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RESEARCH ARTICLE

Morphometric features and genesis of the lake basins of the natural monument "Lakes Svetlye, Lake Elovoe and the surrounding swampy massif" of the Oka-Volga interfluve within the Nizhny Novgorod region

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ABSTRACT

The article presents the results of research of the morphometric characteristics of a complex of lakes, located in the Nizhny Novgorod section of the Oka-Volga interfluve within the natural monument "Lakes Svetlye, Lake Elovoe and the surrounding swampy massif". These lakes have serious scientific and environmental significance, forming the hydrological framework of the marsh-dune landscape, complicated by numerous large forms of karst relief. The territory is also valuable because it is the habitat of a number of plant species, listed in the Red Book of the Nizhny Novgorod region. Lakes have a pronounced function of regulating the hydrological regime, the morphology of lake basins reflects the nature of geomorphological processes occurring in the researched area and to some extent determines their direction and intensity. To establish the genesis of lake basins, the authors used both stock data – materials of the geological research of the vicinity of the Lakes Svetlye, geological maps and geological sections, and the results of their own field research, performed by the method of bathymetric survey. The analysis of the stock data showed, that at a depth of 98 m there are fractured cavernous gypsum of the sakmar layer of geology of the lower perm, overlain by clays of the urzhum layer of geology of the middle perm, over which sands of quaternary age lie. During the field work, 8 lakes were surveyed, a total of 966 depth measurements were performed. Based on field materials, digital relief models were created using QUANTUM GIS, volumetric and bathygraphic curves of the researched lakes were made, and their morphometric characteristics were calculated. The morphometric characteristics obtained during field research, coupled with the features of the geological structure of the territory, allow us to confidently assume the karst origin of the researched lakes.

INTRODUCTION

The territory of the Nizhny Novgorod region in general, and the Nizhny Novgorod part of the Oka-Volga interfluve in particular, are an area of intensive karst development. This process in itself is an important landscape-forming factor, a condition for conducting economic activity and one of the criteria for conducting a comprehensive geoecological assessment of the territory. Having large-scale manifestations on the territory of the Oka-Volga interfluve, karst often creates prerequisites for the formation of lakes, which are an important component of the hydrological framework of the landscape.

The hydrological regime of the territory, the nature and intensity of geomorphological processes occurring in the surrounding landscape, and even the composition and species diversity of plants and animals inhabiting the landscape largely depend on the morphometric characteristics of lakes. Understanding the structural features of the lake basins of the natural monument "Svetlye Lakes,

Lake Elovoe and the surrounding swampy massif" is especially important due to its conservation status. The research results are in demand by geomorphologists, landscape scientists, biologists, environmental organizations and government authorities.

For a more complete understanding of the characteristics and structure of the landscape, it is necessary to have a reliable understanding of the structure and genesis of the lake complex. In addition, the geomorphological features of the lake complex of the territory under consideration can serve as a basis for understanding the conditions and factors of the state, sequence and mechanism of development of the karst massif, and gain an understanding of the forms of the buried roof relief of the karst stratum (Kovaleva and Kataev, 2014; Kovaleva, 2015). However, since karst formations are flooded with water, understanding their specifics and estimating quantitative characteristics (depth, volume, etc.) is difficult. To solve this problem, accurate digital models of the relief of lake basins like bathymetric maps are needed. Morphology studies of several other lake basins in the Oka-Volga interfluve were conducted in the 21st century (Astashin et al., 2020; Astashin et al., 2021a; Astashin et al., 2021b). However, there has been no data on the structure of the basins of the lake complex of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif" to date.

Prominent local scientists studied the origin of lake basins in the Nizhny Novgorod region (Bakanina et al., 2001; Bayanov and Yulova, 2001; Bayanov and Krivdina, 2011; Bayanov et al., 2014). The monograph "Lakes of the Nizhny Novgorod region" provides a detailed classification of lakes of the Nizhny Novgorod region by origin. However, the conclusions drawn by the authors did not take into account data on the structure of lake basins, due to the lack of such data at the time of writing the monograph. In accordance with the genetic classification of lake basins presented in the monograph "Lakes of the Nizhny Novgorod region", the lake complex of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif" belongs to the type of sinkhole-karst lakes, a subtype of karst-terraced (Bakanina et al., 2001, pp. 18-19).

The purpose of the study: To establish the morphometric characteristics and origin of the lake complex of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif", located in the territory of the Volodarsky district of the Nizhny Novgorod region.

Object of research: Lakes of the state natural monument of regional significance "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif" of the Volodarsky district of the Nizhny Novgorod region.

Subject of the study: Hydrological, morphological features and genesis of lake basins of the state natural monument of regional (regional) significance "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif" of the Volodarsky district of the Nizhny Novgorod region.

Hypothesis: The lakes under study are of karst origin.

MATERIALS AND METHODS

In the course of the work, the authors relied on data from thematic maps (pre-quaternary and quaternary formations, geomorphological, topographic), literary sources, remote sensing data, and the results of their own field research. Research methods: Expeditionary, cartographic, morphometric analysis, geoinformation, literature analysis, conjugate analysis of thematic maps, extrapolation.

To establish the morphometric characteristics of the lakes of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif", field studies lasting 5 days were conducted in February 2019. During the expedition, a bathymetric survey of 8 lakes was carried out. Measurements were made using a lot, which was lowered into a drilled ice hole. Measurements were made evenly, every 10 meters along the square grid. Since there was no preliminary data on the structure of the lake basins at the time of the survey, measurements on all lakes were carried out carefully, with high frequency on each lake. A total of 966 depth measurements were performed on 8 lakes (Table. 1), an average of one meter per 110 m2. Using a GPS navigator, the measuring points were recorded, and the depths were recorded in the log of the bathymetric survey.

At the cameral stage of the study, the data obtained were processed in the Quantum GIS geoinformation system, digital relief models, bathygraphic and volumetric curves were constructed,

and quantitative parameters were calculated (Table 1). A part of the lake basins is covered with floating bog, for such areas we constructed hypothetical isobath lines, since it was not possible to carry out direct measurements of the depths – the length of the ice drill, with which holes were drilled in the ice, did not allow to pass through the thickness of the floating bog. According on the research results, digital models of lake basins were built, reflecting their actual state at the time of the research, and not at the time of their occurrence. During the existence of the studied lakes, a layer of sludge has accumulated on the bottom, the instruments used for the bathymetric survey do not suggest reaching the bedrock through the sludge, its thickness has not been established.

Based on the constructed digital models of the relief of lake basins, we calculated their main morphometric characteristics (Bogoslovsky, 1960). The next step was to carry out a morphogenetic analysis – to establish the genesis of lake basins based on their morphometric characteristics. However, due to the objectively existing phenomenon of convergence of relief forms (the similarity of the external appearance of the relief with different factors and conditions of their formation) (Simonov, 1998, p. 53), it was decided to supplement the morphogenetic analysis with an analysis of all components of the surrounding landscape in order to obtain a more reliable conclusion about the genesis of lake basins in the territory under consideration.

Characteristics of the research area.

The territory of the Svetlye Lakes natural monument is located within the Oka-Volga interfluve in the west of the Balakhna lowland (Friedman, 1999) near the western border of the Nizhny Novgorod region in the northwestern part of the Volodarsk district, from the regional center of Volodarsk to the northwest 28 km, from the village of Mulino to the northwest 11 km, from the river Frolishchi village to the south-east is 9 km, from Tsentralny village to the north-west is 7 km (Fig. 1).

The natural monument is a system of eight small lakes of karst origin and adjacent areas of upland and transitional marshes. They are located in the settled forests of the Balakhna lowland. Lakes (except Lake Svetloe 1) of a regular rounded shape. All lakes are of considerable depth. The water is exceptionally clear, which is reflected in the names of these lakes. The coastal slopes, composed of sands, are steep and high (Bakka and Kiseleva, 2008, p. 123).

To understand the processes that led to the formation of the lake, it is necessary to have reliable information about the geological structure of the territory. The pre-quaternary formations within the studied territory are represented by karst sediments of the Permian Period. At a depth of about 100 m, there are sediments of the Sakmara stage of the Lower Permian (gypsum). According to drilling data, the gypsum is severely cracked to destroyed in sections. There are cavities with a capacity of 0.1 m.

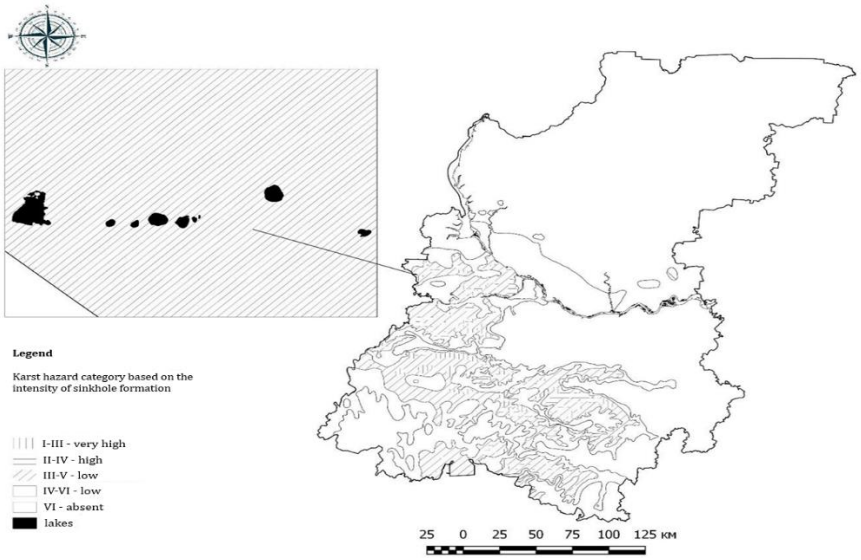

Fig. 1. The position of Svetlye Lakes on the map of karst hazard categories of the Nizhny Novgorod region by the intensity of sinkhole formation

The sulfate stratum of the Sakmara stage is overlain by sediments of the Urzhum stage of the Middle Permian, with a total thickness of about 30 m (calcareous clays with nests and lenses of marl, siltstones and sands (Nikitin, Borozdina and Gorbatkina, 1979).

The quaternary formations are represented by the middle quaternary deposits of the Moscow horizon – fluvioglacial deposits of the first stage of glacier retreat (sands), with a thickness of about 70 m. Sulfate fractured and cavernous strata are overlain by sands and clays (often also fractured) with a thickness of about 100 m, which makes possible the development of karst.

The territory under study lies on the fourth fluvial terrace of the Oka River valley. The relief of the surroundings of the lakes under study is complicated by sand dunes, karst craters, and fens that are post–lake formations that now represent lowland bogs. The studied area has distinct manifestations of the karst process, although it lies in zone III-IV, a reduced category of karst hazard and sinkhole formation (Recommendations for engineering surveys..., 2012). So, in October 2022, 100 m south of the southern shore of the lake Svetloe-1 appeared a 19 m deep sinkhole with a volume of 7,600 m3, which can be considered as a sign of the current activity of the karst process in the studied area. The climate is temperate continental, typical for the Nizhny Novgorod region, with precipitation of no more than 600 mm per year. The hydrographic network is represented by lowland bog, which often turn into drifts on the shores of lakes. A characteristic feature of the lakes studied is the uneven elevation of the water surface above sea level: it ranges from 96 to 105 m (Topographic map), which indicates the absence of a hydraulic connection between the lakes. Podzolic sandy and lowland peat soils. On the high shores of the (dune) lakes, coniferous communities (broom pines) dominate, on lowland areas there are drifts under pine forests with communities of wild rosemary, bog rosemary, leatherleaf, and sphagnum.

According to the scheme of landscape zoning of the Nizhny Novgorod region (Bakanina et al., 2003), the studied territory lies in a zone of mixed coniferous and broadleaf forests in the Balakhninsko-Seiminsky landscape area.

RESULTS

The field research data were processed using GIS. Based on traditional formulas (Bogoslovsky, 1960) the main morphometric characteristics of the lakes of the natural monument "Svetlye Laked, Lake Elovoe and the surrounding swampy massif" were calculated (Table. 1), digital models of the relief of lake basins have been created (Fig. 2-9), area curves (Fig. 10-17) and volume curves (Fig. 18-25).

Table 1. Morphometric characteristics of lakes of the nature monument "Svetlye Lakes"

Name of the lake	Water surface area, m^2	Lake water volume, m^3	Coast line length, m	Coast line indentation	Average depth, m	Maximum depth, m	Maximum length, m	Maximum width, m	Average width, m	Height above sea level, m
Svetloe 1	55463	182916	1273	1.52	3.30	9.1	330	189	168.1	96
Svetloe 2	3332	15551	211	1.03	4.67	8.1	75.5	57	44.1	102
Svetloe 3	2725	8111	199	1.08	2.98	6	74	50	36.8	105
Svetloe 4	12832	81369	415	1.03	6.34	13.1	84.5	54.5	151.9	103
Svetloe 5	7705	42885	363	1.17	5.57	9.6	117	86.6	65.9	102
Svetloe 6	3846	17128	234	1.06	4.45	9.3	81	55	47.5	96

Elovoe 1	16501	118207	472	1.04	7.16	13.5	157	141	105.1	105
Elovoe 2	4447	19888	288	1.22	4.47	9.5	94	83	47.3	101

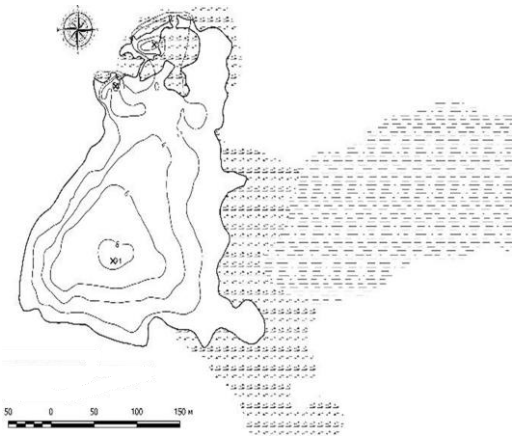

Fig. 2. Relief of the Lake Svetloe 1 basin

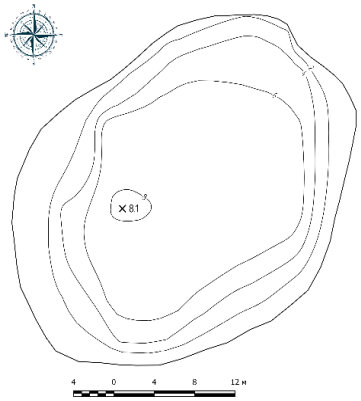

Fig. 3. Relief of the Lake Svetloe 2 basin

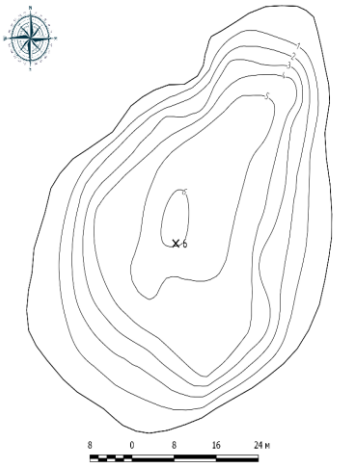

Fig. 4. Relief of the Lake Svetloe 3 basin

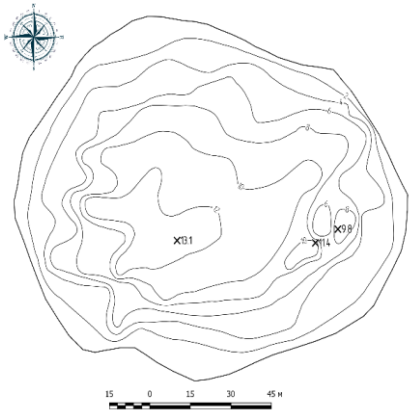

Fig. 5. Relief of the Lake Svetloe 4 basin

Fig. 6. Relief of the Lake Svetloe 5 basin

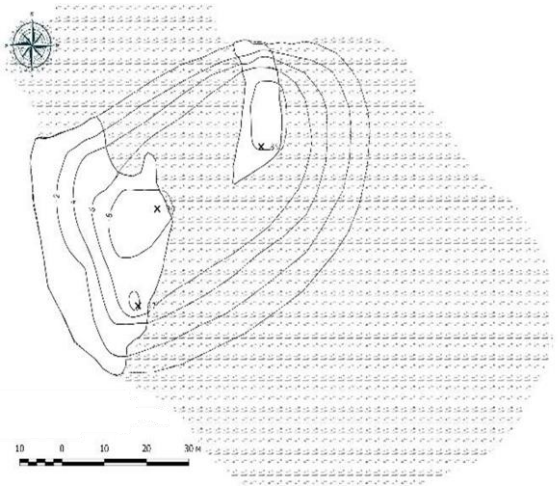

Fig. 7. Relief of the Lake Svetloe 6 basin

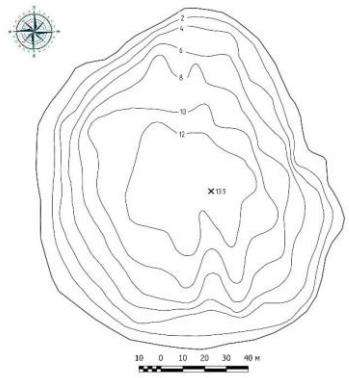

Fig. 8. Relief of the Lake Elovoe 1 basin

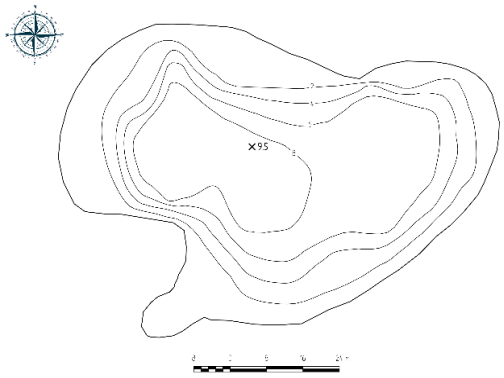

Fig. 9. Relief of the Lake Elovoe 2 basin

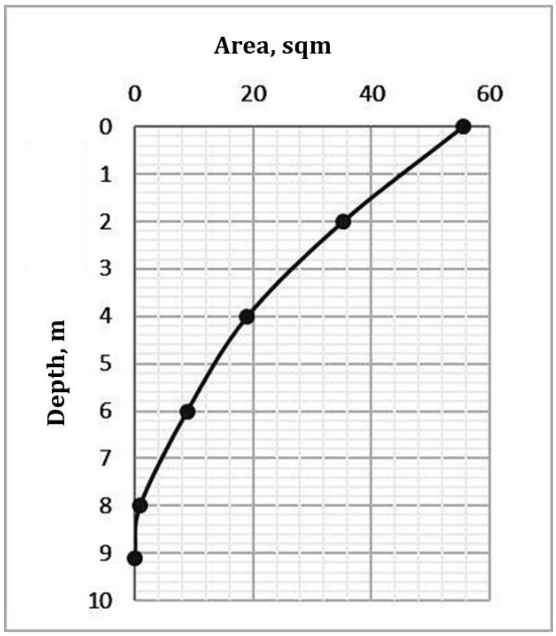

Fig. 10. Area curve of the Lake Svetloe 1

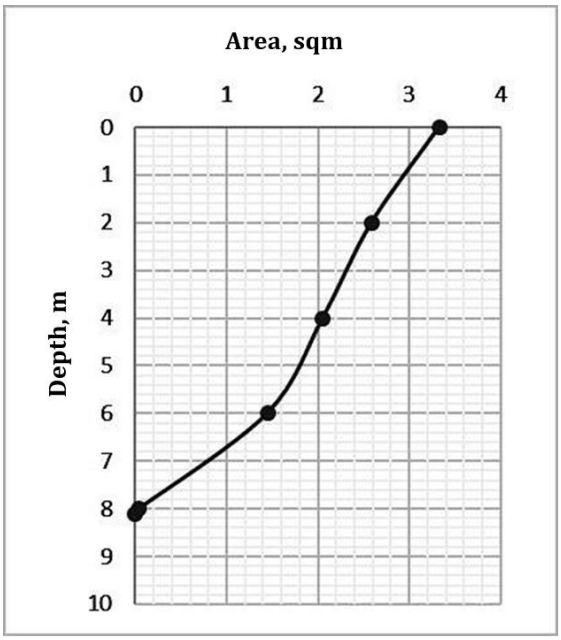

Fig. 11. Area curve of the Lake Svetloe 2

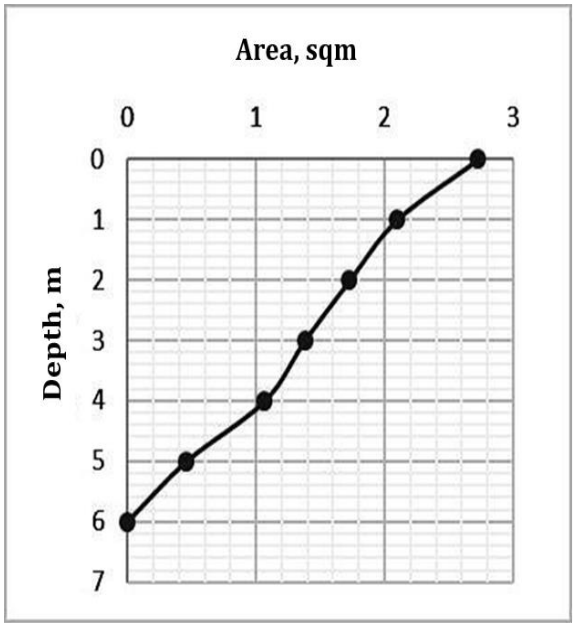

Fig. 12. Area curve of the Lake Svetloe 3

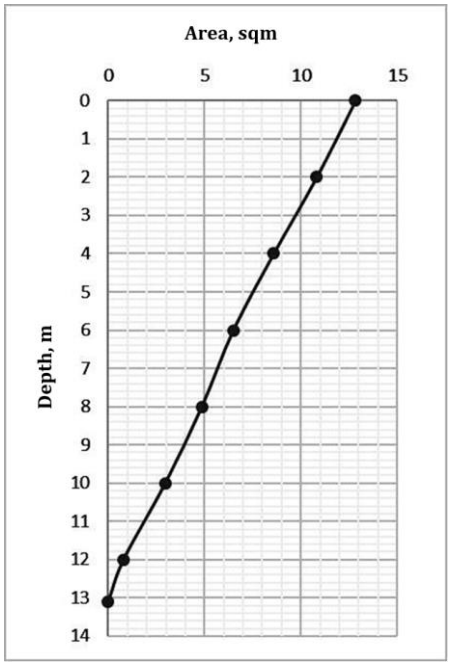

Fig. 13. Area curve of the Lake Svetloe 4

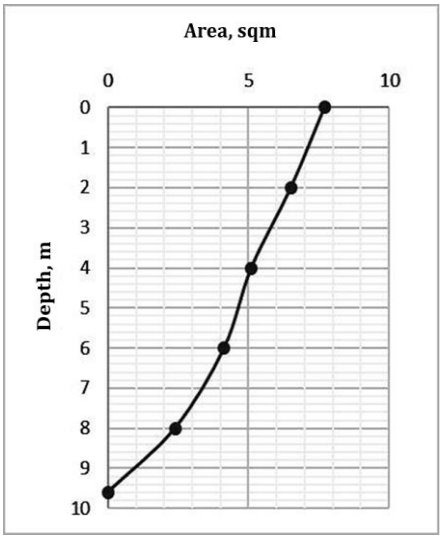

Fig. 14. Area curve of the Lake Svetloe 5

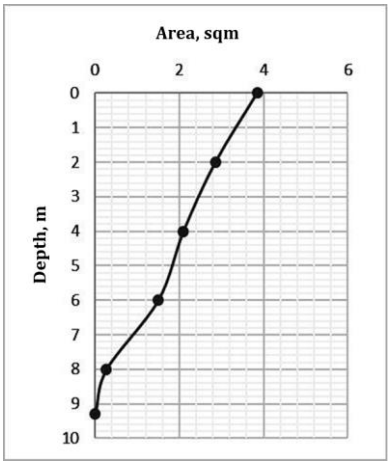

Fig. 15. Area curve of the Lake Svetloe 6

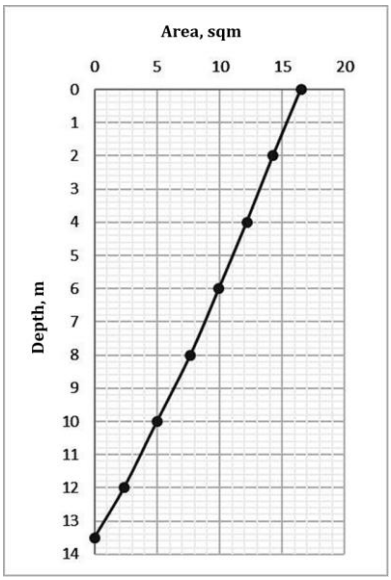

Fig. 16. Area curve of the Lake Elovoe 1

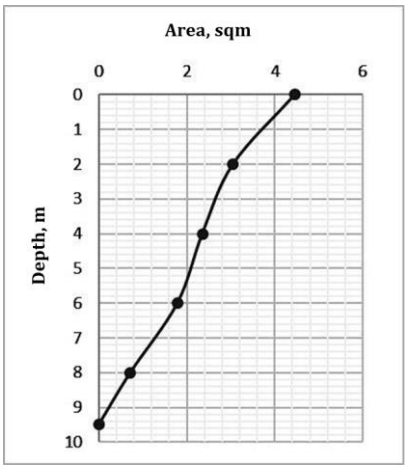

Fig. 17. Area curve of the Lake Elovoe 2

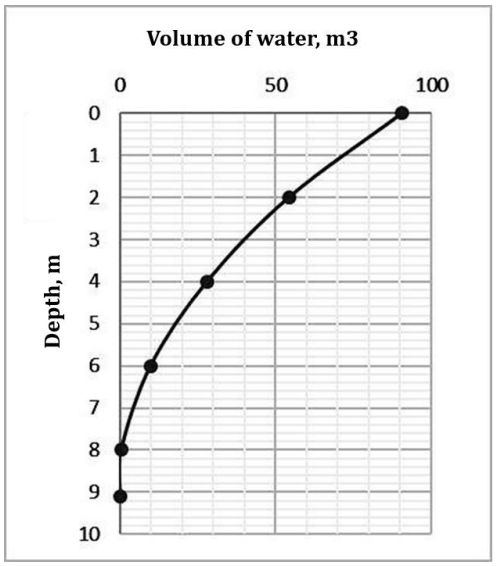

Fig. 18. Volume curve of the Lake Svetloe 1

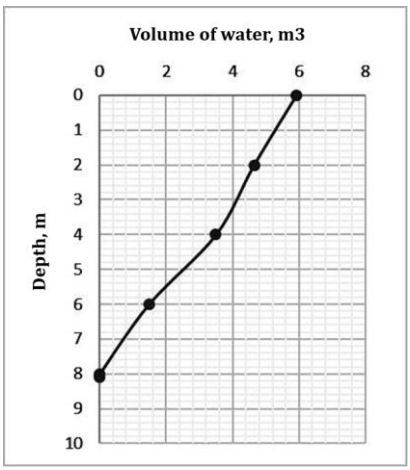

Fig. 19. Volume curve of the Lake Svetloe 2

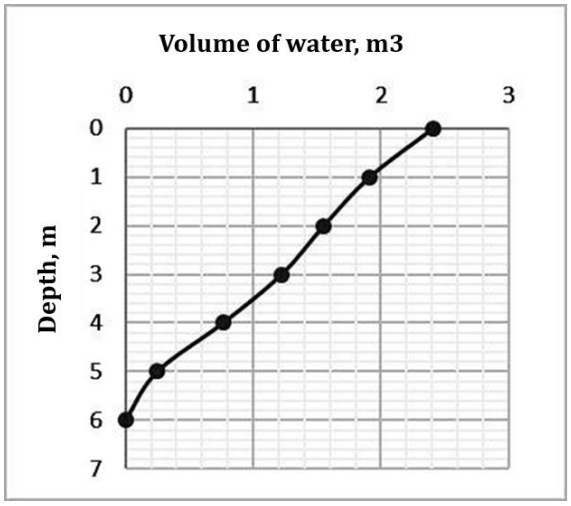

Fig. 20. Volume curve of the Lake Svetloe 3

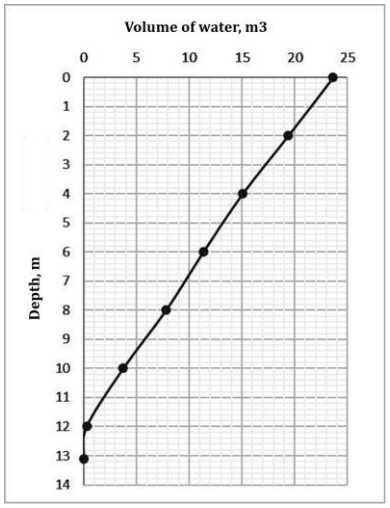

Fig. 21. Volume curve of the Lake Svetloe 4

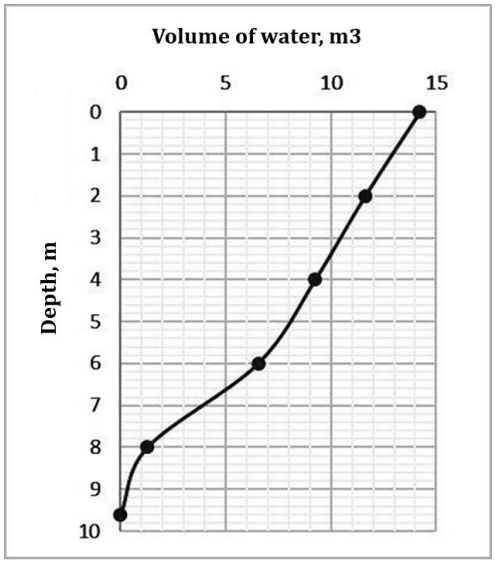

Fig. 22. Volume curve of the Lake Svetloe 5

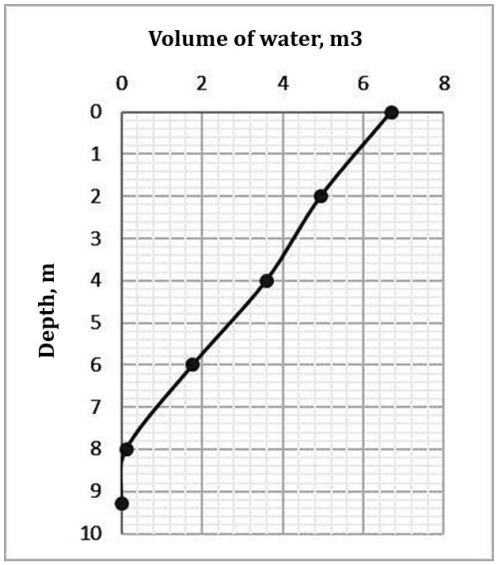

Fig. 23. Volume curve of the Lake Svetloe 6

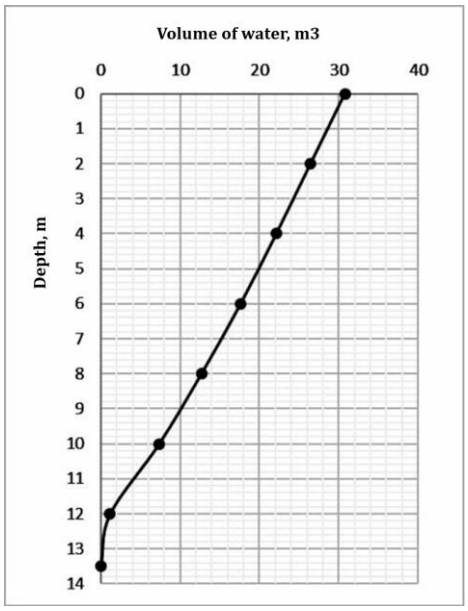

Fig. 24. Volume curve of the Lake Elovoe 1

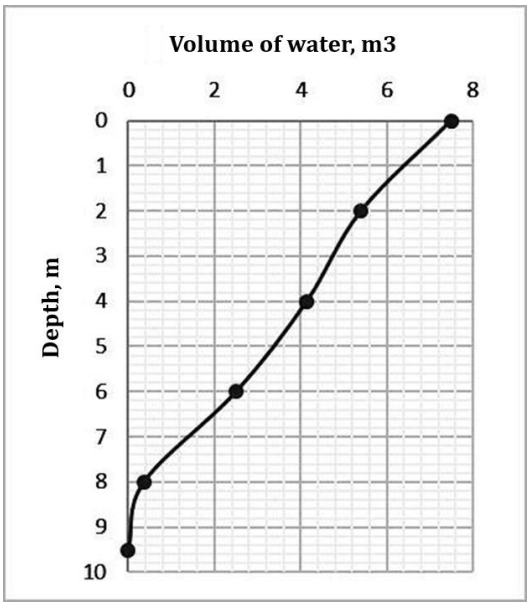

Fig. 25. Volume curve of the Lake Elovoe 2

RESULTS AND DISCUSSION

Most of the lakes within the limits of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif" (Svetloe-2-6 and Elovoe) have the outlines of a water mirror, close to rounded or oval. Lake Svetloe-1 has a complex blade? shape.

Analysis of maps of pre-quaternary formations has shown that karst rocks (gypsum) are widespread on the natural monument territory, overlain by a layer of quaternary-age sands with a thickness of about 100 m. In addition, the territory of the natural monument lies in the area of karst processes, although it is classified as area III-IV, a reduced category of karst hazard and sinkhole formation (Recommendations for engineering surveys..., 2012). According to the Scheme of Development of dangerous karst-suffusion processes in the Nizhny Novgorod region (1997), the natural monument territory also lies in the area of karst processes, however, most of it is classified as territories that are practically not dangerous for most structures, only the extreme eastern tip of the studied territory is included in the area of potentially dangerous territories for construction sites. This suggests a karst origin of the basins of the Svetlye Lakes.

Digital relief models created on the basis of field research demonstrate the different nature of the structure of lake basins. Thus, most of the basins have a complex relief with pronounced craters and outliers, represented by ridges, peaks and plateau-like shoals (Fig. 2, 5, 7). The slopes of lake basins are often complicated by erosive potholes (Fig. 5, 8, 9), probably formed in a short time from the moment of formation of the karst sinkhole to its filling with water.

Morphometric characteristics obtained during the study (a simple rounded configuration of small lakes and a complex lobed? coastline of the lake). Svetloe-1; funnel-shaped profile of small lakes and complex relief of the lake basin. Svetloe-1, full of craters and outliers) indicate the manifestations of the karst process.

The fact that lakes are elongated in a chain is also very typical for karst lakes. One of the conditions of karst formation is the fracturing of rocks (Maksimovich, 1963), which is most likely caused by the formation of deep faults in the crystalline basement. As a result, stress is created in the sedimentary rock layers above the crack, which leads to their cracking, which further significantly increases the intensity of karst development.

Based on the morphological characteristics and the nature of the location of lake basins, certain conclusions can be drawn about the specifics of the buried relief of the karst rocks. So, according to the conclusions of Kovaleva and Kataev (2014), the location of karst craters in a sparse chain (which we have in the case of the lakes under consideration) indicates their attraction to synclines, often grouped in the form of sparse chains oriented from the edge of the synclines to their center, probably tracing disjunctives that were hydrogeologically active during a certain period of karst formation.

The position of the lakes on the fourth above-floodplain terrace makes it possible to mark the lower age limit of their formation. Since the alluvium of the fourth terrace was formed during the Likhva interglacial and the Dnieper glaciation, the age of the lake basins does not exceed the age of the terrace – that is, no more than 270 thousand years (Paleogeographic patterns of development ..., 2013).

Based on the results of large-scale field studies of the lake complex of the natural monument "Svetlye Lakes, Lake Elovoe and the surrounding swampy massif", a bathymetric survey of 8 lakes was carried out. Based on measurements using geoinformation systems, bathymetric maps were created and morphometric characteristics of the studied lakes were calculated (Table 1).

CONCLUSION

Based on the obtained morphometric and geomorphological data and the results of the analysis of the geological structure of the studied territory, it can be concluded that the basins of the Lakes Svetlye are of karst origin.

Further development of the work is seen in the continuation of the study of the lake complexes of the Oka-Volga interfluve on the one hand, and its addition to the study of the landscape structure of the territory and its influence on the lakes of this territory on the other.

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