Methods of decoding of the geoecological conditions of natural-anthropogenic complexes based on the data of Earth remote sensing

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Abstract. There is a steady tendency to significantly increase the volume of extraction and processing of mineral raw materials on our planet in recent decades. It leads to an increase in the volume of industrial waste, which predominant method of disposal is placement on the Earth surface in the form of anthropogenic arrays. There are accumulated billions tons of waste in such anthropogenic arrays, but its height can reach 100 meters. It determines the deterioration of the sanitary and hygienic situation in these territories, an increase in the morbidity and mortality of the population, a decrease in the species diversity of animals and plants, violation and modification of natural landscapes, and loss of natural resources. In addition, such anthropogenic arrays are especially subjecting to the risk of emergencies, which can entail significant social, environmental and economic damage. In this regard, the development and implementation of environmental monitoring systems on the territory of industrial waste storages, which can quickly identify sources of anthropogenic load and carry out their timely elimination, is of particular relevance to society, the economy and the state. Monitoring of the state of components of the environment based on remote sensing data is one of the most innovative and developing areas of environmental monitoring today.

Monitoring of the state of natural objects exposed to the negative impact of the enterprises of the mineral resource complex using the data of Earth remote sensing is of significant practical and scientific interest. The data base of remote sensing of Earth is very extensive today. It is represented by several dozens of different satellite systems and allows getting images of individual territories as soon as possible and with fixed regularity [4]. In this regard, satellite imagery data are one of the most reliable sources of information in environmental mapping and interpretation of geoecological conditions [11].

However, the availability of a satellite image does not allow us to immediately draw a conclusion about the ecological state of the territory in question or to establish any quantitative indicators. All obtained satellite imagery materials must undergo appropriate processing, which will allow a qualitative or quantitative assessment of the change in geo-ecological conditions [20].

Despite global computerization, visual decoding is considered more reliable today, and the role of visual decoding increases with the advent of publicly available images with ultra-high spatial resolution. This is due to the fact that the ability of a person to analyze the image so far significantly exceeds the capabilities of computer technology [14].
The ease of obtaining spatial information is one of the main advantages of the visual decoding method over the automated method. The operator easily determines the shape, relative sizes of objects and features of their distribution. Another undoubted advantage of the visual method is the simultaneous use of the whole set of decoding features, especially indirect ones. Also, using a computer programs, it is impossible to carry out logical thinking processes that allow a person to extract information from an image not only about objects and their properties, but also about processes and phenomena [12, 14].

The advantages of the computer decoding method include the ability to convert the brightness of digital images to improve their perception, as well as a variety of mathematical operations, classification according to specified criteria. The advantages of this method are undeniable in process of multi-zone images decoding and especially when comparing satellite images and cartographic materials of different times in order to study changes in objects [7].

Visual decoding is based on the identification of decoding signs. Decoding signs are usually divided into direct and indirect. Direct decoding signs are the properties of the object that are directly displayed on the image. These include geometric (shape, shadow, size), brightness (brightness level, color, spectral image) and structural (texture, structure, pattern) [16].

The form is the most reliable sign that does not depend on the survey conditions. The shape of the object in the image can change somewhat with a change in the scale of it, due to the disappearance of details, shape is simplified. The shape in the image is often used in the recognition of objects associated with human activities, as they usually have a shape close to the correct geometric [9].

A shadow is a decoding feature that allows one to judge the spatial shape of objects in a single image. It is distinguished own shadow of object - the part of the object that is not lit by direct sunlight, and the incident shadow of object - the shadow from the object on the earth's surface or the surface of other objects. Own shadow allows to judge the surface of objects that have a three-dimensional shape. For example, a sharp border of the shadow is characteristic of angular objects, such as roofs of houses, and blurry indicates a smooth surface, such as tree crowns. The falling shadow characterizes the vertical extent of the object [6, 12].

Brightness decoding signs are associated with spectral reflectivity, which is fixed in the image depending on the type of survey and the type of material used in the interpretation. The reflective properties of objects are not constant in time and depend on the height of the Sun, the transparency of the atmosphere, the phase of vegetative development and other factors. The variability of the spectral brightness of the objects, as well as the ambiguity of the visual properties of the survey systems, explains the low reliability of the brightness decoding signs [16]. The brightness decoding signs of the same objects can vary greatly in different images, but, despite this, they are widely used in visual decoding, while in computer interpretation they are currently the main ones [4]. The dependence of the spectral brightness of the main natural objects on the wavelength is shown in figure 1.

![Figure 1. The dependence of the spectral brightness of the main natural objects on the wavelength.](image-url)
Structural signs are a reflection of real-life landscape drawings, horizontal landscape differentiation. These signs are a combination of images of objects and their parts of a certain shape, size and tone (color) in the image. In addition, satellite images can reveal the spatial distribution of objects, their location and repeatability. Due to these properties, the structural features are little dependent on the lighting conditions, season and technical parameters of the survey, despite the variability of the individual components of the image [17].

Several different structures often form fairly stable combinations typical of certain objects on the earth's surface. Such combinations are image pattern. The pattern reflects both the natural features of the territory (the structure of the soil and vegetation cover, the distribution of geomorphological elements, lithological features of the constituent rocks, tectonic conditions), and the spatial relationships of objects of anthropogenic origin. Very often, a pattern of the territory is determined by its topography and vegetation [1, 16].

Indirect signs are conventionally divided into three groups: indicators of objects, indicators of properties of objects, and indicators of movement or changes. Thus, differences in the cutting of agricultural fields, the structure of the organization of the territory, and the state of vegetation cover can serve as an indicator of administrative and state borders. By indirect signs, the hidden properties of the objects clearly readable in the image are determined. More often this refers to the objects of economic activity [19].

Automated decoding is based on the use of digital images. Computer processing of remote sensing materials includes geometric and brightness transformations, and classification [3].

Most brightness transformations are aimed at improving the quality of the image for visual decoding on the screen, but sometimes the desired final result can be obtained through the transformations. An increase in the contrast of the image for its best display, performed by changing the histogram of brightness values, is among the most commonly used transformations. Besides such processes as quantizing an image by brightness, synthesizing color images, merging (synergism) of images with different spatial resolutions, creating index images often use [2].

Quantization is a method of brightness transformations of a single image, which consists in grouping the brightness levels into several relatively large steps. A new image in which small details disappear, a gradual change in brightness is replaced by a clear boundary, and the patterns of brightness distribution in the image become more clearly expressed is as a result of such transformation [15]. The entire range of brightness can be divided into equal steps. But in most cases, the best effect can be achieved if the operator chooses the boundaries of the new steps, using the histogram or measuring the brightness intervals for each of the objects of interest to him in the image. Quantization is often used in cases of uncertain boundaries, gradual transitions [7].

The brightness transformations of a multi-zone image have two main objectives: to compress information, that is obtaining one image instead of several, or to improve the visual perception of the image [13].

The vegetation in the image has red tones, due to its high brightness in the near infrared region of the spectrum. If the combination of survey channels and colors change, and set the infrared zone to green, a color rendering that is close to natural can be getting. Multi-time images and images obtained as a result of more complex transformations can be synthesized too, not only multi-zonal images [2].

Improving the spatial resolution of a color image can also be accomplished through software transformation of multiple satellite images. It is necessary one high-resolution image (usually this is an image in the panchromatic channel, but there may be an image of another filming system, for example, radar) and two zone images, for example, in the infrared and red channels for this transformation [19].

The widespread transformation of satellite images is the definition of indices - the conversion of images based on differences in the brightness of natural objects in two or more parts of the spectrum. The largest number of indices refers to the decoding of green vegetation, the separation of its image from other objects, primarily from the soil cover and the water surface [4, 11].
Vegetation indices are based on the ratio of brightness values in the spectral zones, the most informative for the characteristics of vegetation - red and near infrared. The most commonly used is normalized difference vegetation index (NDVI), calculated by the formula:

$$NDVI= \frac{(NIR-R)}{(NIR+R)}$$

where R – brightness value in the red zone, but NIR – brightness value in the near infrared zone.

Index values range from -1 to +1. Vegetation is characterized by positive NDVI values, and the larger its phytomass, the higher they are. The values of the index are also affected by the species composition of the vegetation, its closeness, state, to a lesser extent exposure and the angle of inclination of the surface [17]. The result of determining the NDVI is presented in figure 2.

![Figure 2. The result of determining the NDVI: 1 – source image; 2 – NDVI image.](image)

Index images are created based on other zonal relationships too. For example, the content of phytoplankton in water is determined by the differences in the blue and green zones, but the concentration of mineral particles (suspensions) is determined by the differences in the red and blue zones [18].

Classification of a multi-zone image consists in recognition of objects in the image through specialized software. The use of multi-zone images for object recognition is based on the characteristics of their spectral reflectance, which result in differences in brightness characteristics in zone images. Classification of a digital image is a grouping of pixels in accordance with the accepted classification rule.

Two approaches are possible. In the first case, the classification is based on signs of objects whose belonging to a particular class on the ground is known (for example, signs of objects on reference areas). It is a supervised classification. Another approach is to group pixels with similar brightness levels in survey areas without prior knowledge of the number and characteristics of classes of objects on the ground. It is an unsupervised classification [13].

The meaning of unsupervised classification is to divide all the image pixels into groups (clusters), the name, spectral characteristics and even the existence of which are previously unknown. The similarity of spectral characteristics is the criteria for assigning pixels to a particular cluster. The assigned clusters are assigned serial numbers, and the task of the operator includes the subsequent determination of their correspondence to classes on the earth's surface. This method is often used in the absence of reliable reference data.

Supervised classification involves the assignment of each of the pixels in the image to a specific class of objects on the ground, which corresponds to a certain area in the space of features. Supervised classification involves several stages [7, 10].

The first stage is to determine which classes of objects will be allocated as a result of the entire procedure. These can be vegetation communities, crops, forest species, hydrographic objects, and others. At the second stage typical pixels are selected for each of the object classes. The third stage is the...
calculation of the parameters, the spectral image of each of the classes, formed as a result of a set of reference pixels. The set of parameters depends on the algorithm that is supposed to be used for classification. The fourth stage of the classification procedure is viewing the entire image and assigning each pixel to a particular class [10].

The use of remote sensing data for monitoring in general is reduced to comparing different-time data to identify both short-period and long-term changes.

The simplest operation is to subtract (or add) images of different times. However, in many cases, this approach requires the observance of certain conditions, which partially limit its application in practice. Images must be taken by the same or similar survey system and brought to the same survey conditions, for which it is necessary to perform additional correction - to exclude the influence of the atmosphere. Otherwise, with sufficient confidence, only significant changes in the external appearance of the territory or individual objects can be detected [8]. Figure 3 shows the image obtained by subtracting fragments of two satellite images.

![Figure 3](image_url)

**Figure 3.** The image, obtained by subtracting fragments of two satellite images: 1 – 2005.05.; 2 – 2017.05; 3 – differential image, where shades of orange-red color show forest cuttings over the past period.

A sharp difference of color histograms, for example, one image looks dark and the other bright, is typical situation when comparing two images of different times. In this case, either images or one of them must be transformed so that the minimum and maximum brightness values are the same [13].

The appearance of fictitious changes is associated with two main reasons. The first of these is a comparison when studying the long-term dynamics of images that recorded different seasonal states of the landscape. The identification of seasonal changes in geographic features is a necessary condition for obtaining reliable data on long-term changes. The second reason for the appearance of fictitious changes is the inevitable "technical" errors in the position of the boundaries of decoded objects in images of different times [18].

Satellite imagery has taken a strong place in the system of tools used in environmental monitoring nowadays. The list of thematic tasks to be solved according to the data of Earth remote sensing is huge. In this regard, environmental monitoring of territories exposed to the negative impact of the enterprises of mineral resources complex, based on the data of Earth remote sensing, is a promising and actively developing method of environmental monitoring [16].

However, it should be understood that this method is quite time-consuming and requires not only the availability of source data and specialized software, but also the appropriate operator qualifications. Therefore, the reliability of the information extracted from the survey materials, to the greatest extent depends on the properties of the studied objects and the qualification of the performer. The reliability of recognition of natural objects in an image is to a decisive extent due to their spectral properties, the
severity of boundaries, the degree of variability, as well as the presence of stable relationships with other objects.

Based on the review, it can be concluded that the most reliable method of the decoding of geoecological conditions is working with multi-time satellite imagery data. This method allows determining not only qualitative but also quantitative indicators of the ecological condition of the territory, as well as the dynamics of changes in these indicators.

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