Mon25-049

Investigation of water eutrophication processes in the Sofiyivka Reservoir using RS (remote sensing) and GIS

N. Magas *(Admiral Makarov National University of Shipbuilding)*, **** K. Isaieva*** *(Admiral Makarov National University of Shipbuilding)*

SUMMARY

The results of the study on the causes of the formation and development of eutrophication processes in the Sofiyivka Reservoir in the Mykolaiv region are presented. The main hydrochemical and hydrographic parameters of the reservoir, which is an important source of water supply for the region, are determined. It is established that the increased concentrations of nitrogen and phosphorus compounds, identified through the results of the reservoir's own monitoring laboratory studies of water quality, contribute to the intensive development of eutrophication processes. Using GIS and remote sensing methods, the characteristics of water blooms in the reservoir during the hottest period of 2024 were investigated using Landsat-8 satellite images. Images of the Sofiyivka Reservoir's territory in terms of brightness temperature and Normalized Difference Vegetation Index (NDVI), Normalized Difference Turbidity Index (NDTI), and Normalized Difference Algae Index (NDAI) were generated. The analysis of the spatial features of water blooms in the reservoir confirmed the massive nature of the eutrophication process. The results of the calculations allowed for assessing the ecological state of the reservoir and identifying areas with intense water blooms, which is represented in the form of cartographic material. A correlation between the water temperature in the reservoir and eutrophication processes was established. It was found that the warming of the water area of the Sofiyivka Reservoir is the cause of its excessive blooming.

Introduction

The North-Western Black Sea region, with its well-developed hydrographic network, is generally a water-scarce region due to climatic and hydrogeological conditions and the specific water balance of local water bodies, the complex of which significantly limits the water management potential of the region. (Vyshnevskyi, 2003).Issues related to drinking and irrigation water supply are particularly relevant for the steppe territory of Mykolaiv region (Khilchevskyi et al., 2009), where the concentration of settlements traditionally tends to be near the Southern Bug water network. The critical shortage of water resources in the region already in the middle of the last century initiated the need for more extensive use of the water potential of medium-sized rivers, including the right tributary of the Southern Bug, the Ingul River. Four channel reservoirs were created to accumulate river runoff to provide drinking and partially irrigation water. Of particular importance as a key link in the Ingul hydro system, and as an independent facility of the sub-regional drinking water supply network, is the Sofiyivka reservoir, which serves as an extremely important source of water supply for the arid areas of Mykolaiv region. However, in recent years, intensive processes of eutrophication and deterioration of water quality have been increasingly observed.

Modern research on eutrophication of water bodies in Ukraine is represented by the works of Kirman V. (2014) and Lastochkina M. (2014), who theoretically analysed the process of eutrophication and the causes of the phenomenon of 'water bloom' as a course of excessive eutrophication. Vishnevskiy V., Shevchenko I., and Shevchuk S. characterised eutrophication in the Dnipro reservoirs (Shevchuk et al., 2014). Similar studies on the example of anthropogenic eutrophication of the Shatsk Lakes were conducted by Yanko N., Stankevych V. and Koval N. (Yanko et al., 2014). Fedorovskyi O. (Fedorovskyi, 2013), Shevchenko I. (Shevchenko, 2013), Shevchuk S. (Shevchuk, 2014), Vishnevskiy V. (Vyshnevskyi, 2018), Tomchenko O. (Tomchenko, 2014) and others have carried out studies on eutrophication and blooming of water bodies using GIS and remote sensing tools. It is the use of satellite images and their interpretation that allows objectively assessing and analysing the spatial and temporal features of the emergence and spread of this process, to predict the consequences of water blooms for the environment, etc.

Method and Theory

The material used to prepare this article was based on actual data from hydrochemical monitoring of water samples from the Sofiyivka Reservoir, obtained as a result of field surveys and laboratory studies conducted between 2021 and 2024. The input data for satellite monitoring and studying the eutrophication phenomenon in the Sofiyivka Reservoir consisted of raw Landsat-8 satellite images from the USGS Earth Explorer NASA website for the summer and autumn of 2024. Image processing and subsequent research were carried out in the QGIS software environment. Using the RS&GIS plug-in, with a combination of Landsat-8 channels B10 and B11, a map of water temperatures in the Sofiyivka Reservoir and a map of the Normalised Difference Vegetation Index (NDVI), which is determined using a combination of NIR and RED channels, were obtained. For water bodies, the NDVI acquires negative values; for soils and dry vegetation, it approaches zero; it acquires maximum values for vegetation that is growing and intermediate values for different states of vegetation cover. To establish the relationship between water temperature and the process of water eutrophication, calculations were performed in the QGIS software environment using Landsat-8 satellite data to obtain the Normalized Difference Algae Index (NDAI) and the Normalized Difference Turbidity Index (NDTI). The NDAI index is calculated using a combination of Green, NIR, Blue, and Red channels, which allows for detecting eutrophication processes and assessing the degree of development of aquatic flora. The index values do not depend on atmospheric interference or the influence of the reflection spectrum of the water itself. They are normalized in such a way that values below 0.5 correspond to clear water, around 0 to low algae growth, and above 0.5 to rapid water bloom. A combination of Red, Green channels was used to determine the

NDTI index, which reflects the turbidity of the water, which is mainly caused by suspended sediment in the surface water and the nature of the organisms' activity. The highest observed NDTI values (closer to zero) indicated images with turbid water, while the lowest NDTI values (usually the most negative) indicated images with the best water conditions. A correlation between the water temperature in the Sofiyivka Reservoir and the intensity of its bloom was established using correlation analysis.

Results

The Sofiyivka Reservoir is located in the valley of the Ingul River and is entirely within the administrative territory of Mykolaiv region. It is a typical channel reservoir formed in the canyon section of the river, which overcomes the final breaks in the rocky basement of the Ukrainian crystalline shield and opens onto the flat Black Sea Lowland (Barshchevska, 2014). The reservoir covers an area of 470 km² and holds about 36 million m³ of water. It is 18 km long, with an average width of 0.26 km, a maximum width of no more than 0.7 km, and a maximum depth of 19.5 m. The coastline is 43.20 km long.

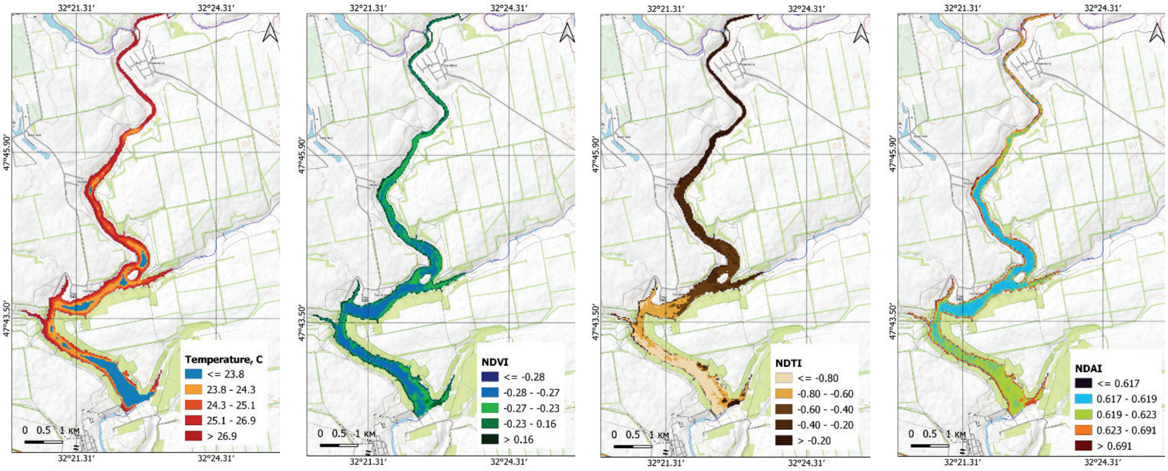
Hydrochemically, the water of the Sofiyivka Reservoir is of the sulphate-chloride-sodium type, with a significantly unstable mineralisation level over the seasons - from 800 mg/l in spring to 3500 mg/l and even in recent years reaching 3800-4020 mg/l (August 2024). In the upper part of the river, Ingul water generally has a pronounced colour and, due to the significant proportions of solid (up to 42 mg/dm3) and colloidal runoff, relatively high turbidity (from 0.029 to 6.41 mg/dm3). Due to the flotation processes in the reservoir, the salinity and turbidity parameters of the water below the Ingul River confluence are slightly reduced (from 3% to 11% according to various indicators), but due to the high organic content, bloom phenomena are increasingly common in summer. The average water temperature in the reservoir is +10°C in April, +25°C in June, and +13.6°C in October.

The content of dissolved oxygen in water is a limiting factor for the existence of aerobic aquatic organisms, including fish. In the reservoir water, the dissolved oxygen content was within normal limits and ranged from 7.92 to 9.4 mg/dm^3, with a saturation level of 86%.

Biogenic compounds in water serve as elementary materials for the synthesis of plant biomass, and thus, an increase in their content contributes, to a certain extent, to the enhancement of the bioproductivity of water bodies. However, once a certain critical limit is reached, the balance of production and destruction processes in aquatic ecosystems becomes disturbed, which threatens to eutrophicate the water body and cause water blooms. The nutrients that contribute to eutrophication are primarily nitrogen and phosphorus compounds. It is believed that 'blooming' begins when the water contains nitrogen at a concentration of 0.2-0.3 mg/dm³ and phosphorus at a concentration of 0.01-0.02 mg/dm³ or more. In 2024, the phosphate content in the water of the Sofiyivka Reservoir ranged from 0.85-1.22 mg/dm³ in the upper reservoir and 0.19-1.17 mg/dm³ in the lower reservoir. At the same time, the seasonal concentration of phosphate increases by an average of 25% in spring and summer, due to the ingress of phosphate fertilizer residues from surrounding fields. The nitrate content in the upper part of the reservoir ranges from 1.8 to 7.64 mg/dm³. In the lower part of the reservoir, there is a slight increase in nitrate content, averaging 6%. The nitrite content varies from 0.04 to 0.19 mg/dm³ depending on the season. The highest nitrite concentrations are observed during the summer months. Ammonium is the most toxic form of inorganic nitrogen compounds, with ion concentrations in the reservoir water ranging from 0.02 to 0.58 mg/dm³ in the upper reservoir and from 0.09 to 0.87 mg/dm³ in the lower reservoir. The main reason for the accumulation of nitrogenous compounds is mineral fertilizers and pest control products washed into the reservoir by rainwater.

By analyzing the data from the Landsat-8 satellite for August 1-26, 2024, it was possible to visually observe the state of the reservoir bloom, which was noted throughout the month. For a detailed study of the eutrophication phenomenon in the Sofiyivka Reservoir, we selected images with the lowest cloud cover from August 6, 2024. According to the nearest meteorological station (Bashtanka), this period was one of the hottest, with a complete lack of precipitation in the area in 2024.

In this paper, we calculated the temperature value (converted to Celsius) for Landsat scenes from 06.08.2024 and found the NDVI index value. The values of these two quantities, averaged for pixels belonging to the reservoir territory, are shown in Figs. 1a and 1b. Positive NDVI values in the reservoir area are observed only near the reservoir shores, indicating the presence of overgrowth processes and aquatic vegetation.



a b c d

Figure 1*. Remote sensing of the state of the Sofiyivka Reservoir as of 6 August 2024: a - surface temperature; b - maps of the distribution of the normalized vegetation index (NDVI); c - maps of the normalized relative turbidity index (NDTI); d - maps of the normalized relative algal index (NDAI).*

The results of the water quality assessment in the reservoir based on the water turbidity index are shown in Fig. 1c. The results obtained correlate well with the water quality monitoring data for the same period and confirm the increased water turbidity in the upper part of the reservoir at the point where river water enters the reservoir.

The distribution of water eutrophication processes on the surface of the Sofiyivka Reservoir is shown in Fig. 1d. The intensive process of water "blooming" is mostly observed in the upper part of the reservoir and near the shores. The NDAI value in these areas of the reservoir is greater than 0.5, indicating a significant spread of algae. This area is also characterized by the highest temperature in the reservoir, as can be seen from Fig. 1a.

To establish the relationship between the water temperature in the reservoir and the intensity of its bloom, a correlation analysis of the relationship between temperature and bloom in the Sofiyivka Reservoir was conducted. According to the results of the analysis, an inverse relationship was found only between temperature and the turbidity index (NDTI), where the correlation coefficient was -0.79. The correlation coefficient between temperature and the vegetation index (NDVI) is 0.63, indicating a significant relationship between these indicators. The correlation coefficient between temperature and the algal index (NDAI) is 0.73. Such indicators confirm a strong relationship among these indicators and suggest that excessive warming of the reservoir is one of the causes of water blooms in the reservoir.

Conclusions

Based on the application of remote sensing methods and the digital processing of remote sensing data, an image of the territory of the Sofiyivka Reservoir was created in terms of brightness temperature and normalized difference indices NDVI, NDTI, and NDAI. The analysis of the reservoir's temperature regime made it possible to identify the areas of the reservoir with the highest temperature values in the satellite images. The calculated values of vegetation indices revealed the highest activity of water bloom processes in these areas. The analysis of the spatial and temporal features of water bloom in the Sofiyivka Reservoir on August 5, 2024, confirmed the massive nature of this process, which is most common in the upper reaches and near the shores. The correlation analysis of the relationship between water bloom in the reservoir and its temperature revealed a significant and strong correlation between water temperature and the vegetation index (NDVI) and algal index (NDAI). This confirms the effectiveness and feasibility of using remote sensing data processing methods for environmental monitoring and assessment of water bodies, including reservoirs.

References

Borshchevskaya, N.M. (2014). Analysis of the latest geodynamics in connection with the formation of the relief of the Ingul River basin. Physical geography and geomorphology, 2 (74), 94-103. [in Ukrainian]

Clean water: Interactive map 'Monitoring and environmental assessment of water resources of Ukraine'. State Agency of Water Resources of Ukraine. Retrieved from https://texty.org.ua/water/

Khilchevskyi, V. K., Chunariov, O. V. et al. (2009). Water resources and river water quality in the Southern Bug basin. K. [in Ukrainian]

Kirman, V.V. (2014). Water blooms and its causes. Means of control: scientific manual. ONEU.

Lastochkina, M.A. (2014). Features of the eutrophication process. KHNU.

Rules for the operation of the Sofiyivka Reservoir in the Novobuzkyi district of Mykolaiv region. Mykolaiv, (2008). 37 c.

Shevchuk, S.A., Vishnevskiy, V.I., Shevchenko, I.A. (2014). Use of remote sensing data to determine the ecological state of the Dnipro reservoirs. Proceedings of the Central Geophysical Observatory. Central Geophysical Laboratory, 10 (24), 72-78.

Tomchenko, O.V. (2014). The use of space-based remote sensing information for monitoring the state of a large reservoir Hydroacoustic Journal (Problems, methods and means of research of the World Ocean). STC PAS NAS of Ukraine, 11, 135-143.

Tomchenko, O.V., Pidhorodetska, L.V., Fedorovskiy, O.D. (2013). Comprehensive assessment of the ecological state of water bodies based on space-based remote sensing information (on the example of Lake Svityaz and the upper reaches of the Kyiv reservoir). Hydroacoustic Journal (Problems, methods and means of research of the World Ocean), 10, 111-117.

Vishnevsky, V. I., Kosovets, O. O. (2003). Hydrological characteristics of rivers of Ukraine. Kyiv, Ukraine.

Yanko, N.V., Stankevych, V.V., Koval, N.M. (2014). Anthropogenic eutrophication of Shatsk lakes. Environment and health, 3, 51-55.

Zub, L.M., Tomiltseva, A.I., Tomchenko, O.V. (2016). Assessment of the state of water protection areas using remote sensing methods (on the example of the Dniester HPP and PSPP complex). Hydropower of Ukraine, 3-4, 51-56.