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Assessment of water losses from Badovc Lake, Kosovo: Isotopic 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 isotopic composition of H-2 and O-18. According to lake water balance, a water loss of 3,738,905 m³ for the hydrologic year 2014, 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 isotopic analysis (H-2 and O-18) of the sampled waters. Most of water samples taken from hydrologic components of Lake Badovc fall on a linear plot of δ^2H versus $\delta^{18}O$ showing an isotopic variation typical for waters evaporated from a lake and fits very well with Global Meteoric Water Line (GMWL), while two rain water samples are isotopically lighter (more negative δ values). Water samples taken from water leakages on the right side of the dam, the piezometer, two wells drilled in the valley downstream of dam, Hajvalia mine gallery and the water flow downstream of the dam, have isotopic composition similar with that of the lake water. Water of Hajvalia mine well shows isotopic composition that falls between that of rain water and lake water. Considering δ values of rain water (δ^2H= -129.6‰, $\delta^{18}O$= -16.56‰) and lake water (δ^2H= -67.2‰, $\delta^{18}O$= -9.20‰) and mine water (mixture) (δ^2H= -73.3‰, $\delta^{18}O$= -10.15‰) was found that the fraction of rain water in mine water ranges from 6% (according H-2) to 10% (according O-18), while the fraction of lake water in mine water varies from 94% (according H-2) to 90% (according O-18).

Keywords: isotopic composition, isotopic mass balance, rainfall, lake water balance, water loss.

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1. INTRODUCTION

Badovc Lake, that is built in 1965 along the course flow of Graçanca river, represents the main source for drinking water supply of Prishtina city. Its watershed consists of limestone, terrigenous formations (ophiolitic melange, sandstone, siltstone, mudstone), magmatic (gabbro-diabase, andesite, peridotite) and metamorphic (quartz-mica schist, chlorite schist, sericite schist, phyllite, gneiss, marble) rocks (Elezaj and Kodra, 2008). The geological formation where the dam is located is mostly composed of altered and fissured serpentinites. Water inflow in the lake for 2014 was 22,334,517 m^3 (table. 1) 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}). A water volume of 700,000 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 Water outflow from the lake comprises (i) evaporation from the lake surface (V_E), water abstraction (V_A) and infiltration of water from the lake bottom (V_{GO}). The total volume of water outflow from the lake over the hydrologic year 2014 was 11,295,420 m³ (table. 1). 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 *(Bublaku and Beqiraj, 2014, 2015)*. Most of loosed water from the lake was drained to Hajvalia mine voids as confirmed by the data of isotopic (H-2 and O-18) composition of water sampled. In fact, water of Hajvalia mine well shows isotopic composition that falls between that of rain water and lake water on the linear plot of δ^2H versus δ^{18}O. In this case, the isotopic composition of the mixture (mine water) of various proportions of the two waters (rain and lake) will lie on the straight line connecting the δ values of the two waters and is determined by isotope mass balane *(Cook and Herczeg, 2000)*:

$$\delta_1 n_1 + \delta_2 n_2 + \delta_3 n_3 .... = \delta_f (n_1 + n_2 + n_3 ....$$

where δ_1 is the δ value of component 1, n_1 equals the amount of substance in component 1, and δ_f is the δ value of the product. Rain water has δ^2H= -129.6‰ and δ^{18}O= -16.56‰ while lake water has δ^2H= -67.2‰ and δ^{18}O= -9.20‰. Water of mine (mixture) has δ^2H= -73.3‰ and δ^{18}O= -10.15‰. By knowing the isotopic composition of two waters that are mixed, was found that the fraction of rain water in mine water ranges from 6% (according H-2) to 10% (according O-18), while the fraction of lake water in mine water varies from 94% (according H-2) to 90% (according O-18).

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. Measurement of evaporation is made with a standard evaporation pan located close to lake. Calculation of the annual water budget components is made through direct measurements and calculations. The precipitation on the lake (Vp) is calculated from measurements rain gauge located near the lake. Amount of water surface runoff from the catchment (V_R) is calculated based on the determination runoff coefficient by measurements stream flow to the lake. Stream flow to the lake (Vs) is calculated by flows measurements in three independent perennial tributary rivers that flew into the lake. Abstraction of water from the lake (V_A) is calculated by daily amount abstraction water provided by water supplier of Prishtina. 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). Changes in the water volume of Lake (ΔV) 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.

25 water samples were taken for isotopic analysis of H-2 and O-18 (Fig. 2). Water was filled in 50 ml, double capped, polyethylene bottle directly from the water source, without any sample filtration or preservation. Isotopic analysis of H-2 and O-18 are made at the Chemical-physical Laboratory of Institute of Geoscinces and Georesources, Pisa, Italy. Deuterium was directly measured in the vapour phase of the water molecule, the instrument use was Liquid Water Isotope Analyzer (LWIA) produced by Los Gatos Research (LGR) which is based on technic of cavity ringdown spectroscopy (CRDS). Standard di riferimento: SMOW *(Standard Mean Ocean Water) (Craig, 1961).*

Oxygen-18 was determined through isotopic equilibration of water with CO_2 at 25°C and isotopic analysis of CO_2 by mass spectrometer type MAT 252 produced by Finningan. Standard di riferimento: SMOW (Standard Mean Ocean Water) *(Craig, 1961).*

3. GEOLOGICAL OVERVIEW

Badovc basin belongs to Vardar zone which represents the boundary between Drino-Ivanica (as peripherical part of Dinaride zone) and Serbia-Macedonian massif *(Elezaj and Kodra, 2008).* It consists of limestone, terrigenous formations (ophiolitic melange, sandstone, siltstone, mudstone), magmatic (gabbro-diabase, andesite, peridotite) and metamorphic (quartz-mica schist, chlorite schist, sericite schist, phyllite, gneiss, marble) rocks (fig.1). Serpentinites, which are the most spread formations at the dam zone, occurs as irregular lenses with dimensions that range from several meters to some kilometers. Serpentinites have schist and/or netting structure and are intensively fractured where cracks and cleavages are filled with calcedone, opal, carbonate and argyle. The presence of an almost vertical tectonic zone *(Institute for Hydro-economy "Jarosllav Çerni", 1982)* in the dam profile complicates the situation of water drainage from Lake toward underground waters. Serpentinite formations are separated in several big blocks due to tectonic faults and gabbro intrusions. The tectonization of serpentinites was probably caused by orogenic movements and Miocene vulcanization in this region *(Hyseni, 2000)*. Tectonic faults are mainly overthrust type but there are also some strike slips. The complex geological construction of catchment area determined formation of several aquifer types *(KPMM, 2006)*.

Low-permeable fissured aquifer – It is related with metamorphic schists, serpentinites, gabbros, diabases and is mainly charged by rainfalls and discharges through springs with yield under 1.0 l/s, which emerge through weak tectonic zones. Accumulation of underground water in these rocks is controlled by the development of fissure system which has conditioned a high variation of spring yields that ranges from 0.01 l/s to 1.0 l/s.

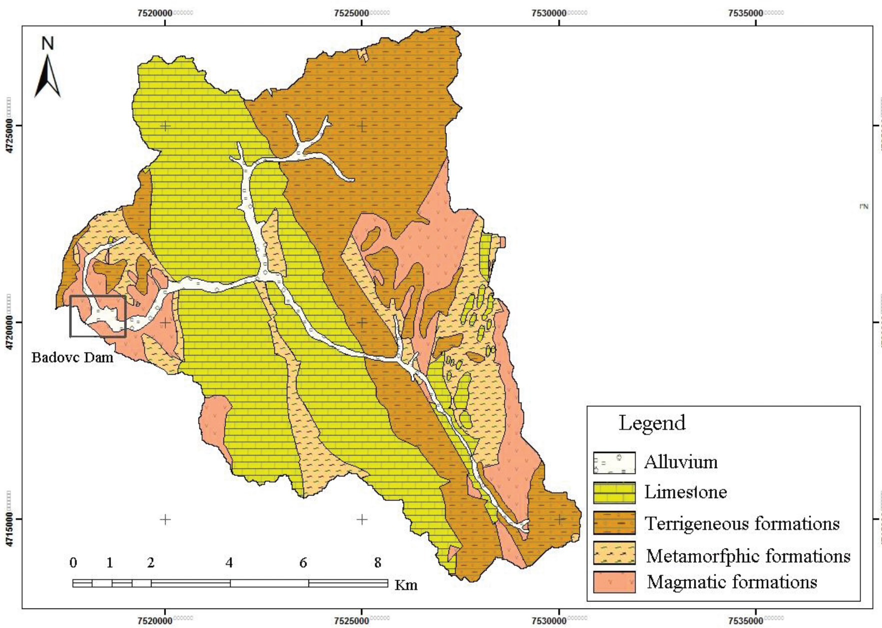

Fig. 1. Geological map of Badovc basin, scale 1:100.000 (KPMM-2006)

Karst aquifer – it is related with limestone which present an important aquifer. Springs that emerge from these rocks have yields over 1.0 l/s.

Porous aquifer – it is related with alluvial formations which present the most important aquifer of the basin. Its thickness ranges from 3 to 7m. This aquifer is mainly developed through river valleys. Water yields of wells opened in these formations ranges from 2 to 10 l/s.

4. 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 *(Gebreslase, Hagos and Samuel, 2012; 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 for 365 days. The results of Badovc lake water balance in 2014 showed that inflow volume into the Lake was 22,334,517 m^3, while outflow volume from the lake was 11,295,420 m^3. As it can be seen in (table. 1), where level and volume variations during 2014 are shown, the volume change during 2014 was 7,341,000 m^3 which is 3,698,097 m^3 less than the difference (11,039,097 m^3) between inflow and outflow water volumes (table 1).

Water inflow in the lake for 2014 was 22,334,517 m^3 (table. 1) 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}). A water volume of 700,000 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 water outflow from the lake comprises (i) evaporation from the lake surface (V_E), water abstraction (V_A) and infiltration of water from the lake bottom (V_{GO}). The total volume of water outflow from the lake over the hydrologic year 2014 was 11,295,420 m^3 (table. 1).

Table 1: Monthy and annual water balance for the Badovc Lake, year 2014

Month	Level (m.a.s.l)	Inflow (m³)	Outflow (m³)	Volum change in the lake (m³)	Inflow-Outflow (m³)	Groundwater outflow (losses) (m³)
	0	1	2	4	5=(1)-(2)	(4)-(5)
January	636.65	392,622	754,602	-412,000	-361,980	-50,020
February	636.10	345,455	715,546	-422,000	-370,091	-51,909
March	635.83	791,971	771,313	-213,000	20,658	-233,658
April	641.50	7,071,817	778,195	5,834,000	6,293,622	-459,622
May	645.45	6,691,739	961,415	5,087,000	5,730,324	-643,324
June	645.26	1,308,136	1,069,970	-360,000	238,166	-598,166
July	644.77	788,884	1,119,282	-567,000	-330,398	-236,602
August	644.00	421,489	1,101,856	-1,084,000	-680,367	-403,633
September	643.50	724,771	1,031,265	-650,000	-306,494	-343,506
October	643.25	758,906	1,019,451	-678,000	-260,545	-417,455
November	643.27	1,587,383	973,002	487,000	614,381	-127,381
December	643.60	1,451,344	999,523	319,000	451,821	-132,821
Annual		22,334,517	11,295,420	7,341,000	11,039,097	-3,698,097

5. WATER LOOSES

The results of Badovc lake water balance in 2014 have shown a difference in water volume of 3,698,097 m³ between inflow and outflow into the Lake. This amount represents about 17% of annual inflow into the Lake for 2014, and is considered as water loss from Lake and 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. Near the Lake there are three mines, but Hajvalia mine is the nearest one and a possible hydraulic communication between lake and this mine can be assumed. In fact, a raise of 114 m of water level in abandoned Hajvalia mine was registered by the measurements performed from 2004 to 2014 *(Hajvalia Mine, 2014)*. Assuming that the whole infiltrated rainfall water drained downward as groundwater 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 order to confirm this opinion, the data of isotopic analysis from several hydrological water components of the Badovc watershed were confronted (Table 2).

6. ASSESSMENT OF WATER LOSSES FROM THE LAKE BY USING ISOTOPIC COMPOSITION OF H-2 AND O-18 IN WATER

Stable isotopes have been among the most used techniques for solving problems of age, origin especially of pathways of the water movement in a watershed *(Michener and Lajtha, 2007)*. Stable isotopes of water (hydrogen (^{2}H or D for Deuterium) and oxygen (^{18}O) have been used since the pioneering work of (*Craig ,1961)*. Unlike applied tracers, stable isotopes are added naturally at the watershed scale by rain and snowmelt events. These environmental isotopes can be used to trace and identify different air and water masses contributing precipitation to a watershed since the stable isotope composition of water changes only through mixing and well-known fractionation processes that occur during evaporation and condensation *(Michener and Lajtha, 2007)*. Once in the subsurface, and away from evaporative effects, the stable isotopes of water are conservative in their mixing relationships. This means that isotopic composition of the mixture of two water sources will fall on a strait line and is position is dependent only on the proportions of the two sources *(Michener and Lajtha, 2007)*. ^{2}H and ^{18}O, the elemental basis for H_2O molecules, are ideal tracers because they behave exactly as water would as it undergoes transport through a watershed. Oxygen – 18 and deuterium occurs in water at abundances of 0.204% pf all oxygen atoms and 0.015% of all hydrogen atoms, respectively *(Clark dhe Fritz, 1997)*. These relative abundances change slightly as a result of thermodynamic reactions that fractionate or partition atoms of different mass (isotopes). Isotopic fractionation is strongly temperature dipendent such that it is greater at low temperature *(Majoube, 1971)*. Under equilibrium conditions, the heavy isotopes are always enriched in the more condensed phases because they have lower rates of evaporation, i.e. lower rates of diffusion across the water-atmosphere layer *(Gat, 1996; Kendall dhe Caldwell, 1998; Mook, 2000)*.

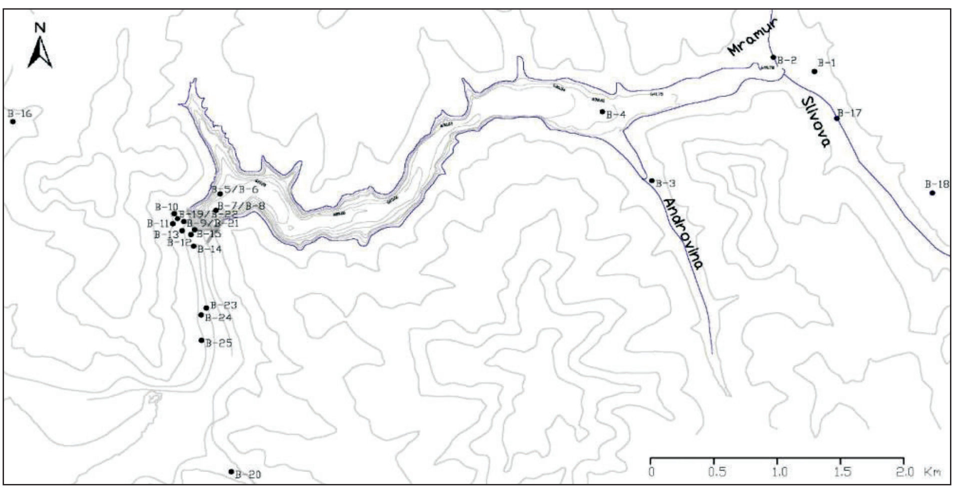

Fig. 2- Topographic map of the Badovc basin where sampling points are shown

Table 2. Isotopic composition of Oxygem-18 and Deuterium of Badovc water

No. Sample	Location	Oxygen-18 (V-SMOW)	Deuterium (V-SMOW)
B-1	River Mramor	-9.73	-68.1
B-2	River Slivovë	-10.15	-71.9
B-3	River Androvinë	-9.83	-68.6
B-4	Lake	-9.37	-67.9
B-5	Lake	-9.2	-67.2
B-6	Lake	-9.3	-67.3
B-7	Lake	-9.35	-67.6
B-8	Lake	-9.23	-66.9
B-9	Upper leakage	-8.85	-65.4
B-10	Lower leakage	-9.07	-66.5
B-11	Stream	-8.47	-63.3
B-12	Well no. 1	-8.7	-63.8
B-13	Gallery of Hajvali	-8.85	-64
B-14	Well no. 2	-8.78	-63.5
B-15	Pellg nën dige	-8.17	-60.2
B-16	Hajvalia well	-10.15	-73.3
B-17	Rain water	-16.56	-129.6
B-18	Rain water	-16.12	-129.1
B-19	Piezometer	-8.65	-63.6
B-20	Mine Kishnice	-9.97	-71.5
B-21	Lower leakage	-9.02	-65.4
B-22	Piezometer	-8.9	-65.7
B-23	Spring	-8.66	-64.6
B-24	Spring	-8.7	-65.1
B-25	Water flow downstream of the dam	-8.7	-64.2

Most of water samples taken from hydrologic components of Lake Badovc (fig. 2) show an isotopic variation typical for waters evaporated from a lake and fits very well with Global Meteoric Water Line (GMWL) *(Craig, 1961)* (Table 2; Fig. 3). Two rain water samples are isotopically lighter (more negative δ values) and fall below the GMWL being compatible with a high quota lake or with evaporated clouds.

Lake water shows uniform isotopic composition. Water samples fallen within blue circle have isotopic composition similar with that of the lake water that means these waters are derived from the lake (Fig. 4). Water of Hajvalia mine well shows isotopic composition that falls between that of rain water and lake water.

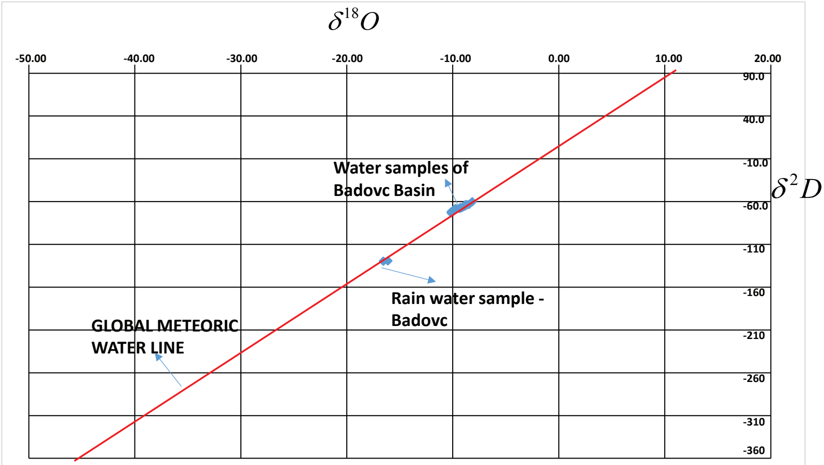

Fig. 3. Isotopic composition of sampled waters confronted with Global Meteoric Waters

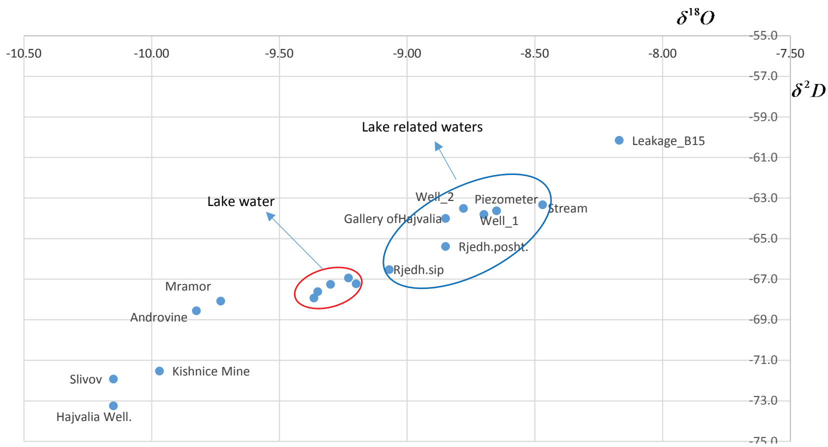

Fig. 4. Variation of δ^2D versus δ^{18}O for sampled waters

The isotopic composition of substances formed by combining two or more components with different isotopic compositions is additive, and is determined by isotope mass balane *(Cook and Herczeg, 2000)*(equation 1)

$$\delta_1 n_1 + \delta_2 n_2 + \delta_3 n_3 .... = \delta_f (n_1 + n_2 + n_3 .... \qquad (1)$$

where δ_1 is the δ value of component 1, n_1 equals the amount of substance in component 1, and δ_f is the δ value of the product. In our case, rain water and lake water represent two end members, while the final component is represented by Hajvalia mine water. Because all the samples fall on a linear plot of δ^2H versus δ^{18}O, the isotopic composition of the mixture of various proportions of the two waters will lie on the straight line connecting the δ values of the two waters. Rain water has δ^2H= -129.6‰ and δ^{18}O= -16.56‰ while lake water has δ^2H= -67.2‰ and δ^{18}O= -9.20‰. Water of mine (mixture) has δ^2H= -73.3‰ and δ^{18}O= -10.15‰. By knowing the isotopic composition of two waters that are mixed, one can determine the fraction derived from each component. Fractions of rain water and lake water in this mixture are determined by equation 2:

$$n_{rain}\delta_{rain} + n_{lake}\delta_{lake} = n_{\min}\delta_{\min} \ldots\ldots. \qquad (2)$$

$$(-129.6)n_{rain} + (-16.56)n_{lake} = (-73.3)(n_{rain} + n_{lake}) \qquad \text{for deuterium}$$

and

$$(-16.56)n_{rain} + (-9.20)n_{lake} = (-10.15)(n_{rain} + n_{lake}) \qquad \text{for oxygen 18}$$

Because we have only two end members, it is true the equation

$$n_{rain} + n_{lake} = n_{\min} = 1 \ldots\ldots. \qquad (3)$$

By solving the above equations was found that the fraction of rain water in mine water ranges from 6% (according H-2) to 10% (according O-18), while the fraction of lake water in mine water varies from 94% (according H-2) to 90% (according O-18). The deviation between two estimates (H-2 and O-18) is only 4% which is lower than the range of acceptable values (5-10%) (*Cook and Herczeg, 2000)*.

7. CONCLUSIONS

A difference in water volume of 3,698,097m³ between inflow and outflow into the Badovc Lake resulted by its water balance for the year 2014. This water volume vis considered as water loss from Lake and 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.Hajvalia mine is the nearest one and a possible hydraulic communication between lake and this mine was assumed and this was confirmed by isotopic data of oxygen 18 and deuterium.Water of Hajvalia mine has isotopic composition that falls between that of rain water and lake water, showing that its water represents a mixture of rain water and lake water.The fraction of rain water and lake water in the water of Hakvalia mine ranges from 6% (according H-2) to 10% (according O-18), and from 94% (according H-2) to 90% (according O-18), respectively.

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