a mechanism is needed here that allows you to export satellite data to GIS and insert it into its archives.

Consider the second approach. In GIS, queries are generated to obtain the necessary information from the relevant space data archives. GIS also implements interfaces that allow you to combine heterogeneous information.

This approach, which is widely used at the present time, simplifies issues related to maintaining distributed CS archives and updating information received from the spacecraft.

Let's consider the basic principles of the global remote monitoring system (GSDM), in particular WDF-IW.

Fig. 9 suggests a basic scheme for building a WDF-IW GSDM. It follows from this figure that the GSDM includes the following main blocks:

- data processing;
- maintaining archives;
- data presentation and analysis;
- management and performance monitoring.

Let's consider the work of the main blocks of the system presented in Fig. 9. Modern realities in the field of RSE are such that the preprocessing of space information moves into a new category — the formation of basic products. Basic information products have a number of qualitative properties that make it possible to carry out SI thematic processing painlessly — stable radiometric calibration, illumination, atmospheric condition, geographical and temporal reference, etc. The modern CS user is interested in receiving information in the form of basic products. In exceptional cases, data processing systems are created to obtain thematic products used in our case when monitoring territories for the presence of WDF and IW. Recently, there has been a certain situation regarding the implementation of the GSDM and the work of its individual blocks. The equipment necessary for the operation of these units is provided to the centers for receiving and processing space information. In such situations, the speed of information processing increases, since there is no need to transfer data in large volumes from the centers to the GSDM.

There is a tendency to maximize the automation of information processing in the implementation of GSDM; respectively, based on this, the work of the SI thematic processing unit in different information systems is organized in a certain way.

We have to deal with situations related to the fact that a variety of software environments are used in the processing of space information, and possibly also different operating systems. It is necessary to organize the interaction of these procedures and control over their implementation.

The implementation of distributed computing resources requires different approaches for their proper application in RSE data processing.

Data archiving (subsystem) is one of the main elements of the GSDM. Above, we described in detail this block and the principle of its operation (see Fig. 9).

The presentation and analysis of information (subsystem) is certainly one of the main elements of the GSDM. Let's consider the main factors forming this subsystem.

The first factor influencing the formation of the system is the provision of a distributed user with space information and tools for its analysis in order to ensure remote monitoring. To perform this function, it is necessary to have a web interface — this is a modern trend in the development of information systems. The advantages of these interfaces are that you do not need to purchase and maintain a large number of licenses, as is done for desktop applications, the same GIS.

The second factor is the involvement of various Internet technologies for the development of complex tools in the implementation of distributed data analysis in GSDM.

The third factor is the possibility of online access to information from external information systems, as well as to the resources of RSE providers.

And finally, speaking about the control and performance monitoring unit of the GSDM, it is important to note that in order to check its performance, it is necessary to increase the level of automation of this process. To identify system failures, it is necessary to have technologies for their automated detection and automated diagnosis.

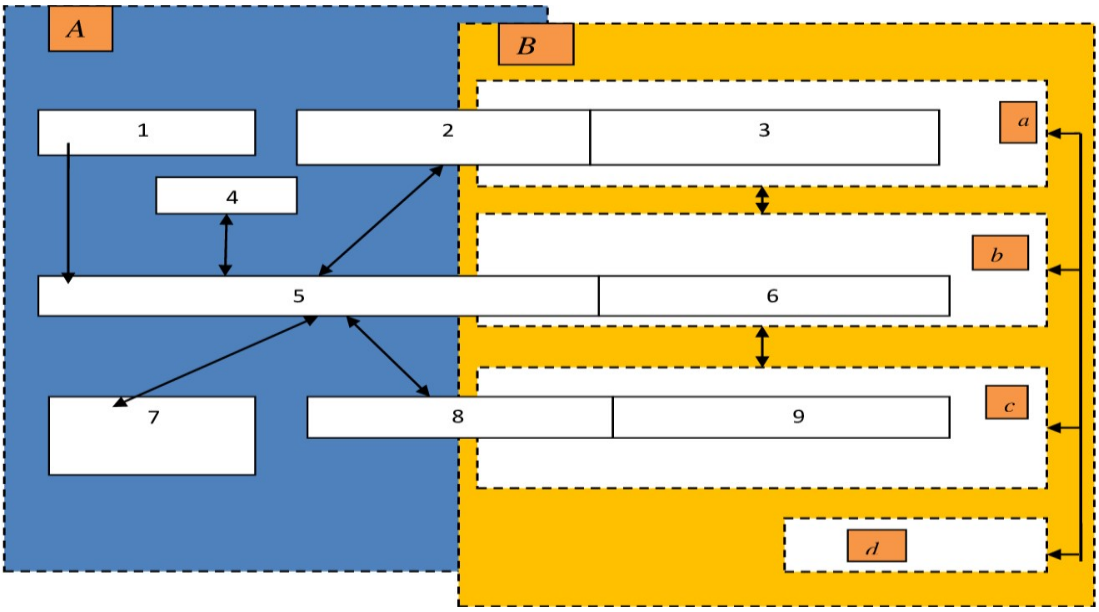

Fig. 9. The basic scheme for constructing the GSDM WDF-IW: 1 — reception, data logging; 2 — formation of special thematic products at the request of the GSDM; 3 — block for automated processing of data from the GSDM; 4 — a system for the formation of basic products; 5 — data (archives) and processed results; 6 — GSDM (archives); 7 — a system for forming "standard" thematic products; 8 — data "presentation" system; 9 — programs specialized for GSDM; A — centers for receiving, archiving, processing and distribution of SI; B — Global Remote Monitoring System (GSDM); a — subsystem for processing data of the GSDM; b — subsystem for maintaining the data archives of the GSDM; c — subsystem for presentation and analysis of data from the GSDM; d — control unit and performance monitoring

RESEARCH RESULTS AND DISCUSSION

Prospects for the practical implementation of an automatic global remote monitoring system

Let's look at some developments regarding the software that is developed in the basic utilities of the system.

1. The adaptation of existing image processing algorithms to the problem of research is performed. These algorithms include:

- affine transformations on the image (rotation, shift, scaling);
- image enhancement;
- object selection;

- filtering by the spectrum and size of objects, dilation, erosion, opening, closing, morphological image processing (border selection, filling in areas, selection of connected components);
- clustering and classification by methods of K-intragroup averages and ISODATA, etc.

These algorithms adapt to the characteristics of the WDF: size, distribution, component composition, spectral composition, and environmental characteristics.

2. Development of special image processing algorithms for the detection and analysis of OZONE [*Kazaryan* et al., 2023]. These algorithms include:

- algorithms for dividing a time series of images into a time series of sections of these images;
- algorithms for detecting textures of components in the composition of WDF and the surrounding environment;
- algorithms for evaluating the morphological composition of WDF components;
- special training algorithms for detecting WDF;
- algorithms for obtaining polygons of components in the composition of WDF and its surrounding natural environment;
- algorithms for obtaining the relief of WDF from a pair of images;
- algorithms for estimating the dynamics of changes in the surface and body of the WDF and its basic geometric characteristics;
- algorithms for evaluating chemical processes occurring in landfills;
- WDF classification algorithms based on satellite image data;
- algorithms for calculating the linearity of polygonal objects;
- algorithms for evaluating component, temperature, vegetation, technological, and other characteristics of WDF.

3. Investigation of the state of soil and vegetation [*Kazaryan* et al., 2019].

Special algorithms for assessing the degree of soil degradation have been developed to study the state of soil and vegetation. These algorithms are based on the calculation of vegetation reaction indices depending on various influencing factors. Factors, vegetation reaction indices, and the degree of soil degradation are presented in a normalized form. At the same time, the factors themselves are ranked according to the degree of importance according to the results of the analysis. This method of assessing the degree of soil degradation is the cheapest, because it does not require additional archival data, like most other methods of assessing soil degradation. In addition, it is fast-acting, although less accurate, and allows you to assess the tendency of the soil not only to degradation, but also to restoration. The condition of the soil is also determined by assessing the yield of the soil, since in most cases landfills are located in close proximity to rural settlements. To assess soil productivity, many algorithms based on multiple regression have been developed and implemented.

4. Evaluation of the geometric characteristics of the WDF.

Algorithms for estimating geometric characteristics of WDF are divided into algorithms for planar and spatial characteristics. A single image is used to evaluate the planar characteristics, and a stereo pair is used to evaluate the spatial characteristics.

A time series of images of a single territory is used to assess changes in geometric characteristics.

Planar geometric characteristics include area, perimeter, polygonal area, contour and contour bypass, linearity, ellipticity, center of mass, scattering coefficient, planar component parameters.

Spatial geometric characteristics include volume, spatial parameters of components, WDF body, surface relief, slope coefficient, average height of the ozone layer, number of tiers. The change in geometric parameters is divided into the average and in the direction. The direction is given by a vector on the plane for planar parameters and a vector in space for spatial parameters. The change in parameters is characterized by a rate, i. e. an increment of the parameter per unit of time. By changing the parameters, you can make a short-term forecast of future values of geometric parameters.

5. Development of attribute databases. Attribute databases are developed in database management systems. Structurally, they consist of many tables connected to each other through special connection tables. Different tables characterize objects of different types. Attribute databases have been developed: on the general information of the WDF, on individuals and legal entities associated with them, on administrative-territorial units, on the component composition of the WDF, on the spectral characteristics of the WDF, on satellite images and image metadata, etc. Each database has its own data schema, and all developed databases are combined into a data warehouse. Special programs have been developed to manage each database, which implement procedures for creating, opening, closing, replenishing, updating, etc. To combine databases into a data warehouse and manage this storage, programs are also implemented in special software environments. Each database and the data warehouse itself have their own interface that allows you to interactively manage databases. A description of databases and data warehouses has been developed. The initial data to be read by the database is normalized. Some of them are obtained using programs from textual information taken from various sources. The other part is calculated using WDF detection and analysis algorithms.

6. Development of geobases. WDF geobases are a structure of attribute and geographic data obtained in an automated mode. Geobases are built for objects of the classes “WDF”, “administrative-territorial units”, “natural objects”, “anthropogenic objects”, etc. Attribute data is signed for each object of the geobase in the form of data tables of one type or another. Geographical data is the display of an object on the map in the form of a placemark, line, polygon with geo-referenced data. The geobase of data provides filtering, which is required for display and analysis.

The system of global space monitoring of the processes of littering of the planet Earth discussed above can be implemented as a joint Russian-Chinese project based on the reception and processing of remote sensing data from Russian and Chinese satellites.

With the help of this system, it is possible to automatically identify unauthorized landfills throughout the globe using artificial intelligence technology, including in marine and oceanic waters, to determine the correct operation of existing municipal solid waste landfills (SMW) in accordance with current international and national regulatory documents, to determine the order of liquidation of landfills of certain SMW landfills, depending on the degree of their negative impact on the environment and human health. The results of processing the received data can be displayed on the Internet on an interactive digital map of the Globe.

CONCLUSIONS

The paper proposes the design and further use of a global information system for remote monitoring using remote sensing methods and technologies. Here we consider the features and trends in the development of modern geoinformation systems in certain thematic areas, in our case we consider the OZONE and software. The article analyzes the current prospects in the creation and operation of such automatic geoinformation systems using certain knowledge in the field of ultra-large, distributed, and open data archives. As an implementation of theoretical reasoning, the practical part on the formation of mathematical support for the remote monitoring system of ozone and software is given. A further series of articles on this area of research is expected to be published.

ACKNOWLEDGEMENTS
It is advisable to implement the proposed system of global space monitoring of the planet Earth debris processes as a joint Russian-Chinese project within the framework of the BRICS.

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