Assessment of Water Losses from Badovc Lake, Kosovo: Hydrochemical Implications

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Abstract: This paper aims to quantitatively assess water losses of Badovc Lake-Kosovo based on both water balance of the lake and water hydrochemistry. This attempt was strongly prompted by both the importance of this lake for water supply of Prishtina city and the lack of water. According to lake water balance, a water loss of 3,738,905 m³ and 1,722,552 m³ for the hydrologic year 2014 and the period January-May (2015) was evaluated. These consistent data favour the opinion that a continuous groundwater outflow from the lake is present and it is conditioned by the intensively developed fracture system in the lake basement formations. This was also supported by the chemical data (chloride, sulphate, hardness and electric conductivity etc.) of the water. Water from the leakages on the right side of the dam shows the same chemical signature as the water from the lake. Whereas, water from the piezometer, monitoring well and the gallery of Hajvalia mine show similar values with those of the water from the lake. The calculations of the chloride mass balance showed that the fractions of lake and rainfall waters in the water mixture of Hajvalia mine were 67% and 33% respectively.

Key words: Chloride, mass balance, rainfall, lake water balance, water inflow and outflow, water runoff.

1. Introduction

The Lake of Badovc represents the main source for drinking water supply of Prishtina city. It was built in 1965 along the course flow of Graçanica river (Fig. 1). The geological formation where the dam is located is mostly composed of altered and fissured serpentinites with subordinate phyllite schist, clastic formations and gabbro-diorite rocks. A tectonic zone dipping just vertically is developed beneath the dam [1]. The catchment area of Badovc basin is about 104.1 km² and lies between elevations 608 m and 1,200 m above sea level. It is characterized by a high vegetation cover where 90% are forests.

Three rivers (Mramor, Slivov and Androvina) drain their waters into Badovc Lake. The maximum values of surface and volume that correspond to water level 649.75 m.a.s.l. are 1.72 km² and 25,590,000 m³ respectively. The average historical

rainfall (1947-1994) was 647.36 mm [2], whereas the monitored rainfall for 2014 and the period January-May (2015) was 859.95 mm and 345.27 mm respectively. A difference of 3,738,905 m³ water in the lake water balance for the year 2014, between inflows and outflows, was attributed to water losses from the Lake [3-6]. A water loss of 1,722.522 m³ was found in the lake water balance for the period January-May, 2015 too. Two groundwater emergences along the right slopes of the dam represent the best visible groundwater outflow from the lake (Fig. 2).

Drainage of lake water to mine voids was also confirmed by the data of water chemistry. In particular, the conservative ion of chloride was applied to show the hydraulic connection between lake and other hydrologic components of the watershed. According to results of chloride mass balance, 67% of the Hajvalia mine water comes from the lake, while 32% from the rainfall. This investigation will help the decision making authorities to better manage the water

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Fig. 1 Hydrologic basin of Badovc Lake (Hydrographic and pluviometric network and monthly rainfall distribution for the year 2015 (January-May) are shown).

Fig. 2 Leakage of lake water on the right side of the dam.

of the lake and to undertake measures to prevent further loss of the water.

2. Material and Methods

A digital Hydrographical Echo Sounder-HydroBox 2010 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 gauges with diameter 250 mm 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. Amount of evaporation is made with a measurement standard evaporation pan located close to lake.

Water samples from all the hydrologic components of Badovc lake were taken: four (B-4, B-5, B-6 and B-7) from the lake, two (B-9 and B-10) from leakages on the right side of the dam, two (B-12 and B-19) from the boreholes and two (B-13 and B-16) from the mine (Fig. 3). Sampling of water for chemical analysis in the lake and from wells was done with Staphylococcal Enterotoxin B Antiserum (SEBA) Liquid Sampler KLL-S. Chemical analysis are made in Chemical laboratory of the Institute of Hydrometeorology of Kosova.

3. Results and Discussion

3.1 Hydrology of Badovc Basin

During the period 2013-2015, several measurements of rainfall, water flows and evaporation etc. were made at Badovc basin aiming to determine water balance at the Lake. The bathymetry survey of the lake bottom was accomplished in October 2013.

At the end of this survey, the bathymetry model (Fig. 3) of the lake was constructed and the volume and surface curves were generated. 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. Annual amount of rainfalls for 2014, calculated according to the method of Thissenit [7] was 870.28 mm. Whereas, during the observation period January-May (year 2015) was 345.27 mm (Fig. 1, Table 1).

3.2 Water Inflow and Outflow of the Lake

The annual water inflow into the lake for 2014 was 22,577,663 m³ [3, 4] and it comprises: (i) River flow to the Lake (VS); (ii) Volume of runoff from the catchment (VR); (iii) Volume of direct precipitation on the lake (VP) and groundwater inflow (VGI). For the first five months January-May (2015), water inflow was 21,765,060 m³. The total volume of water that flew into the lake through three independent perennial tributary rivers (VS) during the above observation period (January-May, 2015) was 18,493,705 m³ and represents about 85% of the total water inflow into the lake (Table 2). In the same period, the direct surface

Fig. 3 Bathymetric map of the Badovc Lake where location of water samples is shown.

Table 1 Annual rainfall (in mm) for the Badovc basin (January-May, 2015).

Pluviometer station	P ₁	P ₂	P ₃	P ₄
Precipitation by station	334.0	331.0	343.0	364.2
Basin precipitation	345.27			

Table 2 Volume of water inflow (January-May, 2015).

Month	V _S	V _R	V _P	Total
January	3,159,145	472,924	54,145	3,686,214
February	4,391,712	657,439	125,600	5,174,751
March	6,613,013	989,968	150,801	7,753,782
April	2,916,120	436,543	65,493	3,418,156
May	1,413,716	211,633	106,808	1,732,157
January-May	18,493,705	2,768,508	502,847	21,765,060
Total Inflow	21,765,060			

Table 3 Volume of water outflow (January-May, 2015).

Month	V _A	V _{GO}	V _E	V _{OF}	Total
January	1,020,000	10,714	14,700	/	1,045,414
February	880,000	10,714	32,000	/	922,714
March	1,002,333	10,714	58,450	2,800,000	3,871,497
April	1,080,000	13,392	141,930	1,806,588	3,041,910
May	1,180,000	10,714	192,660	91,600	1,474,974
January-May	5,162,333	56,246	439,740	4,698,188	10,356,508
Outflow 2015	10,356,508				

runoff flow (VR) to lake [8] is 2,738,508 m³ and represents about 12.7% of the total runoff of the Badovc basin. The volume of rain water (VP) falling direct over the lake surface was estimated to be 502,847 m³ and represents about 2.3% (Table 2) of the total water inflow.

The water outflow from the lake is comprises of evaporation from the lake surface (VE), water abstraction (VA) and infiltration of water from the lake bottom (VGO). The overflow from the lake (VOF) represents an additional component of the water outflow from the lake.

The total volume of water outflow from the lake over the hydrologic year 2014 was 11,494,758 m³ [4], while for the first five months January-May (year 2015), water outflow was 10,356.508 m³. Water abstracted from the lake (VA) during the above period, used for household purpose was 5,162,333 m³ (Table 3). The volume of water evaporated from the lake

surface (VE) for the same period was 439,740 m³ and represents 252 mm. Groundwater flow to (VGI) or from (VGO) the lake is an important component of the lake water balance and the most difficult to quantify as it cannot be measured directly [9].

The designed water infiltration from the lake dam for January-May (year 2015) was 56,246 m³ (Table 3). During the month March-April (year 2015), an amount of 4,698,188m³ overflow (VOF) the dam of the lake because the water level in the lake raised above its maximum level (Table 3).

3.3 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 [10]. All of lake water gains and losses and the corresponding changes in the

measured lake level over the above period are taken into account in order to compute the lake water budget, as it appears in Eq. (1) [9]:

$$\Delta V = (VP + VR + VS + VGI) - (VA + VGO + VOF) \quad (1)$$

Where,

ΔV = change in lake volume (m^3);

VP = precipitation on the lake (m^3);

VR = surface runoff from the catchment (m^3);

VS = stream flow to the lake (m^3);

VGI = groundwater inflow to the lake (m^3);

VA = abstraction from the lake (m^3);

VE = water evaporation from the lake (m^3);

VGO = groundwater outflow from the lake (m^3);

VOF = overflow from the lake (m^3).

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 [11]. Water volume in Badovc Lake on January 1, 2014 was 9,509,000 m^3 while on December 31, 2014, it was 16,853,000 m^3 that corresponds to water level 637.15 m and 643.60 m.a.s.l (Fig. 4) respectively. In May 31 2015, water volume was 26,539,000 m^3 (Table 4) that corresponds to water

level 649.70 m.a.s.l (Fig. 4). The change of water volume in 2014 was 7,344,000 m^3 while in January-May (year 2015) was 9,686,000 m^3 (Table 4, Fig. 5).

3.4 Water Loss from the Lake

The results of Badovc lake water balance in 2014 showed that a difference in water volume of 3,738,905 m^3 between inflow into the Lake and outflow from the Lake existed. This amount represents about 17% of annual inflow into the Lake for 2014 and is considered as water loss from Lake [3, 4]. The water loss during the period January-May 2015 was 1,722,552 m^3 (Table 4) which is similar with that found for the same time period of the year 2014. Such a consistent difference in the water balance of the lake confirms that a continuous groundwater outflow from the lake happens and it is conditioned by the intensively developed fracture system.

3.5 Chemical Evidences of Water Lose

The above groundwater outflow, which represents the water loss from the Badovc Lake, was considered to drain mostly into the Hajvalia mine voids [3-5]. In order to confirm this opinion, the data of chemical analysis from several hydrological water components

Fig. 4 Volume inflow, outflow, overflow and lake water level during 2014 and 2015.

Table 4 Monthly water balance for the Badovc Lake (January-May, 2015).

Month	Level (m.a.s.l)	Inflow (m ³)	Outflow (m ³)	Volume of lake (m ³)	Volume change in the lake (m ³)	Overflow (m ³)	Inflow-Outflow w (m ³)	Groundwater outflow (losses) (m ³)
	0	1	2	3	4	5	6 = (1) - (2)	7 = (4) + (5) - (6)
January	643.60	3,686,214	1,045,414	19,131,000	2,278,000	0	2,640,800	-362,800
February	645.25	5,174,751	922,714	22,991,000	3,860,000	0	4,252,038	-392,038
23-March	649.75	4,569,203	794,982	26,590,000	3,599,000	0	3,774,222	-175,222
31-March	649.75	3,184,578	276,515	26,590,000	0	2,800,000	2,908,063	-108,063
April	649.75	3,418,156	1,235,322	26,590,000	0	1,806,588	2,182,834	-376,246
15-May	649.75	898,251	669,374	26,590,000	0	91,600	228,877	-137,277
31-May	649.72	833,906	713,999	26,539,000	-51,000		119,907	-170,907
Jan.-May		21,765,060	5,658,320		9,686,000	4,698,188	16,106,740	-1,722,552

Fig. 5 Water balance for the Badovc Lake (January-May, 2015).

of the Badovc watershed were confronted. In general, solutes that are present in groundwater are derived from two main sources [12]: (1) inputs from atmospheric precipitations and (2) acquisition during weathering and water-rock interaction. According to their behaviour, the chemical signatures are divided into inert and reactive tracers and they may be used effectively to derive physical parameters such as recharge rates and mixing [13]. Among the inert tracers, chloride is the most useful because it is highly mobile and is not involved in the common geochemical reactions that occur in groundwater. In addition, chloride is a conservative element with a mobility in water very similar to the water molecules [14]. Based on the chloride content in the sampled waters (Table 5, Fig 6), it may be seen the strong

influence of the lake water in the waters from leakages on the right side of the dam, piezometer and Hajvalia mine gallery. At the same conclusion could be arrived considering the content of sulphates and values of general hardness and electric conductivity of the water (Table 5, Figs. 7-9). Thus, water from the leakages, piezometer and Hajvalia mine gallery may represent a mixture between lake and rainfall waters. In this case, mixing between two waters may often be estimated from a simple mass balance as from Herczeg and Edmunds [13]:

$$[Cl]_M = x \times [Cl]_A + (1 - x) \times [Cl]_B$$

Where, $[Cl]_M$ is the Cl concentration in the mixture (water of Hajvalia mine gallery), x is the fraction of water A (rainfall water, $Cl = 1.92$ mg/L) and $1-x$ is the fraction of water mass B (lake water, B-4, B-5,

B-6 and B-7). With assumption that the mixing process is conservative with respect to solutes, water fractions of rainfall and lake mixed to give water of Hajvalia mine gallery were evaluated to be 33% and 67% respectively. In the case of water leakages (B-9 and B-10), the fractions of rainfall and lake water are estimated to be 8% and 92% respectively, showing a stronger influence of the lake water. The fractions of lake and rainfall water in the mixture depends on the seasons when the measurements are made. One could

expect higher influence of water from lake during the drying periods and vice versa. Finally, the extent of lake water influence in other water drainages is conditioned by the permeability of fracture systems that serves as pathways for ground water flow.

4. Conclusions

The lake of Badovc is characterized by a consistent water loss caused by the groundwater outflow from the lake thanks to intensive fracture system developed

Table 5 Chemical composition of water.

Parameters	Unit	B-4	B-5	B-6	B-7	B-9	B-10	B-19	B-12	B-13	B-16
Temperature	°C	15	13.5	9.5	12.5	15.7	15.5	-	13.7	14.1	22.8
pH		9.7	9.9	8.2	9.5	5.7	5.5	7.76	8.37	8.1	6.56
Dissolved oxygen	mg/L	8.66	8.71	-	8.7	7.44	7.41	-	4	7.3	1.1
Electric conductivity	µS/cm	317	263	271	250	264	262	455	746	1,030	1,703
Total dissolved solids	mg/L	159	138	135	126	134	133	227	375	515	852
General hardness	d°H	12.15	12.01	11.26	11.76	11.56	11.91	15.18	30.03	40.81	58.4
Ca ²⁺	mg/L	58.14	57.53	52.93	56.13	22.05	19.44	24.1	24.46	56.94	281
Mg ²⁺	mg/L	24.31	23.98	23.3	23.62	51.12	55.43	71.3	160.5	198.1	116
Na ⁺	mg/L	4.101	4.086	4.176	4.083	2.846	2.869	2.797	6.316	4.528	22.1
K ⁺	mg/L	2.244	2.319	2.484	2.251	0.14	0.227	0.294	4.144	2.994	26.1
NH ₄ ⁺	mg/L	nd	nd	nd	nd	0.585	nd	0.011	nd	nd	nd
NO ₂ ⁻	mg/L	0.141	0.133	0.109	0.137	0.148	0.19	0.038	0.075	0.126	0.1
NO ₃ ⁻	mg/L	0.3	0.3	0.3	0.3	0.2	0.3	0.3	1	0.7	0.2
HCO ₃ ⁻	mg/L	245.2	251.3	226.9	228.1	259.9	258.6	361	568.5	789.3	921
SO ₄ ²⁻	mg/L	35.5	35.4	40.4	43.6	39.1	48.9	36.7	232	269.7	435
Cl ⁻	mg/L	11.1	11.35	11.46	11.31	10.38	10.4	13.25	6.37	8.09	18.8
PO ₄ ³⁻	mg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.099	< 0.01	0.06	< 0.01
H ₂ SiO ₃	mg/L	0.997	nd	nd	0.034	0.777	1.859	0.91	14.03	0.86	4.23

Fig. 6 Variation of chloride content in the waters from different sites of Lake Badovc.

Fig. 7 Variation of sulphide content in the waters from different sites of Lake Badovc.

Fig. 8 Variation of hardness values in the waters from different sites of Lake Badovc.

Fig. 9 Variation of nitrate content in the waters from different sites of Lake Badovc.

through the lake basement geological formations. This water loss represents about 17% of the total water inflow into the lake. The water emergences on the right side of the dam represent the best visible exhibition of the groundwater outflow from the lake. The chemical signatures of water further supported the loss of water from the lake.

The water from the gallery of Hajvalia mine represents a mixture of lake and rainfall water in proportions 67% and 33% respectively.

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