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Water Balance and Water Loss Implications in Badovc Lake, Kosovo

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Abstract

This paper aims to evaluate the water balance and possible water losses for Badovc Lake – Kosovo based on the hydrological monitoring made during the year 2014. A decrease of 1,000,000 m³of the lake physical volume, due to the sedimentation on the lake bottom, was revealed by the recent bathymetric survey which found that the current maximum volume (corresponding to height 649.75 mabove sea level (a.s.l)) of the Lake is 25,590,000 m³. The average annual rainfall of the basin was 860.7 mm, whereas the overall water inflow into the Lake was 22,577,663 m³. The annual amount of the calculated evaporation from the Lake surface was 849,535 m³ (or 644.50 mm), while an annual infiltration rate of 94,608 m³ through the clay screen was reported. A quantity of 10,550,615 m³ water was abstracted from the lake during 2014. A residual water volume of 11,082,905 was evaluated considering the above cited inflow and outflow quantities (22,577,663 m³ and 11,494,758 m³, respectively). On the other hand, the positive volume (7,344,000 m³) of the Lake in 2014, calculated according to water level variations, was3, 682, 905 m³ less than the above residual water volume. This difference between the above water volumes is considered as "water loss" from the Lake and it represents about 17% of the total volume of Lake, or 35% of its current water abstraction. This water loss from the lake was attributed to water infiltration through cracks that involved geological formations of the lake bottom and beneath its dam, possibly towards the nearest Hajvalia mine.

Keywords: Rainfall, lake water balance, water inflow and outflow, water runoff, evaporation and infiltration

1. Introduction

The dam of Badovc Lake, thatcrossed Graçanka river flow, was built in 1965 for agricultural irrigation and mining water supply while after 1980 it was used for drinking water supply of Prishtina city and its surroundings.

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The geology of Badovc basin consists of limestone, clastic formations, magmatic and metamorphic rocks, which are faulted and fissured to different extent (Elezaj and Kodra, 2008; Hyseni, 2000). The dam area is mostly composed of altered and fissured serpentinites with subordinate phyllite schist, clastic formations and gabbro-diabase rocks. A tectonic zone dipping just vertically is developed beneath the dam (Institute of Hydro-Economy "Jarosllav Çerni", 1982). Most of geological formations show low aquifer capacities and low permeability (ICMM, 2006) besides karstic limestone and intergranular alluvial sediments. The catchment area of Badovc basin, that is located in the north-eastern part of Kosovo (between 21º03' e 21º23' E and 42º40' e 42º36' N) (fig 1), is about 104.1 km² and lies from elevation 608 to 1200 m above sea level. It is characterized by a high vegetation cover where 90% are forests, 5% are cultivated land, 1.5% is water and 1.5% construction area. The Badovc basin comprises 7% gentle slopping, 25% undulating terrain, 42% rugged terrain and 26% steep mountains. Badovc catchment is characterized by a centripetal river patterns (comprising Mramur, Slivovë and Androvina rivers) that originate from surroundings highlands and drained towards the lake (fig. 1). The maximum values of surface and volume that correspond to highest water level in the lake (649.75 m a.s.l.) are 1.72 km² and 25,590,000 m³, respectively.

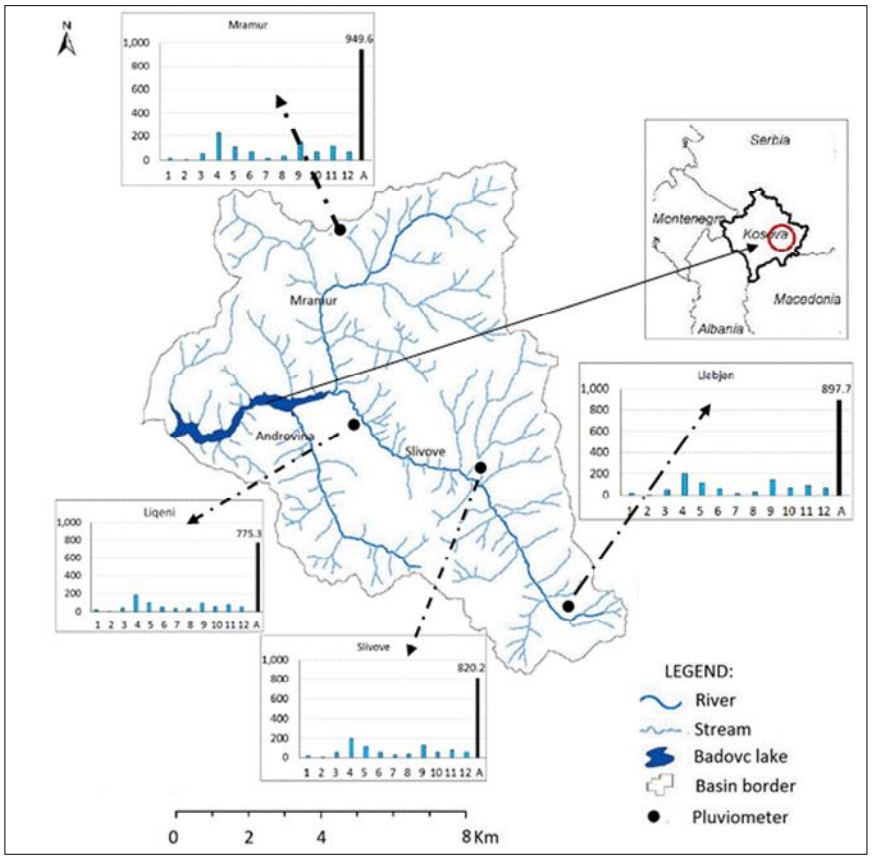

Figure 1: Hydrologic basin of Badovc, (Hydrographic network and Annual Rainfall Distribution for the year 2014 are shown)

The climate of the Badovc Lake basin is typically continental and according to historical data (Institute of Hydro-Economy "Jarosllav Çerni", 1982) average temperature is 10.4 ºC. Monthly temperatures and relative humidity ranged from 2°C (December) to 21.9°C (August) and from 86.1% (December) to 67.6% (August), respectively. Wind speed varied from 1.0 m/s (September) to 2.3m/s (February), whereas sunshine varied from 1.3 hours/day (December) to 11.0 hours/day (August) (HIK, 2014). The average historical rainfall (1947-1994) was 647.36 mm (HIK, 2014), whereas the monitored rainfall for 2014 was 859.95mm. The total water inflow and outflow for the year 2014 were 22,577,663 m³ and 11,494,758 m³, respectively. As from the variations of the lake water level, the change of lake water volume in 2014 was 7,344,000 m³.

On the contrary, the inflow-outflow water balance in the Lake showed a lack of 3,682,905 m³ water which is considered as a water loss from the lake (Bublaku and Beqiraj, 2014, 2015; Bublaku et al., 2015). In addition, the water level in Hajvalia mine was raised about 114m during the period 2004 – 2014 (from 386.0 m.a.s.l. in 2004 to 500 m a.s.l. in 2014), while pH value of mine water was increased from 6.5 to around 7.0 (Hajvalia Mine, 2014). Variation of above mentioned parameters favours the opinion of a possible hydraulic communication between the lake and mine which was stimulated from activation of the crack system due to mine explosions.

2. Materials and Methods

A digital Hydrograhic Echo Sunder-HydroBox2010 device, with measuring frequency every 5 sec, was used for generating bathymetric data which were then interpolated by the Arc-GIS for the construction of the Lake bathymetry. In 2013 four manual rain gauge with diameter 250mm have been installed for a daily monitoring of the rainfall in the basin. A continuous geodesic survey was applied for the monitoring of water level variations in the lake. The evaluation of the rivers flow was made across hydrometric regular profiles, where the water speed was measured with Flowatch-JDC instrument. The daily abstraction of water from the lake was provided by water supplier of Prishtina. Evaporation rates were calculated based on the meteorological data provided by the Institute of Hydrometeorology of Kosova. Finally, changes in lake water volume were used to calculate the rate of groundwater inflow and outflow.

3. Results and Discussions

3.1. Lake Bathymetry

The bathymetry survey of the lake bottom, that is the first one made since the closure of the lake (1965), was accomplished in October 2013. At the end of this survey, the bathymetry model of the lake was constructed and the volume and surface curves were generated (fig. 2). In addition, a volume of 1.000.000 m³ mostly fine sediments was deposited on the bottom of the lake (near the dam) since its closure, which represents a depletion of 3.9% of the total (25,590,000 m³) water storage capacity of the lake.

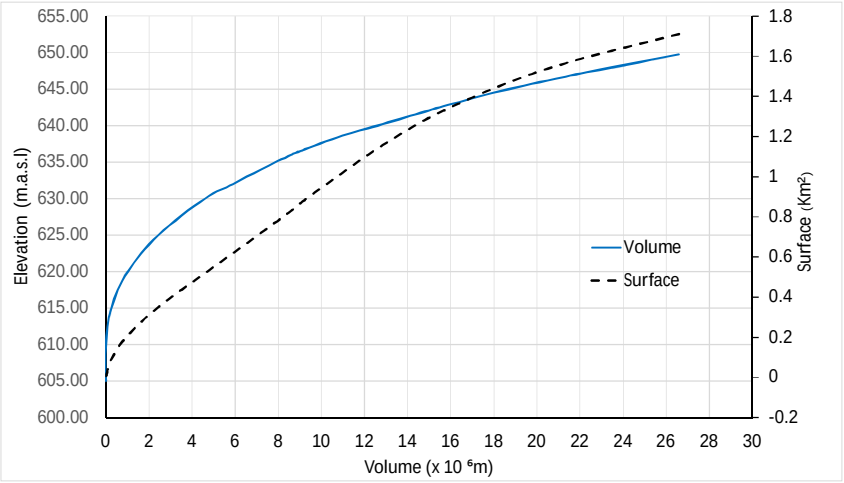

Figure 2: Volume and Surface Courves after Bathymetric Survey

3.2. Annual Inflow into the Lake

The first measurements of water inflow into the lake, which belong to dam design (1956-1962) time, reported an annual water inflow of 32,482.080 m³ (or 1.03 m³/sec) (Institute of Hydro-Economy "Jarosllav Çerni", 1982). The annual inflow for 2014 was 22,577,663 m³ (table 2) and it comprises (i) river flow to the Lake (V_S), (ii) volume of runoff from the catchment (V_R), (iii) volume of direct precipitation on the lake (V_P) and groundwater inflow (V_{GI}). The total volume of water that flew into the lake through three independent perennial tributary rivers (V_S) during the observation period (year 2014) was 18,198,579 m³ and represents about 83% of the total water inflow into the lake (table 1). Another important component of water inflow is direct overland flow (V_R) to lake (Neff and Killian, 2003)which, in our case, is 3,419,328 m³ and represents about 13% of the total runoff of the Badovc basin. Taking into account an average surface of the lake and depth of rainfall during the observation period (775.3 mm), the volume of rain water (V_P) falling direct over the lake was estimated to be 959,756 m³ (table 1). The total inflow into the lake was artificially modified because in April 2014 a water volume of 70,0000m³ was added into the lake due to the decrease of water in the lake under the minimum level of utilization (table 1).

3.3. Annual Outflow from the Lake

The water outflow from the lake comprises (i) evaporation from the lakesurface (V_E), water abstraction (V_A) and infiltration of water from the lake bottom (V_{GO}). The total volume of water abstracted from the lake (V_A) over the entire observation period (2014) for household purpose was 10,550,615m³ (table 1). The volume of water evaporated from the lake surface (V_E) was calculated using Pennman equation (Penman, 1948) and the results were compared with values obtained using Meyer equation (Show, 2005). The total evaporation from the lake surface was 849,535 m^3 (table 1). Evaporation was calculated based on temperature, relative humidity, windy speed and insolation data reported by the Hydrometer logical Institute of Kosovo (Institute of Hydro-Economy "Jarosllav Çerni", 1982). Groundwater flow to (V_{GI}) or from (V_{GO}) the lake is an important component of the lake water balance and the most difficult to quantify as it cannot be measured directly (Gebreslase, Hagos and Samuel, 2012). The interactions between surface (lake) water and groundwater (mine water) systems is controlled by hydraulic properties of lake beds (Sophocleous, 2001), but these properties are normally difficult to quantitatively assessed. The designed water infiltration from the lake dam (V_{GO}) was 94,608.00m³ (table1).

Table 1.Volume of Water Inflow and Outflow for the lake Badovc in 2014 (m3)

Inflow Volume components	Annual volume	Outflow volume components	Annual volume
V_S	18,198,579	V_A	10,550,615
V_R	3,419,328	V_{GO}	94,608
V_P	959,756	V_E	849,535
Total Inflow	22,577,663	Total outflow	11,494,758

3.4. Change in Lake Water Volume in 2014 (ΔV)

Changes in the water volume of Lake are calculated based on the fluctuations of water level in the Lake which, in turn, are a function of the balance between precipitation on the lake, runoff to the lake, evaporation, abstraction and groundwater outflow from the lake (Van der Camp et al., 2008). Water volume in Badovc Lake on January 01, 2014 was 9,509,000 m³ while on December 3aa2, 2014 it was 16,853,000 m³ that corresponds to water level 637.15 m and 643.60 m (a.s.l) and surface water area of 0.92km^2 and 1.38km^2, respectively (fig. 3). The lake water volume in 2014 was increased with 7,344,000 m³(table 2, fig. 4).

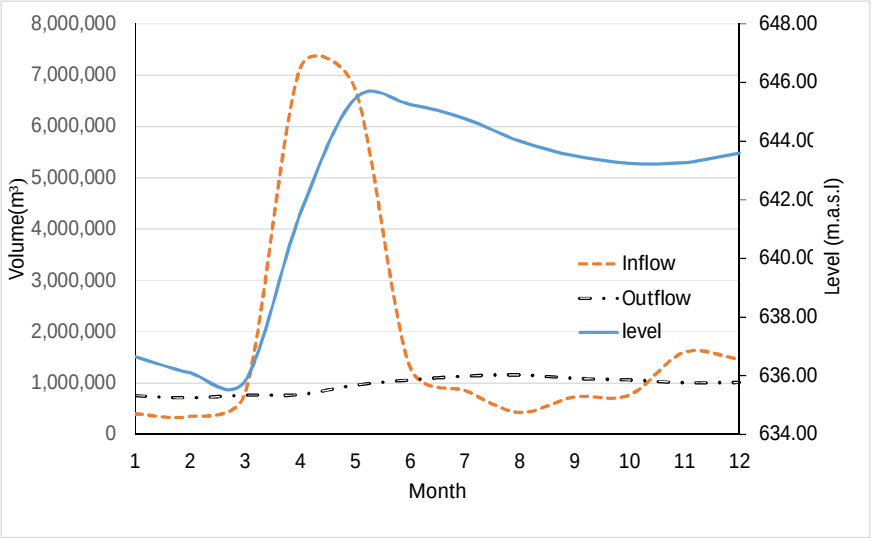

Figure 3: Volume Inflow and Outflow and Lake Water Level During 2014

3.5. Lake Water Balance

The water balance equations are based on the premise that the difference between water inflow and water outflow over a given time period for the hydrologic system of a lake must equal to the change in water storage in that system(Radwan, 2009). All of lake 's water gains and losses and the corresponding changes in the measured lake level over the same period are taken into account in order to compute the lake water budget, as it appears in the following equation (Gebreslase etal., 2012):

$$\Delta V=(V_P+V_R+V_S+V_{GI})-(V_A+V_E+V_{GO})$$

where:

ΔV=change in lake volume (m^3)
V_P=precipitation on the lake (m^3)
V_R=surface runoff from the catchment (m^3)
V_S=stream flow to the lake (m^3)
V_{GI}=groundwater inflow to the lake (m^3)
V_A= abstraction from the lake (m^3)
V_E= water evaporation from the lake (m^3)
V_{GO}=groundwater outflow from the lake (m^3)

Data collection of the water balance components of the lake was carried out throug 365 days. A water volume of 700000 m^3 was transferred from another lake to Badovc lake in April 2014 because of the water lack in this later and this quantity of water was considered as an additional inflow component in the lake water balance. The results of Badovc lake water balance in 2014 showed that inflow volume into the Lake was 22,577,663m^3, while outflow volume from the lake was 11,494,758 m^3. As it can be seen in fig. 4, where level and volume variations during 2014 are shown, the volume change during 2014 was 7,344,000 m^3 which is 3,738,905 m^3 less than the difference (11,082,905 m^3) between inflow and outflow water volumes (table 2, fig. 5).

3.6. Water Loss from the Lake

The above difference (3,738,905 m^3) in the Badovc lake water balance, which represents about 17% of annual inflow into the Lake for 2014, is considered as a water loss from the Lake and it can be attributed to groundwater outflow due to water infiltration through cracks and tectonic zones that involved geological formations of the lake bottom and beneath the dam (Bublaku and Beqiraj, 2014). In the vicinity of the Badovc Lake there are three mines, but Hajvalia mine is the nearest (less than one km distance, fig. 6) one and a possible hydraulic communication between lake and this mine can be assumed.

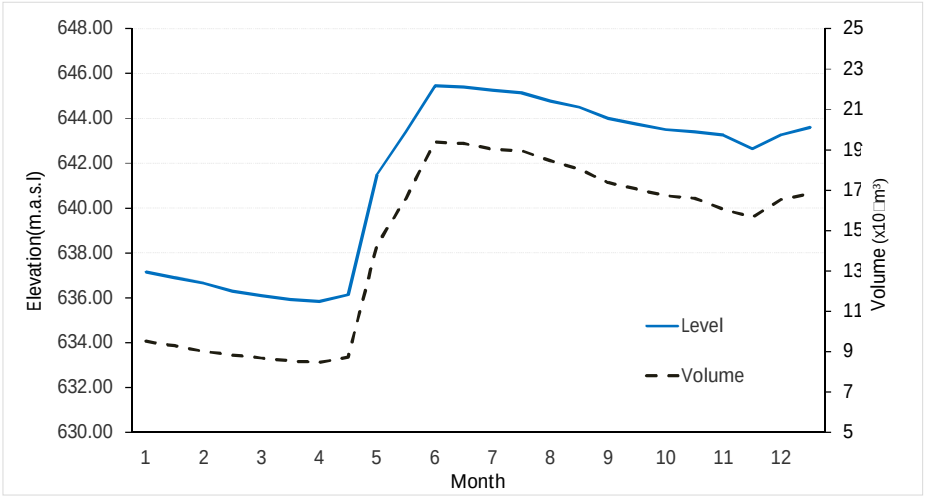

Figure 4: Level and Volume Variations for Lake Badovc During 2014

In fact, a raise of 114m of water level in abandoned Hajvalia mine was registered by the measurements performed from 2004 to 2014(Hajvalia Mine, 2014).

Another indicator of water infiltration from the lake towards mine voids is represented by the increase of pH value of mine water from 6.5 to 7.0 (Hajvalia Mine, 2014). Neither the raise of water level in the mine nor the increase of its pH value can be explained only with contribution of water infiltration from rainfalls into the mine. In fact, an amount of 2.5 million m^3 water could be expected to infiltrate to mine from its catchment area (1.5km^2) during the above period (2004-2014). On the other hand, a volume over 5.0 million m^3 water filling the empty spaces of the mine was calculated (Hajvalia Mine, 2014), which corresponds to the above water level raise in mine. Assuming that the whole infiltrated rainfall water drained somewhere prior to mine operation, we can consider that the above mine watering was related with groundwater outflow from the Lake. This can also be supported by the fact that no consolidation measures of the formations beneath the dam were undertaken during the closure of the lake. In addition, the mine explosions have possibly activited the crack systems of the bottom geological formations of the lake, favouring the downward infiltration of the lake water.

Table 2: Monthly and Annual Water Balance for the Badovc Lake, year 2014

Month	Level (m.a.s.l)	Inflow (m^3)	Outflow (m^3)	Volum change in the lake (m^3)	Inflow-Outflow (m^3)	Groundwater outflow (losses) (m^3)
	0	1	2	4	5=(1)-(2)	(4)-(5)
January	636.65	395,480	753,730	-497,000	-358,250	-138,750
February	636.10	348,500	709,970	-474,000	-361,470	-112,530
March	635.83	798,521	765,290	-73,000	33,233	-106,233
April	641.50	7,125,100	774,607	5,831,000	6,350,793	-516,793
May	645.45	6,748,712	960,103	5,087,000	5,788,610	-701,610
June	645.26	1,318,836	1,061,127	-360,000	257,709	-617,709
July	644.77	858,668	1,135,758	-567,000	-277,089	-289,911
August	644.00	425,000	1,160,069	-1,084,000	-735,069	-348,931
September	643.50	730,000	1,091,061	-650,000	-361,061	-288,939
October	643.25	765,000	1,062,666	-678,000	-297,666	-380,334
November	643.27	1,600,000	1,007,155	487,000	592,845	-105,845
December	643.60	1,463,542	1,013,223	319,000	450,320	-131,320
Annual		22,577,663	11,494,758	7,344,000	11,082,905	-3,738,905

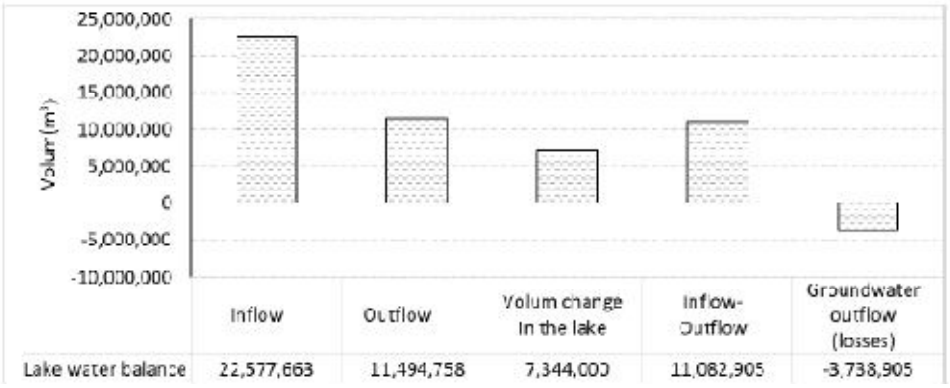

Figure 5: Annual Water Balance in Badovc Lake

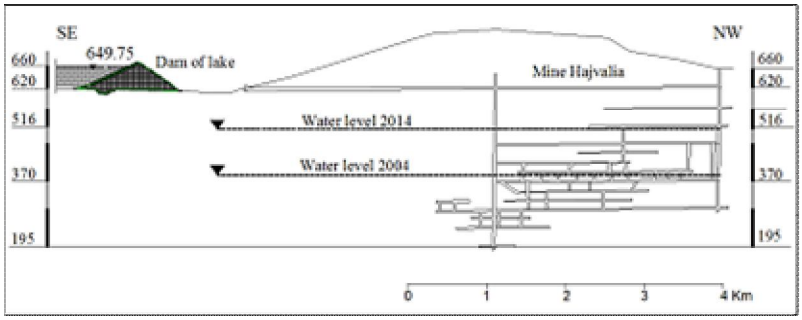

Figure.6: Cross Section from the Dam of Badovc Lake to Hajvalia Mine

4. Conclusions

Badovc catchment area is a typically closed centripetal river pattern, composed by low permeable, but highly faulted and fissured geological formations. The total water inflow volume into the Lake in 2014 was 22,577,663m³, while outflow volume from the lake was 11,494,758 m³.The lake water volume in 2014 was increased with 7,344,000 m³. Thus, a differenceof 3,738,905 m³ water resulted from the 2014 lake balance which was considered as water loss from the Lake due to groundwater outflow through fissure systems into the Hajmalia mine void spaces. The raise of 114m of water level in abandoned Hajvalia mine along with the increase of pH value of mine water from 6.5 to 7.0 are considered as two preleminary indicators in favor ofa possible hydraulic communication between lake and mine. The missing consolidation measures along with mining explosion works favored crack system of bottom formations to be further activated enhancing the infiltration rate.

5. Acknowledgments

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