

Morphometric characteristics of the Krasnyj Klyuch lake Complex (Republic of Bashkortostan, Russia)

Andrej Astashin^{1,2*}, *Mihail Badin*¹, *Ol'ga Vatina*¹, *Valeriya Podkovyrina*¹, and *Elena Il'ichyova*²

¹ Kozma Minin Nizhny Novgorod State Pedagogical University (Minin University), 603950, Ul'yanova, 1, Nizhny Novgorod, Nizhny Novgorod Region, Russia

² Nizhny Novgorod state engineering and economic university, 606340, Oktyabrskaya St., 22a, Knyaginino, Nizhny Novgorod Region, Russia

Abstract. The article presents the results of researching the morphometric features of the Krasnyj Klyuch lake complex, located on the Ufa Plateau in the Republic of Bashkortostan on the left bank of the Ufa River. According to available data, the largest karst spring in Russia and the second in Europe in discharge of spring wells at the bottom of the lake complex, which makes the task of researching the morphometric characteristics of the lake complex itself an important step towards researching the unique spring. To date, detailed data, reflecting the features of the relief of the lake bottom have not been available. During the research, a bathymetric survey of the lake complex 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, a digital model of the relief of the lake basin was created and its main morphometric characteristics were calculated. The results of the research have both scientific significance, allowing to detail knowledge about the morphometric characteristics of the unique lake complex Krasnyj Klyuch, and applied – being the center of gravity of recreants, the lake complex Krasnyj Klyuch requires a detailed research of morphometric parameters in order to effectively organize recreation.

1 Introduction

The Krasnyj Klyuch lake complex is located in the southwestern part of the Ufa Plateau, on the left bank of the Ufa River in the Nurimanovsky district of the Republic of Bashkortostan. Due to the unique hydrological features – there is a powerful karst spring at the bottom of the lake - in 1965 it was taken under protection, currently it has the status of a natural monument of regional significance "The Spring "Krasnyj Klyuch", an area of 3.2 hectares [1]. In addition, the Krasnyj Klyuch is included in the World Preliminary List of Geological Heritage.

* Corresponding author: astashinfizgeo@yandex.ru

Krasnyj Klyuch is a unique karst-hydrological system, formed by a powerful karst spring and two adjacent karst lakes with areas of groundwater discharge at the bottom – due to the complex structure of this karst-hydrological object, we will call it a lake complex in the future. The natural monument has scientific, educational, economic, aesthetic and recreational significance. Lakes form the hydrological framework of landscapes of low floodplain terraces, which is why understanding the morphology of their basins, which largely determines the properties and functioning, is important not only from the point of view of limnology, but also landscape researches. Lakes are the most pronounced center of gravity of recreants, the main recreational pressure falls on lakes and coastal complexes. In view of this circumstance, reliable information about the morphological parameters of lakes is in demand not only from the point of view of regulating the tourist flow and controlling recreational pressures, but also for organizing a safe and comfortable rest of the population [2].

Detection the features of the relief of the lake basin is an important step towards clarification the age of the lake, its origin, evolution, current state and the forecasting of development in the future. The research of lakes is of interest to landscape scientists [3], limnologists [4], hydrologists [5], biologists [6], ecologists [7], as well as recreationists. Lakes with springs at the bottom of which are sometimes very powerful – a fairly common phenomenon in areas of karst development. For example, in the north-west of the Volga upland, two large springs are known, welling at the bottom of the Vadskoye [8] and the Klyuchik [9] lakes.

The beginning of the research of nature and, especially, the su geological structure of the Republic of Bashkortostan was laid by the works of P.-S. Pallas, A. Humboldt, R. Murchison. During the Soviet period, the research of the geological structure of the Republic of Bashkortostan received a new impetus, the results were reflected in the works of G.V. Vahrushev, V.A. Balaev [10], V.L. YAhimovich, S.V. Semihatova, K.R. Timergazin, T. B. Zdorik, L. G. Fel'dman [11]. In the post-Soviet period, the work was continued by the research of karst processes was carried out by R.F. Abdrahmanov [12-15], V.I. Martin, V.G. Popov, A.P. Rozhdestvenskij, A.I. Smirnov, A.I. Travkin, A.G. Lykoshin [16], E.Z. Gareev [17, 18].

Previous researches were aimed at establishing the most important features of the nature of a unique spring – the geological structure, hydrological characteristics. This paper presents detailed data on the morphometric characteristics of the basins of the Krasnyj Klyuch lake complex.

2 Materials and methods

The purpose of the research: to develop the morphometric characteristics of the Krasnyj Klyuch lake complex of the Republic of Bashkortostan.

Object of research: Krasnyj Klyuch lake complex of the Republic of Bashkortostan.

Subject of research: morphometric characteristics of the lake complex.

In the course of the work, the authors relied on the data of thematic maps (pre-quaternary and quaternary formations, geomorphological, topographic), literary sources, Earth remote sensing data, the results of their own field research.

Research methods:

- expedition,
- cartographic,
- Analysis of Earth remote sensing data,
- analysis of literature and thematic maps,
- geoinformation,
- mathematical.

In 2022 the authors carried out work on the research of the relief of two adjacent lake basins within the Krasnyj Klyuch nature monument. Depth measurements were carried out from the board of the boat, using an echo sounder, combined with the navigator Lowrance HOOK Reveal 5 SplitShot. 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 was used to build a digital model of the relief of lakes and calculate their main morphometric characteristics.

3 Results

The nature monument of regional significance Krasnyj Klyuch is located in the southwestern part of the Ufa Plateau, on the left bank of the Ufa River in the Nurimanovsky district on the southern outskirts of the village Krasnyj Klyuch.

The pre-quaternary formations of the researched territory are represented by deposits of the Artinsky and Kungursky tiers of the Permian system (limestones, dolomites) [19].

Quaternary formations are represented by deposits of the first over-floodplain terrace of the Ufa River. The carbonate rocks here differ in composition and water permeability, geostructural and geomorphological conditions of distribution, are overlain by cover deposits of different composition and thickness, and therefore the degree of their karsting in the section and in area is very uneven. Funnels, often with sinkholes, karst ravines, blind creeks, disappearing rivers, powerful karst springs with lakes (Krasnyj Klyuch) are characteristic [20].

The spring is located on a hilly-rocky plain at the southwestern tip of the Ufa plateau, known for the wide spread of karst forms.

The climate is temperate continental. Summers are hot, winters are long and cold. Most of the precipitation falls in the summer [21].

The soil cover on the territory of the natural monument is represented by floodplain soils. Vegetation in the vicinity of the lake is represented by dark coniferous-deciduous forests.

Karst has a generally regulating effect on runoff. It is most effective in the catchments of lowland rivers (Yaman-Elga) [22].

The Krasnyj Klyuch is an exit to the surface of the underground Yaman-Elga River (translated from Bashkir means "bad" - because of karst craters and dry holes). This river originates on the northern slope of the Karatau ridge, then goes underground and flows there for more than 60 kilometers, again the waters of this river come to the surface at the bottom of Lake Krasnyj Klyuch. The Krasnyj Klyuch lake complex consists of two interconnected lakes, at the bottom of which springs are welling – in the northern lake small, in the southern large, with a flow rate from 5000 to 58000 liters per second [22], thanks to which Krasnyj Klyuch became widely known. A short stream flows out of the southern lake, flowing into the Ufa River. At the beginning of the XX century, a wooden dam was built on it, which now does not exist.

Before the Revolution, the spring and the lake were called the Belyj Klyuch because of the whitish color of the water due to the high content of carbonates. According to another version, the name Belyj Klyuch arose due to the clouds of white fog, that often appear over the cold surface of the lake. After the Revolution, the spring was renamed Krasnyj Klyuch for ideological reasons.

In the 90s of the XX century, a dam was built on the southern shore of the southern lake in order to install a hydroelectric power station, which caused the water level in the lake to rise, the hydrological regime changed [23].

The results of depth measurements were processed using the QGIS geoinformation system, digital models of the relief of the lake basins were constructed (Fig. 1), volumetric

and bathymorphic curves were constructed (Fig. 2-5) and the main morphometric characteristics were calculated (table 1).

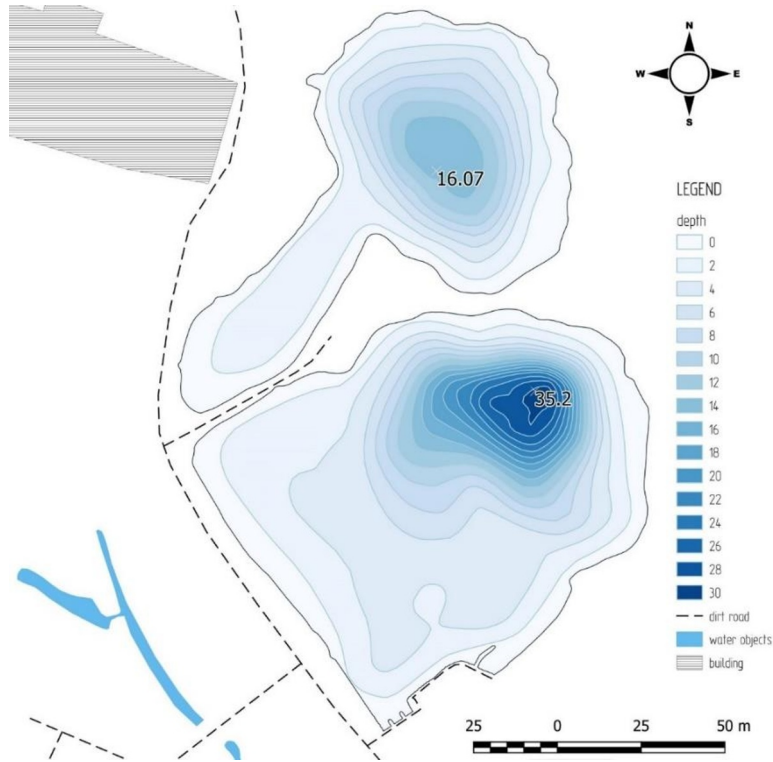


Fig. 1. Relief of the basins of the Krasnyj Klyuch lake complex.

Table 1. The main morphometric characteristics of the Krasnyj Klyuch lake complex.

Name of the lake	Number of depth measurements	Maximum depth, m	Average depth, m	Maximum length, m	Maximum width, m	Average width, m	Water surface area, m ²	Volume of water in the lake, m ³	Shoreline length, m	Shoreline roughness	Shape of the basin	Openness indicator
Northern Lake Krasnyj Klyuch	1589	16,07	5,19	149	88	43,7	6511	33761	419	1,46	0,32 conical	moderately open
Southern Krasnyj Klyuch	1385	35,2	6,88	125	101	88,6	10854	74637	444	1,20	0,19 conical	moderately open

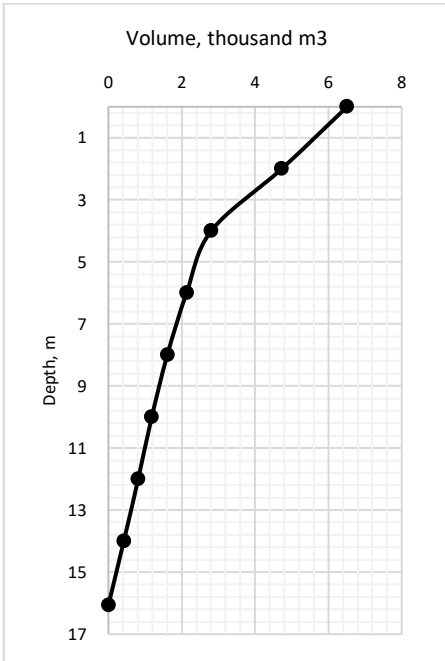


Fig. 2. Volume curve of the Northern Lake Krasnyj Klyuch

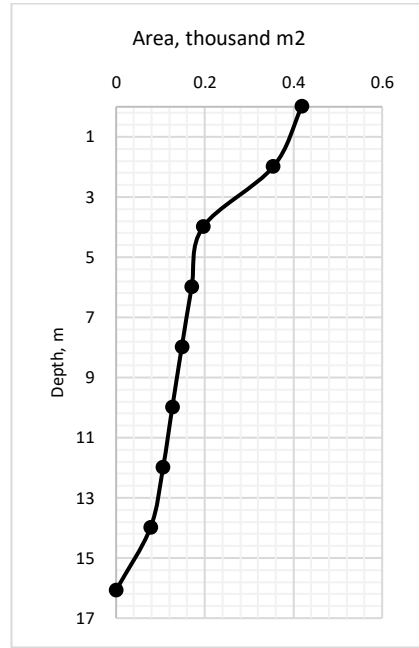


Fig. 3. Bathygraphic curve of the Northern Lake Krasnyj Klyuch

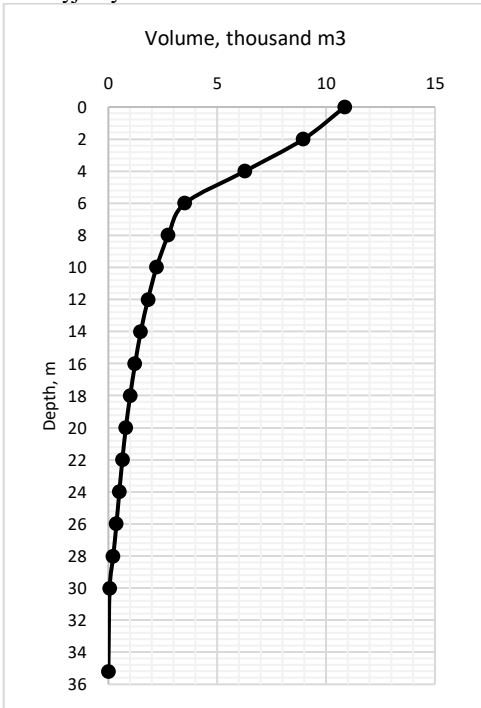


Fig. 4. Volume curve of the Southern Lake Krasnyj Klyuch

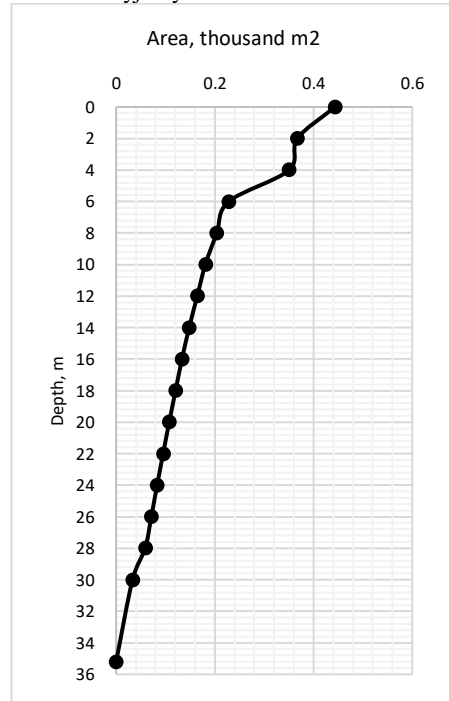


Fig. 5. Bathygraphic curve of the Southern Lake Krasnyj Klyuch

4 Conclusion

The researched lakes are large sinkholes, however, their depth was artificially increased after the construction of the dam. The configuration has also undergone anthropogenic transformations. However, despite this, the Krasnyj Klyuch remains a unique karst-hydrological system of colossal proportions, which, of course, necessitates its comprehensive research.

The lake basins of the Krasnyj Klyuch complex are narrow cones, and the maximum depths, established during the measurements, cannot be considered final. These are only the depths, that can be fixed in the conditions of open surfaces. However, in the presence of reverse slopes, measurements in the lake surface are not possible. And due to the fact that a powerful spring wells at the bottom of the lake, the reverse slopes are definitely present. Thus, the indicator of the maximum depth of the lake can be increased if another measurement method is used, involving immersion in an underwater niche.

In the course of the research morphometric characteristics of the Krasnyj Klyuch lake complex were researched, which will allow researchers of related fields to work more accurately – to establish the features of the water balance and water dynamics of the karst-hydrological system, 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 Republic of Bashkortostan, educational, scientific and environmental institutions.

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