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The geoecological analysis of Lake Tuchne (Volyn Polissia) and assessment of sapropel reserves in it

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Abstract. The administrative-territorial reform in Ukraine, which began in 2015, opened up prospects for newly created territorial communities to determine the resource potential of local territories under control and develop strategies for balanced nature use and their progressive development. The lakes, which have a significant potential for sapropel resources, take an important place in the Polissia region of Ukraine. Given the above, there is a need for a comprehensive study of specific lakes and justification of recommendations for the rational use and protection of their water and sapropel resources. The object of our research is Lake Tuchne, Volyn Polissia. The catchment area of Lake Tuchne is 10.05 km^2, and the reservoir itself is 0.39 km^2. A bathymetric model of the lake was built with a depth interval of 0.5 m. The vegetation index (NDVI) for the reservoir over the past five years has been varying from -0.53 (12/02/2021) to +0.48 (07/15/2021). The research presents a stratigraphic section of the reservoir sediments. The area of accumulated sapropel is 20.5 hectares, the average thickness is 4.46 m, and the maximum is 10.0 m. The ash content of sapropel varies within 17.5-37.5% (on dry substance). The content of Fe_2O_3 in the core ranges from 2.53% to 7.26%. The distribution of CaO compounds in the samples ranges from 2.09 to 8.12%. The CO_2 content varies from 1.97 to 9.72%. The concentration of P_2O_5 in sapropel samples is 0.19-0.53%. The distribution of S in sapropel deposits ranges from 0.23 to 1.09%. The pH (salt extract) distribution in the core samples varies from moderately alkaline (7.63) to close to neutral – 5.97. A digital landscape map of the lake was constructed with the selection of the littoral and sublittoral-profundal aqua sub-areas and five types of aquafacies. A landscape-metric analysis of the natural and aquatic complex of the lake was carried out. The potential of water resources of Tuchne lake is 827.0 thousand m^3. Sapropel reserves of category A are 914,000 m^3, and based on a conditional 60.0% humidity, they are 155,000 tons. The species composition of sapropel is represented by zoogenic, organo-ferrous, and organo-limestone species. The total stock of sapropel in the lake basin is 52.5% of its volume. The reservoir is promising for extracting sapropel due to its quality characteristics and hydro-technical prerequisites for operation. Mined sapropel can be used in agriculture, medicine, recreation, etc. Implementing this task will improve the geoecological state of the lake and the quality of its water resources.

Keywords: geoecological analysis, lake, bathymetry, landscape map, complex water basin, sapropel.

Геоекологічний аналіз озера Тучне (Волинське Полісся) та оцінка запасів сапропелю в ньому

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Анотація. Адміністративно-територіальна реформа в Україні, розпочата у 2015 році, відкрила перспективи для новостворених територіальних громад щодо визначення ресурсного потенціалу підконтрольних локальних територій та розробки стратегій збалансованого природокористування й поступального їхнього розвитку. Важливе місце в Поліському регіоні України посідають озера, які володіють значним потенціалом ресурсів сапропелю. З огляду на зазначене, постає необхідність комплексного дослідження конкретних озер й обґрунтування рекомендацій з раціонального використання та охорони їх водних і сапропелевих ресурсів. Об'єктом нашого дослідження обрано озеро Тучне, Волинське Полісся. Площа водозбору озера Тучне 10,05 км^2, а самої водойми – 0,39 км^2. Побудована батиметрична модель озера з інтервалом глибин через 0,5 м. Вегетаційний індекс (*NDVI*) для водойми протягом останніх п'яти років варіює у межах від -0,53 (02.12.2021 р.) до +0,48 (15.07.2021 р.). У роботі наведений стратиграфічний розріз відкладів водойми. Площа акумульованого сапропелю становить 20,5 га, середня потужність 4,46 м, а максимальна 10,0 м. Зольність сапропелю варіює у межах 17,5-37,5% (на суху речовину). Вміст Fe_2O_3 у керні становить від 2,53% до 7,26%. Розподіл сполук CaO у пробах коливається від 2,09 до 8,12%. Вміст CO_2 варіює у межах від 1,97 до 9,72%. Концентрація P_2O_5 у пробах сапропелю – 0,19-0,53%. Розподіл $S_{заг.}$ у покладах сапропелю коливається у межах від 0,23 до 1,09%. Розподіл pH (сольової витяжки) у пробах керну змінюється від середньолужного (7,63) ступеню до близького до нейтрального – 5,97. Побудована цифрова ландшафтна карта озера з виділенням літорального та субліторально-профундального аквапідурочища і п'яти видів аквафацій. Здійснено ландшафтометричний аналіз природно-аквального комплексу озера. Потенціал водних ресурсів оз. Тучне становить 827,0 тис. м^3. Запаси сапропелю за категорією А – 914 тис. м^3, а в перерахунку на умовну 60,0% вологість – 155,0 тис. тон. Видовий склад сапропелю представлений зоогенним, органо-залізистим та органо-вапняковим видами. Загальний запас сапропелю в озерній улоговині становить 52,5% від її об'єму. Водойма є перспективною для видобування сапропелю з огляду на його якісні характеристики, а також гідротехнічні передумови щодо експлуатації. Видобутий сапропель можна використовувати в аграрному секторі, медицині, рекреації тощо. Реалізація цього завдання дозволить оздоровити геоекологічний стан озера та покращити якість його водних ресурсів.

Ключові слова: геоекологічний аналіз, озеро, батиметрія, ландшафтна карта, складне акваурочище, сапропель.

Introduction

The administrative and territorial reform in Ukraine, which began in 2015, opened up prospects for newly created territorial communities (TC) through the determination of the resource potential of controlled local territories and the development of strategies for balanced nature use and progressive development of territorial communities. An important place in the Polissia region of Ukraine is occupied by lakes, which have a significant potential for sapropel resources. Because of the above, there is a need for a comprehensive study of lakes and the development of recommendations for the rational use and protection of their water and sapropel resources. Today, many lakes (Shatski Lakes, Zgoranski Lakes, Ozerianski Lakes, Ostrivski Lakes, Lakes Brono, Doshne, Luka, Orihivske, Richytske, Sviate, Bile, Somyne, Radozhychs, Turske, Chyste, and others) of the Polissia region are part of the nature reserve fund (NRF) of Ukraine. They perform landscape-hydrological, water-accumulating, rarity-bioprotection, biostation, and aesthetic-landscape functions. In connection with the further silting of the shallow Polissia lakes, which are filled with sapropel deposits, a problem arises as to whether to leave such lakes as natural monuments with a predictable transformation into swamp areas or to carry out their restoration. A striking example of the restoration of a lake in Volyn is the extraction of sapropel from Lake Synove (Maniukhina, 2019), which made it possible to create additional jobs and provide the territorial community with organic and mineral fertilizers, and improve the ecological condition of the lake. The lakes, which are the subjects of the NRF, should not be used as potential deposits for the extraction of sapropel. They are under the authority and management of bodies and departments of the Ministry of Environmental Protection and Natural Resources of Ukraine, and the ban on issuing mining licenses is based on the Law on the Nature Reserve Fund of Ukraine (Law of Ukraine..., 1992). If these factors are taken into account, there will be no contradictions between the tasks of lake protection and sapropel extraction. From these positions, the research topic is relevant and requires the development of a regional comprehensive program for resource assessment of lakes and the selection of promising deposits for sapropel extraction.

The geo-ecological research on the substantiation of lake sapropel reserves of the Polissia region was carried out in line with the research topic of the Department of Ecology, Geography, and Tourism of Rivne State University of the Humanities "Ecological and geographic monitoring of the geo-systems of the Ukrainian Polissia in conditions of natural and anthropogenic transformations" (State registration number No 0119U000510).

The State Service on Geology and Mineral Resources of Ukraine keeps records of Lake Sapropel resources (Analysis of the State..., 2000; 2005). Prospective sapropel deposits are put up for auctions for the sale of special permits for mineral resources used by the mentioned service. Very often, local self-government bodies find out about this when the land areas have already been sold and the environmental impact assessment process is being discussed. The problems of assessing sapropel resources have recently been considered in the works of Ukrainian scientists, namely V. Konishchuk et al. (2015), O. Ilina & M. Pasichnyk (2016), O. Ilina et al. (2016), V. Martyniuk (2017), V. Martyniuk a & I. Zubkovych (2020), M. Pasichnyk et al. (2021), O. Demianiuk et al. (2022),

V. Khilchevskyi et al. (2022) and other scientists. Foreign publications on Lake Sapropel and its use are quite diverse. In works E. Baksiene et al. (2012), Z. Vincevica-Gaile et al. (2018), K. Stankevica et al. (2019), S. Murunga et al. (2020), P. Dmitriyev et al. (2023) the attention is focused on the practical use of lake sapropel in agriculture as a potential fertilizer for improving the quality of soil composition. It is noted that the removal of sapropel from the lakes will contribute to the restoration of their condition and functional properties. There is a positive experience in the restoration of lakes due to the extraction of sapropel in Ukraine (Shevchuk, 1996) and Latvia (Baksiene, 2015). Sometimes dredging work has short-term positive effects on the lake ecosystem (Jing et al., 2019). Therefore, concerning the restoration of lakes, most researchers support complex methods and technologies, including the mechanical extraction of sapropel sediments (Klapper, 2003; Alhamarna & Tandyrak, 2021; Sellergren et al., 2023). There is also growing interest in the use of sapropel resources in medicine, including cosmetology and peloid therapy (Strus et al. (2018); Baricz et al. (2021); Vanadziņš et al. (2022)). The works J. Kozlovska-Kedziora et al. (2011), K. Stankevica et al. (2012; 2015), M. Klavins et al. (2014), D. Vasiliu et al. (2020), A. Kostka & A. Le´sniak (2021), G. Ignatavičius et al. (2022), E. Skorbiłowicz et al. (2022) deal with the geo-ecological aspects of the bottom sediments of lakes, in particular the accumulation and migration of heavy metals in lake sapropel, to the assessment of the impact of anthropogenic factors on lake sediments.

At the same time, there are currently not enough studies that analyze not only the geo-component features of lakes promising for sapropel extraction, but also geo-complex aspects that involve the development of landscape maps of lakes and their catchment areas with details of the lithological composition and thickness of lake sediments at the level of aquafacies, and the structure of the land use of the lake-basin system (LBS) as a factor influencing water quality.

The purpose of the article is to reveal the geo-ecological features of the LBS and assess the resource potential of sapropel in Lake Tuchne (Volyn Polissia).

Materials and methods

The article is based on the author's field expedition research of landscape complexes (territorial and aquatic) of the upper Pripyat basin (Klestov et al., 2001; Kovalchuk & Khilchevskyi, 2003; Zubkovych & Martyniuk, 2020) and analysis of the materials of the Kyiv Geological Exploration Expedition (Kyiv GEE). When choosing the research methodology, we relied on works on limnology (Evans, 2021), landscape and limnology analysis of the LBS (Kovalchuk & Martyniuk, 2015; Kovalchuk et al., 2020), GIS mapping of the LBS (Kovalchuk, 2014) and geo-ecological assessment of the LBS (Martyniuk et al., 2023). The object of the research was Lake Tuchne, located in the Upper Prypyat physical-geographical district of Volyn Polissia (Fig. 1) and confined to swampy terrace depressions with sedge and grass-sphagnum bogs and meadows overgrown with

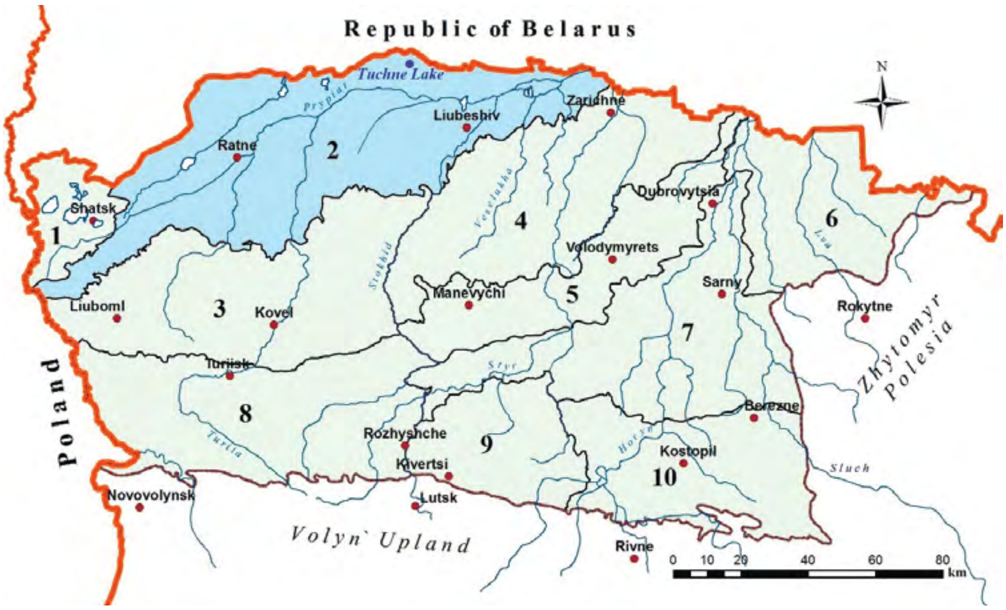


Fig. 1. Localization of Lake Tuchne in the scheme of physical and geographical zoning of Volyn Polissia.

Physiographic regions: 1 – Shatsk, 2 – Upper-Prypiat, 3 – Liuboml-Kovel, 4 – Lower-Styr, 5 – Manevychi-Volodymyrets, 6 – Lva-Horyn, 7 – Kolky-Sarny, 8 – Turiisk-Rozhyshche, 9 – Kivertsi-Tsuman, 10 – Kostopil-Berezne.

shrubs, on peat-swamp soils and peatlands, partially drained.

From the positions of departmental affiliation, the basin of Lake Tuchne is located on the lands of the "Liubeshiv forest and hunting enterprise" branch of the state-specialized enterprise "Forests of Ukraine" (Mukoshyn Forestry). Administratively, the lake is located in the northwestern part of the Liubeshiv territorial community of the Kamin-Kashyrskyi district of the Volyn region.

The lake partly also has a bio-stationary (as protection of animals, especially migratory birds) significance. Ducks (*Anas platyrhynchos*), coots (*Fulica atra*), gulls (*Vanellus vanellus*), and wild geese (*Anser anser*) nest here. Black stork (*Ciconia nigra*) is found in the catchment area; grey heron (*Ardea cinerea*) and white heron (*Ardea alba*) are found in the marsh areas. Beavers (*Castor*), otters (*Lutra*), and minks (*Lutreola*) live in the lake. Among the ichthyofauna, there is the common bream (*Abramis brama*), crucian carp (*Carassius*), perch (*Perca fluviatilis*), common roach (*Rutilus rutilus*), pike (*Esox lucius*), crayfish (*Astacidea*) (Ozero Tuchne, 2023). The experience of assessing the impact of sapropel extraction on lake ecosystems of various types and research on the processes of restoring their functioning after the completion of such a procedure (Shevchuk, 1996; Baksiene, 2015; Alhamarna & Tandyrak, 2021) give reason to be optimistic about the future of lakes suitable for sapropel extraction.

Results and analysis

The lake is close to an oval shape, stretched from south to north. The slopes of the lake basin are quite steep. The southern and western slopes of the reservoir basin are gentle. The shores of the lake are low, marshy, and peaty. The shoreline of the lake is slightly indented. The banks rise above the watermark by 0.1-0.2 m.

The width of the coastal terrace of the lake reaches 400-500 m. It is covered with verbose bushes, birch (*Bétula*), alder (*Alnus*), and pine (*Pinus L.*). Along the western shore, the surface is covered mainly with grassy vegetation (*Carex*) with alder and osier bushes. The catchment area, according to our estimates, is 10.05 km^2. The main canal from the north and the reclamation system from the southeastern side are the limiting factors for the allocation of the catchment area. Canals are connected to the lake from the southwest and northeast sides, but they are overgrown with bushes and do not function. During floods, the water level in the lake rises by 0.4-0.5 m, flooding the coastal terrace with water. No springs were found during field surveys of the coastal terrace. The main overflow of the lake during floods occurs in the southern direction.

In the structure of land areas of the catchment area, a significant share (76.0%) is occupied by forests, including swampy forests, 18.47% is occupied by swampy lands, mainly transitional and upland swamps, 3.86% is occupied by the lake, 0.68% – by roads, 0.77% – by hayfield lands, 0.23% – by melioration canals (Fig. 2). The area of the ecologically stabilizing lands (S_{ESL}) of the catchment area makes 995.0 hectares (99.0%), and of the anthropogenically transformed lands (S_{ATL}) – 10.0 hectares (1.0%). Thus, the indicator of the economic development of the catchment area, as the ratio of S_{ATL} and S_{ESL} is very low and makes 0.01.

The lake is fed mainly by precipitation and surface runoff. The surface area of the lake is 0.39 km^2. The length of the lake is 0.83 km, the maximum width is 0.60 km, and the average is 0.47 km. The maximum water depth is 4.7 m, and the average is 2.4 m. The depth in the reservoir gradually increases from the coast to the central part of the lakebed (Fig. 3).

The length of the coastline is 2.33 km. The volume of water masses of the lake is 827.0 thousand m^3. Coefficients and other morphometric and hydrological parameters of the lake-catchment area system are presented in Table 1.

Table 1. Morphometric and hydrological characteristics of Lake Tuchne

*F, km^2	$H_{abs.}$, m	$h_{mid.}$, m	$h_{max.}$, m	L, km	$W_{max.}$, km	$W_{mid.}$, km	l, km	$C_{l.}$	$C_{len.}$
0.388	144.9	2.4	4.7	0.830	0.596	0.467	2.331	0.596	1.777
$C_{cap.}$	$C_{op.}$	$C_{dep.}$	V_{lake}, thousand m^3	A	ΔS, km^2	$W_{influx.}$**, thousand m^3	$a_{wat.}$	$\Delta_{awat.}$, mm	$A_{layer.}$ mm
0.511	0.162	3.292	827.0	0.039	25.902	1267.7	0.153	0.652	82.3

*Area (*F*); absolute height of the water level ($H_{abs.}$); maximum ($h_{max.}$) and average depth ($h_{mid.}$); length (*L*); maximum ($W_{max.}$) and average ($W_{mid.}$) width; length of the shoreline (*l*); coefficients: of shoreline unevenness ($C_{l.}$); of the lake lengthening ($C_{len.}$); of capacity ($C_{cap.}$); of openness ($C_{op.}$); of depth ($C_{dep.}$); lake volume (V_{lake}); area index (*A*); specific catchment (*ΔS*); volume of inflow water from the catchment (W_{influx}); conditional water exchange ($a_{wat.}$); specific water exchange ($\Delta a_{wat.}$); water storage level on the catchment surface (A_{layer}). **The average annual runoff module, dm^3/s*km^2 – 4.0.

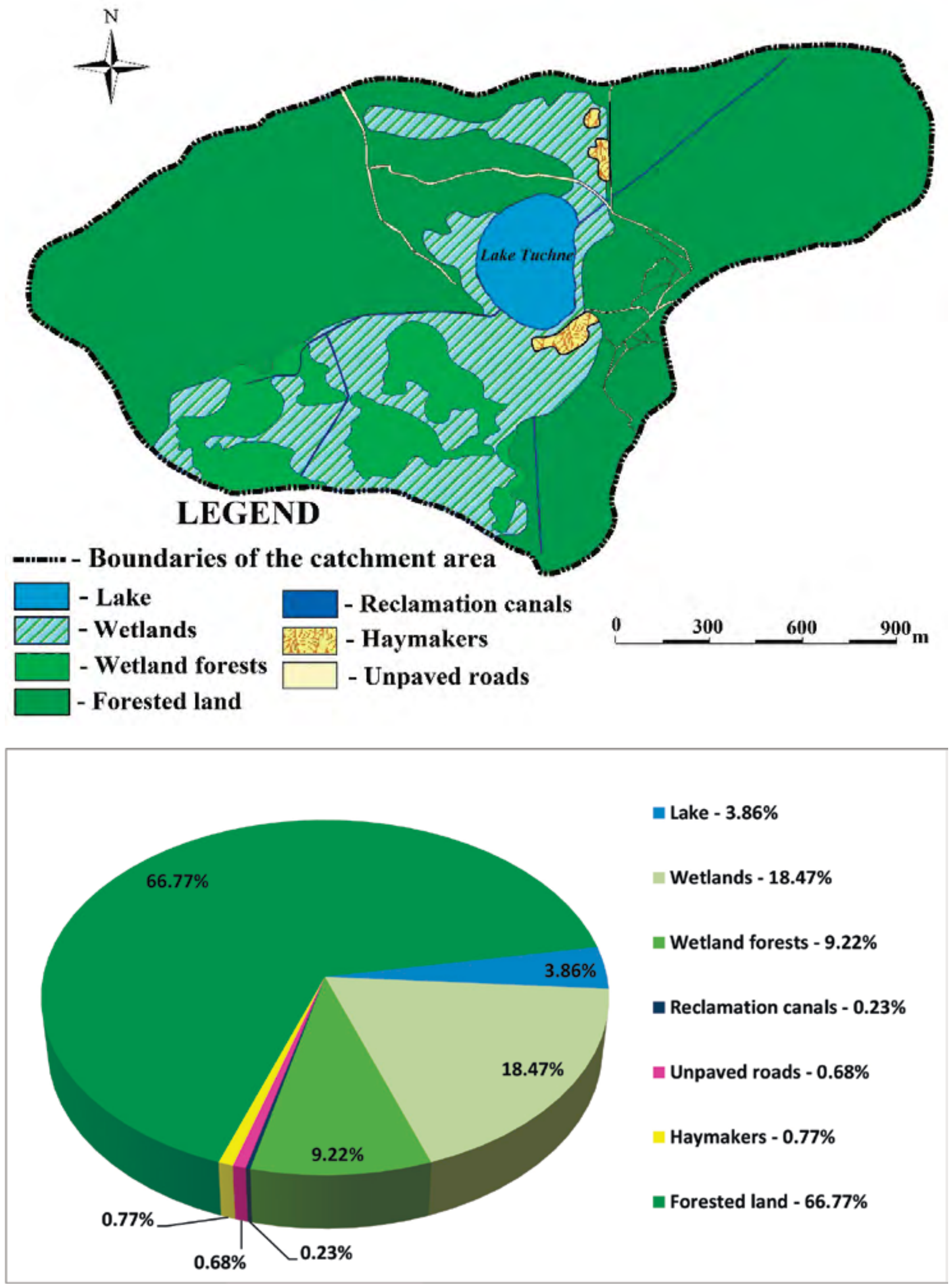


Fig. 2. Land structure model of the Lake Tuchne basin

Above-water vegetation in the lake is developed in a strip with a width of 20.0-100.0 m along the shore and is mainly represented by *Typha*, *Phragmites,* and *Júncus*. There is no surface vegetation along the southern shore of the lake. The overgrowth of the water surface of the lake is about 10.0%. Among plants with floating leaves, *Nymphaea alba* and *Nuphar lutea* are common. They are found in the strip of surface vegetation. The underwater vegetation is represented mainly by *Elodea*, *Stratiotes aloides*, and *Callitriche hermaphroditica*. The underwater vegetation does not have continuous planar development. The percentage of bottom overgrowth with underwater vegetation is 30.0-35.0%.

Using the *EO Browser* resource, we determined the vegetation index (*NDVI*) for the reservoir and its dynamics over the past five years. It varies from -0.53 (December 2, 2021) to +0.48 (July 15, 2021). As a rule, the growth of the *NDVI* indicator has a clear dependence on the temperature factor and the anticyclone type of weather conditions in the warm season of the year (Fesiuk et al., 2022). The dynamic series of space images of the lake obtained at cloud cover of 0-10% with *NDVI* is shown in Fig. 4.

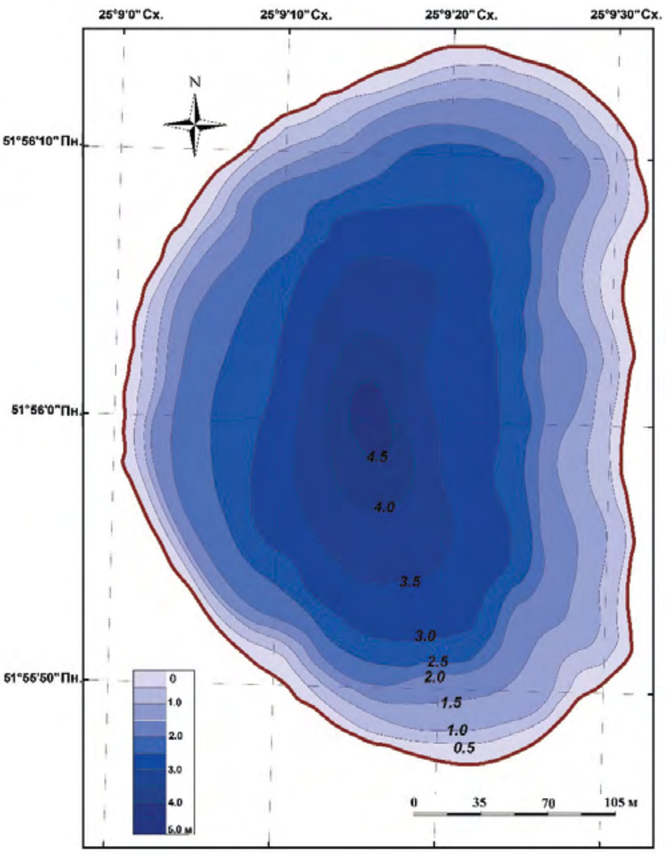


Fig. 3. Bathymetric map of Lake Tuchne

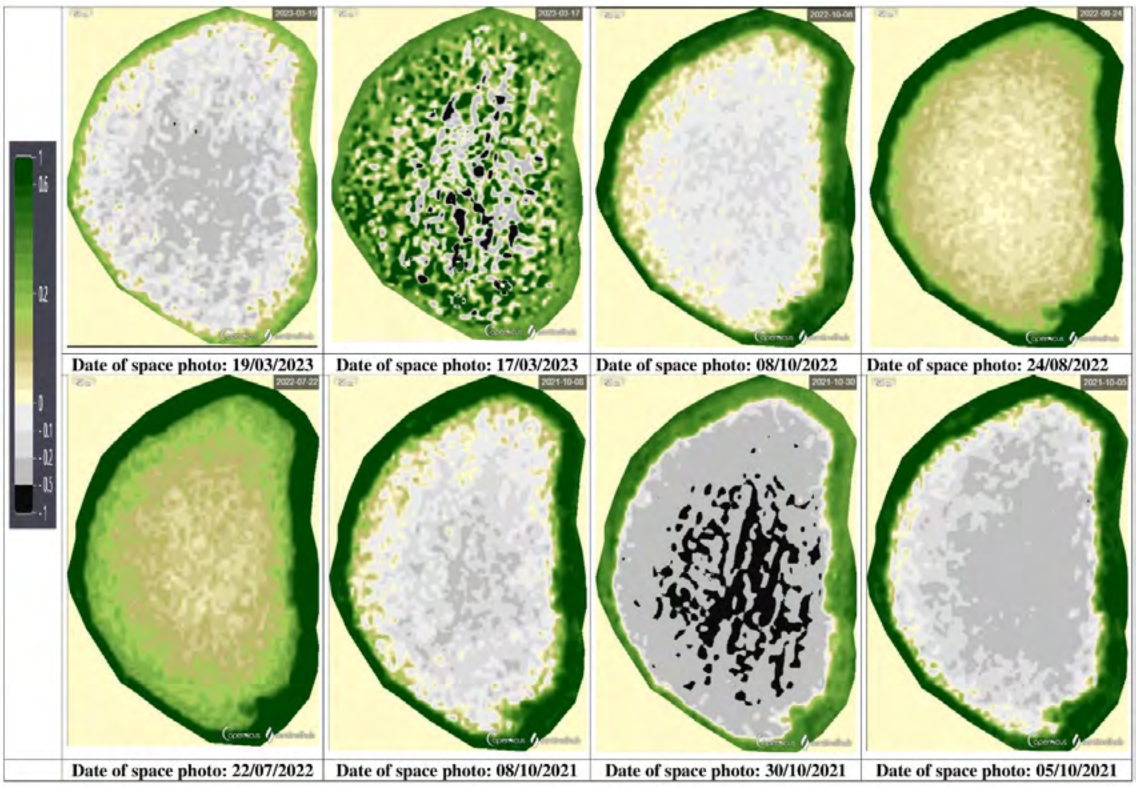


Fig. 4. A dynamic series of space images of Lake Tuchne (2021-2023) according to the NDVI indicator (built using the *EO Browser* platform)

We discovered that the activation of vegetation processes in the reservoir was clearly manifested on March 17, 2023. Other space photographs show that the peripheral part of the lake has a green color with various shades. This indicates a high degree of phytomass increase in the littoral shallow (0.5-1.5 m) zone of the lake. The modern view of the lake is shown in the photo (Fig. 5).

The bottom sediments of the lake are represented by sand and sand mud fractions, peat, and sapropel. Sapropel deposits are observed only within the lake basin, in particular in its central part. The area of sapropel, according to the Kyiv GEE, is 20.5 ha, the average thickness is 4.46 m, and the maximum is 10.0 m (Fig. 6).

Fig. 5. The water area of Lake Tuchne, in the background a belt of macrophytes (Ozero Tuchne, 2023)

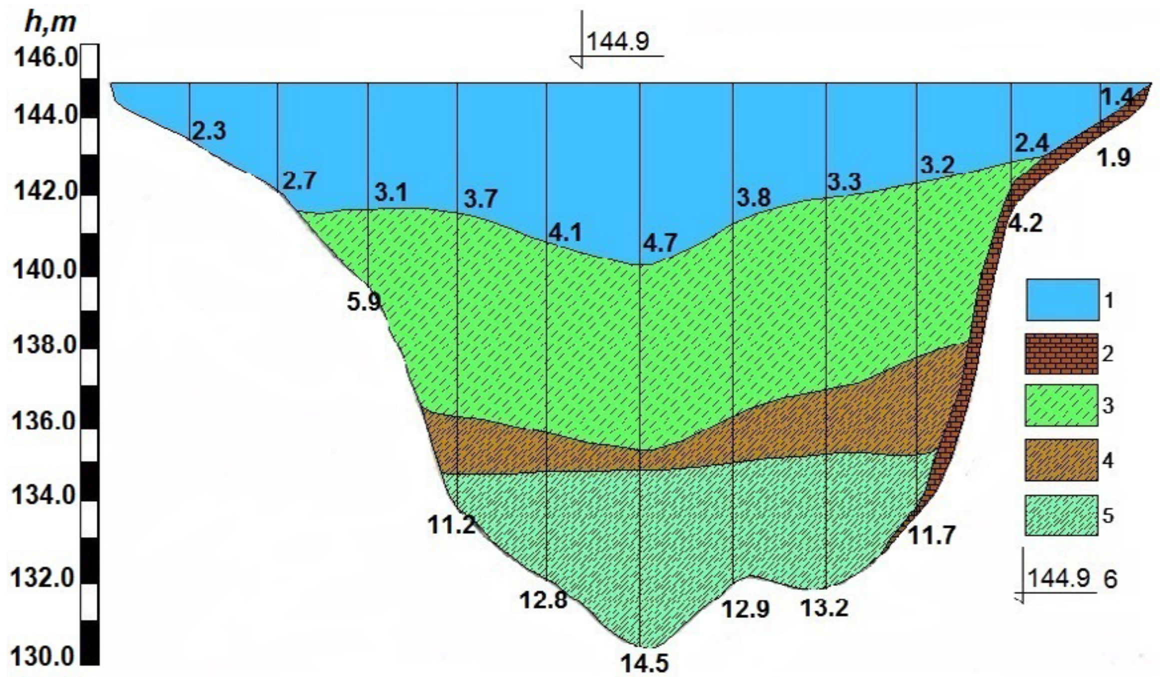


Fig. 6. Stratigraphic section of Lake Tuchne (built by us using the materials of the Kyiv GEE)

Symbols: 1. – water, 2. – peat; sapropel: 3 – zoogenic, 4 – organo-ferruginous, 5 – organo-limestone.

Water cut above sea level (according to the Baltic system of heights) – 144.9 m.

The thickness of the pelogen (sapropel upper layer) is 0.2-0.5 m. Sapropel reserves of category A amount to 914,000 m^3, and based on a conditional 60.0% humidity make 155 thousand tons. Within the basin of Lake Tuchne, the following types of sapropel are widespread: zoogenic, organic-ferrous, and organic-limestone. The zoogenic type of sapropel is limited to the upper part of the section; it covers an area of 20.5 hectares. The maximum thickness of deposits is 8.2 m, and the average is 3.05 m. The sapropel reserves of category A reach 623.3 thousand m^3, and based on a conditional 60.0% humidity make 90.9 thousand tons.

Organic-ferrous sapropel deposits are widespread in the central part, occupying an area of 10.4 ha. They lie at a depth of 7.0-11.5 m under zoogenic deposits. Their maximum thickness is 2.5 m, and the average is 1.24 m. The reserves of organic-ferrous sapropel deposits of category A make 129,000 m^3, and based on a conditional 60.0% humidity make 22.7 thousand tons.

The organic-limestone type of sapropel is found in the central part of the lake basin, on a total area of 10.1 ha. It lies in the lower part of the bottom sediments, under the organic-ferrous deposits of sapropel at a depth of 5.3-12.6 m. The maximum thickness of this layer is 4.5 m, and the average is 1.43 m. The reserves of category A make 144.4 thousand m^3, and based on a conditional 60.0% humidity make 28.5 thousand tons (Vasylenko, 1982).

The analysis of the properties of sapropel samples taken from one of the points of the lake shows that its ash content varies between 17.5-37.5% (on dry matter). The content of Fe_2O_3 (on dry matter) ranges from 2.53% до 7.26%. The distribution of CaO compounds in the samples ranges from 2.09 to 8.12%. The content of CO_2 varies from 1.97 to 9.72%. The concentration of P_2O_5 in sapropel samples varies from 0.19 to 0.53%. The distribution of S_{gen} in sapropel deposits ranges from 0.23 to 1.09%. The distribution of pH (salt extract) in samples varies from moderately alkaline (7.63) to close to neutral – 5.97 (Vasylenko, 1982) (Fig. 7).

The results of geo-component studies, which are given above, became a prerequisite for the landscape analysis of the lake as a natural aquatic complex (NAC). According to the methodology (Kovalchuk & Martyniuk, 2015), the lake is considered a NAC of the rank of a complex aquatic tract. In the NAC of Lake Tuchne, based on the obtained results of bathymetry, the composition and thickness of bottom sediments, the species diversity of plant communities, and the temperature regime of water in the warm season of the year (April 15-October 15), we distinguished two aquatic sub-tracts and some aquafacies (Fig. 8).

I. Littoral aquatic subtract on peat, swamp, sandy-silty, and sapropel deposits formed on alluvial sands with species diversity of surface and underwater vegetation.

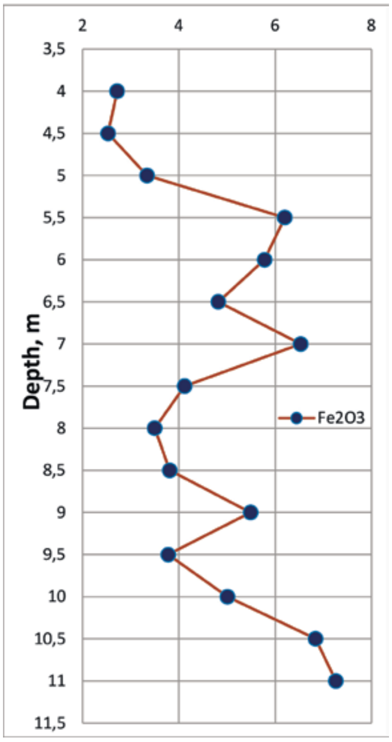
Aquafacies: **1.1.** Littoral, abrasion-accumulative, peat-swamp of a low thickness (0.4-0.6 m), *Juncus-Typha-Phragmites*, without temperature stratification. **1.2.** Littoral, accumulative-transit, muddy, and sandy-muddy of a low thickness (0.5-0.8 m), *Stratiotes aloides-Callitriche-Elodea, and locally Nymphaeaceae, without temperature stratification.* **1.3.** Littoral, transit-accumulative, zoogenous-sapropel of low and medium thickness (0.8-3.0 m), *Elodea-Potamogeton, without temperature stratification.*

II. Sublittoral-profundal aquatic subtract on sapropel deposits underlain by alluvial sands with an impoverished species diversity of underwater vegetation.

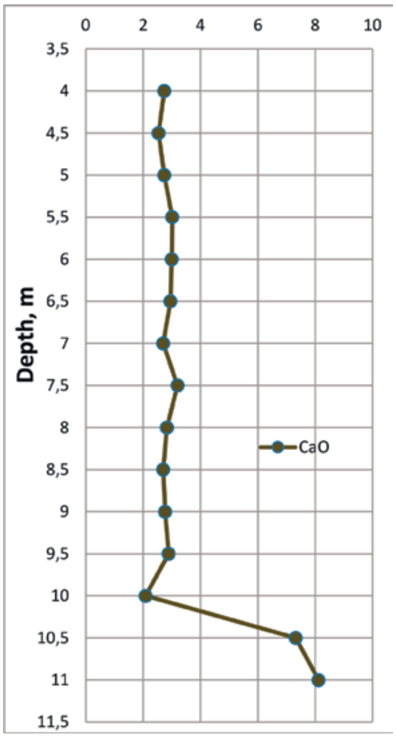
Aquafacies: **2.1.** Sublittoral, accumulative-transit, zoogenic-organic-ferrous, underlain by organic-limestone sapropel, of medium thickness (3.0-5.0 m), *Filamentous-Chara*, without temperature stratification. **2.2.** Profundal, accumulative zoogenous-organic-ferrous, underlain by organic-limestone sapropel, thick (5.0-6.0 m) and very thick (over 8.0 m), free-floating algae, with a heterogeneous temperature regime.

The performed morphometric and analytical research on the lake made it possible to obtain the following characteristics of the lake (Table 2). The largest area (71.86%) is occupied by the littoral aquatic subtract with three types of aquafacies. The area of the sublittoral-profundal aquatic subtract is insignificant and makes 28.14%; it has two types of aquafacies and occupies the central-western part of the lakebed. The average area of the NAC species is 7.76 hectares, the fragmentation index is 0.13, the complexity coefficient is 0.64, and the landscape fragmentation coefficient is 0.80.

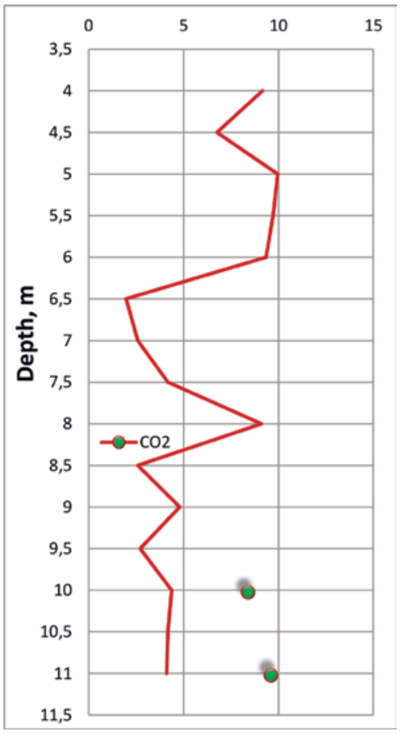
This reflects the general mosaic character of the NAC landscape structure. According to the number of landscape contours (5 pieces), the NAC is a weakly differentiated natural formation. The fragmentation index, which is the ratio of the number of landscape features to the area of the lake, indicates that the NAC is not highly fragmented. This index depends on the variety of the aqua complex and its area. The complexity coefficient takes into account the ratio of all NAC contours to their average total area. Since within the NAC of Lake Tuchne, there is a small number of relatively small contours, the calculated index does not exceed 1.0. The coefficient of landscape fragmentation indicates how the average total area of all con-



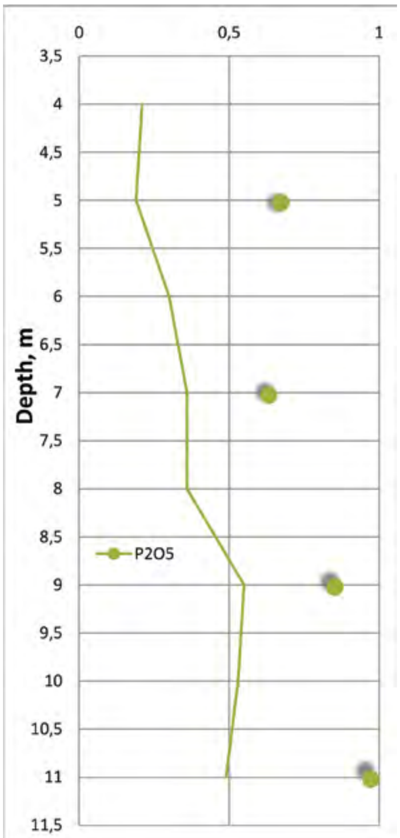
Distribution of Fe_2O_3 (% on a dry-matter basis) in bottom sediments



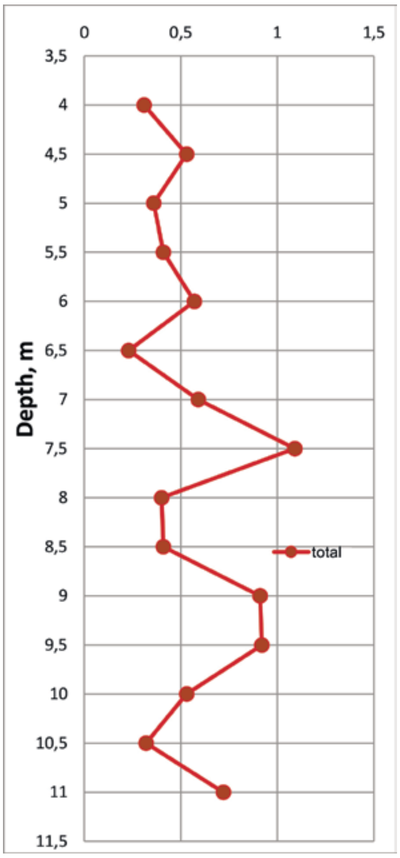
Distribution of CaO (% on a dry-matter basis) in bottom sediments



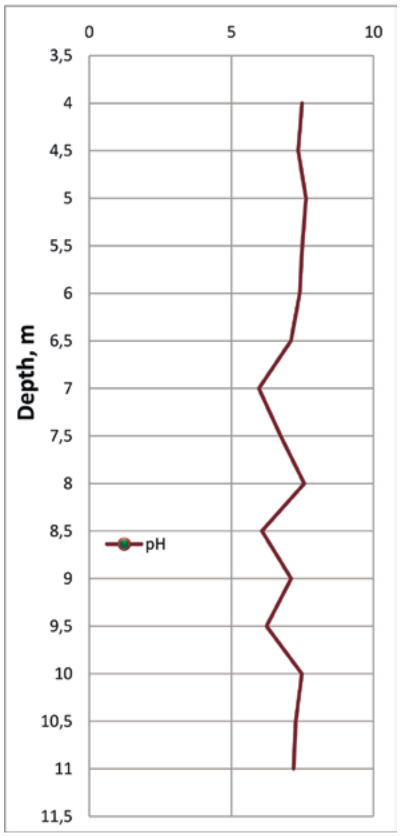
Distribution of CO_2 by content CaO 8% (% on a dry-matter basis) in bottom sediments



Distribution of P_2O_5 (% on a dry-matter basis) in bottom sediments



Distribution of S_{total} (% on a dry-matter basis) in bottom sediments



pH distribution (salt extraction) in bottom sediments

Fig. 7. Distribution of chemical elements (compounds) and pH in the bottom sediment profile of Lake Tuchne (the graphs are based on the data of the Kyiv GEE)

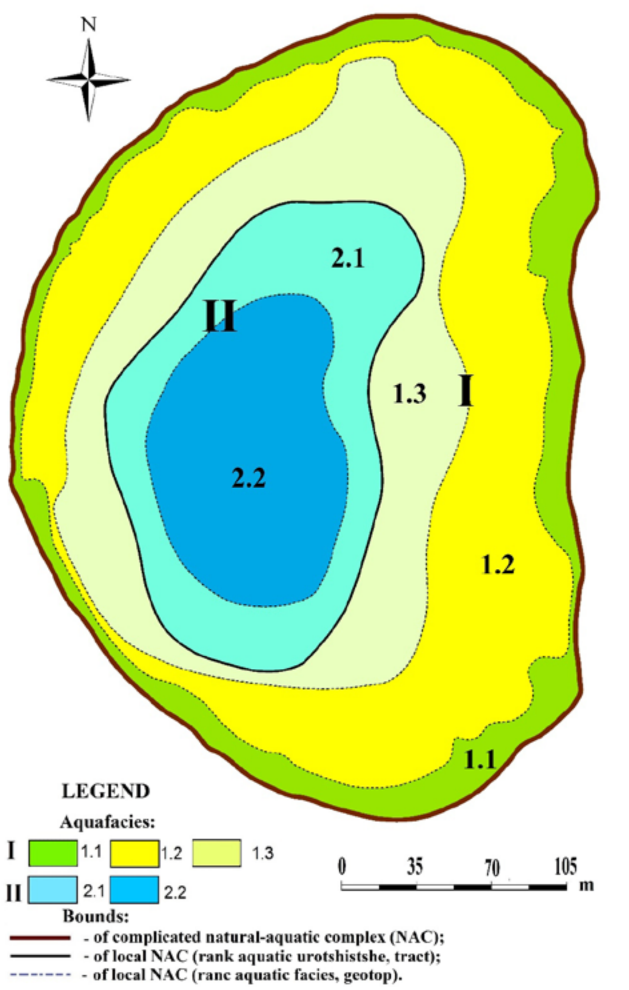


Fig. 8. Landscape structure of the natural-aquatic complex of Lake Tuchne

tours fragments the NAC of the lake. This coefficient will be significant if the average area of the NAC contours has higher values. With a small area, which is typical for this NAC, this coefficient is insignificant. In general, high indicators of the mosaic character of the landscape structure of Lake NAC indicate the variegation of bottom sediments, primarily of sapropel, and the influence of changes in paleo-climatic conditions on sedimentation processes.

Scientific studies (Shevchuk, 1996; Pasichnyk et al., 2021) show that the following features are characteristic of the lakes with significant layers of sapropel: 1) these lakes, as a rule, are shallow, therefore, in the conditions of global and regional climate changes, their water masses are strongly heated, evaporation and eutrophication processes in them increase, the quality of water resources deteriorates; 2) the recreational value of such lakes is low due to the presence of muddy sediments and overgrowth of shallow water areas with hygrophilous vegetation; 3) the trajectory of the development of such lakes without human intervention (extraction of sapropel, cleaning of hydrophytes, prevention of water bloom, etc.) leads to a gradual transformation into a swamp. It is possible not to prevent the natural transformation of lakes into swamp ecosystems, but global climate changes accelerate the landscape-successional changes of the NAC. The research of S. Ivaniuta et al. (2020) shows that the average annual temperature in Ukraine since the beginning of the 20th century has increased by more than 2 °C, and over the past 30 years – by 1.2 °C. If such rates of increase in average temperatures continue, then the problem of the formation of local reservoirs of fresh drinking water will become acute. Lakes may become the source of drinking water.

In connection with the danger of the active development of such processes, extracting sapropel from lakes of this type, increasing their depth, reducing the degree of heating of water masses, slowing down eutrophication processes, and improving the quality of surface waters will contribute to the preservation

Table 2. The complexity of the NAC territorial structure of Lake Tuchne

NAC type		Area (*S*) of NAC type, ha		% of the type area from the total area		No. of units of facies within NAC	% of the total number	The mean area of the facies (ha)	*The index of the fractionality of landscape contours	*Index of landscape complexity	*The index of landscape fragmentation
Sub-tract	Aqua-facies	Sub-tract	Aqua-facies	Sub-tract	Aqua-facies						
I		27.89		71.86		3	60.0	9.30	0.11	0.32	0.67
	1.1		5.56		14.33						
	1.2		13.43		34.60						
	1.3		8.9		22.93						
II		10.92		28.14		2	40.0	5.46	0.18	0.37	0.50
	2.1		5.78		14.90						
	2.2		5.14		13.24						
Усього		38.81	38.81	100.0	100.0	5	100.0	7.76	0.13	0.64	0.80

*Indices and coefficients were calculated according to the formulas proposed by A. Domaranskyi (2006) of Polissia lakes and their water resources, which has already been proven by examples of other lakes of Polissia (Shevchuk, 1996).

Today, various sapropel extraction technologies are available, including hydraulic, mechanical, and pneumatic (Tsiz et al., 2017). Each of them has its advantages and disadvantages, depending on the geomorphological structure of the lake basin, the depth of the water mass, and the strength of sapropel deposits, landscape, and geographical features of the catchment area. It is also important to create a suitable access road for the removal of sapropel, which will further promote the development of tourism. For the lake (or a potential deposit of sapropel), a perfect ecological-technical-economic rationale for its exploitation and recommendations for the use of the most optimal technology for the extraction of organic-mineral raw materials should be developed.

Conclusions

1. The performed bathymetric studies established that the potential of Lake Tuchne water resources is 827.0 thousand m^3. The area of the lake occupied by sapropel is 52.8%. The reserves of sapropel of category A amount to 914,000 m^3, and based on a conditional 60.0% humidity make 155 thousand tons. The composition of sapropel is represented by zoogenic, organic-ferrous, and organic-limestone types. The total stock of sapropel in the lake basin makes up 52.5% of its volume.

2. The construction of reclamation systems affected the violation of the hydrological regime of the lake: a) the main canal, which was built in the northern sector of the lake, actually cut the geomorphological configuration of the natural catchment area, where the relative height differences are 0.4-0.9 m, which led to the interception of surface runoff into the reservoir and its diversion into the Zhyrivskyi canal, which is located on the border with Belarus; b) the limiting factor of the surface runoff was the construction of a reclamation system in the southeastern sector of the lake, which today draws the surface runoff into the main canal that carries water to the state border; c) reclamation systems and their functioning led to the limitation of the area and changes in the geomorphological configuration of the catchment area and transformed the surface runoff to the lake. There are no residential complexes within the catchment area. Regarding land use, ecologically stabilizing lands (forests and swamps) prevail here. The rate of economic development of the catchment area is very low (0.01). As a result of global climate changes, the littoral aquatic subtract is undergoing natural transformations, as evidenced by the increase in phytomass (according to the vegetation index). Aquafacies 1.1 of the NAC with depths of up to 0.5 m are transformed over time into near-terrace catchment area complexes. Today, the lake is used as an object of recreational fishing.

3. The reservoir is promising for the extraction of sapropel due to its qualitative characteristics, as well as favorable hydrological conditions for the operation of the deposit (the average depth of the reservoir is 2.4 m). Sapropel is valuable as an organic mineral fertilizer, especially if proper drying and composting technologies are used. Applying bio-sapropel fertilizers to the podzolic soils of the Ukrainian Polissia will stabilize their acid-alkaline balance, enrich them with important elements (calcium, phosphorus, ferrum) and microelements (cobalt, manganese, copper, boron, molybdenum, zinc, iodine, etc.) and will help increase the productivity of agricultural crops. The extracted sapropel can also be used in other fields, including medicine, recreation, animal husbandry, etc. The implementation of this task will improve the geo-ecological condition of the lake and improve the quality of its water resources.

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