Quantification of the hydrological components to estimate water balance of lake Badovc, Kosovo

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Abstract: This paper aims to quantify the hydrological (Rainfalls, surface runoff, stream inflow, evaporations, water level fluctuation and abstraction) components of Lake Badovc watershed for the period 2013-2015. For the scope of water administration of the lake, it is important to understand which factors are affecting the unexpected lowering of water level in Lake Badovc. The main hydrological components are quantified based on the annual (501.6, 871.36 and 626.0mm) rainfalls measured during the observation (year 2013, 2014 and 2015, respectively) period. The lowest (92.1 mm) runoff value was in 2013 which represents 18.3% of annual rainfalls, while the highest (250.1 mm) one was in 2015 representing 40.0% of annual rainfalls. Real evaporated rainfalls from catchment are almost equal for each monitored year. Contribution of groundwater discharge in the amount of water runoff for each monitored year is more than 50%. High (417.8mm) water infiltration rates were found in 2014 and they are considered to be caused by low soil moisture conditions and high amount of rainfall. Water loss from lake and low runoff rate from catchment basin are the main factors affecting the water level in Lake Badovc. An average annual deficit of 3,701,327 m3 was found in lake water balance calculations which was considered as water loss from the lake.

Key-Words: rainfall, lake water balance, water runoff, evapotranspiration, infiltration, groundwater discharge.

1 Introduction

The Lake of Badovc represents one of the main sources for drinking water supply of Prishtina city which is the capital of Kosova. The catchment area of Lake Badovc, that is located in a distance of 6.5 km from Prishtina, is about 104.1 km^2. The recently consistent growth of population of the city, followed by respective increase of water demand, has further evidenced the importance of the Lake in this regard. In general, the rates of water abstraction from the Lake have been lower than water demands due to the lack of water in the Lake, as showed by its low water level. The lowest (635.83 m.a.s.l) lake water level was registered in April 2014 which corresponds to the minimum lake water volume. In fact, an average water inflow of 1.05 m^3/s to Lake Badovc was calculated since the Badovc dam design in 1965 [1], [2], but the annual average abstracted water from the lake, through all its operational time, was less than 0.40 m^3/s [2],[3]. The quantification of hydrological components and successive water balance computation was the best way to evaluate this discrepancy. A water balance, which is an accounting of all water entering and leaving a water body, for a given period of time, can be mathematically expressed as “inflow equals outflow plus change in storage” [4]. Thus, water balance computation in 2014 found a difference of 3,738,905 m^3 water between water inflow in the lake and water outflow from the lake [5] that was not equal to the change in lake water volume, as might be expected [6]. This difference is considered as water loss from the Lake and could be attributed to groundwater outflow through geological formations of the Lake bottom [5]. The same water losses from the lake are founded by lake water balance computation of the year 2015 and they have been also confirmed by water chemical and isotopic investigations [7, 8]. Fundamental components of the hydrologic cycle, such as precipitation, runoff and evapotranspiration have been computed in the frame of water balance studies on small catchments [9]. The historical (1948-1998) rainfall for Lake Badovc watershed was 647.36 mm [2], [10], whereas the average monitored rainfalls for the period 2013-2015, calculated according to Thiessen's polygons method, were 666.3 mm [11], [12]. Year 2013 was characterized by very low (501.31 mm) rainfall, whereas year 2014 was the highest (871.17mm) rainfall one not only for the monitored (2013-2015) period, but also in the last fifty years. Runoff is a term that describes that part of precipitation that makes its way towards streams, channels, lakes or oceans as surface or subsurface flow. There are four paths which water may enter a water body in a watershed: direct precipitation, overland flow, shallow subsurface stormflow and groundwater flow [13]. Computed water runoff of Badovc basin for the observation period was very low ranging from 92.1 mm to 214.52 mm for the year 2013 and 2014, respectively. These values represent only 18.3 and 24.6 % of the respective 501.6mm (2013) and 871.36mm (2014) amount of annual rainfalls. Low water runoff means the highest amount of water are loosed through evaporation and infiltration process.–Potential evapotranspiration is defined as the rate at which water, if available, is lost from wet surfaces and plant surfaces [14], and losses to regional groundwater through infiltration process represents water that leaves the watershed as groundwater and thus does not contribute to streamflow [15]. Evaporated water from catchment for the period April-September involved almost all amount of rainfalls and is similar through three monitored years. The amount of underground water in the basin Badovc is very scarce and it has no importance for the water balance. Portion of the infiltrated water goes back to the surface as groundwater discharge into water runoff. Groundwater discharge is that part of streamflow which is ground water that was discharged to the stream channel upstream of the measuring point [16]. For the monitored (2013-2015) period as a whole, this amount computed with Graphical Method (Constant Slope Method) [17], [18] was 317.05 mm and it represents more than 50% of the water runoff amount. Low rainfall in 2013 was accompanied by low moisture in soil which was followed by high (417.02mm) rates of infiltration. The relationship between runoff and rainfalls, expressed by runoff coefficient, for three monitored years, is 0.278, that converted to flow, it is 0.61 m³/s. This value is evidently lower compared to the average runoff flow computed when the Lake Badovc dam was built. The precipitations are mostly lost through evaporation and infiltration processes. Low rate of runoff and water losses from lake through geological formations seems to be the major factors for low water level and the lack of water in the Lake Badovc. Quantification of the hydrological components of Lake Badovc watershed for the period 2013-2015 in this paper clearly shows which factors are affecting the unexpected lowering of water level in Lake Badovc.

2 Materials and methods

The boundary of the catchment area of the Badovc basin was determined from the Digital Elevation Model (DEM) of Kosova by using ArcGIS software. A digital Hydrographic Echo Sunder-HydroBox2010 device was used to generate bathymetric data. These later were used for the construction of the Lake bathymetry and computation of the current volume of the lake. In 2013 four manual pluviometers with diameter 250mm have been installed for a daily monitoring of the rainfall in the basin which were incorporated into Thiessen's polygons method to compute rainfall in the basin. The evaluation of the rivers flow was made across hydrometric regular profiles, where the water speed was measured with Flowatch-JDC instrument. A standard evaporation Pan was located close to the lake to measure the evaporation. A continuous geodesic survey was applied for the monitoring of water level variations in the lake. The meteorological data were taken from the Institute of Hydrometeorology of Kosova. The daily abstraction of water from the lake was provided by water supplier of Prishtina. Potential water evaporated from the lake surface and evapotranspiration from basin were calculated using Penman equation. Constant slope method and water balance of basin is used to determine amount of water loss through soil infiltration process and discharged water which is a part of water runoff.

3 Description of study area

The Badovc drainage basin (Fig. 1) is located in the north-eastern part of Kosovo, between 21º03' e 21º23' E and 42º40' e 42º36' N and it has a total area of 104.1 km². Its dam crosses Graçanka river flow, which is a branch of Sitnica River and belongs to

Iber basin. The Badovc drainage basin occurs about 6.5 km far from Prishtina and lies from elevation 600 to 1200 m above sea level. In Badovc catchment area, that consists of three main rivers (Mramur, Slivovë and Androvina), four drainage sub-basins are distinguished: drainage sub-basins I, II and III discharge water into the lake through rivers Slivova, Androvina and Marmur, respectively, while sub-basin IV discharges water through overland flow (Fig. 1). Lake Badovc was built in 1965 for agricultural irrigation and mining water supply, but after 1980 it was used for drinking water supply of Prishtina city and its surroundings. The maximum values of surface and volume of Lake Badovc, that correspond to water level of 649.75 m.a.s.l, are 1.72 km² and 26,590,000 m³, respectively

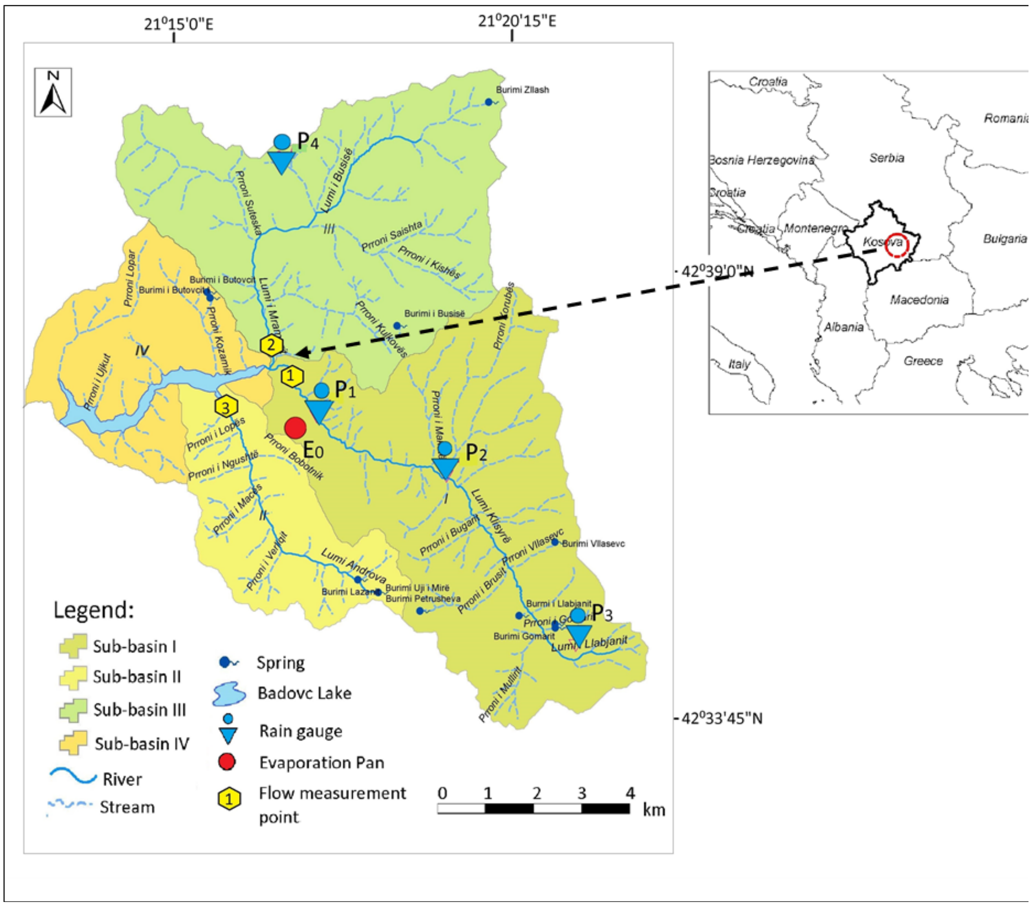

Figure 1: Hydrologic drainage basin of Lake Badovc (Hydrography, Rain and Flow measurement points and Evaporation Pan, are shown)

4 Results

4.1 Change in lake water volume, (2013 - 2015)

Changes in lake water volume are calculated based on the fluctuations of water level in the Lake which, in turn, are function of the balance between precipitation and runoff to the lake, on one hand, and evaporation, abstraction and groundwater outflow from the lake, on the other [19]. Water volume in Lake Badovc on January 01, 2013, January 01, 2014, January 01, 2015 and December 12, 2015 was 14,870,000 m³, 9,509,000 m³, 16,853.00 m³ and 20,840,000 m³, corresponding to water level 642.00m, 637.15m, 643.60 and 646.40 m.a.s.l, respectively (Table 1, Fig. 2). During the month March-April (year 2015) an amount of 4,698,188 m³ overflow (V_{OF}) the dam of the lake because the water level in the lake rose above its maximum level Water volume change in the lake for year 2013 was negative (-5,361.000 m³), while for years 2014 and 2015 it was positive (7,377,000 and 3,987,000 m³, respectively) (Table 1).

Table 1. Variation of water level and volume in Lake Badovc (2013-2015)

Date/Month/Year	Lake water level (m.a.s.l)	Lake volume (m^3)	Volume change in the lake (m^3)
01.01.2013	642.00	14,870,000	
01.01.2014	637.15	9,509,000	-5,361,000
01.01.2015	643.60	17,246,000	7,737,000
31.12.2015	646.40	20,840,000	3,987,000

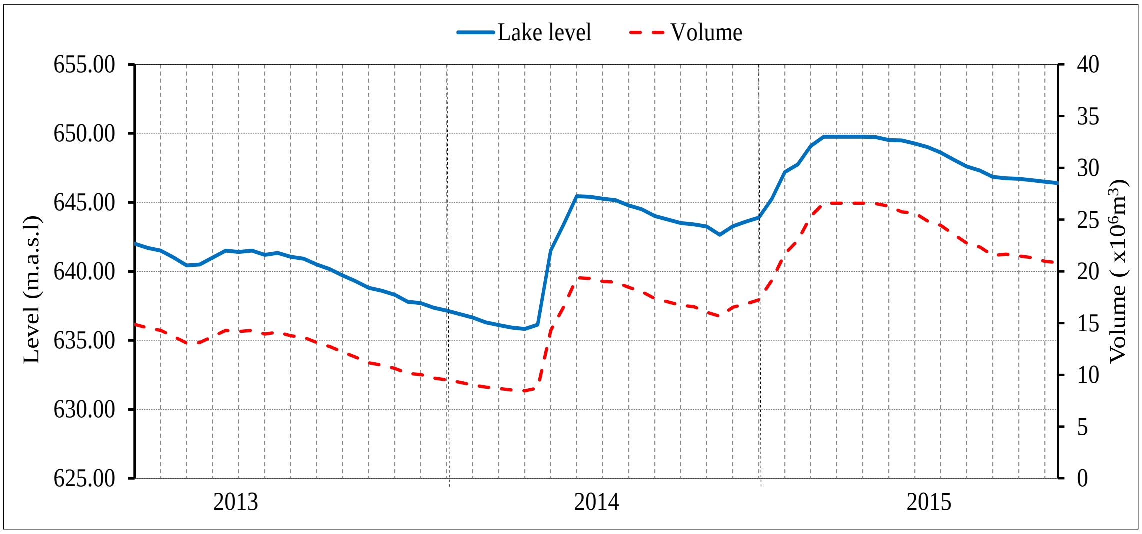

Figure 2: Level and volume variations for Lake Badovc (2013-2015)

4.2 Rainfall

Rain gauges used to monitor the rainfalls are located in such a way to register the representative rainfall amount of the basin (Fig.1). The annual amount of rainfalls for each year are calculated according to Thiessen polygons method, [11], [12] The amount of rainfalls was 501.60 mm, 871.36 mm and 626.00 mm for the year 2013, 2014 and 2015, respectively (Table 2)

4.3 Runoff

Runoff gauged portions of each subbasin have been considered to calculate the total runoff of the Lake Badovc basin. Inflow from rivers (Slivova ,Mramuri and Androvina) was continuously measured across hydrometric regular profiles (No.1,2 and 3, respectively) (Fig. 1) during the years 2014 and 2015. Direct overland flow to the lake from sub basin IV, which represents around 13% of the total runoff of the Badovc basin, is calculated based on runoff gauged portions of the other three sub basins. The water runoff of the basin was computed for the monitored (2013-2015) period taking into account the weighted rainfalls. The amount of water runoff was 92.08 mm, 214.52 mm and 250.10 mm for the year 2013, 2014 and 2015, respectively (Table 2).

4.4 Evaporation and Evapotranspiration

Water loss through both evaporation and evapotranspiration (ET) is one of the major components of the hydrologic cycle affecting water resources availability [20]. The water evaporation from Lake surface, computed using the Penman equation [21], was 588.33, 506.63 and 603.31 mm, for the years 2013, 2014 and 2015, respectively. The potential evapotranspiration of catchment area, calculated using the Penman-Monteith method (FAO-56 Method) [22], while real evapotranspiration was 204.18, 239.83 and 220.8 mm (Table 2), for the years 2013, 2014 and 2015, respectively.

Table 2. Rainfall, runoff, evapotranspiration and infiltration, (mm) (2013-2015)

	Rainfall			Runoff			Evapotranspiration			Infiltration		
Month	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
January	52.43	19.93	65.96	5.49	3.75	35.43	1.59	6.99	3.37	45.35	9.18	27.16
February	46.71	3.62	81.32	3.30	3.34	48.43	17.03	0.27	14.07	26.38	0.00	18.82
March	49.22	54.22	99.79	14.17	7.58	73.84	32.25	26.63	25.94	2.79	20.01	0.00
April	19.52	205.97	42.22	18.06	67.98	32.64	1.45	39.06	9.58	0.00	98.94	0.00
May	60.09	105.44	58.45	11.53	64.48	16.31	48.56	40.96	42.13	0.00	0.00	0.00
June	39.54	62.20	38.42	10.73	12.49	8.37	28.82	49.71	30.05	0.00	0.00	0.00
July	33.96	24.51	2.52	6.35	8.11	6.95	27.60	16.40	0.00	0.00	0.00	0.00
August	6.25	33.31	55.89	3.39	3.96	2.22	2.86	29.35	53.22	0.00	0.00	0.45
September	79.61	137.29	50.29	3.32	6.69	2.42	34.06	20.37	34.47	42.23	110.23	13.40
October	39.64	66.24	96.69	5.26	7.15	6.08	9.79	8.73	5.52	24.59	50.37	85.09
November	60.91	94.02	30.97	4.91	15.11	9.03	0.16	1.35	1.70	55.84	77.56	20.24
December	13.74	64.61	3.49	5.56	13.87	8.37	0.00	0.00	0.01	8.17	50.74	3.10
Annual	501.60	871.36	626.00	92.08	214.52	250.10	204.18	239.83	220.08	205.34	417.02	168.26

4.5 Infiltration

Water arriving at the ground surface may be accumulated on the surface, infiltrated into the forest floor and soil, and/or flow over the surface. The water, that infiltrates downward, partially enters the soil and is lost" in regional groundwater (G) [15] while the remaining water emerges back to the surface representing groundwater discharge (R_G). Water balance equation (3) and (4) are used to quantify these two components [15]:

$$P = R + E + \Delta S \ldots .(3)$$

$$\Delta S = G + R_G \ldots \ldots \ldots (4)$$

Where:
P=Rainfall (mm)
R=Runoff (Streamflow) (mm)
E=Evaporation (mm)
ΔS= Change in water storage (mm)
G= Water (mm) that leaves the watershed as ground-water through infiltration process which does not contribute to stream flow. Computed amount of water infiltration was 205.34, 417.02, and 168.26 mm for the year 2013, 2014 and 2015, respectively (Table 2).
R_G= Ground-water discharge which represents the ground water that has discharged from the aquifer to the stream channel, upstream of the measuring point [15].

. According to results, the discharged groundwater amount for each of three monitored years represents over 50% of runoff. The highest (417.02 mm) groundwater losses through infiltration process belong to year 2014 and are considered to be conditioned by both the highest (871.36 mm) amount of rainfall during this year and the lowest soil moisture conditions during the year 2013 due to low (501.31 mm) rainfall.

4.6 Lake water balance

All 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 the change in water storage [30]: Water budget of Lake Badovc was made by using the following equation (2) [6]:

$$\Delta V= (V_P+V_R+V_S+V_{GI}) - (V_A+V_E+V_{GO}+V_{OF})\ldots (2)$$

Where:
Δ_V=change in lake volume (m³)
V_P=precipitation on the lake (m³)
V_R=surface runoff from the catchment (m³)
V_S=stream flow to the lake (m³)
V_{GI}=groundwater inflow to the lake (m³)
V_A= abstraction from the lake (m³)
V_E= water evaporation from the lake (m³)
V_{GO}=groundwater outflow from the lake (m³)
V_{OF}=overflow from the lake (m³)

Water inflow to the lake for the year 2015 was 26,444,716 m^3 (Table 3) 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}). On the other hand, water outflow from the lake, which comprises (i) evaporation from the lake surface (V_E), (ii) water abstraction (V_A), (iii) infiltration of water from the lake bottom (V_{GO}) and overflow from the lake (V_{OF}), was 13,988,452 m³ (adding the amount water overflow 4,698,188m³). The computation of 2015 lake water balance found that a difference in water volume of 3,771,076 m^3 between water inflow and outflow which is similar with that revealed from the lake water balance of the hydrological year 2014 (3,738,905 m³) (Table 3).

Table 3. Computation of Lake Badovc water balance for the year 2015

Month	Level (m.a.s.l) 0	Inflow (m³) 1	Outflow (m³) 2	Volume change in the lake (m³) 4	Overflow (m³) 5	Inflow-Outflow (m³) 6=(1)-(2)	Groundwater outflow (losses) (m³) 7=(4)+(5)-(6)
January	643.60	3,726,688	1,052,713	2,278,000	0	2,673,975	-395,975
February	645.25	5,096,343	849,811	3,860,000	0	4,246,532	-386,532
March	649.75	7,755,408	1,077,028	3,599,000	2,800,000	6,678,380	-279,380
April	649.75	3,427,834	1,220,613	0	1,806,588	2,207,221	-400,633
May	649.72	1,745,161	1,500,433	-51,000	91,600	244,728	-204,128
June	649.26	893,568	1,463,605	-789,000	0	-570,037	-218,963
July	648.60	725,600	1,284,519	-910,000	0	-558,919	-351,081
August	647.60	270,000	1,221,463	-1,280,000	0	-951,463	-328,537
September	646.85	276,646	1,168,699	-1,220,000	0	-892,053	-327,947
October	646.70	694,108	1,055,142	-680,000	0	-361,034	-318,966
November	646.50	959,252	1,011,914	-330,000	0	-52,662	-277,338
December	646.40	874,108	1,082,513	-490,000	0	-208,405	-281,595
Annual		26,444,716	13,988,452	3,987,000	4,698,188	12,456,264	-3,771,076

5 Discussion

The recorded rainfalls in the basin during the monitored period 2013-2015 showed both monthly and annual variations. Thus, the lowest (501.31 mm) rainfall was registered in 2013 which were accompanied by low water flow of rivers and, consequently, low level of water in the lake. On the contrary, the highest (871.17 mm) rainfall is registered in 2014 which is the highest rainfall year in the last fifty years, as well. Finally, the 2015 average rainfall was 626.36 mm and fits the average historical (647.36 mm) rainfall.

The above variation of annual rainfall amount along with variable grade of soil moisture conditioned different amount of water runoff in Badovc basin. Thus, the lowest rainfall year (2013) was characterized by a runoff amount of 92.08 mm water which represents only 18.5 % of rainfalls (Table 2). The ground water discharge of 60.5 mm was responsible for 65% of the water runoff amount, as it could be expected by low rainfall scenario. About 81.5% of the annual rainfalls were loosed through real evaporation and infiltration. Main amount of water runoff into the lake happened during the spring (March- May) season and almost all amount of rainfall during the period May-August was evaporated because of high temperature. Water loss through infiltration process (groundwater recharge) happened during the low-temperature (autumn – winter) period, correlating with low evaporation rates (Fig. 3).

Water runoff in 2014 was much higher than in 2013 but lower than in 2015, even the highest (871.36mm) rainfall registered in 2014. The reason was high (417.02 mm) infiltration rate through an unsaturated soil profile due to low amount of rainfall during the previous (2013) year. The highest infiltration rate during the year 2014 belongs to low-temperature winter period, as well (Fig 3). High moisture conditions of soil at the end of year 2014 and high amount of rainfall at the beginning of year 2015 caused higher runoff rate in 2015 (Fig. 3).

The average annual rainfall for the three above three monitored years was 666.3 mm which is slightly higher compared to the long-term (647.36mm) rainfall amount. The relationship between runoff and rainfalls for 2013, 2014 and 2015, expressed by runoff coefficient, was 018, 024 and 0.40, converted to flow, it is 0.30, 0.71 and 0.82 m^3/s. The average relationship for three monitored years was 0.278, converted to flow, it is 0.61 m^3/s. The main amount of water runoff into the lake occurred during the period March-June, where groundwater discharge represents the main (57.0%) water source. The rates of evapotranspiration are similar through three monitored years showing the highest values during the period April-July, when all amount of rainfall was evaporated and soil had water deficit (Fig 3).

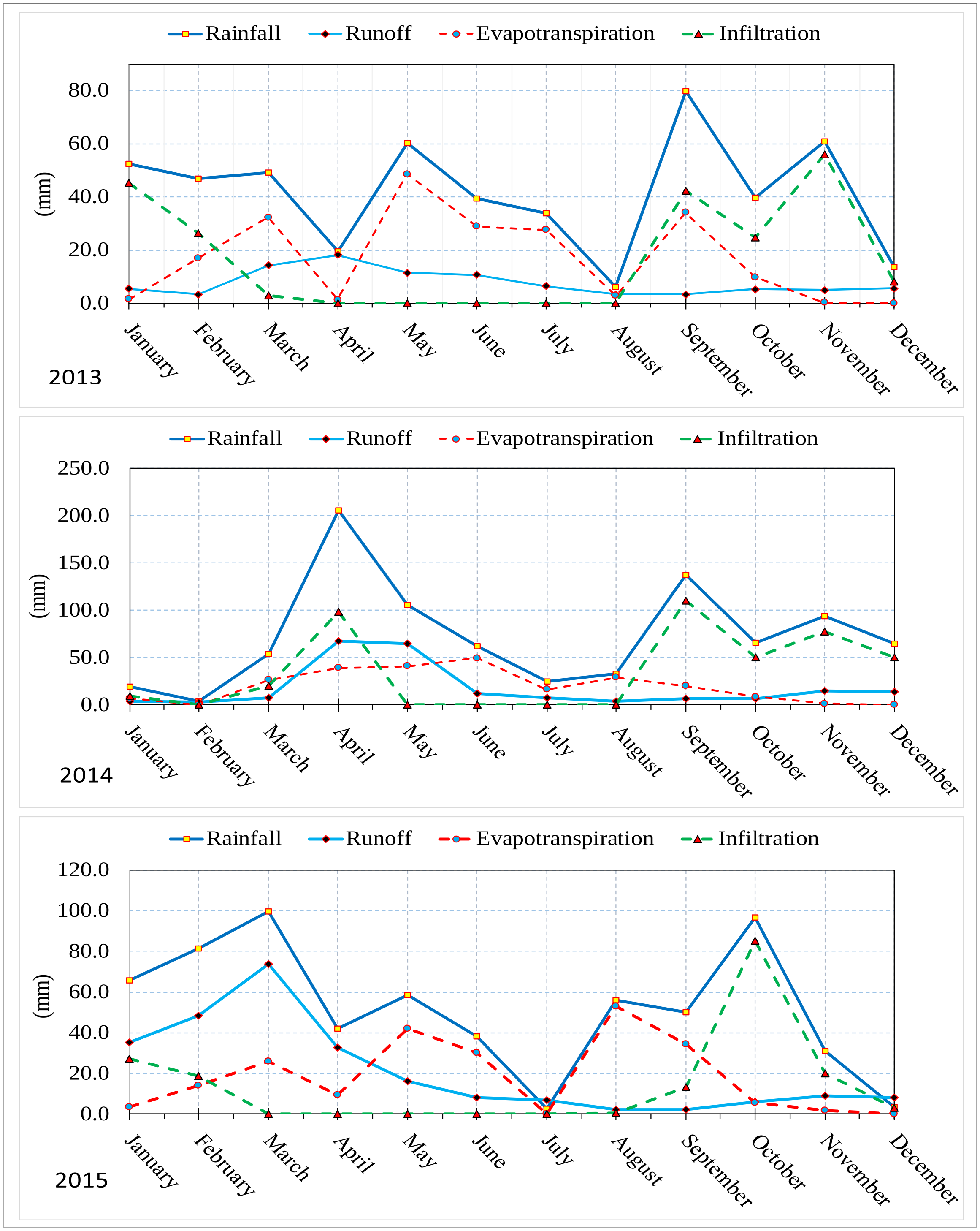

Figure 3. Monthly hydrological components of Badovc drainage basin for the period 2013-2015

Computations of lake water balance for the period 2013 - 2015 found an annual difference of 3,701,327 m^3 water which is considered as water loss from the Lake. This water loss was attributed to infiltration of water through the intensively fissured geological formations of the lake bottom and beneath its dam [7], [8]. This amount represents 35% of the current water abstraction which is a great concern due to very high losses amount.

The chemical and isotopic (O-18 and D) signatures of water from lake and the nearest Mine Hajvalia further supported the loss of water from the lake to the voids of Mine Hajvalia due to infiltration through the fissured geological formations [7], [8]. The isotopic balance showed that the contribution of lake water to mine water ranges from 90% (according O-18) to 94% (according H-2) [8].

6 Conclusions

The variation of hydrological conditions of Badovc watershed for the period 2013-2015 were directly reflected in water level and water volume of Lake Badovc. The recorded average rainfalls (663.3 mm) were slightly higher than the long term historical average (647.36mm) value.

The relationship between runoff and rainfall was 0.278, or converted to flow, it is 0.61 m^3/s. This value is evidently lower than water inflow (1.01m^3/s) computed during the building of the Lake Badovc dam. Evapotranspiration and groundwater loss are higher compared to water runoff. These hydrological components are among the factors responsible for the lack of accumulated water in the lake. Losses from lake due to water infiltration, which represent 35% of abstracted drinking water, is another factor for the low water level and the lack of water in the Lake Badovc. Authorities should take measures to reduce losses caused by the infiltrations and review the rates of water abstraction under the current hydrological conditions. Understanding the change of hydrological conditions is important for the planning of water usage from the lake. Also it is important to consider hydrological conditions in the context of dry and wet periods since changes in hydrological components are visible. The relationship between runoff and rainfall is expected to be lower in the future assuming that precipitation would be lower than the current average. Annual rainfalls which were quite different in years 2013 and 2014 along with very low water runoff rate should be taken into consideration as indications of climate change which had their impact on the hydrological conditions of the region.

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