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ASSESSMENT OF THE CURRENT ECOLOGICAL STATE OF THE FASTIV RESERVOIR USING GROUND AND SATELLITE DATA

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Abstract. *The article presents the results of researches on assessing the ecological state of the Fastiv Reservoir using ground and satellite data according to the developed scientific approach, which provides for the following sequence for a water body with a large area: conducting field observations, involving satellite information, and creating a resulting map of the current ecological state based on a certain set of indicators, which is the goal of the research. The relevance of the research is defined by the significant deterioration of the water condition in the reservoir, which was caused by an increase in air temperature, uneven distribution of precipitation throughout the year, a decrease in the reservoir filling to 92.7 % of the design level, intensive increase in water use and discharge of domestic wastewater. In the conducted studies, it was advisable to compensate the lack of spatially concentrated information (from points of field measurements) with spatially distributed information. During field surveys, hydrobiological and physicochemical indicators were determined in 3 sections of the reservoir – points observations, and maps of water depth, temperature, and transparency were created based on the results. Such results of field observations as an increased turbidity and low transparency made it necessary to use satellite data, especially those containing red and infrared ranges, when calculating spectral indices. From the perspective of remote sensing, water bodies have their own spectral characteristics, which depend on the concentration of various substances dissolved and suspended in water – diffuse reflectance. To compensate the lack of information, the Sentinel-2 L2A image was used, which is the closest with no cloud cover to the date of field observations, and spectral indices were calculated in the open software product Land Viewer: NDVI, GCI, NDWI. Only the NDWI map was useful, providing an insight about the transparency within the entire reservoir. The obtained comprehensive information made it possible to create a resulting map of the current ecological state of the Fastiv Reservoir based on the ground and satellite data.*

Keywords: *reservoir, ecological state, ground surveys, satellite data, spectral indices, resulting map*

Relevance of the research. Increasing greenhouse gas concentrations lead to climate changes, air temperature increasing, changes in the annual distribution of precipitation throughout the year, biomass increasing, and intensification of biochemical processes in surface waters, which has significantly worsened their ecological state. To these negative factors an increase in man-made load on water bodies due to unauthorized sources of pollution and discharges of domestic wastewaters should be added. Another problem that needs to be addressed is the pollution of water bodies with untreated and insufficiently treated return waters due to the unsatisfactory technical condition of treatment facilities, which leads to the entry of insufficiently treated wastewaters into natural waters. Therefore, timely assessment of the ecological state of surface waters is an urgent task. An example of an unsatisfactory ecological state of waters is the Fastiv Reservoir, which is a vital reservoir for the city of Fastiv, as the water level in it affects the water debit in wells and provides a stable water supply to over 45 thousand residents. Due to the unsatisfactory technical condition of the gates of the hydraulic structure and the lack of flushing in the reservoir, its basin silted up, and the influx of insufficiently treated wastewaters from the city's industrial enterprises has caused a significant deterioration in the ecological condition of the reservoir today. For a comprehensive assessment of the large reservoir state, field surveys of the reservoir's hydromorphological state and the physicochemical characteristics of the water are not enough, as those results represent point-based data that correspond to the locations of direct water sampling. For a more in-depth analysis of the water bodies' eutrophication processes, there is a need for spatially distributed data, which is provided to specialists by satellite images. In the case of the Fastiv Reservoir, when assessing the current ecological state, it was advisable to complete the point-based data with spatially distributed information [1]. The issue of completing the indicators during the environmental assessment using ground data by aerospace data is also addressed in the work of H. Godı´nez-Alvarez, J.E. Herrick, M. Mattocks, et al. [2].

Analysis of recent research and publications. The issues of assessing the transparency and turbidity of waters is covered in the works [3, 4]. The thesis of Pichura V.I. describes the identification of water transparency in individual Dnipro reservoirs using remote sensing (RS) data. Also, one of the important issues of the water bodies ecological state, which has been addressed by a large number of researchers, is the spread of blue-green algae, which is known as water "bloom". It is necessary to highlight the work of Adam Trescott [5], who in his papers obtained empirical models based on remote sensing data for the estimation of chlorophyll concentration in open water bodies. Scientists have found that the best results for assessing algae development are obtained from the relationships that use the values of B1, B2, and B3 bands of the Landsat 7 satellite mission. The work of the American researcher Mohammad Haji Gholizadeh stands out for its thoroughness [6]. The author analyzed numerous research results, which dedicated to study the application of remote sensing in the water bodies ecological assessment. The Chinese scientist Shengkun Zhang devoted his research to the assessment of the chlorophyll concentration in Laizhou Bay (China) [7]. The paper describes how, based on data from the Landsat 8 OLI and the results of field surveys, a regression model was obtained and, based on it, the spatial distribution of chlorophyll concentration was estimated and the water quality in the coastal waters of the studied bay was assessed. Analysis of research and publications shows that the main attention while assessing surface waters using satellite data is devoted to determining transparency and turbidity, as well as the possibility of compensating for the lack of ground-based information with satellite data.

The aim of the research is to assess the ecological state of the Fastiv Reservoir using ground and satellite data.

Research methods and materials. The work presents an analytical analysis of scientific works on the ecological survey of surface waters using ground and satellite data, ground surveys and experimental studies of the Fastiv Reservoir using generally accepted and certified methods, and a geospatial and system analysis of the obtained results.

The research methodology included the following components:

– analytical analysis of scientific works on the identified problem;

– conducting field surveys, which included measuring the depth of the reservoir, water sampling, measuring transparency, turbidity (content of suspended solids), color, and water temperature;

– search for publicly available satellite information and analysis of the possibility of its application to the research problem;

– calculations of spectral indices for vegetation, green chlorophyll, and water;

– analysis of the obtained results.

During field surveys, hydrobiological and physicochemical indicators were determined in 3 sections of the reservoir – point observations and, additionally, spatially distributed satellite data on the ecological state of the reservoir were obtained.

Research results and their discussion. The Fastiv Reservoir is located on the Unava River, which is a right tributary of the Irpin River. The reservoir is located on the southwestern edge of the Fastiv city, partially wedged into the city limits. The reservoir has existed since 1907, but acquired its modern appearance after the commissioning of hydraulic structures on the Unava River in 1935. The length of the reservoir is 6.20 km, the average width is 390 m, the widest section is 700 m, the average depth is 3.77 m. The normal supporting water level (NSWL) is set at 158.00 m (Baltic height system). The area of the water mirror at NSWL is 2.41 km^2, and the volume of the reservoir is 5.06 million m^3. The usable volume is 4.87 million m^3.

The area of the Unava River catchment to the hydroelectric power station is 462 km^2. The river is fed by snow and rain, the flow volume at 50 % of availability is 26.65 million m^3. The reservoir is the main water supply source for the railway junction and some industrial enterprises in Fastiv city. During the operation time of the reservoir, the hydraulic facilities were reconstructed in 1929, 1932, 1961, and 1998. Over the past 15-25 years, flow regulation by gates has been practically not carried out, which has led to significant silting of the reservoir. According to the results of the survey of the reservoir by the specialists from the Institute of Water Problems and Reclamation of the National Academy of Agrarian Sciences (IWPiM of NAAS) in August 2022, it was noted that the water level in the reservoir was below the NSWL and the regulated volume of water in the reservoir was 4.69 million m^3, which is 92.7 % of the reservoir's design capacity. The main reason for the decrease in the reservoir filling was low water conditions of the current year on the background of significant filtration losses through the hydraulic facility, which is due to the unreliable operation of the gate valves (Fig. 1).

Figure 1. Hydraulic facility of the Fastiv Reservoir

However, not only hydrotechnical and climatic (air temperature increase, uneven distribution of precipitation throughout the year) conditions have caused the deterioration of the ecological state of water in the reservoir. In recent decades, there has been an intensive increase in water use, which has also led to a deterioration in water quality. Surface runoff from agricultural fields, which contains mineral fertilizers, pesticides, and biogenic substances, also causes harm. A significant negative environmental impact on the water body is caused by LLC "Eko-Vtor", which is engaged in the extraction of polyester fibers from PET bottles and incineration of polymer waste, resulting in the formation of various toxic substances – acetaldehyde, terephthalic and other organic acids. Also, the State Environmental Inspection and the Fastiv Prosecutor's Office discovered violations of water legislation in the work of the communal enterprise "Fastivvodokanal". Such violations contributed to the increase in water "bloom" (Fig. 2) from year to year.

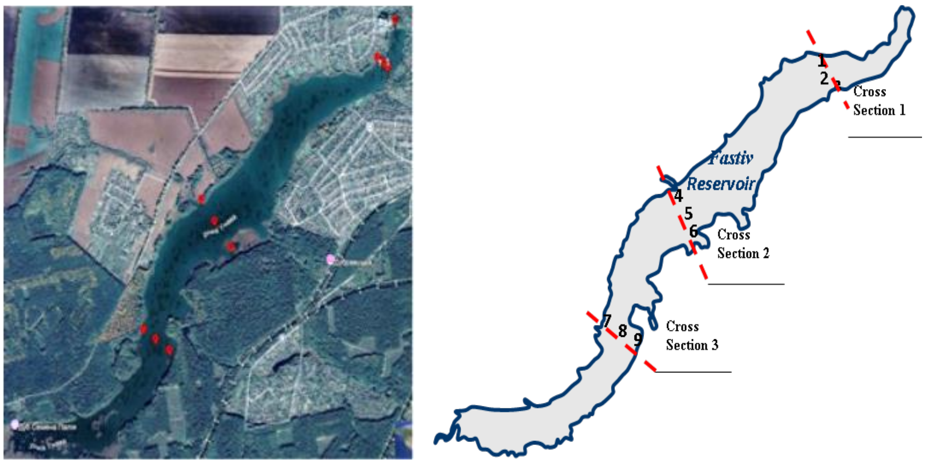
a

b

Figure 2. Water pollution in the Fastiv Reservoir: a – upstream, b – downstream.

Therefore, in August 2024, specialists from the IWP&LR of NAAS conducted a survey of the Fastiv Reservoir regarding the ecological state of the waters – hydrobiological (turbidity, transparency) and physicochemical (soluble iron content in the water). Three lines were selected: line 1 with observation points 1–2–3 closer to the dam; line 2 with points 4–5–6 in the middle of the reservoir; line 3 with points 7–8–9 in the ending part. The schemes of the research are shown in Fig. 3.

During the survey (Fig. 4), depth measurements, water sampling, and measurements of transparency, turbidity (content of suspended solids), color, and water temperature were performed.



a b

Figure 3. Schemes of research: a – the coordinates of observation points on a satellite image, b – layout of observation lines

a b

Figure 4. Survey conducting: a – the upperstream; b – using a boat to measure the depth of water and take water samples

The results of field surveys and laboratory analyzes of water samples from the Fastiv Reservoir are given in Tables 1, 2.

1. The results of field survey of the Fastiv Reservoir

Coordinates of observation points	Water sampling point number	Water temperature, °C	Transparency, m	Depth, m
1	2	3	4	5
50°4'27,00" 29°53'42,00"	1	23,8	0,32	2,2
50°4'25,44" 29°53'44,82"	2	23,8	0,35	4,6
50°4'23,6" 29°53'47,17"	3	23,8	0,32	2,6
50°3'49,44" 29°52'1,15"	4	24,0	0,30	1,9
50°3'42,58" 29°52'7,46"	5	22,3	0,31	6,9
50°3'34,18" 29°52'15,56"	6	23,0	0,30	1,2

Table 1 (ending)

1	2	3	4	5
50°3'12,17" 29°51'25,24"	7	24,0	0,33	2,0
50°3'8,82" 29°51'31,35"	8	23,8	0,33	2,8
50°3'5,11" 29°51'38,28"	9	22,8	0,31	1,4

2. Results of laboratory analyzes of water from the Fastiv Reservoir

Water sampling point number	Turbidity, mg/dm³	Fe, mg/dm³	Transparency, cm
1	30,16	0,70	19
2	31,90	0,74	11
3	33,06	0,62	5,8
4	34,80	0,74	4,5
5	40,80	0,68	6,2
6	33,64	0,74	5,5
7	40,60	0,54	5
8	38,28	0,79	5,3
9	31,90	0,70	16,5

Since the dispersion of observation points is significant, instead of creating the dependence graphs, we created schematic maps based on field and laboratory observations using the method of approximation between the points (Fig. 5).

From the maps it is clear that the water temperature decreases with the increase of depth, and the water transparency changes in a small range, which is explained by the total spread of blue-green algae during the active development phase in the summer time. Data from field surveys and laboratory analyzes differ. Transparency is usually determined by two methods – using a Secchi disk in the field conditions and using a Snellen device in the laboratory. In this case, the results of the certified Snellen device method were used.

The concentration of iron oxide was determined as a physicochemical characteristic of water. Normally, it should decrease with the increase of water body volume, which is a natural phenomenon. However, the reservoir filling was equal to 92 % and the concentration of soluble iron in average was 0.7 mg/dm³ throughout the water area and is not significant as a characteristic.

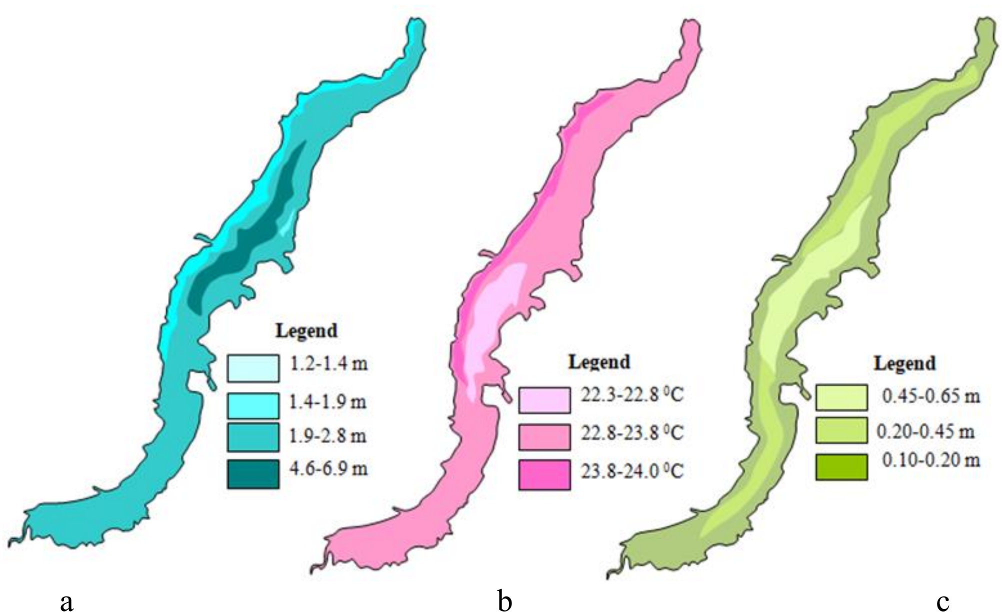


Figure 5. Schematic maps of the field survey results: a – depths; b – temperatures; c – transparency

Water turbidity is determined by the content of finely dispersed impurities suspended in water – insoluble or colloidal particles of various origins. Turbidity of water also determines some other characteristics of water, in particular, the presence of sediment, suspended solids, coarse impurities. Water turbidity is one of the important indicators of its quality. This indicator reflects the presence of inorganic and organic undissolved particles in water and was equal to 30–40 mg/dm^3 during the observation period.

Such results of field surveys as increased turbidity and low transparency have made it necessary to use satellite data, especially those contain red and infrared bands, in calculating spectral indices. From the point of view of remote sensing, water bodies have their own spectral characteristics, which depend on the concentration of various dissolved and suspended substances in water – diffuse reflectance.

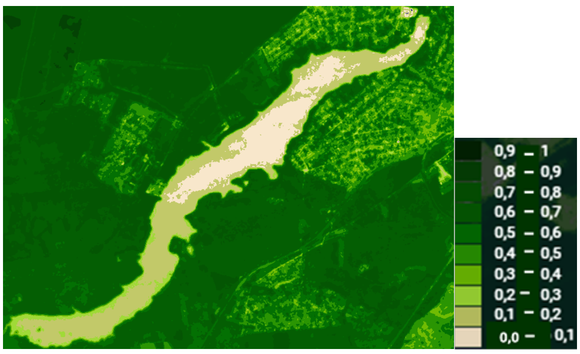


Figure 6. Map of NDVI distribution within the Fastiv Reservoir

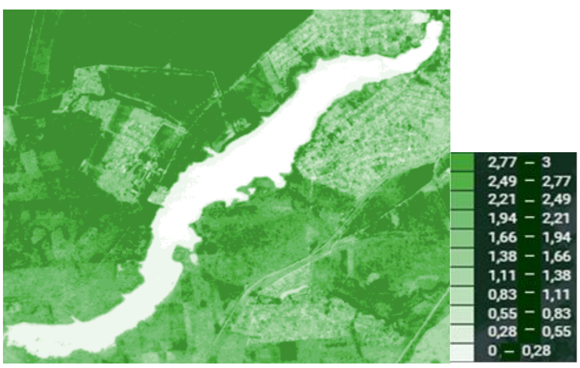


Figure 7. Map of GCI distribution within the Fastiv Reservoir

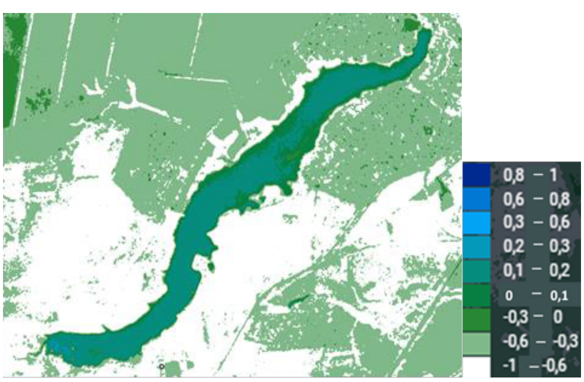


Figure 8. Map of NDWI distribution within the Fastiv Reservoir

For the study we used the Sentinel-2 L2A image dated 25.07.2024, the closest date with no cloud cover to the date of field surveys, and calculated the following spectral indices in the open software product LandViewer: Green Chlorophyll Index (GCI), Normalized Difference Water Index (NDWI) [8, 9, 10], Normalized Difference Vegetation Index (NDVI) [11]. Based on the results of the calculations, maps of these indices were obtained (Fig. 6–8).

The classical NDVI map distinguishes coastal vegetation – reeds in the range of 0,30–0,40 microns and finely dispersed impurities in the water in the range of 0–0,10 microns. The GCI map is not informative, since it only concerns vegetation, and on the surface of the reservoir it is absent, and gives only clear contours of the reservoir itself. However, the NDWI map is obtained by the calculation that uses the near-infrared (NIR) band with a wavelength range of 0,78–0,90 microns and the mid-infrared (SWIR) band with a wavelength range of 1,56–1,66 microns, provides the most information about the trophic state of the reservoir. With an NDWI value above 0,3, an open body of water is distinguished; the values from 0 to 0,3 shows the presence of vegetation with a high water content or partially submerged areas of vegetation; a value of 0 usually indicates dry soil or vegetation with a low water content. It is important to note that these threshold values can vary depending on the specific environment and should be calibrated according to local conditions. Thus, during the research, more information about transparency was obtained, which made it possible to produce a resulting map of the current ecological state of the Fastiv Reservoir (Fig. 9) based on ground and satellite data.

On the resulting map produced according to the existing methodology [12], yellow color corresponds to “satisfactory” water condition at NDWI values of 0,3–0,6 and transparency of 0,45–0,65 m, brown color corresponds to “bad” condition at NDWI values of 0,2–0,3 and transparency of 0,20–0,45 m, red color corresponds to “very bad” condition at NDWI values of 0,0–0,2 and transparency of 0,10–0,20 m.

Conclusions. The use of the Normalized Difference Water Index in combination with ground measurements and laboratory studies made

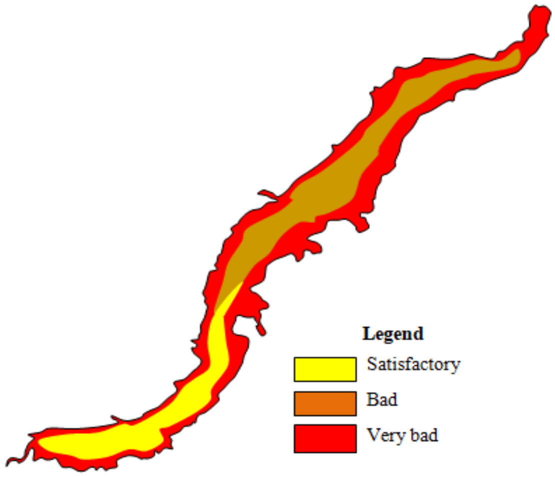


Figure 9. Resulting map of the current ecological state of the Fastiv Reservoir based on ground and satellite data

it possible for the first time to assess the current trophic state of the Fastiv Reservoir as a whole during the period of active water "blooming".

During the conducted research, it was found that based on the results of ground surveys of a large water body, it is advisable to create schematic maps, rather than graphs, due to the large dispersion (scatter) of observation points.

It has been established that increased turbidity and poor water transparency necessitate the use of satellite data, especially those containing red and infrared ranges of the electromagnetic radiation spectrum, when calculating spectral indices.

It is proven that it is possible to produce the resulting map of the current ecological state of a water body, which may contain individual water areas of different ecological states, based on certain indicators obtained in the complex. The allocation of categories of the ecological state of different areas in the corresponding color (yellow – satisfactory, brown – bad, red – very bad) is carried out in accordance with the existing methodology for assigning a surface water body, as well as a significantly modified surface water body, to one of the classes of ecological potential of an artificially or significantly modified surface water body.

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ОЦІНКА СУЧАСНОГО ЕКОЛОГІЧНОГО СТАНУ ФАСТІВСЬКОГО ВОДОСХОВИЩА ЗА НАЗЕМНИМИ ТА СУПУТНИКОВИМИ ДАНИМИ

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Анотація. *У статті викладено результати досліджень з оцінки екологічного стану Фастівського водосховища за наземними та супутниковими даними за розробленим науковим підходом, який передбачає наступну послідовність для водного об'єкта з великою площею: проведення натурних спостережень, залучення супутникової інформації та побудови за певним комплексом показників результуючої карти сучасного екологічного стану, що є метою досліджень. Актуальність проведення досліджень випливає з значного погіршення стану води у водосховищі, яке спричинили підвищення температури повітря, нерівномірний розподіл опадів впродовж року (зменшення наповнення 92,7 %), інтенсивний ріст водокористування та скидання господарсько-побутових стічних вод. У проведених дослідженнях доцільним було компенсувати нестачу просторово зосередженої інформації просторово розподіленою. При натурних обстеженнях визначали гідробіологічні і фізико-хімічні показники у 3-х створах водосховища – точкові спостереження, а за результатами було побудовано карти глибин, температури та прозорості води. Такі результати натурних спостережень, як збільшена каламутність та слабка прозорість, а також неможливість обстеження з технічних причин третьої частини водосховища (акваторія у хвості), викликали необхідність застосувати супутникові дані, особливо ті, що містять червоні та інфрачервоні канали при розрахунках спектральних показників. З точки зору дистанційного зондування, водні об'єкти мають свої спектральні характеристики, які залежать від концентрації різних розчинених і завислих у воді речовин – дифузного відбиття. Щоб компенсувати нестачу інформації, було задіяне знімок Sentinel-2 L2A, який є найближчим з відсутньою хмарністю до дати проведення натурних спостережень і розраховано спектральні індекси у відкритому програмному продукті LandViewer:NDVI,GCI, NDWI. Корисною виявилася лише карта NDWI, яка давала уявлення про прозорість у межах всього водосховища. Отримана комплексна інформація дала можливість побудувати результуючу карту сучасного екологічного стану Фастівського водосховища за наземними та супутниковими даними.*

Ключові слова: *водосховище, екологічний стан, наземні обстеження, супутникові дані, спектральні індекси, результуюча карта*