LAKE WATER VOLUME CALCULATION USING BATHYMETRIC SURVEY, RS AND GIS

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Estimates of lake volume and other morphometric parameters are needed to understand the role of water bodies in territorial resilience to climate change. Modern GIS methods for calculating lake volume improve on more dated technologies, but most of them do require detailed bathymetric data. In this research we describe a method to estimate lake volume with a set of data that consists of a bathymetric survey measurement, a GIS modeling and layer of Svitiaz Lake shoreline derived from remote sensing data.

Keywords: water volume calculation, bathymetric survey, GIS, remote sensing, Svitiaz Lake

Estimating the water volume is extremely important for monitoring and preserving the natural environment. The balance between water inflows and outflows allows us to understand exactly which processes affect the water level in the lake and its ecosystem. The volume of water in the lake is an important indicator of the health of the aquatic ecosystem. Changes in volume can have serious consequences for aquatic flora and fauna. A decrease in the water level can cause drying up of banks, disruption of the reproduction of fish and other aquatic organisms, changes in the physical and chemical properties of water, and environmental pollution. All of the above aspects are particularly important today for regions with a large number of aquatic complexes and in terms of the intensification of the impact of climate change on them.

Lakes Svitiaz, the deepest lake in Ukraine, play an essential role in the Biosphere Reserve “Shatskyi” ecosystem and have a substantial impact on the lives of the locals. It’s the primary source of drinking water for the local populace. The necessity of detailed bathymetric surveys of Svitiaz Lake was conditioned by a significant fluctuation of its hydrological regime because of climate changes and anthropogenic factors influence on water level.

The standard method for determining lake volume is to calculate the area of depth contours from paper maps using a planimeter. A more modern approach today is the use of GIS and RS data in combination with bathymetric surveys.

The purpose of this work was to test the method of integration of GIS capabilities, RS and bathymetric survey data for the purpose of calculating the water volume of the reservoir on the example of Svitiaz Lake.

A bathymetric survey of Svitiaz Lake area was conducted by authors in 2013. According to echo-sounding results, a bathymetric database, digital relief model and depths map [1] were created.

Analysis of morphometric characteristics of Svitiaz Lake was performed by parameters, shown in Table 1. These characteristics were calculated using the Earth Remote Sensing data from Sentinel 2-A, B per 2013, 2019 and 2021 (Table 1, 2). Also, the data of Svitiaz Lake bathymetric survey, conducted by authors, were used [2].

Table 1. Lake Svitiaz morphometric measures
(* averaged per 2013, 2019, and 2020 calculated data)

Name	Area, sq.km F_0	Length, km L	Width , km B_{max}	Width , km $B_{avr.}$	Coefficient of lengthening $K_{length} = \frac{L}{B_{avr.}}$	Coefficient of shoreline sinuosity $K_{sinuous} = \frac{L}{2\sqrt{F * \pi}}$
Svitiaz	24.77	7.76	4.29	3.19	2.43	0.44

According to water surface area, as provided by L. Ilin [3], Svitiaz Lake refers to very a large ($F_0 = 24.77$ sq.km.) with a lengthened form of a basin ($K_{length} = 2.43$) [4]. Pursuant to the coefficient of shoreline sinuosity, the Svitiaz Lake shoreline refers to weakly sinuous (Table 2).

Table 2. Lake Svitiaz morphometric measures (* calculated data)

Name	Maximum depth, m	Mean depth, m	Classification according to depth	
			Mean depth, m	Maximum depth, m
Svitiaz	-58.4	6.8	Medium	Very large

The coefficient of openness indicates the water masses mixing degree and opportunities of stratigraphy appearance. The average value of this coefficient for Svitiaz Lake is 3.62 that allow one to refer this water object to sufficiently opened, according to the appropriate classification [3]. However, the openness, large water masses, and the depth of the Lake don’t allow one to avoid water stratification and thermocline formation.

The form of the basin is the most important morphometric characteristic that defines dynamic processes in water objects, such as heating and mixing. The coefficient of water object basin size (C) is calculated as the ratio between mean and maximum depths. Svitiaz Lake basin has a specific form – concave cone ($C < 0.33$) [5]. GIS modeling shows that the bottom relief of Svitiaz Lake differs from most Shatsk Lakeland water objects.

Determination of water volumes was performed using previously created isobaths maps [1], based on the «prism technique». If areas restricted by isobaths are f_1, f_2, f_3, f_n, and vertical distances between isobaths planes are $h_1, h_2, h_3 \ldots$, so lake volume (W) will be calculated according to the Eq. (1):

$$W = h_1(f_1 + f_2)/2 + h_2(f_2 + f_3)/2 + ... + h_{n-2}(f_{n-2} + f_{n-1})/2 + h_{n-1}(f_{n-1} + f_n)/2 \quad (1)$$

In case of water mass volume calculation, the water object area is the most important parameter. Comparison analysis of Svitiaz Lake shorelines over a period 1988-2033 using Landsat and Aster satellite data showed that during 15 years the lake area (26.2 sq. km) had hardly changed. Exactly this area corresponds to Svitiaz Lake water mass volume of 180.8 mln. cbm. Such value one can find in all Web sources.

However, during the last decades, except seasonal fluctuations, one can observe some changes both in lake area and water mass volume because of the intensification of different natural and anthropogenic factors influence (Table 3).

Table 3. Water mass volume (* calculated data)

Water mass volume, mln. cbm	2013	2019	2021	Data from Web sources
Svitiaz	170.08	169.01	169.67	180.8

For most lakes with cone-shaped and parabolic forms of basins, one can see a similar tendency: at depth increasing, the value of water masses volume decreases. But, a specific form of Svitiaz Lake basin allows one to trend this only up to some depth, equal to 42 m.

Figure 1 shows that a maximum isobaths area is fixed on 2m and equal to 19985800.41 sq. m. (2013 – 79%, 2019 – 82%, 2021 – 80%). The smallest belongs to the isobaths area that fixes on 58 m and is equal to 201.67 sq. m.

Given the fact that Svitiaz Lake has a specific form of the basin, so beginning from the isobaths area, which fixes on 42 m and is equal to71500.41 sq. m. (2013 – 0.28%, 2019 – 0.29%, 2021 – 0.28%), the further change of areas is insignificant.

Analysis of volume curves (Fig. 2) shows that increasing the water masses volume is observed for depths of 10 m and 18 m that corresponds to sinkholes, located within the plane part of the Lake.

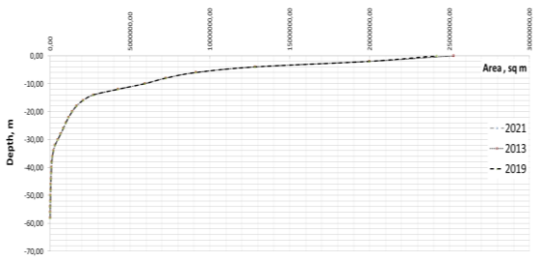

Fig. 1. Bathygraphic curve of Svitiaz Lake (dependence between area and depth).

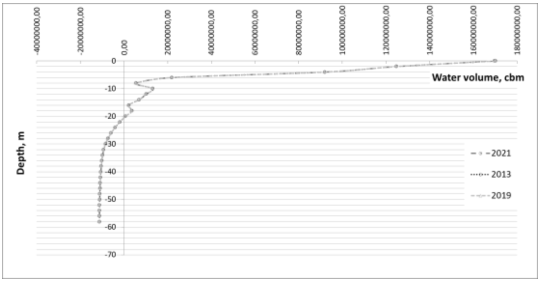

Fig. 2. Volume curve of Svitiaz Lake (dependence between water volume and its depth).

As can be seen from the calculations above, the key parameter is the area of the water mirror and the volume of the reservoir's water mass substantially depend on it. Today, RS data are an invaluable source of information for following changes in this parameter. This enables monitoring of changes in the volume of the reservoir's water mass at any time using data from terrestrial bathymetric studies and GIS tools, which can be important for ensuring the stability of aquatic ecosystems, particularly during periods of sharp drop in water levels due to factors of various origins.

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