
ІННОВАЦІЙНІ АСПЕКТИ ПІДВИЩЕННЯ РІВНЯ ЕКОБЕЗПЕКИ

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INNOVATIVE APPROACHES OF USING THE METHODS FOR REMOTE SENSING OF THE EARTH FOR MONITORING THE ECOLOGICAL-TECHNICAL CONDITION OF WATER ECOSYSTEMS

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The features of using the methods of remote sensing of the Earth to monitor the ecological and technical state of water technological systems are considered. The technology of conducting monitoring of surface waters according to Earth remote sensing data is proposed. The method of satellite monitoring of intensive algal blooms (monitoring of planktonic alga clusters) has been substantiated. An approach to the assessment of flood and flooding risks using satellite observation data is proposed. The technique of quantitative assessment of water quality according to the space monitoring of surface waters is substantiated. As a result of the research it was found that when assessing the complex effects of pollutants on the ecological state of aquatic ecosystems using aerospace technology, it is advisable to take into account changes in biological indicators (indicators of biomass and species composition of phytoplankton and higher aquatic plants). A method has been developed for predicting long-term risks of emergency situations of a hydrological and hydrometeorological nature based on physical and mathematical modeling and the use of satellite observations and spatially distributed data. The next stage of research will be the creation of predictive maps of the distribution of flood risks, flooding, degradation of surface water quality, and an assessment of the risks of air and soil pollution. *Key words:* aerospace technologies, water system, remote sensing of the Earth, ecological status of ecosystems, ecological risks, surface water, satellite monitoring, bloom of algae.

Інноваційні підходи використання методів дистанційного зондування землі для моніторингу еколого-технічного стану водних екосистем. Машков О.А., Жукаускас С.В., Нігородова С.А., Косенко В.Р. Розглянуто особливості використання методів дистанційного зондування Землі для моніторингу еколого-технічного стану водних систем. Запропоновано технологію проведення моніторингу поверхневих вод за даними дистанційного зондування Землі. Обґрунтовано метод супутникового моніторингу інтенсивного цвітіння водоростей (моніторинг скупчень планктонних водоростей). Запропоновано підхід до оцінки ризиків повеней із використанням даних супутникових спостережень. Обґрунтовано методику кількісної оцінки якості води за даними космічного моніторингу поверхневих вод. Було встановлено, що для оцінки комплексного впливу забруднюючих речовин на екологічний стан водних екосистем із використанням аерокосмічних технологій доцільно враховувати зміни біологічних показників (показників біомаси та видового складу фітопланктону і вищих водних рослин). Розроблено метод прогнозування довгострокових ризиків надзвичайних ситуацій гідрологічного і гідрометеорологічного характеру на основі фізико-математичного моделювання та використання супутникових спостережень і просторово розподілених даних. Наступним етапом досліджень стане створення прогнозних карт розподілу ризиків повеней, повеней, погіршення якості поверхневих вод та оцінки ризиків забруднення повітря і ґрунту. *Ключові слова:* аерокосмічні технології, водна система, дистанційне зондування Землі, екологічний стан екосистем, екологічні ризики, поверхневі води, супутниковий моніторинг, цвітіння водоростей.

Introduction. World experience has proved that it is necessary to apply modern innovative means and technologies to improve the quality, efficiency and effectiveness of the environmental monitoring system. These include: automated and automatic measuring systems; aerospace technology using satellites, aircraft and unmanned aerial vehicles; automated remote sensing data processing systems; geoinformational analytical systems for information processing, taking into account

the laws of its change both in time and in space; integrated multi-level environmental monitoring and control systems; methods and technologies for analyzing environmental monitoring data and determining the level of technological and environmental safety, etc.

The development of the scientific foundations for the creation and implementation of such systems, methods and technologies complies with European and global approaches to environmental management, and also

complies with the requirements and directives of the Association Agreement between Ukraine and the EU. The results of this study will significantly expand the possibilities of international cooperation of Ukraine in the field of environmental protection and will help to bring the state of the environment in line with European and international requirements.

Currently, the problem of intense “flowering” of water is characteristic of a wide variety of water areas. It is known that intensive flowering is characteristic, first of all, for reservoirs with weak currents in particular, such as the cascade of the Dnieper reservoirs. Recently, this factor is characteristic of other aqua techno-systems. The “bloom” of water is a consequence of the massive development of microscopic algae (usually blue-green) and is accompanied by a significant deterioration in water quality. The cause of this phenomenon is a whole complex of factors, such as climate change, the flow of large amounts of various mineral and organic substances into the water. Therefore, control using remote sensing systems (Earth remote sensing) is relevant in two aspects. First, it is the control of the hydrothermal mode, the development of proposals to improve the ability to cool the circulating water. Secondly, it is the control of the ecological state, namely the level of flowering and overgrowing of water by aquatic plants. Thermal control is also important at hydropower facilities.

Problem Statement. The study of the problems of assessing the status of aquatic ecosystems causes difficulties due to the difficulty of conducting relevant research in terrestrial conditions. Traditional methods of studying the state of aquatic ecological systems do not provide an opportunity to obtain a spatial picture of the phenomena and processes that occur in aquatic ecological systems. Recently, aerospace technology and geo-information systems have been used to solve problems of monitoring the state of aquatic ecological systems. Therefore, there is a problem of assessing the features of using the methods of remote processing of the Earth to control the ecological and technical state of aquatic ecosystems.

Literature review. The formation of the scientific foundations of modern environmental monitoring was devoted to the works of academician I.P. Gerasimova (Gerasimov, 1975, 1976) and professor Yu.A. Israel (Israel, 1984), which developed the basic principles for the establishment of the environmental monitoring system, as well as partly reflects the international aspects of the global monitoring system.

Such scholars as Scientists have made a significant contribution to the development of environmental monitoring problems. [2–4; 6; 13; 19] G.A. Belyavsky, V.M. Bogolyubov, A.I. Bondar, A.N. Bugor, N.A. Emetz, V.M. Isaenko, M.O. Klymenko, I.V. Korinka, I.Yu. Kostikov, V.Lisichenko, A.M. Hello, T.A. Safranov, V.M. Tkach, A.I. Fedorenko, R.S. Furdui, A. Shapar.

Questions of the application of multi-spectral methods of remote sensing of the Earth in the prob-

lems of nature management are considered in the papers P.A. Akimenko, L.M. Zuba, I.M. Kopachevsky, Yu.V. Kostyuchenko, S.S. Lyubimaya, V.I. Kukla, N.A. Popova, A.I. Sakhatsky, D.N. Solovyov, S.A. Stankevich, A.I. Tomiltsevoi, A.V. Tomchenko, A.D. Fedorovsky, A.Ya. Khodorovsky, M.V. Yushchenko and others [1; 5; 7–9; 17].

The study of the use of aerospace observations from the earth’s surface for the control of the ecological and technical condition of aquatic technetium systems is devoted to the publications of V.E. Vasiliev, A.I. Matn’eva, O.A. Mashkova, A.A. Protasova, S.B. Protsenko, V.D. Romanenko, L.A. Sabliya, V.F. Frolova, V.I. Shcherbak [10; 11; 15; 18].

Materials and Methods. Features of conducting monitoring of surface waters according to remote sensing data. The study of the interaction of terrestrial ecosystems and water bodies has shown that the NDVI vegetation index can be used as an environmental indicator for both coastal (NDVIL) and 50–70 km of coastal zone (NDVIW). Spatial distributions for the aquatic environment are correlated with such optical-biological parameters as the concentration of chlorophyll and mineral suspension, the transparency of the water and the associated characteristics. The relationship between the NDVIL and NDVIW values is manifested in the general trend of increasing NDVIW (concentration of impurities in the aquatic environment) with increasing NDVIL for land.

According to the measurement data of NDVIW by optical satellite sensors and sampling for the concentration of suspended matter in water, the dependence of the concentration of the total CS suspension on the NDVIW value was obtained (Fig. 1).

In this case, NDVIW is calculated as:

$$NDVI_w = \frac{L_w(0,8585) - L_w(0,645) + L_A(0,8585) - L_A(0,645)}{L_w(0,8585) + L_w(0,645) + L_A(0,8585) + L_A(0,645)}$$

Where $L_{w,A}$ is the brightness of the ascending radiation from the water surface at the wavelength λ and the brightness of the molecular and aerosol scattering at the same wavelength.

This, in turn, can be rewritten taking into account the components of molecular scattering:

Where L_{AZ} is the brightness of aerosol scattering, L_M is the brightness of molecular scattering, which is calculated in accordance with:

$$NDVI_w = \frac{L_A(0,8585) - L_A(0,645)}{L_A(0,8585) + L_A(0,645)} = \frac{L_{AZ}(0,8585) + L_M(0,8585) - L_{AZ}(0,645) - L_M(0,645)}{L_{AZ}(0,8585) + L_M(0,8585) + L_{AZ}(0,645) + L_M(0,645)}$$

where $\tau_r(\lambda)$ is the optical thickness of the molecular scattering layer; τ_{O_3} – optical thickness of the ozone layer;

$L_M(\lambda) = \tau_r(\lambda)F_0(\lambda)R(\alpha_s, \alpha_v, \varphi_s, \varphi_v) / 4\pi$ – irradiance on the water surface; F_0 – irradiance at the upper atmosphere; $\alpha_s, \alpha_v, \varphi_s, \varphi_v$ – respectively, the zenith and azimuthal angles of the Sun and the satellite photometer.

Another component of scattering on aerosols in general is calculated by the ratio:

Table 1

Empirical coefficients of the calculated scattering equations

λ , microns	F_0 , W / (m ² microns)	τ_R	T_{0z}
0,645	162,7	0,0504	0,0214
0,8585	104	0,0162	0,00154

$$L_{AZ}(\lambda) = F_0'(\lambda) \cdot C_{AZ} \cdot \lambda^{-n}$$

Assuming in the first approximation $L_M = 0$, we find:

$$NDVIW = \frac{F_0'(0,8585) \cdot C_{AZ} \cdot 0,8585^{-n} - F_0'(0,645) \cdot C_{AZ} \cdot 0,645^{-n}}{F_0'(0,8585) \cdot C_{AZ} \cdot 0,8585^{-n} + F_0'(0,645) \cdot C_{AZ} \cdot 0,645^{-n}}$$

Where do we get from $n = -1,56 - 3,5 \ln \frac{1 + NDVIW}{1 - NDVIW}$.

The estimates are consistent with the experimental data as well as the empirical relationship $C_S = 0,214|NDVIW|^{-3,0}$. Indeed, at the specified $NDVIW$ value, the suspension concentration is 1,54 g/m³. Taking into account variations of empirical dependence $L_A(8585) = f[L_A(645)]$ minimum value of $NDVIW$ for transparent water may with probability 0,95 reach -0,625, while the concentration of the suspension is 0.9 g/m³.

The $NDVIW$ value for clear water varies from -0.45 to -0.6. The index of Angstrom is in the range from 1.82 to 3.28. The variability of the parameter n is related to the characteristic size of aerosol particles – large values of n correspond to small particles.

Analysis of a large number of $L_M(0,645)$ and $L_M(0,8585)$ values for clear waters with an insignificant suspension concentration showed that there is a high correlation between these values, equal to $R = 0.94$. The corresponding dependence is shown in Fig. 2. This dependence is used to refine the distribution under average conditions. So for clear water, the value of $NDVIW$ is $(31.0 - 1) / (0.31 + 1) = 0.5167$, which corresponds to the observations. The weight factor C_{AZ} under these conditions is 0.017.

The obtained estimates correspond to experimental data, as well as empirical dependence $C_S = 0,214|NDVIW|^{-3,07}$. Indeed, at the indicated value of $NDVIW$, the concentration of the suspension is 1.54 g/m³. Taking into account variations of the empirical dependence, the minimum $NDVIW$ value for clear water can reach -0.625 with a probability of 0.95. The concentration of the suspension in this case is equal to 0.9 g/m³.

Thus, we obtain a theoretical and methodological basis for determining the concentrations of suspensions and suspended substances in water using spectral reflection indices, which can be measured using satellite imagery. This approach can be applied in assessing the ecological status of water areas, determining water quality indicators and assessing the risks of pollution, studying the interaction of land-water systems, and the like.

In water, both marine and terrestrial water objects, there are two main types of particles: scattering light and forming the brightness of the ascending radiation. These are particles of mineral and organic suspensions. Consider their relationship and the impact on the measured value $NDVI$.

It is known that the ratio of the energy of light emanating from the irradiation of two particles with different refractive indices n_1 and n_2 with respect to water is:

$$\left(\frac{n_1^2 - 1}{n_1^2 + 2}\right)^2 \bigg/ \left(\frac{n_2^2 - 1}{n_2^2 + 2}\right)^2$$

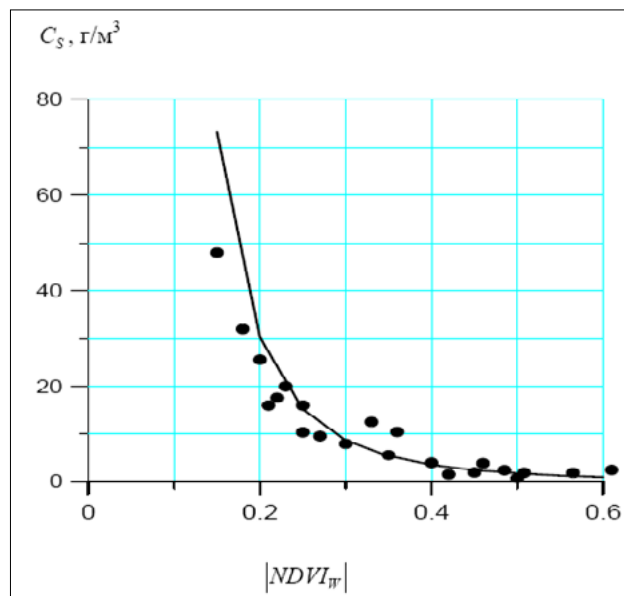


Fig. 1. Dependence of the total suspension concentration on the magnitude $NDVIW$ (empirical dependence on the data of satellite measurements): $C_S = 0,214|NDVIW|^{-3,07}$

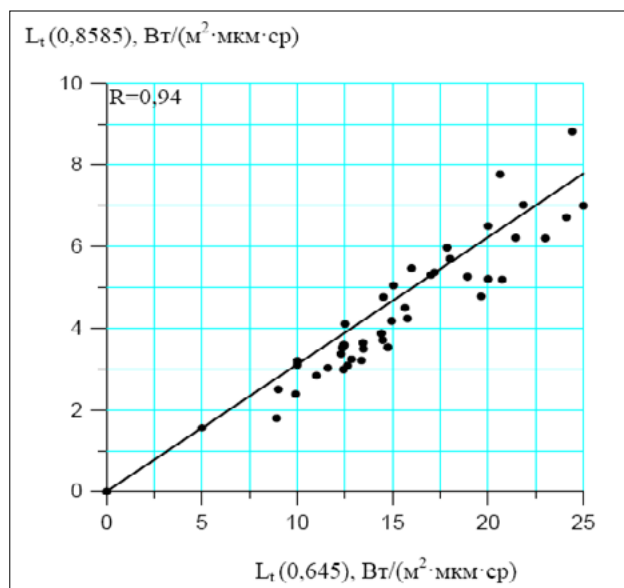


Fig. 2. Dependence of the minimum brightness values of the ascending radiation, characteristic for waters with minimum suspension concentrations ($L_A(8585) = f[L_A(645)]$)

For mineral suspension $n_1 = 1.15$, for organic – $n_2 = 1.02$. Other things being equal, the energy of light scattering by mineral particles will be about 50–70 times the energy of scattering by organic particles. The same ratio is obtained for backscattering indices (Kopelevich model), for the concentration of small P_s and large P_l particles. This allows us to consider the values of P_s and P_l as the concentrations of the mineral and organic suspensions, respectively.

The Mobli-Kopelevich model for backscattering of light by pure water, mineral and organic particles can be represented as:

$$b_b(\lambda) = 0,5b_w(\lambda) + B_s b_{ps}(\lambda)P_s + B_l b_{pl}(\lambda)P_l$$

where the indices w, s, l , refer respectively to pure water, small particles and large particles; $B_s = 0.039$, $B_l = 0.00064$ – respectively, the probability of backscattering by small and large particles; P_s and P_l – respectively, the concentration of mineral and organic particles in g/m^3 ; $b_w(\lambda) = 5,826 \cdot 10^{-3} (400/\lambda)^{4,322}$, $b_p(\lambda) = 1,1513(400/\lambda)^{1,7}$, $b_{\beta}(\lambda) = 0,3411(400/\lambda)^{0,3}$ – respectively, scattering indicators for clean water, small and large particles; λ – wavelength, nm.

Using empirical dependencies, as well as the relationship between P_s and P_l in the Kopelevich model, we find:

$$P_s + 0,01P_l = 11,43(P_s + P_l)^{-0,652} - 21,46(P_s + P_l)^{-0,326} + 10,06.$$

In fig. 3. shows the dependence of the concentration of fine particles of mineral suspension and large particles of organic origin are given depending on the total concentration of the suspension. It is seen that statistically the concentration of large organic particles prevails. The ratio between the concentrations of mineral

and organic particles in the marine environment is characterized by significant variability. It strongly depends on the productivity of water and with its increase the concentration of organic particles increases. On average, organic suspension (living plankton, detritus and other organic substances) accounts for about 80%, and mineral suspension – about 20%.

The corresponding regression dependencies are as follows:

$$L_t(0,645) = 96,836(NDVI)^2 + 109,95NDVI + 47,415;$$

$$R^2 = 0,85$$

$$L_t(0,8585) = 113,42(NDVI)^2 + 133,44NDVI + 43,671;$$

$$R^2 = 0,93$$

Thus, we are able to determine the distribution of concentrations of individual components of suspended substances by spectral features.

Methods of satellite monitoring of intensive algal blooms (monitoring of planktonic alga clusters).

It should be borne in mind that the existing EU Water Framework Directive, when assessing the ecological status and monitoring the environment, provides for an assessment of the hydromorphological characteristics of waterbodies and streams. Therefore, remote sensing methods are essential for monitoring changes in the coastline.

In addition, phytoplankton has a direct impact on the quality of drinking water: suspension, color, toxicity; and with a significant development of biomass causes fish freeze, disruption to the work of sewage treatment plants, pollution of the coast and beaches. Indicators of the quantitative development of phytoplankton are widely used in determining the trophic status of water bodies and for making decisions on the ecological rehabilitation of water bodies. However, obtaining data

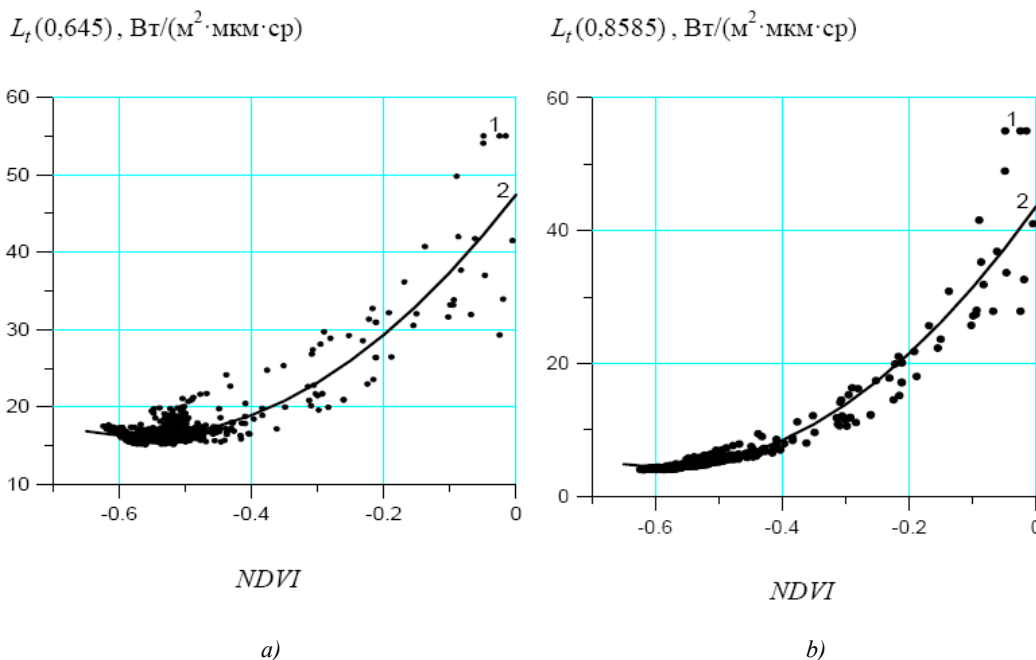


Fig. 3. The brightness of the ascending radiation of the aqueous surface at a) $\lambda = 0.645$ microns, b) $\lambda = 0.88585$ microns

on the status of phytoplankton is quite time-consuming and costly process. All this requires the use of can be seen that areas of intense flowering are elongated along the currents and participate in vortex movements. Wind has a significant effect on the transfer of algae. During periods of prolonged warm, sunny and windless weather, cyanobacteria are combined into aggregates that float to the surface, forming surface or subsurface accumulations. However, it should be borne in mind that the data obtained using satellite observations should be confirmed by the results of field ground surveys.

Flood and flooding risk assessment using satellite observation data. The ability to determine the risks of flooding is determined by the relationship between changes in the spectral characteristics of the surface reflection and the response of ecosystems to external factors (Q_{stress}). To describe the spectral reflection of a specific type of surface N (where N is a class, in accordance with the preliminary classification of land covers), we introduce an integrated indicator – the spectral reflection index SRI . This index is represented as a fixed combination of spectral characteristics in separate

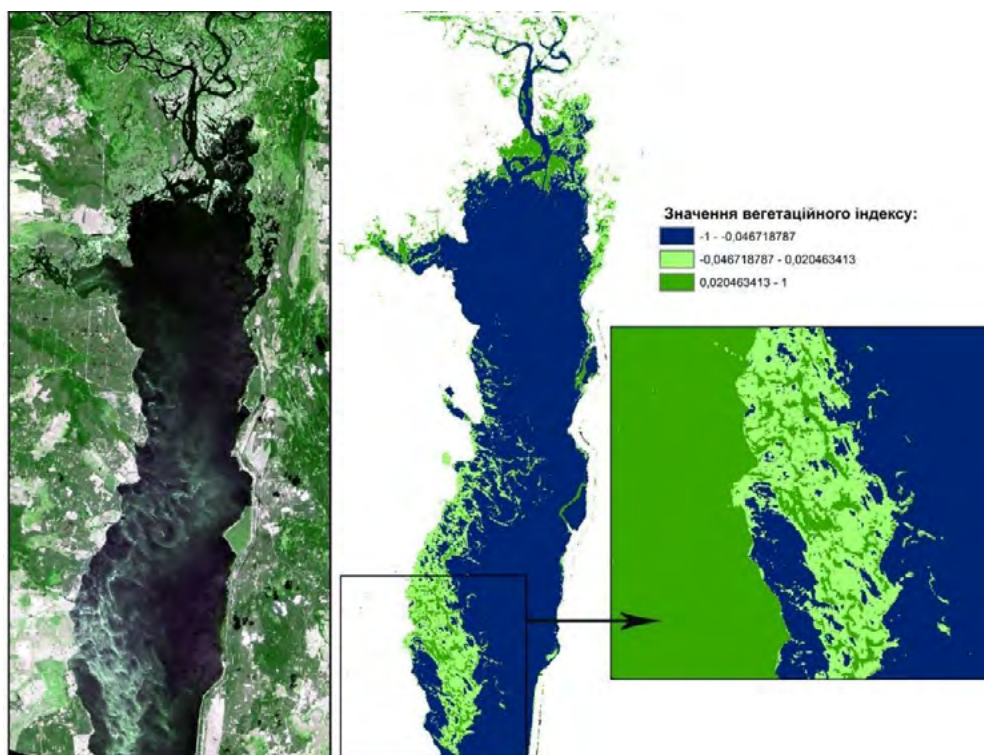


a



b

Fig. 4. Image of the phenomenon of “water bloom”, obtained by the satellite Sentinel-2 on the example: a – Kremenchug reservoir received on August 22, 2015; b – Kakhovsky reservoir (received August 10, 2016)



a

b

Fig. 5. Study of the spatial distribution of blooming areas of blue-green algae on the territory of the Kiev reservoir (a – a fragment of the Landsat satellite image 8 August 13, 2013; b – distribution of the values of the vegetation index in the “bloom” area in the area of Kozarovichi – Lyutezh settlements)

bands of the spectrum r_λ . In general, its appearance can be represented as: $SRI_\tau = f(r_\lambda)_\tau$, where τ is the moment of shooting.

In our case, any of the *NDVI* (or *ARVI*) indices, *EVI*, allows us to determine the trends in the studied ecosystems. Also, the *PRI* (Photochemical Reflectance Index) can be useful, as well as the “Stressful” indexes: the *SIPI* (Structure Intensive Pigment Index), the *NDWI* water index and the Plant Stress Index. Depending on the controlled parameter, any of the existing spectral indices can be used as an integrated indicator (*PRI*, *SIPI* or *NDNI* indices – Normalized Difference Nitrogen Index). Considering the possibility of obtaining multiple surveys, we introduce an index reflecting the changes

in the studied spectral parameters over the observation period – the normalized spectral reflection index:

$$SRI^*_\tau = \frac{\max\{SRI_\tau\} - SRI_\tau}{\max\{SRI_\tau\} - \min\{SRI_\tau\}}$$

Then you can consider the informative attribute ΔSRI^* – the difference between the average value SRI^* for the observation period and the value obtained as a result of the experiment SRI^*_τ .

The equation that determines the probability of stress based on the totality of the spectral characteristics of the earth’s surface is derived from the use of Bayes’ rule:

$$P(\Delta SRI^*(x, y) | Q_{stress}) = \frac{P_s(x, y) \cdot \prod_N P_N(\Delta SRI^* | Q_{stress})}{\int P_N(\Delta SRI^* | Q) dP_s(x, y)} =$$

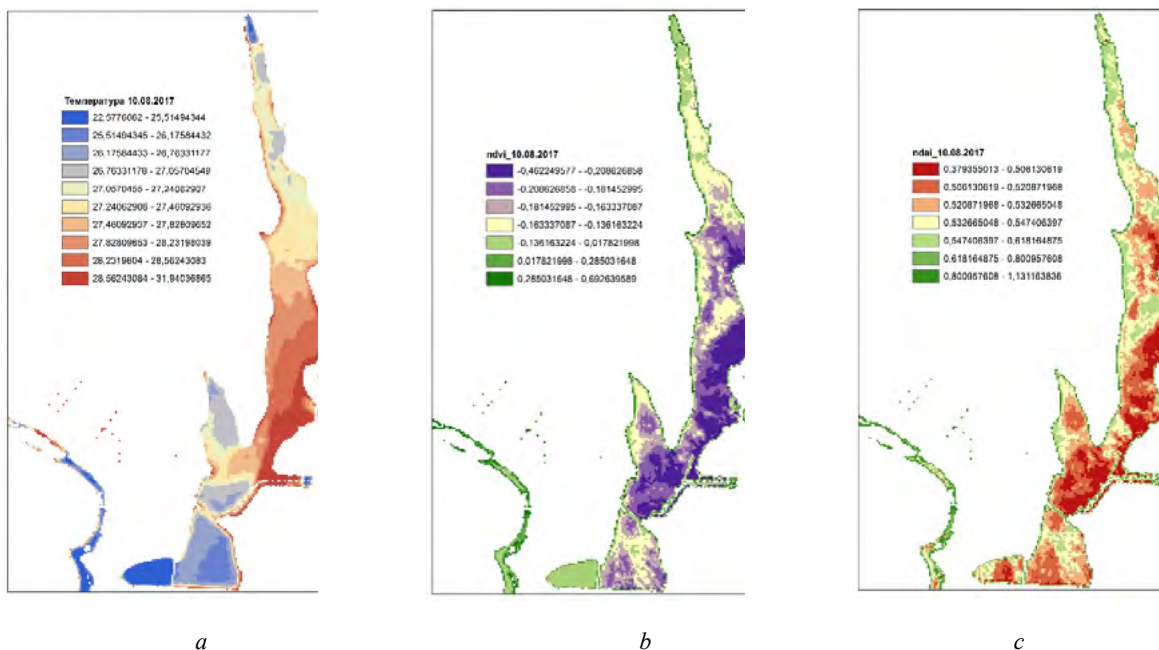


Fig. 6. Remote study of reservoirs of the South-Ukrainian energy complex on the example of the Tashlykyskaya PSPP (as of 10.08.2017): a – surface temperature; b – maps of the distribution of the normalized vegetation index (NDVI); c – maps of normalized relative algo-index (NDAI)

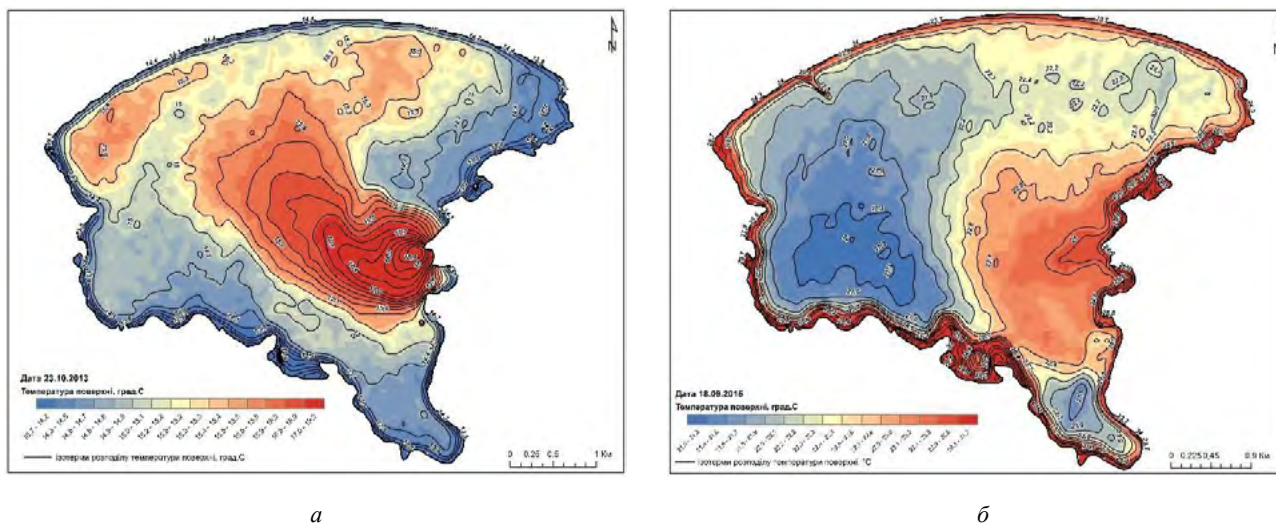


Fig. 7. Dynamics of distribution of surface temperature indicators of the Netishinsky reservoir (water reservoirs – the Khmelnytskoe nuclear power plant) (a – as of October 23, 2013; b – as of 09/18/2015)

$$= \frac{P_s(x, y) \cdot P_N(\Delta SRI^* | Q_{stress})}{P_N(\Delta SRI^* | Q_{stress})P_s(x, y) + P_N(\Delta SRI^* | Q_0)P_0(x, y)}$$

In this equation, the Q_{stress} index refers to areas under the influence of stress factors, and the Q_0 index denotes the class of pixels in which the action of such factors is not present. The probability $P_s(x, y)$ is determined on the basis of the distribution of observational data, that is, semi-empirical. The ratio of the probabilities $P_s(x, y)$ and $P_0(x, y)$ is determined as $\lim_{x,y,\tau} (P_s(x, y) + P_0(x, y)) = 1$.

To determine the probability $P_s(x, y)$, one can use the rule based on the use of the Gauss function

$P_s(x, y) = P_{min} + (P_{max} - P_{min}) \cdot e^{-d_s^2/2\sigma_p^2}$. Here $P_s(x, y)$ is the probability of a threat occurring; P_{max} – the maximum possible probability of occurrence of a threat in the studied place, which depends on the sensor type, physical and geographical features of the region and surface type (P_{max} for Landsat TM and ETM sensors is 0.25–0.3) P_{min} – minimum probability (P_{min} is close 0.01) $d_s(x, y)$ – distance from the nearest place that is under the threat; σ_p is an empirical indicator, determined on the basis of field studies, based on the characteristics of the vegetation cover of the research area and the type of sensor (for example, for Landsat TM and ETM in the region

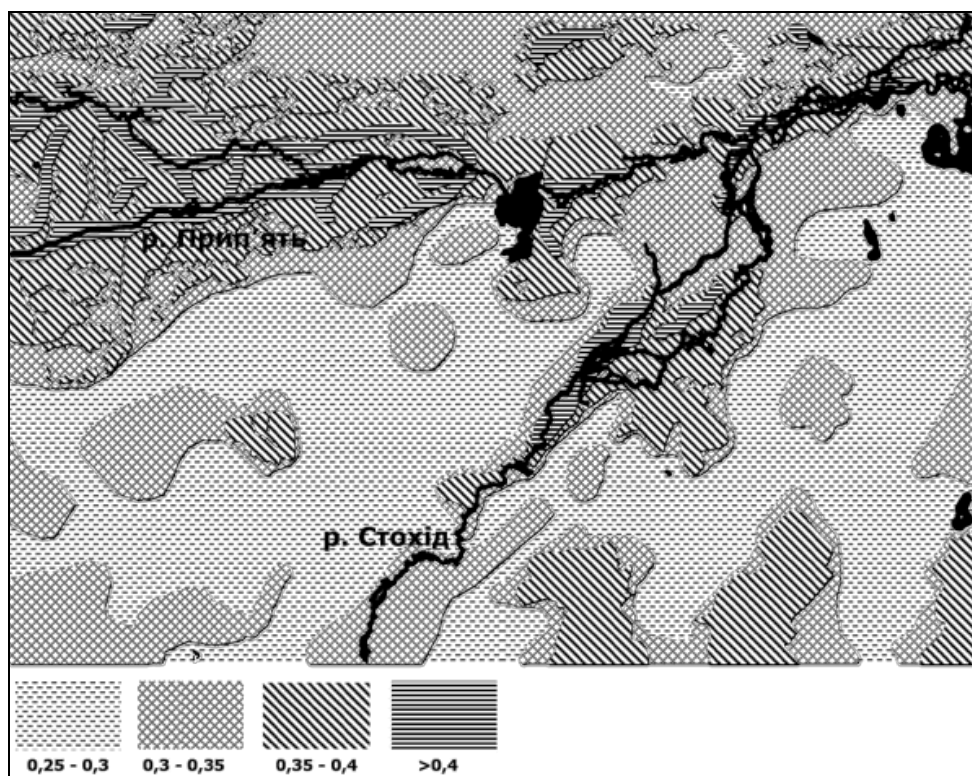


Fig. 8. Estimated risks of flooding of the territories between the Pripjat and Stokhod rivers in the Polesye region

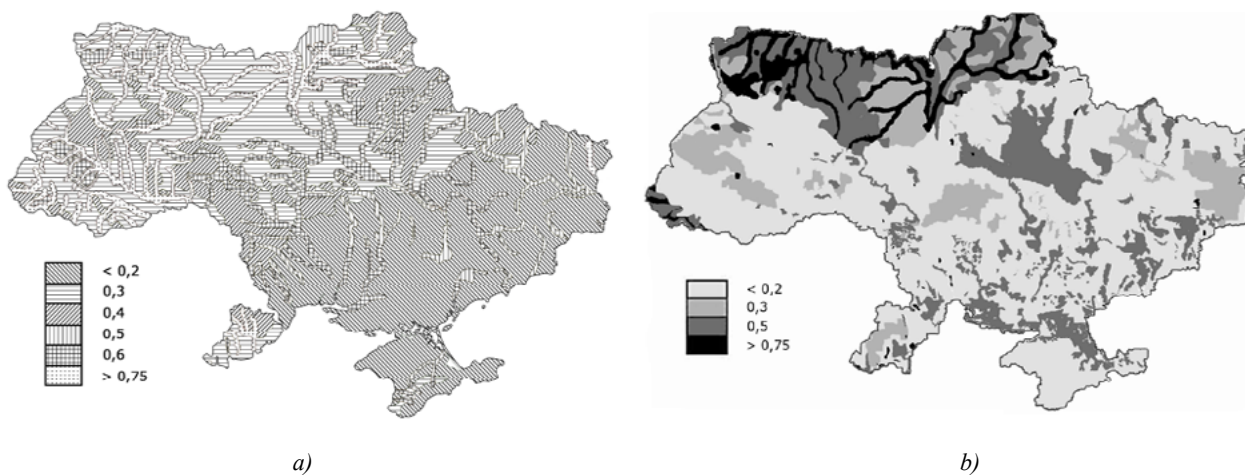


Fig. 9. a) Scenario calculation of indicators of flood risk for the period 2030; b) Scenario calculation of risk indicators for flood processes for the period 2030

of research, the indicator σ_p is 1.1–1.5 km). Thus, for the region of research and sensors, Landsat TM and ETM $P_s(x, y)$ can be determined using the formula: $P_s(x, y) = 0,01 + 0,26 \cdot e^{d_s^2/1,69}$. The task of identifying areas within the N classes with x, y coordinates (under the influence of stress caused by the influence of the factors Q_{stress}) can be reduced to the problem classification of images within the selected periods i , spectral bands r_{λ} , types of sensors and the region of research.

The calculated local risk values are presented in Fig. 8.

These risks are evaluated as the probability of negative consequences. Thus, a risk value of 0.5 means that in conditions of reliable exceeding the average level of seasonal fluctuations in the amount of precipitation, a flood event will be recorded.

Based on local and regional risks, flood, flood and flood risks were assessed. The calculation results are presented in Fig. 9.

Thus, the proposed approach to the assessment of risks of flooding and the method of calculating the spatial distribution of regional indicators of risks of flooding using satellite observations in the optical range.

Methods for quantitative assessment of water quality by observations and measurements. The idea of the method under consideration is to develop a formal approach to the use of heterogeneous data sets for assessing water quality indicators in terms of risk. The likelihood of deterioration in the presence of elevated concentrations of certain pollutants is assessed.

At the same time, we evaluate the quality of water by classes (first through fifth) and categories (first through seventh). Water quality is determined by the water class or water category. Analytically, water quality is determined by sets of indices, which are grouped into three

arrays: mineral-salt indices (three indicators), sanitary and hygienic criteria (another name is trophosaprobiotic indices, 20 of them) and specific indices of toxic pollutants (another name are indices of specific substances of toxic and radiation exposure, this group includes 15 indicators).

In real situations, we have the ability to measure limited sets of indicators that are indirectly related to these indices. The task of reliable assessment of water quality becomes very difficult. However, we can estimate the probability of a change in water quality in accordance with the class (or category) with changes in the observed indicators.

Thus, the problem under consideration can be reduced to a formal algorithm for obtaining dimensionless interval estimates using rank criteria sets based on the theory of fuzzy sets.

The risk assessment algorithm is divided into several stages, and can be represented in a relatively simple form. The set of indices for risk assessment is defined as follows:

$$M = (x_1, x_2, \dots, x_n) = \{x_i\}, i = 1, 2, \dots, n.$$

Where n is the number of selected estimated parameters, x_i is a parameter from the set of i^{th} risk/pollutant parameters (in most real cases they operate with a set of several known pollutants, for example, we will take into account those that we can see by means of remote sensing: transparency, suspended matter, phytoplankton biomass, trophicity, surface-active organic substances, synthetic surfactants, $n = 6$).

Based on the water quality criteria introduced by most of the constituent documents, for example, the European Water Directive, many criteria for risk assessment should be defined as follows:

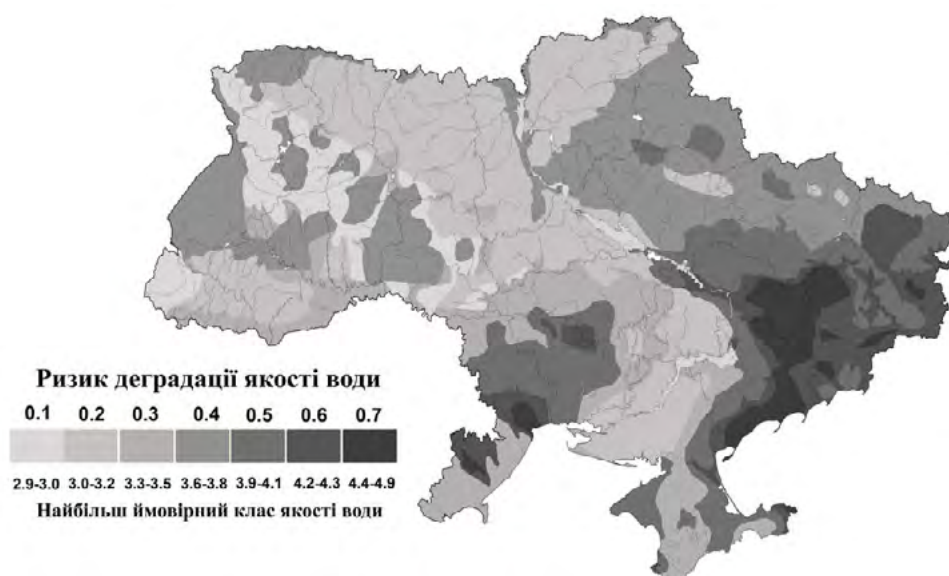


Fig. 10. The risk of deterioration of the quality of surface water resources according to satellite observations MODIS, MISR and AIRS 2002–2014 (model grid 50x50 km)

$$D = (d_1, d_2, \dots, d_m) = \{d_j\}, j = 1, 2, \dots, m.$$

Here m is the number of classes or quality categories (the risk of assignment to which we will determine) d_j , the corresponding quantities of pollutants for which the assessment is carried out, usually $m = 5$ (which corresponds to the number of classes).

Further, the risks associated with water pollution are distributed by a fixed number of degrees (risk assessment intervals): low risk, acceptable risk, unacceptable risk, high risk and catastrophic risk.

The matrix Z , which will link the risk assessment indices (pollutants) M and the water quality criteria D , will look like this:

$$Z = \begin{bmatrix} z_{11} \cdots W \cdots z_{1m} \\ A \cdots C \cdots T \\ z_{n1} \cdots E \cdots z_{nm} \end{bmatrix}.$$

Where z_{ij} is the assessment of the partial risk i^{th} by the criterion of the risk of individual pollution j^{th} from the total set of indices used to assess quality (38 parameters).

Here, to determine the weight of the indices V_i , we will use the coefficients of variation as follows:

$$V_i = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \frac{1}{n} \sum_{i=1}^n x_i)^2}}{\frac{1}{n} \sum_{i=1}^n x_i},$$

where $0 \leq V_i \leq 1$.

Then the risk assessment matrix F can be represented as follows:

$$F = V \bullet Z = (f_1 \dots f_2 \dots \dots f_m).$$

In this case, we can calculate the quantitative indicators of the risk of contamination (in accordance with the definition entered) RI by a simple algorithm:

$$RI = \frac{\sum_{j=1}^n f_i \times j}{\sum_{j=1}^n f_i}.$$

Thus, an algorithm can be proposed for assessing the risk of pollution of water bodies in accordance with the criteria for assessing water quality and sets of indicators, which are obtained from measurements and observations. The proposed method requires testing using field-based spectrometric measurements.

In fig. 10 presents the results of modeling the risk of degradation of the quality of terrestrial water resources according to satellite observations using the above algorithm.

In the future, this technique can be improved by using data from field spectrometric measurements and applying spatial modeling.

Features of the creation and monitoring of surface water. To solve the set tasks, it is necessary to develop spatial-oriented models of key facilities of the state environmental monitoring system and pollution control systems. Such models should take into account the spatial (geographical) and informational characteristics of

objects. Such models are called geo-information models or GIS-models. So, during the synthesis of GIS-models of objects of the environmental monitoring system, all relations between the main objects of this system should be determined for both their spatial and informational characteristics.

Mathematically, the ratio of the spatial components of GIS models will be described using the following notation:

$$O_1 \subset (X_1, Y_1), O_2 \subset (X_2, Y_2), \exists (x_2, y_2) \in (X_2, Y_2): \\ (x_2, y_2) \in (X_1, Y_1),$$

This expression means the following: the object O_1 , the coordinates of the points of which belong to the set (X_1, Y_1) , and the object O_2 , the coordinates of the points of which belong to the set (X_2, Y_2) have "there are common points", that is, there are such ("∃") pairs of coordinates (x_2, y_2) from the set (X_2, Y_2) , which also belong to the set (X_1, Y_1) .

Option, when all points of the object O_3 belong to the points of the object O_2 , can be described as follows:

$$O_3 \subset (X_3, Y_3), O_2 \subset (X_2, Y_2): (X_3, Y_3) \in (X_2, Y_2).$$

The specified pairs of coordinates of points can be Cartesian (abscissa and ordinate), and polar (length and angle), and geodesic (latitude and longitude).

The description of the attribute database of objects that contain the information component of the GIS model will be presented in this form

$$O = [\text{CodeO}, \text{Par01}, \text{Par02}, \dots],$$

where CodeO is the unique object code O in the monitoring system database (the key field for setting informational relations with other models) Par01, Par02 ... are the names of the parameters of the object A.

The description of the information component of the GIS-model of the object O1, which is in a certain relationship with the object B, will look like

$$O_1 = [\text{CodeO}_1, \text{CodeO}, \text{Par11}, \text{Par12}, \dots],$$

where CodeO₁ is the unique object code O₁ in the database of the monitoring system (the key field for establishing information relations with other models, in particular with the model of object O); Par11, Par12 ... – names of the parameters of the object O₁.

Conclusions. Methods are proposed for remote assessment of the ecological and technical state of water technical systems. A comprehensive approach is proposed for predicting the risks of natural disasters based on physical, mathematical, and geospatial modeling using Earth remote sensing data. A method for determining the density of planktonic algae based on satellite imagery data has been developed. Using remote sensing methods, one can obtain maps of the distribution of turbidity, algo-index, lakes and thermal heterogeneity maps in the surface layer of reservoirs. Formed requirements for the protection of aquatic ecosystems using aerospace technology. The development of scientific foundations of multispectral

methods and technical means of monitoring the ecological status of aquatic ecosystems is a prerequisite and the basis for the effective management of their ecological safety. As a result of research, it was found that when assessing the complex impact of pollutants on the ecological state of aquatic ecosystems using aerospace technologies, it is advisable to take into account changes in biological

indicators (biomass indicators and species composition of phytoplankton and higher aquatic plants). In accordance with the Water Framework Directive 2000/60/EC, the monitoring of integral indicators of water pollution should be based on their ecotoxicity, which is determined using biotesting and allows for the synergistic interaction of pollutants to be taken into account.

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