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JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.141571
2022, No. 54 (VII–IX): 184–193

Hydrography, hydrochemistry and composition of sapropel of Shatsk Lakes

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RECEIVED 27.01.2021 ACCEPTED 05.11.2021 AVAILABLE ONLINE 28.09.2022

Abstract: The purpose of the study presented in the article is to implement modern hydrographic characteristics of freshwater of the Shatsk Lakes (28 lakes in Volyn Polissya, Ukraine) by typing water bodies according to the requirements of the EU Water Framework Directive, assessment of the chemical composition of lake water and bottom sediments (sapropel), determination of the opportunity for their recreational use in the special status of the district as a national park. Despite the presence of the two large lakes (Svityaz – 26.2 km^2 and Pulemetske – 15.5 km^2), very small lakes with a water surface area of less than 0.5 km^2 (64%) are dominating in the Shatsk group. Mineralisation of calcium-hydrocarbonate lake waters is 115–303 mg·dm^{-3} and calcium-sulphate aqueous extract of sapropel is – 318–1451 mg·dm^{-3}. Using a Piper diagram, it was found that there is genetic homogeneity between surface and groundwater, indicating a significant share of groundwater in the water supply of lakes. There are eight species of sapropel deposits in 19 lakes of the district. A wide range of chemical composition and physical and mechanical properties of sapropel deposits of the Shatsk Lakes allow us to consider them as an important resource for agriculture and industry. We found that sapropel from Shatsk Lakes meets the requirements for therapeutic mud and can be used for therapeutic and health purposes.

Keywords: bottom sediments, lake, sapropel, Shatsk Lakes

INTRODUCTION

Shatsk freshwater lakes, which are located in the basin of the Western Bug, near the Atlantic–Black Sea watershed, have a karst origin and are a unique natural complex of Volyn Polissya in Ukraine. Most of the lakes are located in the Shatsk National Nature Park (Ukraine – Shats'kyy natsional'nyy pryrodnyy park) (Ukraine – Shats'kyy natsional'nyy pryrodnyy park), which is part of the transboundary biosphere reserve "West Polesie", which was established in 2012 and also includes Polesie National Park (Poland – Poleski Park Narodowy) and the State Reserve "Pribuzhskoe Polesie" (Belarus – landshaftny zakaznik respublikanskaha znachennya "Prybuhskaye Palyessye").

Detailed studies of the geomorphology and hydrology of the Shatsk Lakes were first conducted by Polish scientists in the 1930s [Lencewicz 1931; Rühle 1935]. One of the first studies of the chemical composition of the water of the Shatsk Lakes was related to the construction of the Kopaivka drainage system in the 1970s (the Kopaivka River is a right tributary of the Western Bug). Comprehensive hydrochemical studies of various types of natural waters of the Shatsk natural subregion for the first time were conducted in 1975 (lakes Svityaz, Pulemetske, Pisochne, Lucymer, Luky, Peremut; drainage waters of reclamation canals; groundwater of the Quaternary and Cretaceous horizons) [Peleshenko *et al.* 1978]. At the same time, hydroecological studies of lakes began [Polishhuk *et al.* 1977]. In 1983 the Shatsk National Nature Park was established, comprehensive monitoring and research of lakes were organised [Choiński *et al.* 2012; Fesyuk 2020; Ilyin 2002; Ilyin *et al.* 2010; Khomik 2013; Morozova 2006; Timchenko *et al.* 1994; Zabokrytska *et al.* 2006]. It should be noted that the study of Holocene lakes is relevant among scientists from other countries [Choiński *et al.* 2016; Dawidek *et al.* 2013; Grochowska *et al.* 2019; Vlasov, Szczypek 2020; Wolanin *et al.* 2016].

Along with hydroecological studies in the area of Shatsk Lakes in 1980–1994, the Geological Survey of Ukraine invest-

igated sapropel deposits, too [GEOINFORM 1994]. There were found 11.7622 mln t of sapropel, mainly of organic species (17.7% of the all Ukrainian reserves) in 19 lakes of the Shatsk group. It should be noted that in the 2000s in many countries that have stocks of sapropel, the research on this topic intensified. In particular, in Russia [Strakhovenko 2014], Belarus [Kurzo *et al.* 2017], and Latvia [Stankevica *et al.* 2016]. Poland has also shown some interest [Trojanowski, Antonowicz 2005; Wójcikowska-Kapusta *et al.* 2018].

The ecosystems of the Shatsk Lakes are one of the best-preserved of the plains of Eastern Europe. Due to the lack of significant industrial facilities in the region, large lakes maintain good water quality. Therefore, this area has significant recreational potential, primarily due to the presence of water bodies. Intensive recreational use of lakes lasts for a short period of time (June–August), which allows for the self-restoration of lake ecosystems.

At the same time, almost all small lakes are significantly filled with sapropel deposits (up to 90% of the lake volume). These lakes are at the stage of waterlogging and may disappear if no measures are taken to mechanically clean them [Ilyin, Pasichnyk 2019; Khilchevskyi *et al.* 2021b]. Controlled extraction of sapropel deposits could restore the hydrological regime of the lakes, while the sapropel resource could be directed to expand recreational services in recreation facilities in the region and beyond.

The purpose of the study is to carry out modern hydrographic characteristics of the Shatsk Lakes in accordance with the requirements of the EU Water Framework Directive [Directive 2000/60/EC], to assess the chemical composition of the lake water and bottom sediments (sapropel), to determine their recreational use in the special status of the area as a national park.

MATERIALS AND METHODS

STUDY AREA

The territory of the Shatsk Lakeland is located in the interfluve of the Western Bug and the Pripet in the wetlands of the upper Pripet lowland (Fig. 1). Administratively, it is the territory of the Shatsk district of the Volyn Region, Ukraine. Among the native rocks, chalk and marl of the Upper Cretaceous age predominate, which predetermines the intensive development of karst. This is also facilitated by heavy rainfall and groundwater, which circulate through the cracks and form numerous rising springs in the lakes.

The Shatsk Lakeland consists of 28 lakes with a total area of about 61.56 km^2 and a water mass of 312.8 mln m^3. Of these, 23 lakes are part of the Shatsk National Nature Park.

MATERIALS REQUIRED AND DATA COLLECTION

The research used the stock materials of the regional Office of water resources of the Volyn Region (2019), State Information Geological Fund of Ukraine (1986–2014), Shatsk National Nature Park (2020), and the results of own expeditionary research on the Shatsk Lakes during 2016–2019.

The information was processed in three directions: hydrography of lakes, hydrochemistry of lakes, composition, and properties of sapropel (Fig. 2). To assess the hydrographic

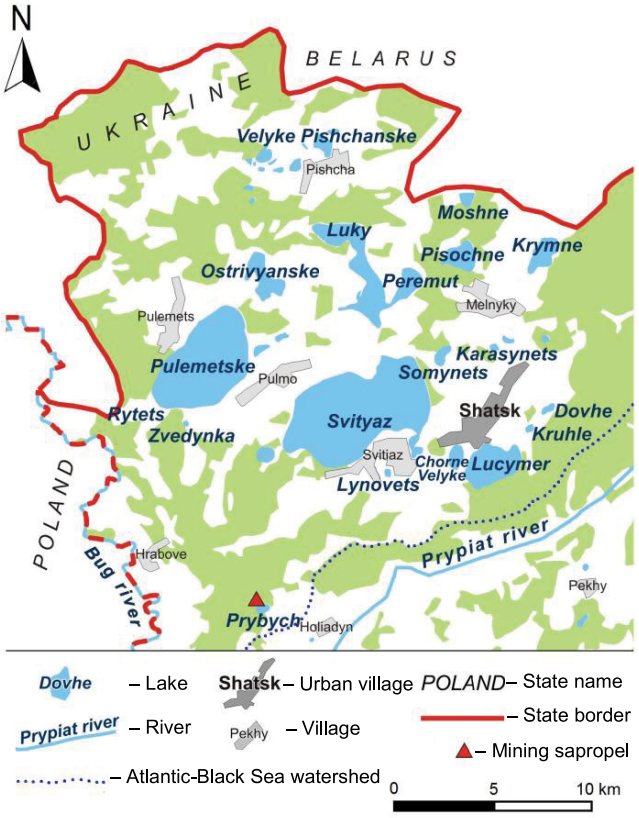

Fig. 1. Location map of the Shatsk Lakes basin in the Volyn Region of Ukraine; source: own elaboration

features of the territory, the morphometric parameters of the lakes were used – area, volume, length, width, average depth, maximum depth. Typification of Shatsk Lakes was carried out in accordance with the requirements of the Water Framework Directive of the European Union [Directive 2000/60/EC], adapted to the conditions of Ukraine [Metodyka ... 2019].

The chemical composition of the water in the lakes was studied according to the pH values, the concentrations of O_2, CO_2, iron, and nitrogen compounds. The concentrations of the main ions (HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, $Na^+ + K^+$) and the total mineralisation of water were also investigated. To determine the chemical components in water, the methods were used according to the reference book [Nabyvanets *et al.* 2007]. To elucidate the genetic connection, we compiled a Piper diagram.

The mineral composition of sapropel was studied using materials from the State Information Geological Fund of Ukraine [GEOINFORM 1994]. Physico-chemical, sanitary and epidemiological analysis of bottom sediments in the samples we took was carried out in the laboratory of soil microbiology of the Volyn branch of the Institute for Soil Protection of Ukraine (Lutsk) [DKZ 2004].

RESULTS AND DISCUSSION

HYDROGRAPHY OF THE SHATSK LAKES

The area of lakes ranges from 0.01 to 26.21 km^2. The typification of the Shatsk lakes by the area of the water mirror according to the requirements of the Water Framework Directive of the European Union (EU WFD) [Directive 2000/60/EC] showed that

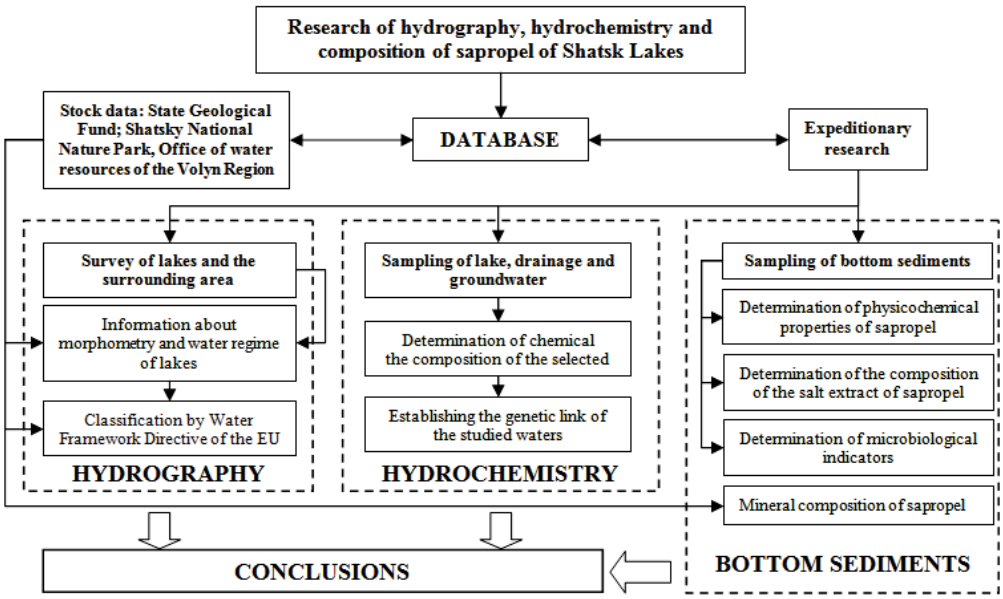

Fig. 2. Flowchart of methodological framework; source: own elaboration

there are 2 large lakes (Svityaz and Pulemetske), 6 – medium, 2 – small, 18 – very small. So very small lakes make up 64% (Tab. 1). While in the basin of the Western Bug in Ukraine very small lakes make up 71% [Khilchevskiy *et al.* 2019]. According to the EU WFD, only two types of lakes are distinguished in the Shatsk group in terms of average depth: medium depth (3–15 m) – 14% of lakes; shallow (<3 m) – 86% of lakes [Khilchevskyi *et al.* 2021a].

The complete typification of Shatsk Lakes, according to Metodyka ... [2019], Khilchevskyi and Zabokrytska [2020], was made and it allowed to distinguish 5 types of lakes by hydrographic features: 1) large lakes in lowland, medium depth, siliceous (Svityaz, Pulemetske); 2) medium lakes in lowland, medium depth, siliceous (Lucymer, Pisochne); 3) medium lakes in lowland, shallow in depth, siliceous (Luky, Ostrivyanske, Peremut, Krymne); 4) small lakes in lowland, shallow in depth, siliceous (Chorne Velyke, Velyke Pishchanske); 5) very small lakes in lowland, shallow in depth, siliceous (18 in total – Somynets, Chorne Male, Moshne, Prybych, Dovhe, Karasynets, Klymivske, Krugle, Ozertse, Lynovets, Gerasymove, Rytets, Zvedynka, Navrattya, Oleshno, Plotychche, Pyavochne, Male Pishchanske). Lakes Prybych, Gerasymove, Pyavochne, Velyke Pishchanske, and Male Pishchanske are located outside the Shatsk National Nature Park.

Table 1. Classification of the Shatsk Lakes by water surface

Type	Area of water (km^2)	Number of lakes	Share of total (%)
Large	10–100	2	7
Medium	1.0–10	6	22
Small	0.5–1.0	2	7
Very small	<0.5	18	64
Total	–	28	100

Source: own elaboration using the data from Water Framework Directive of the European Union [Directive 2000/60/EC].

The largest and deepest lakes are Svityaz (maximum depth is 58.4 m, according to some data – 60.6 m [Choiński *et al.* 2012]) and Pulemetske (19.2 m). With some exceptions, other lakes are shallow with flat bottoms and depths not exceeding 7 m (Tab. 2). The deepest lakes (Svityaz, Pulemetske, Pisochne) have narrow depressions in the basins, the depths of which reach 20–50 m. The bottom of the lakes is sandy and, in deep places, silted up. The shores are mostly low, swampy, and overgrown with vegetation.

The water level in lakes depends on the amount of precipitation and groundwater supply. The average long-term precipitation at the Svityaz meteorological station is 590 mm, with an amplitude of oscillations from 338 mm (1961) to 854 mm (1974). In 2018 the amount of precipitation at the Svityaz meteorological station was 586 mm, and in 2019 – 505 mm (Tab. 3). In Svityaz Lake the water level in 2018–2019 decreased by 35 cm.

In addition to the well-known large and medium-sized lakes, which attract the most vacationers, there are very small water bodies of the dystrophic type with an area of 0.01–0.18 km^2 (15 lakes). Over the last 90 years, their parameters have decreased by 2 times (shallowing, overgrowing). The lakes are in the process of extinction which requires the use of technical means to restore and maintain their sustainability. The share of such lakes is 50% (for example, Pyavochne, Ozertse, Navrattya, Krugle, Dovhe, Gerasymove, Klymivske, Male Pishchanske, etc.). They have already lost their natural state and recreational and tourist significance [Ilyin 2008]. It should be noted that in Ukraine, attention to the study of large and small bodies of water has been increasing in recent years [Khilchevskyi *et al.* 2020; 2022].

In addition, due to drainage reclamation in the region, against the background of which there is a partial shallowing of lakes and, accordingly, improving the growing conditions of hygrophyte and hydrophyte plants, the process of accumulation of bottom sediments is intensifying. Thus, in lakes Krugle, Ostrivyanske, Gerasimove, Zvedynka, Karasynets, Lynovets and others, the thickness of sediments reaches more than 5.0 m, and the water layer is only 1.0–2.0 m [Ilyin, Pasichnyk 2019].

Table 2. Morphometric characteristics of large, medium and small lakes of the Shatsk group

Lake	Water area (km^2)	Volume of water ($m^3 \cdot 10^3$)	Length	Width	Depth		Sapropel deposits
					average	maximum	
			km		m		
Svityaz	26.21	19070.0	7.81	3.36	6.9	58.4	2.5
Pulemetske	15.52	6363.2	6.06	2.56	4.1	19.2	2.3
Luky	6.42	4105.0	5.15	1.25	0.6	3.5	4.2
Lucymer	4.43	1949.2	3.10	1.43	3.4	11.0	4.2
Ostrivyanske	2.11	4853.0	2.42	0.87	1.6	3.8	4.3
Pisochne	1.86	1283.4	1.85	1.00	4.0	16.2	3.1
Peremut	1.47	323.4	1.89	0.78	1.4	6.7	3.0
Krymne	1.41	408.9	2.15	0.65	2.9	5.5	3.0
Chorne Velyke	0.84	169.7	1.36	0.62	1.8	4.8	3.5
Velyke Pishchanske	0.54	884.0	1.31	0.41	1.1	3.0	3.9

Source: own elaboration based on materials from GEOINFORM [1994] and Google Earth Pro.

Table 3. Value of precipitation, inflow from catchments, evaporation, and change of water reserves on lakes of the Shatsk group

Lake	1965–2017				2018				2019			
	x	*y*	*z*	*Δ*	*x*	*y*	*z*	*Δ*	*x*	*y*	*z*	*Δ*
	mm											
Svityaz	598	144	700	+42	586	97	820	−137	505	46	850	−299
Pulemetske		331	700	+229		222	820	−12		140	850	−205
Luky		0	700	−102		0	820	−234		0	850	−345
Lucymer		533	700	+421		357	820	+123		170	850	−175
Ostrivyanske		672	685	+585		450	805	+231		215	830	−110
Pisochne		143	650	+91		95	720	−94		45	790	−240
Krymne		3410	650	+3330		2180	800	+2066		1050	830	+725
Chorne Velyke		341	660	+279		230	785	+31		110	800	−185

Explanations: *x* = precipitation, *y* = inflow from catchments, *z* = evaporation, *Δ* = change of water reserves (*Δ* = *x* + *y* − *z*).
Source: own elaboration based on data of Shatsk National Natural Park.

CHEMICAL COMPOSITION OF WATER

Significant rainfall in the Shatsk Lakes region contributes to good soil leaching and relative depletion of mineral compounds in the surface waters that feed the lakes. The main feeding sources for the region's lakes are precipitation and groundwater.

Chemical composition of lake waters

The acidity of the water of the Shatsk Lakes is neutral with insignificant fluctuations (pH – 6.8–7.2). The water in large lakes is well saturated with oxygen (10.5–10.9 $mg \cdot dm^{-3}$), it has little carbon dioxide (0.3 $mg \cdot dm^{-3}$), and no iron in the form of Fe^{2+} (Tab. 4). The concentration of Fe^{3+} is 0.3 $mg \cdot dm^{-3}$, low ammonium (NH^+_4 – 0.1 $mg \cdot dm^{-3}$), nitrites (NO_2^- – 0.1 $mg \cdot dm^{-3}$) and nitrates (NO_3^- – 0.1 $mg \cdot dm^{-3}$). The main source of nitrogen and phosphorus in the lakes are agricultural lands due to the use of fertilisers [Khilchevskiy 1994] and in the lakes Lucymer and Chorne Velyke – the activities of the population (the use of orthophosphates in everyday life). In total, the highest load of nitrogen and phosphorus is observed in lakes Chorne Velyke and Lucymer [Sytnyk *et al.* 2006].

Table 4. Average annual concentrations of oxygen, carbon dioxide, nitrogen, and iron minerals in the surface layer of water of some Shatsk lakes (2018)

Lake	O_2	CO_2	NH_4^+	NO_2^-	NO_3^-	Fe^{2+}	Fe^{3+}
	$mg \cdot dm^{-3}$						
Svytyaz	10.5	0.3	0.1	0.01	1.7	0	0.3
Luky	11.0	0.3	0.1	0.01	1.3	0	0.3
Pisochne	10.9	0.3	0.1	0.01	1.3	0	0.3

Source: own study.

According to the main ions, the water of the lakes is calcium-hydrocarbonate with mineralisation in the range from 115 mg·dm^{-3} (Pisochne) to 303 mg·dm^{-3} (Chorne Velyke) – Table 5. In the water of Svityaz Lake mineralisation level occupies an intermediate position – 198.8 mg·dm^{-3}. The minimum mineralisation of water indicates a greater role of atmospheric nutrition in lakes, and the maximum – an increase in the role of groundwater supply.

northern and northeastern directions. Groundwater is characterised by much higher mineralisation than surface waters. The waters of the first from the surface of the aquifer, confined to the Quaternary sediments, are calcium-hydrocarbonate, pH – 6.8–7.0. Their mineralisation varies in the range of 310–636 mg·dm^{-3}. The waters of the second horizon from the surface, confined to the Cretaceous deposits, are also calcium-hydrocarbonate with mineralisation of 496–656 mg·dm^{-3}, pH – 6.7–6.8.

Table 5. Average annual concentration of basic ions and water mineralisation in the surface layer of large, medium, and small lakes of the Shatsk group (2018)

Lake	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Mineralisation
	mg·dm^{-3}						
Svityaz	122	10	13	34	4	15	198
Pulemetske	134	14	14	40	5	11	218
Luky	85	3	12	20	4	12	136
Lucymer	171	14	18	50	4	18	275
Ostrivyanske	116	10	14	36	2	12	190
Pisochne	61	9	11	20	3	11	115
Peremut	70	2	12	15	2	15	190
Krymne	140	22	18	40	4	22	246
Chorne Velyke	159	13	46	58	2	25	303
Velyke Pishchanske	79	11	21	24	4	14	163

Source: own study.

From the available materials, it is possible to trace fluctuations in mineralisation of water in Lake Svityaz for many years: 1971–1990 – 195 mg·dm^{-3}; 1991–2010 – 212 mg·dm^{-3}; 2011–2018 – 203 mg·dm^{-3} [Ilyin 2007; Ilyin *et al.* 2010; Peleshenko *et al.* 1978; Sytnyk *et al.* 2006; Veremchuk 2007]. Thus, the mineralisation of the water of Lake Svityaz for many years fluctuates within natural limits, and no sharp tendencies to change are observed (amplitude does not exceed 17 mg·dm^{-3}). This is facilitated by compliance with the environmental regime in the Shatsk National Nature Park [Fesuyk *et al.* 2020; Plichko *et al.* 2021].

Drainage water

The waters of the drainage canals of the Kopaivka drainage system, located in this area, have a pH of 6.7–6.8, the concentration of O_2 – 7.3 mg·dm^{-3}, and above-average mineralisation in lake waters – 497 mg·dm^{-3}. The type of waters is calcium-hydrocarbonate.

Groundwater

The research area is located within the Volyn-Podilsky artesian basin. The functioning of lakes is influenced by aquifers of Upper Cretaceous and Quaternary sediments, which have a hydraulic connection. The aquifer of Quaternary sediments is pressureless and lies first from the day surface (depth 0.3–0.9 m in summer). The second aquifer is located in fractured chalk with a thickness of up to 10 m. It is separated from the Quaternary sediment, above the aquifer, by a clogging zone (waterproof chalk) with a thickness of up to 9 m. The waters of the Cretaceous sediments are pressure. The general flow of aquifers is directed in the

The chemical composition of surface and groundwater has low values of variability for basic ions (Fig. 3). The results of research on groundwater of the Quaternary and Upper Creta-

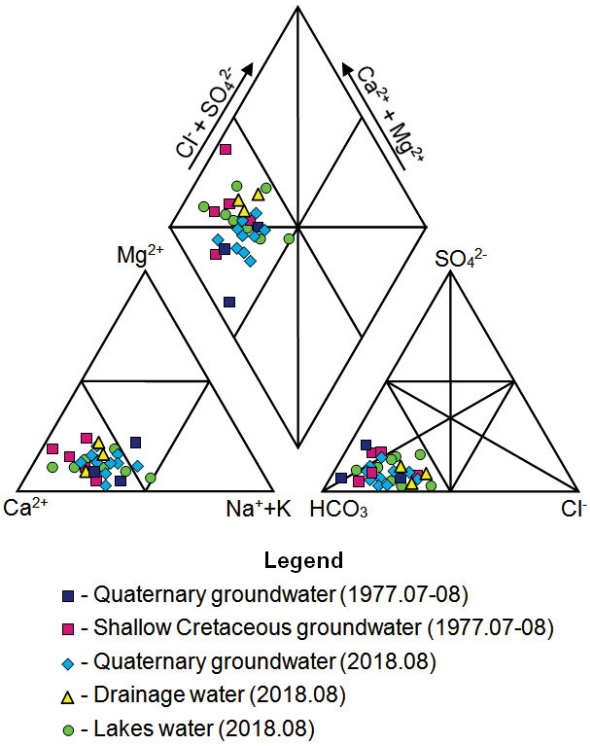

Fig. 3. Piper diagram of groundwater, drainage water and lakes water of Shatsk Lakeland; source: own study

ceous periods, conducted by the Geological Survey of Ukraine in 1977 [Zaleskyi *et al.* (eds.) 2014], as well as our research obtained in 2018, show that the hydrochemical regime of groundwater is stable. In addition, the figure shows that the ionic-salt composition of lake water, in terms of the ratio of components, is identical to the composition of groundwater. In general, all samples of groundwater and surface water are projected into the IV zone of the geochemical facies (Ca^{2+} – Mg^{2+} – HCO_3) which coincides with the 5th type of water (Ca^{2+} – Mg^{2+} and HCO_3 + CO_3). Thus, Piper's diagram shows the genetic similarity of the chemical composition of the studied waters, which indicates a significant role of groundwater in the supply of the Shatsk Lakes.

BOTTOM SEDIMENTS (SAPROPEL)

Bottom sediments of lakes are an organo-mineral substance that is formed in the lake due to the inflow of sediments with surface runoff (allochthonous component) and as a result of the activity of the lake ecosystem (autochthonous component). Sapropel is one of the forms of bottom sediments of freshwater reservoirs formed in anaerobic conditions as a result of physicochemical and biological transformations of the remains of lake aquatic organisms, as well as mineral and organic components of terrigenous runoff. The average annual increase in sediments in lakes ranges from 1.0 to 6.6 mm. The age of sapropel deposits in modern lakes does not exceed 12 thousand years [Ilyin 2003]. Sapropel is considered to be the deposition of freshwater bodies with an organic matter content of more than 15%.

A sapropel deposit should be understood as a geological formation that consists of one or more types of sapropel with a thickness of more than one meter, and by its size and reserves can be the object of economic use (Fig. 4).

Studies have shown that sapropel deposits (2.30–8.47 m) are present in all lakes of the Shatsk group. The Geological Survey of Ukraine has estimated sapropel reserves for 19 lakes. There was explored 11.7622 mln t of sapropel of 4 classes and 8 types: organic (zoogenic-algae – 23%, peat – 19%, mixed-algae – 3%); organo-silicate (organo-clay – 3%); carbonate (organo-limestone – 18%, limestone – 9%, clay-limestone – 4%); iron (organo-iron – 21%). Currently, the process of the development of a deposit of zoogenic-algae sapropel for agricultural purposes – as an organic fertiliser (reserves of 212 thous. t) is only on Lake Prybych. Extraction is carried out by the hydromechanised method (Photo 1).

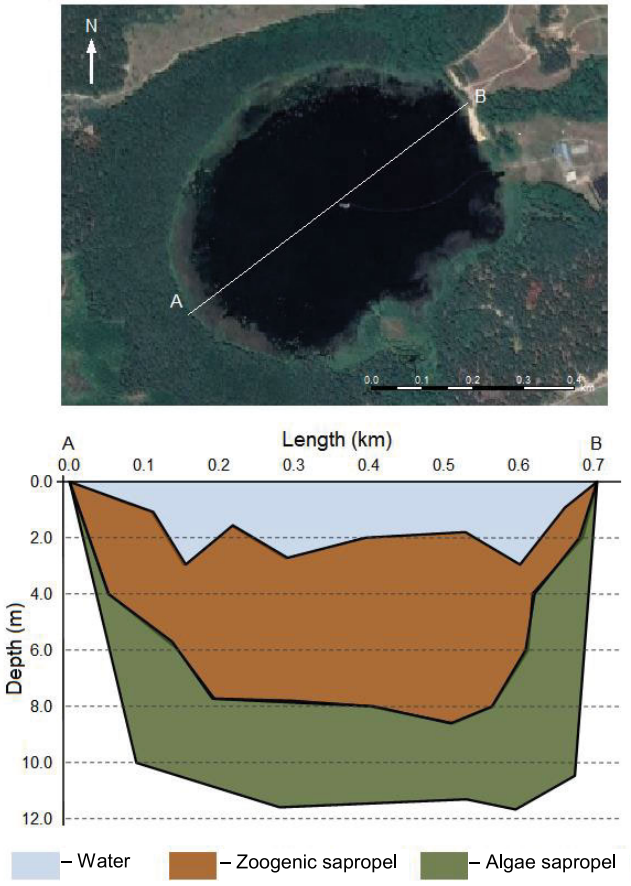

Fig. 4. Distribution profile of bottom sediments of Prybych Lake along the AB line (the Shatsk Lakes, Volyn Region, Ukraine); source: own elaboration based on GEOINFORM [1994] and Google Earth Pro

Photo 1. Hydromechanised sapropel extraction from the field on Lake Prybych (Shatsk Lakes, Volyn Region, Ukraine) (phot.: *M. Pasichnyk*)

It is expected that the cleaning of the lake basin will restore the water regime, stabilise the recreational and water use of the lake.

THE CHEMICAL COMPOSITION OF THE AQUEOUS EXTRACT OF SAPROPEL

The mineralisation of the aqueous extract from the bottom sediments of the Shatsk Lakes is higher than that of the lake water and ranges from 318 mg·dm^{-3} (Svityaz) to 1451 mg·dm^{-3} (Peremut) – Table 6. In contrast to the lake water, the sapropel extract in the composition is calcium sulphate. Its mineralisation usually varies little within the genetically homogeneous type of sediments of one lake. The pH for most solutions of aqueous extract is neutral (7.0) with a range of 6.8–7.2 and does not differ from lake water.

In the process of analysis, it was found that the composition of individual ions of the aqueous extract of sapropel correlates well with the mineralisation of the aqueous extract. The highest correlation coefficient (r) was recorded between the mineralisation of aqueous sapropel extract and the concentration of Ca^{2+} (r = 0.98), SO_4^{2-} (r = 0.96), NO_3^- (r = 0.90) and Na^+ and K^+ ions (r = 0.71). Hundreds of times higher concentrations of NO_3^- in the water extract compared to the content in the lake water indicate the intensity of nitrification processes that take place in the bottom sediments.

MINERAL COMPOSITION OF SAPROPEL

An important typological feature of sapropel is its ash content (A) – the percentage of non-combustible residue (anhydrous mass), which is formed from mineral impurities of sapropel during its complete combustion. The ash content of the sapropel of the Shatsk Lakes varies widely from 9.70 (Luky) to 64.19% (Pulemetske). The main component of ash is silicon dioxide (SiO_2) and calcium oxide (CaO). The maximum content of SiO_2 reaches 48.89% (Pulemetske), and CaO – up to 31.58% (Chorne Velyke).

PHYSICO-MECHANICAL PROPERTIES OF SAPROPEL AND THE POSSIBILITY OF ITS RECREATIONAL USE

According to research [Ilyin, Pasichnyk 2019; Pasichnyk *et al.* 2021; Strus 2015], sapropel of the Shatsk Lakes has good plasticity, high dispersion, thermophysical, antiseptic properties necessary for mud treatment, favorable reaction of the environment (pH), contains a mineral complex of valuable macro- and microelements, is bactericidal, and does not contain pathogens. These characteristics allow us to consider it as a raw material for mud treatment. It meets the regulatory requirements [DKZ 2004], which are set for therapeutic muds (Tab. 7).

In its natural state sapropel has high humidity, which reaches 96.01% (Lake Pisochne). The specific weight (γ) of sapropel changes with increasing ash content (A), from 1.03 kg·dm^{-3} (Somynets) to 1.08 kg·dm^{-3} (Pisochne). The shear strength is in the range of 117–776 Pa (Chorne Velyke). In the particle size distribution, the number of particles with a diameter of more than 0.25·10^{-3} m in the samples from Shatsk Lakes does not exceed 1.0%. Sapropel is characterized by a significant range of reaction media (pH) from alkaline (Chorne Velyke, pH – 7.46) to acidic (Moshne, pH – 5.43) [Ilyin, Pasichnyk 2019]. The high thermal properties of sapropel contribute to the possibility of its recreational use as a peloid. For sapropel of the Shatsk Lakes, the indicator of specific heat capacity is in the range from 3.72 kJ·K^{-1}·kg^{-1} (Chorne Velyke) up to 4.08 kJ·K^{-1}·kg^{-1} (Pisochne).

Microbiological parameters of sapropel are within normal limits. The samples, taken from lakes Prybych, Chorne Velyke, Krymne, Pisochne, Moshne, Somynets, and Peremut, in the period from 15 to 21 October 2018, have a satisfactory sanitary-epidemiological conditions. The total microbial count varied from 2,000 CFU·g^{-1} (Pisochne, Peremut) to 17,000 CFU·g^{-1} (Chorne Velyke). Pathogenic microorganisms were not detected [Ilyin, Pasichnyk 2019].

The analysis of forms of recreational activity on the Shatsk Lakes testifies to monofunctional use of aqua and coastal complexes and a high degree of recreational loading in resort

Table 6. The average concentration of basic ions in the aqueous extract of sapropel in lakes of the Shatsk group (2018)

Lake	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	NO_3^-	Mineralisation
	mg·dm^{-3}							
Svityaz	91	113	15	80	5	2	12	318
Pulemetske	76	632	16	256	19	11	76	1010
Luky	165	176	14	140	9	15	98	617
Lucymer	134	326	21	158	24	8	21	692
Ostrivyanske	195	140	11	114	16	23	98	597
Pisochne	73	248	14	180	80	11	279	829
Peremut	146	201	21	321	5	51	700	1451
Krymne	171	286	21	176	5	3	14	662
Chorne Velyke	171	219	27	240	12	57	464	1190
Velyke Pishchanske	140	185	14	68	17	40	15	464

Source: own study.

Table 7. Regulatory requirements for sapropel peloids and range of values for sapropel of the Shatsk Lakes (2018)

Indicators	The norm for sapropel peloids	Value for sapropel of Shatsk Lakes
Moisture (%)	60–90	86.36–96.01
Clogged with particles the size over $0.25 \cdot 10^{-3}$ m (%)	<2	0.20–1.00
Clogged with particles the size over $5.0 \cdot 10^{-3}$ m (%)	absence	not found
Shear resistance (Pa)	50–750	177–722
Ash content (%)	>30	9.27–67.56
Microbiological indicators		
Total microbial numbers, (CFU·g^{-1})	<500,000	2000–17,000
Escherichia coli, CFU/10 g	>10	>10
Clostridium perfringens, CFU·(0.1 g)$^{-1}$	>0.1	>0.1
Staphylococcus, CFU·(10 g)$^{-1}$	absence	not found
Pseudomonas aeruginosa, CFU·(10 g)$^{-1}$	absence	not found
Fecal coliforms, CFU·(10 g)$^{-1}$	absence	not found
Enterococcus, CFU·(10 g)$^{-1}$	absence	not found
Bacterial index of the peloids (%)	1–100	60–86

Source: own elaboration based on the methodology [DKZ 2004].

areas in of June–August period. Most tourists associate their vacation in the region mainly with bathing and beach recreation.

Involvement of the Shatsk Lakes sapropel in medical and health recreation is a promising area of recreational nature, which will expand the use of natural medicines, diversify the range of services in sanatoriums and promote investment in the recreational sphere. A total of 95.0 million m^3 of sapropel was found in Shatsk Lakes, which can be used in medical and health-improving activities. The largest deposits are found in the lakes Pulemetske, Luky, Svityaz, Ostrivyanske, Pisochne, and Peremut [Pasichnyk *et al.* 2021]. However, mining sapropel for recreational purposes can be organised on reservoirs that are not a part of the park.

CONCLUSIONS

1. The typification of the Shatsk Lakes by the area of the water mirror according to the requirements of the Water Framework Directive of the European Union showed that among the 28 lakes there are two large lakes (Svityaz and Pulemetske), and the share of medium and small lakes is 29%, very small – 64%. There are only two types of lakes in terms of depth: medium depth (14% of lakes) and shallow (86%). In very small lakes, the process of eutrophication and siltation is intensive, which, according to many researchers, is due to drainage reclamation, which was carried out in Polesie.

   Given the similarity of many reservoirs, to some extent their typicality for the territories of West Polesie, and the completeness of data on the studied limnosystems, these objects can be considered representative of the area of coniferous-deciduous forests of the Eastern European plain.
2. The mineralisation of calcium-hydrocarbonate lake waters ranges between 114 and 303 mg·dm^{-3}, and calcium-sulphate aqueous extract from the bottom sediments of sapropel – 318–1451 mg·dm^{-3}. The comparison of the obtained results of hydrochemical composition of surface and groundwater with research data from previous years confirms that the ionic–salt composition of surface and groundwater varies within natural limits, which contributes to compliance with the conservation regime of Shatsk National Nature Park.
3. In the Shatsk Lakes the geological service of Ukraine has discovered significant deposits of sapropel of different species. Extraction is carried out at the lake deposit Prybych. The study shows that sapropel has high fitness and can be used for recreational purposes as a therapeutic mud. The involvement of the sapropel of Shatsk Lakes, which are not under the protection of Shatsk National Nature Park, is a promising area of recreational nature in the region. This requires the implementation of relevant business projects. Preservation of ecological potential should be balanced by the economic development of the region, which is one of the conditions of sustainable development.

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