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Dmytro L. Kreta, PhD, Senior Research Scientist
ORCID ID 0000-0001-5897-0008 *e-mail:* dim.leo@gmail.com

Viktoriia I. Klymenko, PhD, Scientific Secretary
ORCID ID 0000-0002-8911-5773 *e-mail:* klimenko_vika@ukr.net

Yevheniia S. Anpilova, PhD, Senior Research Scientist
ORCID ID 0000-0002-4107-0617 *e-mail:* anpilova@ukr.net

Institute of Telecommunications and Global Information Space of NASU, Kyiv, Ukraine

REMOTE SENSING AND GIS FOR SPATIAL ANALYSIS OF SURFACE WATER QUALITY AND SOIL POLLUTION

Abstract. The paper presents cartographic models for assessing the quality of soils and surface waters, scientific justification for improving existing monitoring, making operational management decisions for ecological security problems based on the use of modern means of Geographic Information Systems (GIS), methods of remote sensing of the Earth (remote sensing) from space, including through cartographic generalizations of data.
Key words: water quality; soil quality; surface water pollution; soils pollution; environmental monitoring; spatial analysis; geographical information systems; remote sensing of the Earth

Introduction

One of the most important monitoring components of any object is to determine its pollution degree. Operational and accurate information about the quality of water facilities and soils is the basis for water and land users activities regulation, ensuring measures for the rational use of nature, informing the relevant authorities and the public about possible hazardous situations.

Cartographic modeling and geoinformation tools allow not only to reflect already known spatial patterns but also to analyze, identify and visualize the interconnections between sources of pollution and the quality of soils and waters, to determine the reliability of information about pollution sources, to perform zoning by factors of their contamination and quality, including insufficient data situation.

Main part

The article presents examples of remote sensing and GIS technologies using for the environmental pollution assessing. The expediency of involving remote sensing of the Earth from the space technologies was justified after analysis of the state monitoring system current organization.

The basic possibility of space images application to monitor pollution on the basis of optical characteristics of the snow cover measuring as an indirect indication of the pollution degree [1, 2] has proved.

The decoding signs to determine snow cover pollution areas were substantiated. The proposed method of their decryption is alternative to the standard one. It consists

of brightness gradient module use as a decoding sign for polluted snow cover contamination. Initially, brightness derivatives calculated in directions x and y. The calculation of spatial derivatives is carried out by convolution with the masks of the Sobele operator H_x and H_y (1):

$$H_x = \begin{pmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{pmatrix}; \quad H_y = \begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}. \tag{1}$$

The gradient module G is calculated as (3):

$$G = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2}, \tag{2}$$

where F is the image brightness.

Unlike existing techniques, it is assumed that for a forest the value of G should be lower than for dirty snow, because in a forestry the image brightness varies only as a result of fluctuations, but for the dirty snow cover region a brightness increasing should be observed as far as the distance from sources of pollution to the contaminated area periphery. Then in the plane F - G training sample points with different repetition are deduced. The disadvantage of the technique is the computer power additional demand and calculation time increasing for a two-dimensional histogram convolution and construction to identify snow and forest clusters contamination. However, it is compensated by a contaminated snow detection accuracy increasing to 20%.

The expediency of satellite data decoding results application has been proved to improve the accuracy of the definition of man-caused territory pollution along the highways. According to the chosen calculation method, the amount of soil contaminant was determined on the basis of assumption that all emissions are distributed across the road in accordance with the normal distribution law (3):

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}, \tag{3}$$

where $\sigma = 60$.

The decoding features of air pollution produced by smoke plumes distribution have determined for the research zone current state estimation. It is substantiated that tasks connected with the earth's surface sites monitoring are based, first of all, on a systematic analysis of investigated objects current state in results of thematic decoding in combination with additional statistical and cartographic data, as well as characteristics and indicators obtained by contact methods.

When switching to the HSV color model (Fig. 1), the decision rule is (4):

$$F(x, y, h, s, v) \in \begin{cases} A_0 & , \text{if} \quad |h_0 - h| < \delta h \\ A_1 & , \text{if} \quad |h_0 - h| > \delta h \end{cases}, \qquad (4)$$

where: A_0 – a smoke zone, A_1 – a zone, where the smoke screen is absent, h_0 – the reference pixel hue value belonging to the smoke zone, δh – the deviation from the reference value.
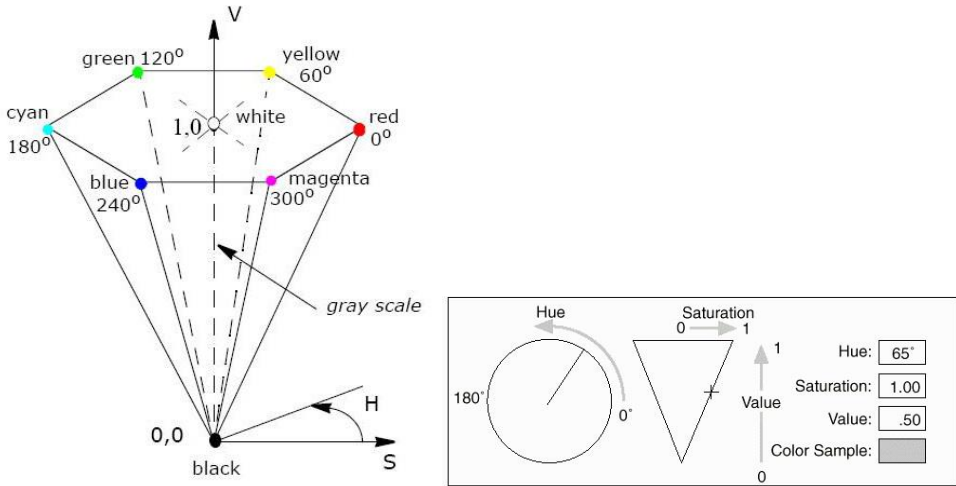

Fig. 1 – HSV color model

The efficiency of the mathematical apparatus of GIS use (its Geostatistical Analyst module) for further evaluation of air pollution has substantiated. The decision reduces processing time for large data volumes. The creation of an environmental pollution comprehensive monitoring system based on remote sensing data and modern GIS technologies application will accelerate scientific and technological progress in the field of environmental safety and increase the efficiency of information provision for decision making on environmental management and environmental protection.

Topographic parameters of snow cover areas with abnormal albedo levels in some areas of the Kiev region were identified by means of the above mentioned information resources and software algorithms. Each GIS made picture was projected on the corresponding section of Ukraine electronic map with the alignment of the scale, and such approach allowed to determine the real contours of urban areas and forest areas as factors that masked snow contamination by technogenic dust, as well as geographic or rectangular coordinates of identified areas of snow cover pollution contours.

Based on the fact that the main contribution to the total emissions from stationary sources of the Kiev region enterprises is made by Trypillya TPP, producing about 75% of the total region stationary sources emissions, it was determined as a test-facility for research possibilities of space images application in the monitoring tasks of the atmosphere pollution by stationary sources of emissions.

The space images of various spatial resolution were used to determine the atmosphere surface layer zone size polluted by the man-made dust of Trypillya TPP.

All space images, used to identify parameters of the emission zones in the atmosphere of Trypillia TPP, were transformed into a cartographic projection of the Kyiv region electronic topographic map M 1: 200 000, usig ArcGIS v.10.2. Taking into consideration that used space images were obtained at random option of wind directions and speeds, they determined the average distance from the emission source to boundaries, where the technogenic dust concentration is approximately equal to the background. Forecast estimates of the land polluted by the technogenic dust of an arbitrary sector around Trypillya TPP could be easy obtained by means of the wind direction statistical data use, as well as taking into account the smoke streams parameters obtained by decoding of high spatial resolution space images random set [3, 8]. Thus, mapping models of quantitative estimations of the land load produced by the man-made dust around the polluting objects were obtained using the winds parameters, the composition and volumes of TPP emission.

Under today's conditions of transition of Ukraine to the basin principle of water resources management, the problem of the most optimal use of the existing network of observations is relevant. Ecological information, collected through long-term observations can serve as the basis for the models of surface water quality assessment. According to statistical data [3–6, 9], there is a tendency of the surface water quality deterioration in the basins of Ukraine's rivers. Reliable, accurate and timely data of the surface water quality must be provided for informational support of decisions to ensure the fulfillment of legislative acts regulating modern water relations in Ukraine.

Now there is a military conflict in the south-eastern region of Ukraine that covers the world's largest coal-mining technogenically-rich region, one of the largest and most dangerous natural-technogenic geosystems with a high density of potentially dangerous objects (more than 4000), its area is up to 20 000 km².

Long-term mining activity in the Donbass region has a very negative impact on the quality of surface water and the flow regime of surface water. The rivers of the Ukrainian part of the Donbass region belong to three river basins – the Siversky Donets, the Dnieper and the Sea of Azov. Determination of the forecasted impact of coal mining enterprises on the formation of surface waters flow, the Siversky Donets River basin (which now is the source of 90% drinking and household water supply for villages and cities of the Donetsk Region and for the Luhansk Region – 60%), now is complicated due to the decrease of the regional water-ecological monitoring level.

A new method for assessing the surface water quality that differs from existing thanks to geostatistical interpolation methods use for monitoring data and an improved data processing method as to quality based on classes and categories, allowing improving the surface water environmental monitoring, were proposed. The regularities of changes of the Siversky Donets River basin surface water quality were determined, in particular, places of high substances concentrations that affect the ecological state of the river basin were determined.

Cartographic modeling, carried out based on GIS tools, allows not only to reflect already known spatial patterns, but also to conduct analysis. In addition, GIS help us to identify and visualize the interrelationships between sources of pollution and water quality, to determine the information reliability for pollution sources, to perform zoning based on contamination factors and surface water quality, in

particular, under the insufficient hydrochemical data volume. The analysis of the Siversky Donets River and its main inflows ecological state study by the chemical composition indexes of one of the most technogenic-loaded regions indicates steady irreversible changes in the qualitative and quantitative composition of its basin surface waters.

For today, we have created a database for making decisions on water resources management of the Siversky Donets River. The maps of network of observations of the State Hydrometeorological Service of Ukraine and localization of using enterprises of Siversky Donets River water, accountable by means of Form №2TP (water management), also have constructed.

In addition to the statistical data for the Siversky Donets River water status assessment, space imagery obtained from various sources: TERRA/MODIS, NOAA, QuckBird, LANDSAT, SPOT, ICONOS, funds of the State Science and Production Center "Pryroda", global computer network Internet were used. Results of the space images decoding were integrated into the geodata of factors influencing the class of the Siversky Donets River basin water quality was connected to the GIS, and a comprehensive spatial analysis was carried out based on investigated object dates of quality classes. Cartographic models of contamination dynamics of the surface water of Siversky Donets River were constructed and based on available geodata. Using the "Methodology for calculating anthropogenic loading and classification of the ecological state of the small rivers of Ukraine Basins"[5] enables us to evaluate the assessment of surface water quality of the Siversky Donets River.

The opportunity to automate the water quality calculating process is opening by means of the mentioned method advantages, on the one hand, and the powerful capabilities of modern GIS technology tools, on the other hand. The calculations of anthropogenic loading and classification of the small rivers of Ukraine basins ecological state inside the environment of the GIS-package of ArcGIS have made in addition to the cartographic model.

The method is programmed on language Python basis, built into the ArcGIS software core and was able to integrate inside numerous protocols of modern programming languages external libraries. As a result, water quality classes were obtained at each monitoring point.

The evaluation of surface water objects condition for classes and quality categories is possible only at sampling points. Under the circumstances of the constant reduction of observation points number and sampling frequency it is difficult to evaluate and make a decision, therefore it is desirable to know the level of pollution at any river basin point. Geostatistical methods included in the additional ArcGIS Geostatistical Analyst module used to construct spatial distribution models of surface water quality. Using the geostatistical methods, such as ordinary, simple; universal; probabilistic; disjunctive and indicator krigings, enables us to research of surface water quality.

The simple kriging method is optimal for the surface water basin quality interpolating. The method of indicator kriging allows us to build probability surfaces of the surface water basin quality changes.

Based on the spatial databases of the State Hydromet monitoring stations through the Geostatistical Analyst module the geostatistical analysis was carred out, resulting in an interpolation surface of the surface waters pollution level values of the Siversky Donets River.

Moreover, the geostatistical analysis indeed has significant advantages in the processing of data large volumes and digital maps preparation, greatly simplifying the environmental components assessment, when the preparation of maps by traditional methods requires considerably more labor and financial resources.

The comparative analysis of technogenic press prevailing factors on the Ukrainian regions environmental components, based on the results of the mapping, was carried out. It contributes to decision-making support on issues of regions environmental safety and natural resources rational use. It is established that each region has its own characteristics and the most influential factors of the environment ecological state (Fig. 2).
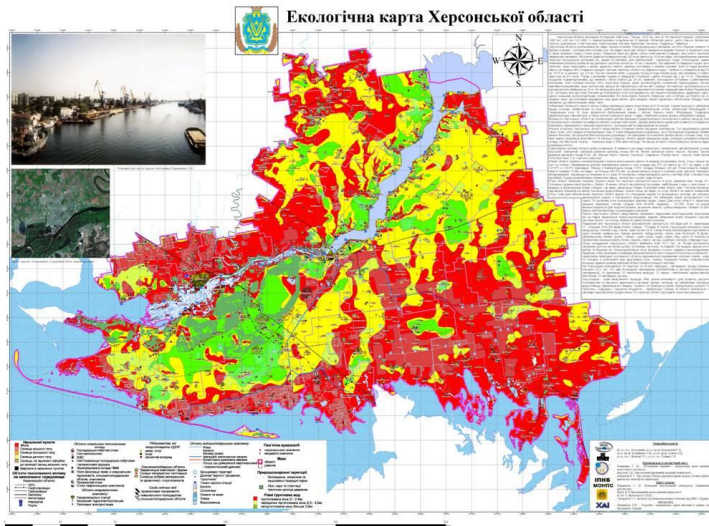

Fig. 2 – Information ecological-cartographic models of environmental pollution on the Kherson region example

Conclusions

In state of emergency situations dealing with traffic accidents, fires, unprovoked explosions accompanied by releases of hazardous chemical (biologically dangerous or radioactive) substances, decisions on planning of measures for their consequences liquidation should be taken in conditions of significant time limitation for the analysis of such events development. In the case of measures planed to prevent emergency events with such consequences, there is no critical time limitation. Therefore, for each potentially dangerous object it is expedient to have in advance calculated geomodels of the area pollution under the most probable parameters of meteorological conditions [7–9].

The information technology of pollution geomodels preparation for atmosphera and underlying land surface polluted by man-made emissions is developed on the basis of cartographic and mathematical modeling methods using databases of attributive data on sources and meteorological conditions at the time of release, space images, software services of geographic information systems. Such geomodels should be included in specialized Internet sites, which will provide distance access to them, not only as to reference material, but also to data upgrade and calculations.

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Д.Л. Крета, В.І. Клименко, Є.С. Анпілова
ЗАСОБИ ДЗЗ ТА ГІС ДЛЯ ПРОСТОРОВОГО АНАЛІЗУ ЯКОСТІ ПОВЕРХНЕВИХ ВОД ТА ЗАБРУДНЕННЯ ҐРУНТІВ

Анотація. У статті представлені методи, що дозволяють виявляти закономірності змін якості ґрунтів та поверхневих водних об'єктів. Побудовані картографічні моделі оцінки якості ґрунтів та поверхневих вод, що базуються на використанні сучасних засобів геоінформаційних систем (ГІС) та методів дистанційного зондування Землі (ДЗЗ) з космосу, в тому числі шляхом картографічних узагальнень даних.

Ключові слова: якість води; якість ґрунту; забруднення поверхневих вод; забруднення ґрунтів; екологічний моніторинг; просторовий аналіз; географічні інформаційні системи; дистанційне зондування Землі

Крета Дмитро Леонідович
кандидат технічних наук, старший науковий співробітник відділу природних ресурсів Інституту телекомунікацій і глобального інформаційного простору НАН України
Адреса робоча: 03186 Україна, м. Київ, Чоколівський бульвар, 13
Тел. +380952075078 *e-mail: dim.leo@gmail.com*
ORCID ID 0000-0001-5897-0008

Клименко Вікторія Ігорівна
кандидат технічних наук, старший науковий співробітник, учений секретар Інституту телекомунікацій і глобального інформаційного простору НАН України
Адреса робоча: 03186 Україна, м. Київ, Чоколівський бульвар, 13
Тел. +380677318920 *e-mail: klimenko_vika@ukr.net*
ORCID ID 0000-0002-8911-5773

Анпілова Євгенія Сергіївна
кандидат технічних наук, старший науковий співробітник відділу природних ресурсів Інституту телекомунікацій і глобального інформаційного простору НАН України
Адреса робоча: 03186 Україна, м. Київ, Чоколівський бульвар, 13
Тел. +380683515387 *e-mail: anpilova@ukr.net*
ORCID ID 0000-0002-4107-0617