The Technology of Aerospace Monitoring of Changes in the Ecological Condition of the Environment Using the Statistical Criteria Method with Virtual Standards, on the Example of Mining and Industrial Territories of Ukraine

O. D. Fedorovskyi, A. V. Khyzhniak, A. YU. Porushkevych(✉), L. P. Lishchenko, and T. A. Yefimenko

State Institution "Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Science of the National Academy of Sciences of Ukraine", Olesia Honchara Str., 55-B, Kyiv 01054, Ukraine

adfedorovsky@ukr.net, aporushkevich@gmail.com

Abstract. The article describes the technology of determining changes in geosystems of the environment based on the satellite images using the method of statistical criteria with virtual standards on the example of the study of mining areas. The modification and adaptation of the statistical criterion was carried out, virtual benchmarks were formed for four categories of ecological changes of the territory (natural, anthropogenically modified, anthropogenic and technogenic). The developed technology was tested on the mining and industrial areas of Nikopol and Kryvyi Rih of Ukraine.

1 Introduction

There is a well-known technology for recognizing and classifying images of objects (or areas of the territory) on satellite images, which makes the conclusion about the classification of the studied object into one or another class is based on the maximum value of the membership function, which is formed by the parameters or one object of the object taken as a standard, or by a compromise set of parameters obtained from averaging the parameters of several standard objects.

The difference and advantage of the proposed technology lies in the fact that in the case of the study of the territory with different geological and landscape conditions, objects of different geological and geophysical nature and dimensions are simultaneously investigated thanks to virtual standards that can be formed as data from satellite images, as well as numerical informative features of standard objects.

H. P. Urbach and H. Jiang (Eds.): ISSOIA 2022, SPPHY 295, pp. 138–147, 2023.
https://doi.org/10.1007/978-981-99-4098-1_14

2 Purpose of the Study

The purpose of the study is to justify the technology of aerospace monitoring of the determination of changes in the ecological state in geosystems of the environment by the method of statistical criteria with virtual standards on the example of the study of the mining and industrial territories of Ukraine.

The calculation of the above parameters is performed by software created on the basis of a statistical criterion (Arhipov, Glazunov, & Hizhnjak, 2018), when several objects of different classes with different sets of values of informative features are taken as standards. The classification of each investigated object is performed by calculating the probability value of its relation to each of the reference object classes presented on the aerospace image, and belonging to a specific class is determined by the maximum value of the probability of its relation to a specific reference object of the corresponding class, which involves a priori input of informative features of all references and automatic calculation of the probability values of the relation of each studied object to the available reference objects.

3 Method

This method provides the possibility of simultaneous classification of researched objects of different classes according to different standards when they are arbitrarily located in the analysis area, which allows for greater objectivity and reliability in the recognition and classification of objects on images.

Geomonitoring of the ecological state with the quantitative assessment of the impact of man-made load through its reflection on aerial images and ground observation simultaneously on several standards, each of which represents the corresponding level of load is relevant. In order to achieve this, the "virtual standards" technology was chosen, which is used to obtain greater opportunities in the formation of standard parameters and increase the accuracy of measurements (Ostapiv, Pindus, Chekhovskyi, & Klochko, 2016). A similar technology is used for images recognition, and for more justified formation of standards thanks to the selection of different levels and load parameters, in accordance with the informative features of the studied objects. Thus, the virtual benchmark of the maximum load level consists of the maximum values of man-made or anthropogenic load indicators. Similarly, the standard of minimum load level consists of minimum values. Accordingly, standards of intermediate load values are made. The number of standards levels is determined by the expert depending on the task (Fedorovskij & Lishhenko, 2003).

The methodology of the statistical criterion with virtual standards that implements the proposed method are the follows: empirical data indicate that the values of the spectral brightness $\overline{\xi}_q = (\xi_{q1}, \ldots, \xi_{qk})$ of a specific section of the studied area under the number q change from section to section in a random manner, taking values around their average values. In accordance with this, we will consider the vector $\overline{\xi}_q$ to be random, the coordinates of which are random normally distributed values.

Correspondence of the specified distributions to normality is determined by sample values using, for example, the χ^2 Pearson's test, or the Kolmogorov's test, or the Smirnov's test.

Average values $D_{q,k}$ and root mean square $\sigma_{q,k}$ values Bare calculated according to standard formulas:

$$D_{q,k} = \frac{1}{N}\sum_{n=1}^{N_q} \xi_{q,k,n}$$

$$\sigma_{q,k} = \pm\sqrt{\frac{1}{N_q - 1}\sum_{n=1}^{N_q} (\xi_{q,k,n} - D_{q,k})^2}$$

where N_q is the sample volume for determining the unknown parameters of a random variable $\xi_{q,k}$, and $\xi_{q,k,n}$ are its sample values.

The function $P_{q,k}(t_k)$, which is the density of the distribution of a random variable $\xi_{q,k,n}$, has the form:

$$P_{q,k}(t_k) = \frac{1}{\sqrt{2\pi\sigma_{q,k}}} e^{-\frac{(t_k - D_{q,k})^2}{2\sigma_{q,k}^2}}$$

And the multidimensional density $P_q(\bar{t})$ of the vector distribution $\bar{\xi}_q$ is defined as a product

$$P_q(\bar{t}) = \left(\frac{1}{2\pi}\right)^{\frac{K}{2}} \prod_{k=1}^{K} e^{-\frac{(t_k - D_{q,k})^2}{2\sigma_{q,k}^2}} \frac{1}{\sigma_{q,k}}$$

The specified value of the vector $\overline{X} = (X_1, \ldots, X_k)$ is considered as a sample value of some random vector $\bar{\xi}_q$ with an unknown value q that needs to be determined. This corresponds to the fact that the area under consideration corresponds to the number q.

The purpose of the study is to specify a criterion that will allow with a high degree of confidence to determine the number q based on the given value of the vector $\overline{X}$. At the same time, it should be known for certain that the area being investigated corresponds to the numbers $1, \ldots, Q$.

This means that from the total number Q of competing hypotheses H_q, one should choose the one that most corresponds to the set $\overline{X}$.

Finally, we get a criterion in the form:

$$C_q = \frac{P_q(\overline{X})}{\sum_{r=1}^{Q} P_r(\overline{X})}$$

An algorithm was developed for the further study of man-made load on mining and industrial areas (Fig. 1).

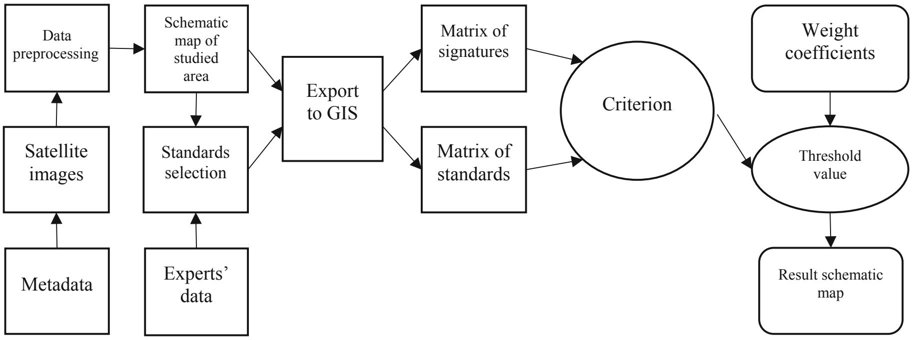

Fig. 1. Algorithm for further determination of changes in the ecological state of mining and industrial territories.

The developed technology was implemented to assess the man-made load on the territory of the Nikopol Mining and Industrial District. The Nikopol area was chosen due to the fact that this area has undergone significant transformations and man-made loads under the influence of economic and mining activities. Since the 2000s, the intensive quarrying of manganese ore raw materials and its beneficiation has decreased significantly. However, this zone requires thorough study and monitoring in connection with the significant deterioration of the environment - lithosphere, soils, air, underground and surface waters, biocenoses and human living conditions. To assess the man-made load in the Nikopol mining and industrial territory, the probability of the ratio of the spectral informative features of the studied objects to the spectral informative features of each reference object present in the aerospace image is calculated (Khyzhniak, Fedorovskyi, & Yefimenko, 2021) (Fig. 2).

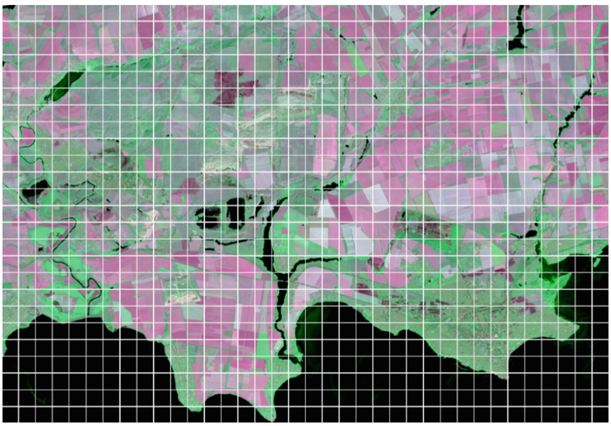

Fig. 2. Research territory of the Nikopol mining district. Landsat 8 space image (OLI/TIRS) for August 31, 2018 (channel combination 4–5–1)

Multispectral space images from Landsat 8 (OLI/TIRS) on August 31, 2018, were used to prepare input data set. For all used channels (1 (0.435–0.451), 2 (0.452 μm – 0.512 μm), 3 (0.533 μm – 0.590 μm), 4 (0.636 μm – 0.673 μm), 5 (0.851 μm – 0.879 μm), 6 (1.566 μm – 1.651 μm), 7 (2.107 μm – 2.294 μm) and 9 (1.363 μm – 1.384 μm)) atmospheric correction was applied.

For the correct operation of the program, reference areas were selected on the space image, 10 reference areas for each degree of load. Figure 3 shows examples of selected benchmark sites for I, II, III and IV levels of man-made load, respectively.

Fig. 3. Examples of reference areas selected on the space image: a) 1st degree corresponds to the natural state; b) 2nd degree of man-made load c) 3rd degree of man-made load; d) 4th degree of man-made load.

Since the study area is heterogeneous and its structure is quite complex, each of the load levels can include several different landscape complexes, with different percentage ratios to the total sample area. For example, areas dominated by natural landscape complexes (LC) (which form the primary background geoecological conditions for the functioning of the LC, strengthen the development of negative natural and natural-anthropogenic processes, including environmental pollution) were assigned to I - “Light”, to a small extent there are anthropogenically modified and almost or completely absent anthropogenic and technogenic. II - “Medium” refers to reference areas mainly with anthropogenically modified landscape complexes (characterized by insignificant variability of individual components of the landscape, when the action of anthropogenic influence is stopped, they are restored and return to the natural evolutionary path of the development of the landscape), to a moderate extent there are natural and anthropogenic, and man-made almost absent. Up to III - “Moderate” - mainly anthropogenic LCs (characterized by the introduction of artificial formations into the LC, which changes the external image of the LC, its physiognomic characteristics and internal dependencies between the components of the LC), and a small percentage are anthropogenically modified and man-made, and up to IV - “Severe» level of load - man-made (landscapes that have undergone fundamental changes in certain natural components, even to their complete destruction, formed in favorable and unfavorable natural conditions), with a small percentage of the presence of 3 other classes of landscape complexes.

In order to systematize the input data, a project in geo-information system of the area under study was created based on the received data of remote information and expert assessments.

Further, on the basis of the obtained data, matrices of informative features were created for the studied plots and reference plots. This process includes the formation of feature values in the form of electronic tables, each row of which contains the results of measurements of all types of remote information, and the columns provide feature values for each of the 900 sites.

This stage of the work was automated using a software specially created on the basis of a statistical criterion.

The final product of this process is the determination of the class of the studied objects based on the maximum value of the probability of their belonging to a specific reference object, the corresponding class, and the creation of a map scheme characterizing the man-made load of the Nikopol mining and industrial district. The results are presented in the form of maps on Fig. 4 in relative gradations of brightness: light color - natural, light gray - light load, gray - medium and black - heavy load, respectively.

Kryvyi Rih is a large industrial city, the center of the Kryvyi Rih iron ore basin, the most important raw material base of metallurgy in Ukraine. The Kryvyi Rih industrial region plays a leading role in the economy of Ukraine and is the main raw material base for the development of ferrous metallurgy, is of strategic importance for the economic independence and security of the state.

There are about 5,000 sources of atmospheric air pollution in Kryvyi Rih. Geologically, the city is located in the central part of the Ukrainian Crystalline Massif and is characterized by a complex geological structure of the crystalline foundation, the structure of which includes dislocated metamorphic and ultrametamorphic worlds of the

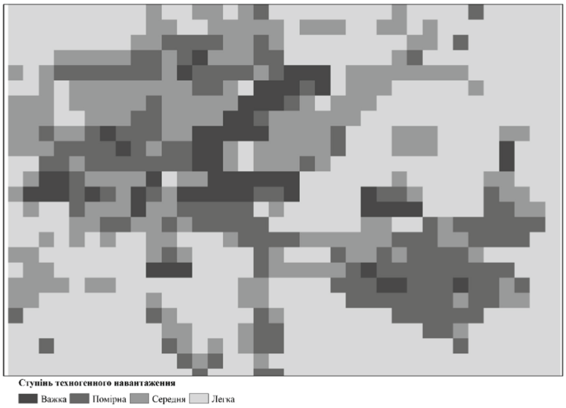

Fig. 4. Map scheme in relative gradations of brightness according to four levels of man-made load, which characterizes the geoecological state of the Nikopol mining district (obtained on the basis of a statistical criterion).

Proterozoic, complicated by fault zones and covered for the most part by sedimentary rocks of the Cenozoic age.

Fig. 5. The territory of research of mining and industrial territory of the Kryvyi Rih industrial district. Sentinel 2 space image for April 20, 2018 (combination of channels 2-3-4)

Below the result of using the method based on a statistical criterion for assessing the anthropogenic-technogenic load on 115 plots with an area of 500 × 500m each of the mining and industrial territory of the Kryvyi Rih industrial region.

Evaluation of man-made load was carried out according to the following informative features: Gravika, Magnitka, Spektr - data of the average value of the brightness of a pixel of optical space images, data from temperature maps, data obtained from radar space images for four classes (degrees) of load: natural - 0 points, light - 3 points, medium - 6 points and difficult - 9 points.

In order to systematize the input data, a geo-information system of the site project was created, which is investigated based on the data of remote information and expert assessments. In addition, in order to obtain the values of all types of features at individual points, a grid with 115 sections (Fig. 5) was drawn on the selected research territory, similar to the example for the Nikopol mining and industrial territory.

The calculation of the value of the probability of assigning the values of the informative features of each researched object to the values of the informative features of each reference object present in the space image was automated, similar to the example with the Nikopol mining area (Table 1).

Table 1. Benchmarks for four categories (classes) of man-made load (0, 3, 6, 9) based on three informative features (Gravika, Magnitka, Spektr).

Signatures\Standard	0	3	6	9
Gravika	−0,50	−1,60	−1,95	4,40
	−0,95	1.50	3,50	4,91
	−1,50	2,00	4,70	5,10
	−1,95	3,25	5,15	5,45
Magnitka	310	−1000	390	−4500
	360	200	415	−8653
	390	420	−2500	−9500
	415	−123	−3500	−10504
Spektr	1200	1280	1320	1220
	1220	1300	1345	1265
	1240	1350	1380	1290
	1260	1370	1418	1600

4 Final Product

The final product of this process is the determination of the class of the studied objects according to the maximum value of the probability of their belonging to a specific reference object, the corresponding class and the creation of a map scheme characterizing the ecological state of the mining and industrial territory of the Kryvyi Rih industrial region. The results are presented in the form of maps in Fig. 6 in points and relative gradations of brightness: light color (0) - natural, light gray (3) - light load, gray (6) - medium and black (9) - heavy load, respectively.

0	3	0	0	6	3	6	6	6	0	6		3	0	0	0	3	6	0	0	0	0	0
6	6	0	0	0	0	6	6	6	9	9		0	0	0	0	0	3	3	9	9	9	9
9	9	3	3	3	3	6	6	6	0	0		9	9	6	3	3	3	3	3	3	3	0
0	0	6	3	3	3	0	6	0	0	0		0	0	0	0	0	0	0	0	0	0	0
0	0	6	6	6	9	9	9	9	9	3		0	3	6	6	6	9	9	9	9	6	6
3	3	3	0	9	3	9	9	0	6	6		3	3	3	0	3	3	0	9	0	6	0
6	3	0	0	0	0	0	0	0	6	6		6	3	0	0	0	0	0	0	0	3	6
6	9	9	9	9	9	6	6	3	0	3		6	6	9	9	9	9	6	6	9	9	9
0	3	3	6	6	6	0	0	0	0	0		3	3	3	0	0	0	0	0	0	0	0
0	0	0	0	0	6	6	0	0	0	0		0	0	0	0	3	0	0	0	0	0	0

Fig. 6. Maps for assessing the ecological state of mining and industrial areas of the Kryvyi Rih industrial region: a) the map is presented in points according to the degree of load according to expert assessments; b) map scheme in points and relative gradations

5 Conclusions

1. Based on the example of assessing the ecological state of mining and industrial areas of the Nikopol and Kryvyi Rih industrial regions, methodological foundations of the technology for determining anthropogenic-technogenic changes in geosystems of the environment using aerospace information and statistical criterion, which involves a priori input of informative features of all standards and automatic calculation of probability values, have been developed the ratio of each investigated object to all presented reference objects.
2. Virtual standards were created based on space images and numerical values of informative features for four classes of anthropogenic-technogenic load: natural - 0 points, light - 3 points, medium - 6 points, and heavy - 9 points. The number of standard levels is determined by the expert depending on the problem.
3. The proposed method was substantiated by determining the correspondence of the results obtained visually with ground observations and using the method of statistical criteria based on space images. For this, the correlation coefficient was calculated, which was 0.7, which is acceptable for practical express assessments of man-made or anthropogenic load.
4. The research perspective is the adoption of the developed methodology for use in other industries, for example, agriculture, water management, urban management.

References

Arhipov, A.I., Glazunov, N.M., Hizhnjak, A.V.: Jevristicheskij kriterij raspoznavanija klassa po spektral'nym jarkostjam [Heuristic criterion for class recognition by spe Kibernetika i Sistemnyj Analiz **54**(1), 105–110 (2018)

Fedorovskij, A.D., Lishhenko, L.P.: Landshaftno-sistemnyj podhod pri ocenke geojekologicheskoj situacii v regione [Landscape-system approach in assessing the geoecological situation in the region]. Dopovidi Natsionalnoi Akademii Nauk Ukrainy (11), 37–40 (2003)

Khyzhniak, A.V., Fedorovskyi, O.D., Yefimenko, T.A.: Kontseptsiia formuvannia metodolohii aerokosmichnoho heomonitorynhu dlia vyrishennia zavdan pryrodokorystuvannia [The concept formation of the aerospace geomonitoring methodology of the decision of problems in natural resource]. Ukrainian J. Remote Sens. **8**(4), 4–11 (2021). https://doi.org/10.36023/ujrs.2021.8.4.203

Ostapiv, V.V., Pindus, N.M., Chekhovskyi, S.A., Klochko, N.B.: Virtualni etalony, yak zasib pidvyshchennia tochnosti vymiriuvan ["Virtual standard" as a means of improving the measurement accuracy]. Syst. Obrobky Informatsii **6**(143), 108–11. (2016)