Research article

Morphological Characteristics of Lake Vlasina (South-East Serbia)

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Abstract

This study is the first bathymetric survey and morphometric description of Lake Vlasina. Some relationships between morphometric and lake characteristics are presented. The purpose of this study was to update current information on the bathymetry and morphometric characteristics of the lake, using Humminbird and Garmin sonar. The bathymetry was based on 1587 points for which depths and geographic coordinates were acquired. Results of the bathymetric map shows that Lake Vlasina is a shallow, flat bottom lake with an ellipsoid form. Lastly we highlight the importance of this study, regarding possible future changes in morphometric characteristics as a consequence of human activity.

Keywords: Vlasina, bathymetry, morphometry, lake, hydrology.

Introduction

There is a noticeable lack of lake morphology research in Serbia, particularly from a geographical standpoint. A description of the morphological characteristics of a lake is a required step in aquatic ecosystem research. It includes the study of lake forms, their genesis and role from a physical standpoint (Håkanson, 1981). A factor that has one of the most important effects on most physical, chemical and biological parameters of a lake is its morphology. The diverse morphologies of lake basins are the result of their origin and later modifications that are initiated by the movement of water within the basin as well as sediment inputs from the surrounding drainage basin (Wetzel, 2001). Most morphometric analyses of lakes that are carried out nowadays are typically based on measures of surface dimensions. These types of studies do not provide enough information to establish a good relationship between the physico-chemical and biological parameters of an aquatic ecosystem. That is why a more comprehensive analysis must include morphometric parameters of both, surface and subsurface dimensions (Castro et al., 2003). The morphology of the lake can be quantified with metrics that can be used to describe the form and size of the lake basin. These analyses provide vital information that can determine an effective approach to lake management. The geographical location of lakes such as latitude, longitude and altitude must also be considered as well as climatic drivers such as insolation, winds and precipitation (Barroso et al., 2014).

Regarding lakes in Serbia, there are few studies on morphometric parameters (see Dolinaj et al., 2008; 2011). The goal of this study is to contribute to this area of research by first conducting morphometric analysis and investigating the bathymetric characteristics of Lake Vlasina in order to provide information that can be used as a basis for a complete limnological study of the lake.

Study Area

Lake Vlasina is situated in the southeastern part of Serbia on the Vlasina Plateau which is surrounded by the Vardenik (1875m), Gramada (1721m) and Čemernik (1638m) Mountains. The center point of the lake is situated at N42° 42' 24.13'' and E 22° 20' 23.33''.

The lake is located 19 kilometres from Surdulica which itself is some 10 kilometres east of the E75 European Route and is easily accessible from the southwestern side. Along the west shore of the lake, the regional road R122 leads across the dam towards the town of Crna Trava located in the north. The Vlasina Plateau was formed during the glacial periods that were characterized by a cold and dry climate. During these climatic changes, an accelerated mechanical decomposition of rocks occurred. Creeks and rivers that were running into the plateau became torrentous, and thus brought large quantities of sediment that accumulated along the contact line with the alluvial plane of the Vlasina River. In the beginning, peat vegetation populated this area. Further settling transformed it into meadow peatland and meadows. This process of accumulation and vegetation growth transformed the lake into a large peatland called Vlasinsko Blato (Cvijić, 1896a). The creation of peatland occurred during the last glacial period around 10,000 years ago. This peatland was the largest peatland in the Balkan peninsula, and possibly in southern Europe with an area of 10.5 km^2 (Cvijić, 1896b; Ranđelović, 1994). Formation of the present day Lake Vlasina began towards the end of 1946 following the construction of the Vlasina Dam. This earthen dam is 246 meters long and has a height of the 34.5 meters. Dam construction was completed in the spring of 1949 when filling of the basin began. This lasted until 1954 when the lake was finally filled with water from the adjacent watershed of the lake. At the time of its completion it became the highest dam lake in Serbia. The elevation of the lake is 1213 m above sea level. Vlasinsko Blato had a surface area of about 10.5 km^2 prior to flooding, one-third of which was peatland with the remaining surface composed of marshy and wet meadows (Cvijić, 1896a).

The climatological database for the 1968–2019 period were taken from the Meteorological Yearbook of the Republic Hydrometeorological Service of Serbia for the Vlasina Meteorological Station. The Mean Annual Temperature on the investigated station is 5.7°C, the coldest month is January, with a mean temperature of -3.6°C, and the warmest month is July, with a mean temperature of 14.4°C (figure 1). The warmest season is summer, with a mean temperature of 13.8°C, and a winter mean temperature of -2.7°C. Mean temperatures for spring and autumn months slightly differ. Mean temperature for the spring season is 5.3°C, whereas the mean temperature for autumn is 6.5°C. The highest temperature ever recorded is 39.8°C, and the lowest -29.5°C. The total annual mean precipitation on Lake Vlasina is 868 mm. It is the highest in the spring, 247.3 mm, and the lowest in autumn, 186.8 mm.

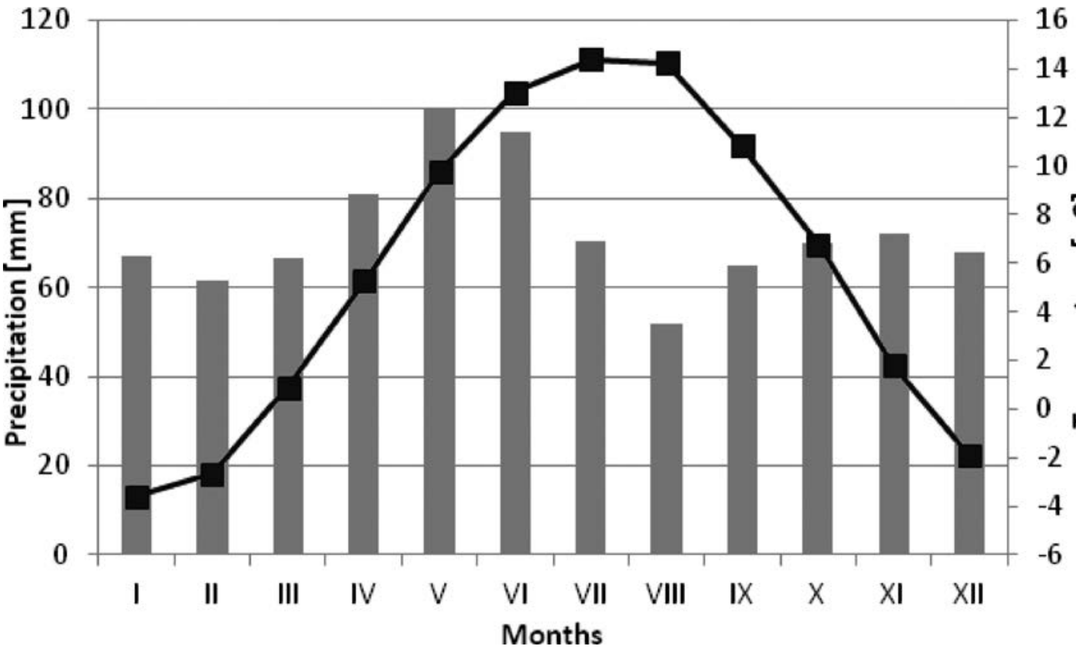

Figure 1: Monthly mean air temperature and monthly mean precipitation recorded at the Vlasina Meteorological Station (1968-2019).

Materials and Methods

No specific permissions were required to collect hydrographic data on Lake Vlasina and investigation of any biological species was not conducted in the field or in the lab. For determining the present state of the lake and its morphometric characteristics, Humminbird and Garmin were used for depth measurements. Further, determination of the cross sections of the lake was done by applying the dual analysis method that is comprised of satellite images (Sarch and Birkett 2000) and field cross sections that were determined with the Laica laser measuring device (Dolinaj et al., 2011). The bathymetric map of Lake Vlasina was created based on the information obtained. The intensity of the survey (L_r) is calculated as the ratio between the lake area in km^2 and the echo sounding track expressed in km. The accuracy of the bathymetric map was assessed with the information value (I), which indicates a completely accurate map when I=1.

Lake perimeters were calculated according to Wetzel and Likens (2000). Maximum length (*L*) is the maximum distance across the lake surface connecting the farthest two points on the opposite shorelines. Maximum width (*b*) represents the maximum distance between the shores that is orthogonal to the maximum length. Maximum depth (Z_{max}) is the deepest point measured in the lake. Lake surface area (A_o) is the surface of the lake when the areas of the islands are excluded. Shoreline length (S_L) is the total length of the lake shorelines. Average width (b_a) is calculated by dividing the surface area with the maximum length:

$$b_0 = \frac{A_0}{L}$$

Volume (*V*) is the amount of the water in the lake (m^3). Average Depth ($\bar{Z}$) is calculated by dividing the volume of the lake with the lake surface area:

$$Z = \frac{V}{A_0}$$

Relative Depth (Z_r) of the lake in % is calculated according to:

$$Z_r = 50 * Z_{max} * \frac{\sqrt{\pi}}{\sqrt{A_0}}$$

Shore Line Development (D_L) represents the ratio of the length of the shoreline to the length of the girth of an area of the circle that is equal to that of the lake:

$$D_L = \frac{S_L}{2 * \sqrt{A_0}}$$

If the ratio is closer to 1, the lake is more circular in shape and if the ratio is bigger than 1 that indicates that the shoreline is more irregular (serrated) and shows the potential for high biological productivity. Development of Volume (D_V) is calculated by using the maximum depth and the average depth as presented:

$$D_V = \frac{3Z}{Z_{max}}$$

In most cases, D_V >1 and it is greater in shallow lakes that have flat bottoms. Index of Basin Permanence (*IBP*) is an index that is calculated by dividing the volume of the lake by the shoreline length. This index demonstrates the littoral effect on the basin volume. For instance, in cases when *IBP* < 0.1, rooted aquatic plants prevail in the lake. This is an indicator of the age of a lake (Kerekes 1977). Calculation of the *A/V* ratio was conducted for the purpose of determining the potential rate of evaporation of lake water as well for the resistance of the water column to mixing (Barosso et al., 2014). The wave base depth (Z_{wb}) was calculated as:

$$Z_{wb} = (45.7 * \sqrt{A})/(21.4 * \sqrt{A})$$

where *A* is in km^2 (Håkanson, 2004). This was used for estimating the volume of the epilimnetic waters. Dynamic ratio (*DR*) is a parameter that is designed to represent the dynamic conditions on the lake bottom (Lindström et al., 1999). DR was calculated according to the equation:

$$DR = \left[\frac{\sqrt{A}}{Z}\right]$$

With *A* in km^2. The turbulence in the surface-water compartment is greater in large and shallow lakes (that have high *DR*) compared to smaller and deeper lakes (Håkanson, 2004). The methodology applied in this paper is different than the methodology that is usually used in limnological studies in Serbia, and as such, represents the first time such methods were applied in geographical and limnological research in our country, as well as a novelty and valuable asset for future researchers. The authors described a dependable methodology for the study of bathymetry and morphometry of lakes that are accepted and widely applied in studies worldwide.

Results and Discussion

The total bathymetric sounding survey track was 25.7 km, yielding a survey intensity (*Lr*) of 0.64. A total of 1587 valid depth points were measured. The shape of the lake is irregular and it stretches along the north-east axis. The central part of the lake is the widest (figure 2), and the narrow part is located in the north, where it gradually narrows until it reaches the dam.

Figure 2: Bathymetric map of Lake Vlasina.

Present morphometric data of Lake Vlasina are given according to the mean water level. The lake is 7.9 km long, it was measured with a broken line which connects the farthest point of the dam with the farthest southern shoreline. In literature the length of the lake is longer, stated as being 9 km (Stefanović, 1994; Stanković, 2005) and 10.5 km (Cvetković, 1985; Momčilović and Petronijević, 2009; Momčilović et al., 2010). At the widest part, the lake width is 2.25 km while Stanković (2005) stated that the largest width is 3.5 km. The mean width of 1.38 km is lesser than 1.77 km presented by Momčilović and Petronijević (2009). The eastern shoreline is a bit more jagged and its length is 24.6 km, in comparison to the western shoreline which is 14.2 km long. The total length of the shoreline is 38.4 km. It changes over the year as the water levels vary.

The depth of the lake varies in different parts. The narrowest part of the lake in the north has a mean depth of 10.3 m. The depth of the lake becomes greater in the middle part with an average depth of 12.7 m and its southern part is the shallowest, with 6.6 m (figure 2). The mean depth of the lake is 10.6 m, which is deeper that 10.3 m that can be found in literature (Momčilović and Petronijević 2009; Momčilović et al., 2010). This parameter is arguably the most useful morphometric characteristic available, because it could be related to the productivity and trophic status of lakes (Håkanson, 1981).

The wide bay on the eastern shoreline also has a large depth of 13.8 m. The largest depth of 25 m is located in the central part of the lake near the Dugi Del Peninsula while the largest depth presented by Stanoković (2005) is 22 m near the dam. In the northern part of the basin the direction of the largest depths coincide with the direction of the former riverbed of the Vlasina River. The average depth of Lake Vlasina is 11.3 m. Because part of the water is being released into the Vrla hydro power plant system, the depth is not constant. The area of the lake is 16.5 km^2, and it changes up to 33% when the water level is lowest and the area is 5.5 km^2. The average capacity of the lake basin is around $176x10^6$ m^3 which is bigger than the volume presented by Momčilović and Petronijević (2009), $165x10^6$ m^3 and Stanković (2005) 168 $x10^6$ m^3.

The lake form metrics were found to have the following values: the shoreline development index was 4.72 in contrast to 2.166 presented by Stanković (2005). According to the DL criteria proposed by Hutchison (Hutchinson, 1957) 2.5 < DL < 5.0, the shoreline form of can be regarded as subrectangular and elongated. The relative depth is 0.55%, the volume development is 1.27 thus indicating that the form of the basin is an overdeepened valley with a relatively flat bottom. This was further confirmed by applying the depth ratio ($\bar{Z}/Z_{max}$) as presented by Neumann (1959) who concluded that this ratio can provide helpful approximation for lake form. The depth ratio of Valsina Lake is 0.424 similar to that of shallow, flat bottom lakes with an ellipsoid form (Carpenter, 1983).

Special morphometry metrics show that the lake basin has a wave base depth that is an indicator of the depth of turbulent mixing of 2.13 m. Z_{wb} is a functional depth which separates areas of sediment transport that occur through resuspension by wind turbulence and areas in which sediment accumulates with no resuspension. This concept can also be useful for demarcating the boundary between epilimnetic (surface) and hypolimnetic (bottom) waters (Barosso et al., 2014). Another function of the Z_{wb} value of 2.13 m is that it can be used as a criteria for measuring the significance of the physical and chemical stratification of Lake Vlasina that occurs during the stratification season (Barosso et al., 2014).

The Basin Permanence Index, 4.58 m^3/km^{-1}, indicates that Lake Vlasina is not so suitable for the advancement of rooted aquatic plants and a littoral zone (Barroso et al., 2014). The ratio between maximum and average depth is 2.35. These results emphasize that the lake water has a low potential for evaporation and its potential for water column mixing is higher. According to these metrics Lake Vlasina is a flat-bottomed, overdeepened basin. The dynamic ratio (DR) had a value of 0.15 indicating the predominance of slope processes over wind/wave processes in sediment resuspension. As illustrated by Lindström et al (1999), the higher DR is usually measured at a lake which has larger bottom areas exposed to wind/wave energy. So it can be concluded that Lake Vlasina has smaller bottom areas exposed to wind/wave energy.

A distribution coefficient ($D_v/3$) can be used as a tool for determining the amount of sediment that is usable for resuspension on the erosion and transport areas, the part that goes into deep waters, and the part ($1-D_v/3$) that goes to surface waters (Håkanson et al., 2000). The results indicate that 42.4% of the eroded matter is transported to deep waters and 57.6% to surface waters.

The drainage basin of the lake also has a north-south orientation with 13 stream tributaries located along the shores, 8 tributaries to the east and 5 to the west. Lake Vlasina discharges into the Vlasina River through the dam in the north. The area/volume ratio is 0.09, indicating a deep basin with a small littoral zone.

Concluision

The methodology used for creating a bathymetric map and determining the morphometric characteristics of Lake Vlasina proved to be a good choice for estimating most morphometric characteristics of small to medium sized lakes. The accuracy of geographic positioning and the precision of depth measurement of the Humminbird and Garmin echo sounder enabled high quality and reliability of the final results presented in figure 2. The updated morphometric parameters presented in this study, together with the new bathymetric map of Lake Vlasina, are valuable tools that can contribute to the further promotion and a better understanding of one of the biggest and most precious lakes in Serbia. The geometry and bathymetry of Lake Vlasina plays a crucial role in the processes occurring within the lake. The bathymetric map presented in this study can be useful to compare changes in the lake's storage capacity and surface area in the near and distant future.

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