Morphometric characteristics of lake bottoms of Lakes CHarskoe and Nuksenskoe (Volga upland, Russia) as the basis of their classification

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Abstract. The article presents the results of researching the morphometric and hydrological characteristics of Lakes CHarskoe and Nuksenskoe and suggests their genesis. Lakes have scientific (zoological, botanical, geological, geomorphological), water conservation significance, perform the environmental function of typical biocenoses of karst lakes. During the research, a bathymetric survey was carried out from the board of a boat, using an echo sounder, combined with a navigator. The results of field research were processed using the geoinformation program QGIS, digital models of the relief of lake basins were constructed, the main morphometric and hydrological characteristics were calculated. Based on the analysis of the morphometric characteristics of lakes and data on the landscape features of their surroundings, primarily on the geological structure (geostructural, lithological, etc.), conclusions are drawn about the karst origin of lake basins and the classification of lakes according to a set of criteria is carried out.

1 Introduction

Under the influence of karst processes, numerous karst landforms were formed in the Nizhny Novgorod region: funnels, hollows, karst wells, karst valleys. Many karst formations are flooded with water, becoming lakes, understanding their specifics and assessing quantitative characteristics (depth, volume, etc.) are difficult. To solve this problem, accurate digital models of the relief of lake basins – bathymetric maps are needed.

The results of the research of the geological structure, karst and karst lakes of the Nizhny Novgorod region were reflected in the works of P.-S. Pallas (1768), I.I. Lepekhin (1771), N.A. Varpakhovsky (1888, 1891), V.I. Monakhov and A.S. Bulochkin (1926), V.I. Ignatiev (1952), N.A. Gvozdetsky and A.I. Spiridonov (1971), A.G. Chikishev (1978). The history of the research of the lakes of the Nizhny Novgorod region is described in the work "Lakes of the Nizhny Novgorod region" [1].

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The morphometric characteristics of lakes largely determine the hydrological regime of the adjacent 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. The main hydrophysical and hydrochemical indicators of Lakes CHarskoe and Nuksenskoe, the quality of their waters and trophic status were researched by N.G. Bayanov in 2014 [2].

Determining the features of the relief of the lake basin is an important step towards establishing the age of the lake, its origin, current state and the base of a forecast of development in the future. The research of lakes is of interest to landscape scientists [3], limnologists [4], hydrologists [5], biologists [6, 7, 8], ecologists [9], as well as recreationists [10]. This paper presents the results of detailed morphometric researches of the basins of the CHarskoe and Nuksenskoe lakes, carried out by the authors in 2022-2023, detailing the results of previous studies [11] and also classifies the researched lakes by a set of features.

2 Materials and methods

The purpose of the research: detailing the morphometric characteristics and classification of Lakes CHarskoe and Nuksenskoe.

Object of research: Lakes CHarskoe and Nuksenskoe.

Subject of research: morphometric features and classification of Lakes CHarskoe and Nuksenskoe.

In the course of the work, the authors relied on the data of thematic maps (pre-quaternary and quaternary formations, geomorphological, topographic), literary sources, remote sensing data, 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 CHarskoe and Nuksenskoe, field researches, lasting 3 days, were conducted in 2022.

Depth measurements were carried out from the board of the boat, using the echo sounder Lowrance HOOK Reveal 5 SplitShot, combined with a navigator. The echo sounder automatically recorded the coordinates and depth of the measurement points every 1.5-2 m. Measurements of the depths of the lakes were carried out along a spiral trajectory with a distance between the turns of the spiral of 10-15 m. QGIS GIS was used to build a digital model of the relief of lakes and calculate their main hydrological characteristics.

3 Results

The lakes under research are located in the south-west of the Nizhny Novgorod region on the north-western edge of the Volga Upland in the center of the Russian Plain.

Pre-quaternary formations are represented by deposits of the Permian system: siltstones, mudstones, clays, sandstones, marls, sands of the Tatar tier with a capacity of about 30 m, under which dolomites and limestones of the Kazan tier with a capacity of about 15 m lie, and under them lies a thickness of gypsum, anhydrites and gypsum dolomites of the Sakmar and Artinsky tiers with a capacity of about 50 m [12].

Quaternary deposits are represented by middle-upper quaternary and modern deluvial-solifluction formations (sands, loams) [13].

The lakes under research lie on the watershed of the Tyosha and Seryozha rivers. So, the Nux River, flowing through the Lake Nuksenskoe, flows into the Tyosha River, and the Chara River, flowing through the Lake CHarskoe – in the Seryozha river.

Exogenous processes of relief formation in the vicinity of the Lakes CHarskoe and Nuksenskoe are primarily associated with karst manifestations. In accordance with the scheme of zoning of the karst of the Middle Volga region [14], the researched lakes have the following position: the karst oblast is Oksko-Surskaya within the Alatyr-Gorky uplifts, the karst region is Tyoshe-Seryozhinsky. According to the map of karst hazard categories of the Nizhny Novgorod region, according to the intensity of sinkhole formation, the lakes lie in zone III-V of the reduced category of karst hazard and sinkhole formation [15] (Fig. 1).

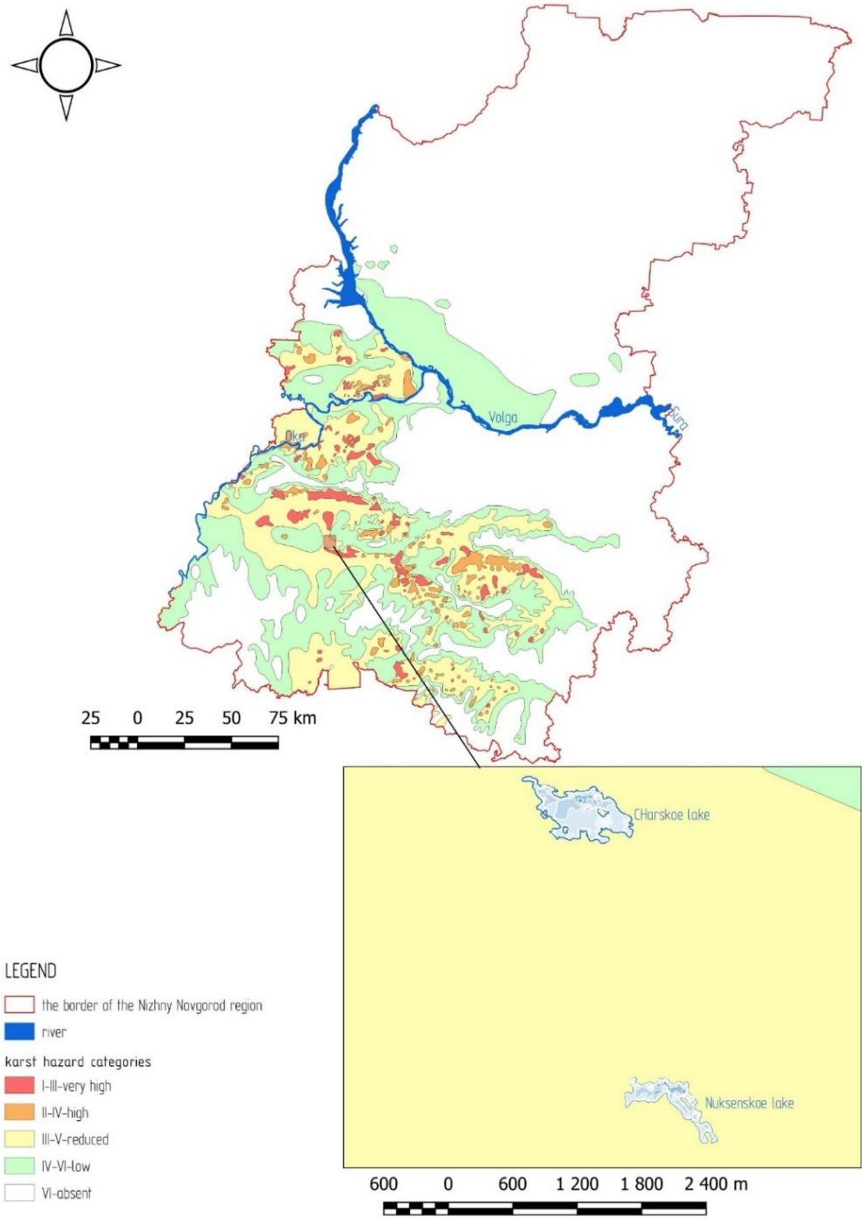

Fig. 1. The position of Lakes CHarskoe and Nuksenskoe on the map of karst hazard categories of the Nizhny Novgorod region by the intensity of sinkhole formation.

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In accordance with the classification of N.A. Gvozdeckij [16], karst forms according to morphological and genetic characteristics are divided into surface, underground and buried. In the vicinity of the Lakes CHarskoe and Nuksenskoe, karst is mainly represented by surface forms, primarily sinkholes, saucers and depressions, funnels of various types are widespread – sinkholes, suction and complex [17].

In addition to karst, aeolian landforms are common in the researched area: in the early Holocene, the sands, covering the pre-Quaternary deposits, were processed by wind, which led to the formation of dunes. Fluvial processes are locally developed – in the valleys of the small rivers CHara and Nux.

The climate of the researched territory is temperate continental; the humidification coefficient is 1.

Within the research area, surface water objects are represented by rivers, lakes, and swamps. Lake CHarskoe is flowing, the CHara River flows through it (the left tributary of the Seryozha River). A characteristic feature of the lake is the unstable water level – in some years the lake becomes very shallow, which, apparently, is due to the discharge of part of the water through underground karst channels. There is no periodicity of falling water level in the lake. The water is soft, pH 6.2 [2].

Nuksenskoe Lake is also flowing. The Nux River flows through it (right tributary of the Tyosha River). The water is yellowish, soft, pH from 6.5 to 6.9 [2].

Sod-podzolic sandy soils are common in the vicinity of lakes.

Lakes CHarskoe and Nuksenskoe are located in the zone of mixed coniferous-deciduous forests, in the Oksko-Donskaya province within the landscape area of the Oksko-Tyoshskoe forested lowland [18]; pine forests and their derivatives predominate in the vicinity of the lakes.

Based on the results of detailed bathymetric survey (on average one meter per 10m^2), digital models of lake basins (Fig. 2, 3), volumetric (Fig. 4a, 5a) and bathygraphic (Fig. 4b, 5b) curves were constructed and the main morphometric characteristics were calculated (Table 1).

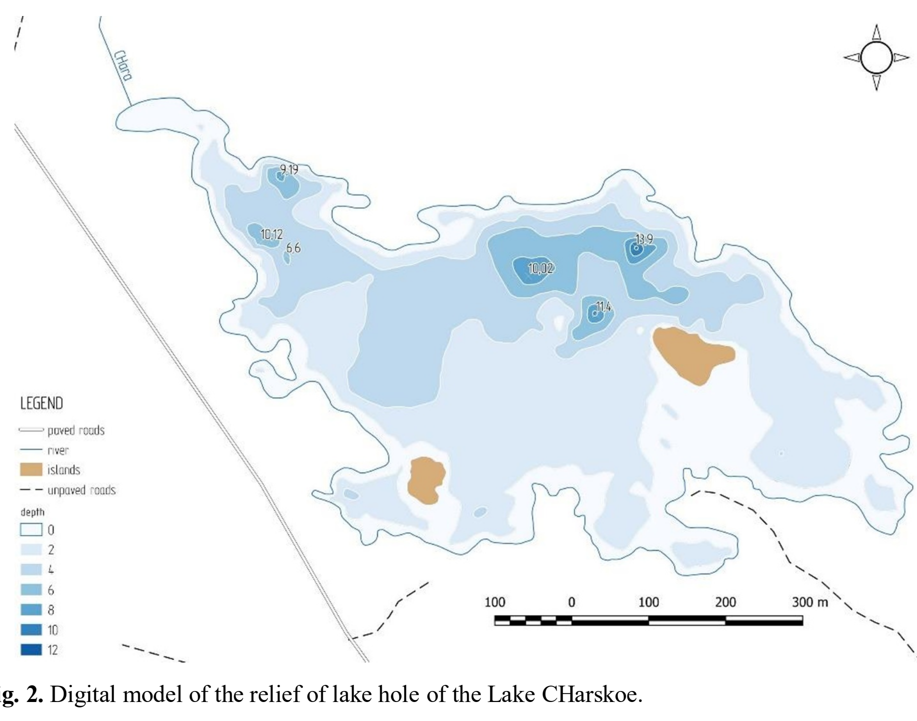


Fig. 2. Digital model of the relief of lake hole of the Lake CHarskoe.

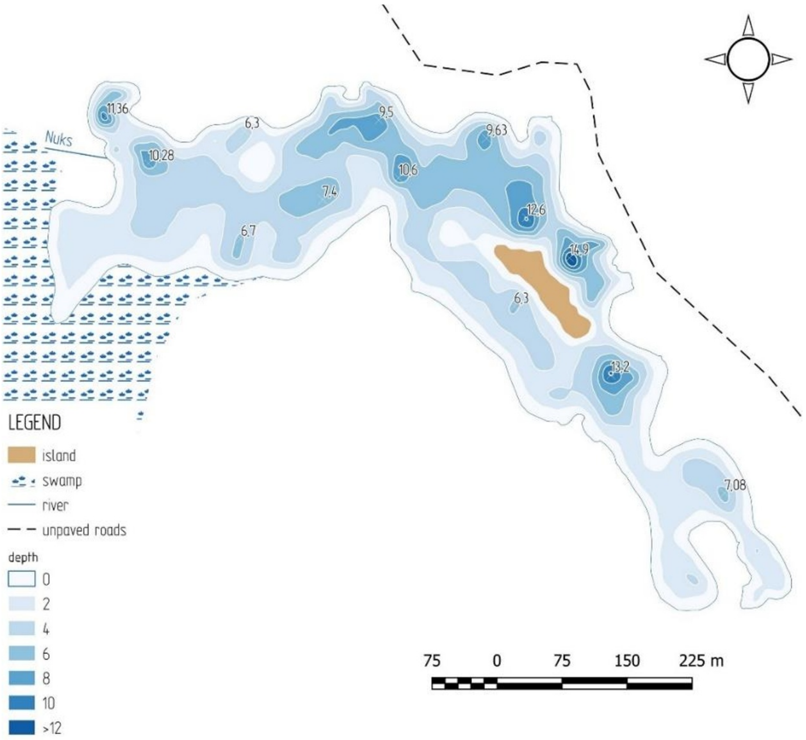
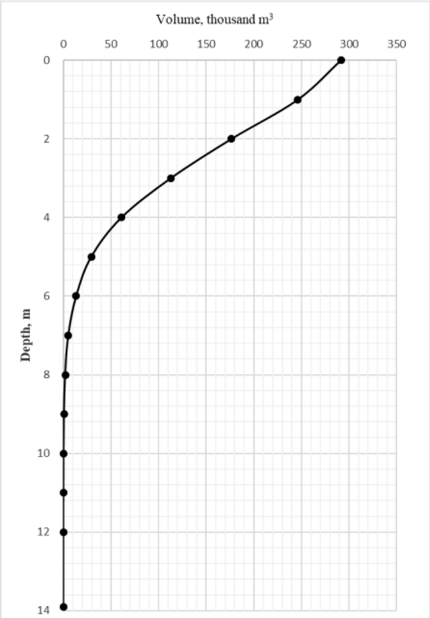
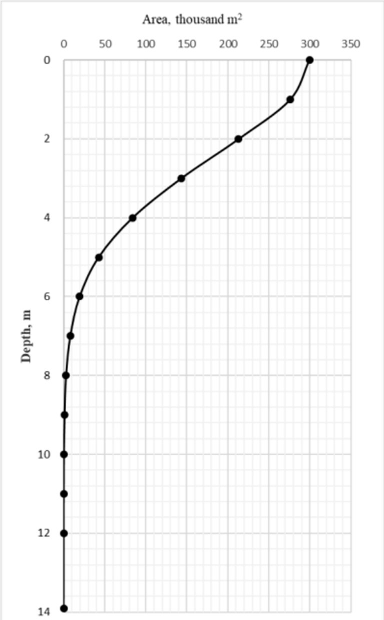


Fig. 3. Digital model of the relief of lake hole of the Lake Nuksenskoe.



a



b

Fig. 4. Volume curve and area curve of the lake CHarskoe

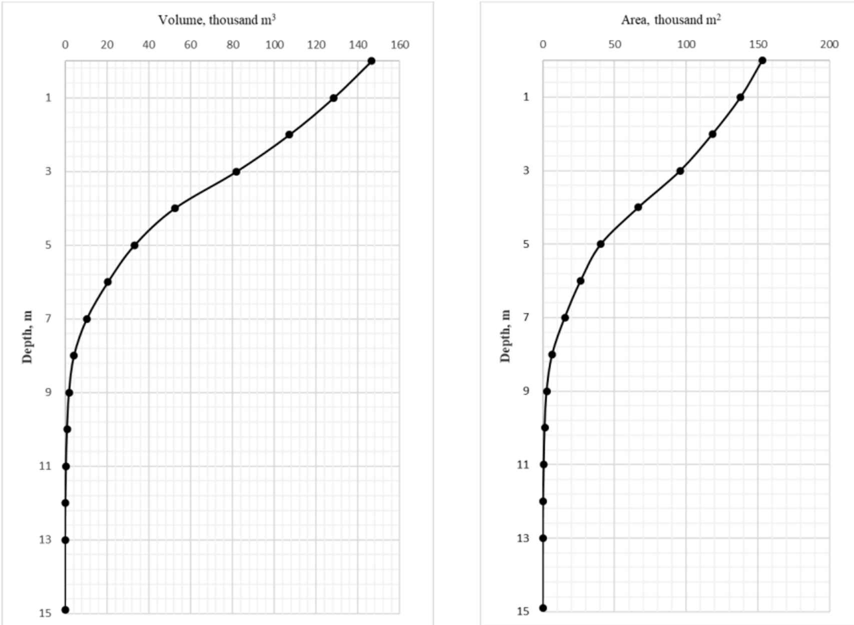


Fig. 5. Volume curve and area curve of the lake Nuksenskoe

Table 1. Morphometric characteristics of the Lakes CHarskoe and Nuksenskoe.

Name of the lake	Number of depth measurements	Water surface area, m^2	Volume of water in the lake, m^3	Shoreline length, m	Shoreline roughness	Average depth, m	Maximum depth, m	Length, m	Maximum width, m	Average width, m	Absolute height of the water surface in the lake above sea level, m	Shape of the basin	Openness indicator
CHarskoe	28 094	299 429	938 640	4 256	2.19	3.13	13.9	1 281	442	233.7	134	0,22 conical	95 664 well open
Nuksenskoe	15 288	153 227	588 186	3 320	2.39	3.84	14.9	1 185	230	129.3	143	0,26 conical	39 902 open

4 Conclusion

Morphometric characteristics of the researched lakes have features, characteristic of lakes of karst origin:

- analysis of maps of pre-quaternary formations showed that the lakes lie within the distribution of karst rocks [12] - gypsum, anhydrite and limestone of the Lower Perm;

- according to the map of karst hazard categories of the Nizhny Novgorod region by the intensity of sinkhole formation [15], the lakes lie within the karst development zone, although not the most active;
- lakes have a conical basin shape;
- the coastline is highly developed and complicated by many bays, peninsulas and islands;
- the bottom is uneven, with numerous hollows, shoals, some of which come to the surface, forming islands;
- the basins of the Lakes CHarskoe and Nuksenskoe are characterized by a significant steepness of the slopes.

One of the conditions of karst formation is the fracturing of rocks, the cause of which, apparently, is the formation of deep faults in the crystalline basement [19]. As a result, stress is created in the layers of sedimentary rocks above the crack, which leads to their cracking, which further significantly increases the intensity of karst development.

The researched lakes have a complex structure of basins, formed as a result of the development of a complex of funnels and their confluence.

According to the results of detailed field researches, the Lakes CHarskoe and Nuksenskoe were assigned to the genetic group of karst lakes, based on characteristic morphometric features. Based on the results of depth measurements processed using geoinformation system QGIS, bathymetric maps were created and morphometric characteristics of the researched lakes were calculated.

Following the classification scheme, proposed by A.V. Stupishin [14], the basins of the researched lakes by geostructural feature belong to the karst within the plakanticlinal regions; by morphometric feature – lowland karst (up to 200 m absolute elevation); according to the lithological feature – to gypsum-anhydrite, limestone and dolomite types of karst; according to the degree of exposure of karst rocks – closed (covered) karst; according to the depth from the earth's surface – surface karst; according to the stratigraphic feature of karst rocks – karst in Paleozoic rocks (Kazan, Sakmar, Artinsky); on the basis of activity karst processes – active karst (above the bottoms of erosive valleys); on a climatic basis – karst of temperate climate; on a morphological basis – forms of reflected karst (craters, depressions, karst lakes); according to geomorphological features – karst on the dividing slopes; according to botanical characteristics – karst of the forest zone.

The data, obtained as a result of the research, form the basis for the work of researchers in related scientific fields, allowing them to establish the features of the water balance and dynamics of the waters of the researched lakes, monitor aquatic ecosystems, predict interaction with other water objects and the surrounding landscape, and effectively solve environmental problems.

The results of the research can be used by the state authorities of the Nizhny Novgorod region, educational, scientific and environmental institutions.

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