THE HYDROLOGICAL BUDGET OF LAKES. CASE STUDIES FÂNTÂNELE AND IZVORUL MUNTELUI RESERVOIRS (ROMANIA)

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Abstract

Studying evaporation, one of the key factors in the hydrological balance, is important for proper management of water resources stored in reservoirs. Therefore, the main objectives of this paper are: (i) to analyze the temporal variability of the evaporation and (ii) to estimate the impact of this process on the water balance by using the hydrological budget equation. Two reservoirs were considered in this study, located in different geographical regions in Romania – Fântânele reservoir (area of 3.25 km^2 and water volume of 31.7 mil. m^3), located in the southwest of the country, in a plain region (102 m a.s.l. altitude), and Izvorul Muntelui reservoir (area of 31 km^2 and water volume of 1230 mil. m^3) in the Eastern Carpathians, at 540 m a.s.l. altitude. The analysis is based on direct measurements of water evaporation and other climatic parameters (air temperature, relative humidity, wind speed and precipitations) during 1961-2012. The analysis shows that the amount of water evaporated from the surface of Fântânele reservoir reaches 655 mm/year, with the maximum value in July (120 mm). For Izvorul Muntelui reservoir, the evaporation of 595 mm/year is lower, due to the mountainous climate, and the maximum evaporation doesn't exceed 100 mm/month in the summer months (July and August). In summer (June – August), the water lost by evaporation represents almost 40% of the total water volume for Fântânele reservoir and only 1% for Izvorul Muntelui reservoir. When analyzing the hydrological balance at the annually level, we can conclude that for the Fântânele reservoir, during the analyzing period, it was deficient, due to drainage or water demanded for crops irrigations (downstream of the dam), but also by the intense evaporation in summer. Meanwhile for the Izvorul Muntelui reservoir, the hydrological balance was excessive, due to the contribution of the tributary rivers and of the headrace, but also to the greater quantities of precipitation.

Keywords: evaporation, evapometric station, hydrological balance, reservoir, water resources management

1 INTRODUCTION

Evaporation is a major component of water balance and a parameter that directly influences the hydrological budget of a lake. The elements that directly influence the variability of the water volume into a lake are: the liquid and solid precipitation fallen on the lake, and also the surface and subsurface water inflow into the water body from outside. The outflow part of the water budget includes water evaporation and surface and subsurface outflow from the water body (Gâștescu, 1963; Sokolov et al., 1974; Redmond, 2007; Ndehedehe et al., 2017).

The evaporation is the meteorological factor which directly influences the water balance and which is one of the most difficult water-loss processes to estimate, due to the different ways to measure it. Several scientific researches present equations to assess the evaporation, based on air and water temperature, relative humidity and wind speed (Penman, 1954; Allen et al., 1998; Xu et al., 2002; Dąbrowski, 2007). However, the direct methods, consisting in measurements by using evapometric pans, steel have the highest accuracy (Al Domany et al., 2013; Stan et al., 2016).

In Romania, the systematic evaporation measurements started in 1954, when the national network of evapometric stations has been organized. Until now, the measurements regarding the water evaporation were made on the surface of 21 Romanian lakes (Figure 1), with different origins (natural and artificial), locations (in altitude) and morphometric features (surface, depth, volume), as well as with different water uses (irrigation, domestic supply, energy).

In Romania many regional studies had, as their main subject, the analysis of the water balance components for some local lakes (Şerban, 2007; Alexe, 2010; Telteu, 2012), but only a few of them focused on the impact of evaporation on the water volume of a lake (Gâștescu, 1963; Neculau et al., 2016). In this context, the main objectives of this paper are i) to analyze the variability of the evaporation, as output of the water budget of lakes and ii) to estimate the impact of this process on the lake water balance. The study is focalized on two reservoirs, Fântânele and Izvorul Muntelui, located in different regions of Romania (Figure 2).

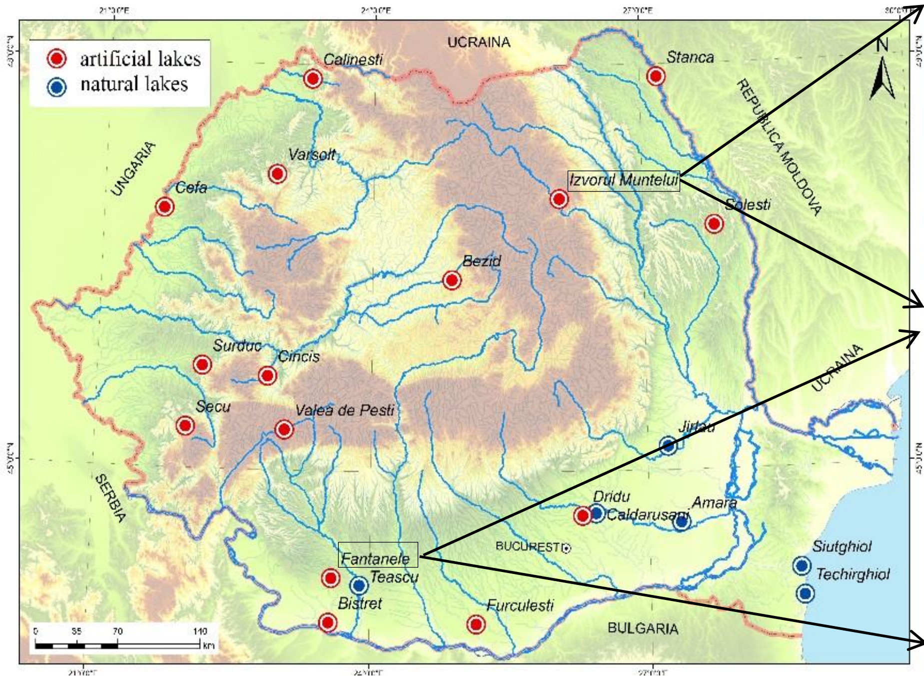


Figure 1. Distribution of evapometric stations situated on the surface of lakes in Romania, and the location of studied reservoirs (source: National Institute of Hydrology and Water Management – NIHWM)

Figure 2. Fântânele and Izvorul Muntelui reservoirs (source: Google Earth, 2017)

Fântânele reservoir is situated in the southwest of the country (Oltenia Plain). It covers an area of 3.25 km^2, and has a volume of 31.7 mil. m^3. Its maximum depth is about 10 m (Table 1). The reservoir was built for multiple purposes: irrigation, fisheries and flood defense.

Izvorul Muntelui reservoir is located in the Carpathians Mountains and it is the largest reservoir on the inner rivers in Romania, with an area of 31 km^2 and a maximum depth of approximately 40 m (Table 1). The total volume of this reservoir is 1230 mil. m^3. The reservoir was built mainly for hydropower generation and water supply.

2 MATERIAL AND METHODS

The study is based on two main types of data: climatic (evaporation, air temperature, precipitation, relative humidity, deficit, sunshine duration) and data related to the lakes (hydrologic and morphometric data: volume, area, surface outflow and inflow, subsurface outflow and inflow) (Table 1).

Table 1. Morphometric data of Fântânele and Izvorul Muntelui reservoirs

Lake	Long.	Lat.	Altitude (m)	Area (km^2)	Volume (mil. m^3)	Depth (m)	Average evaporation (mm)
Izvorul Muntelui	26°03'32"	47°00'53"	540	31	1230	39.6	597.6
Fântânele	23°36'00"	44°12'00"	102	3.25	31.7	9.75	655.0

The equipment used to measure the climatic parameters at the surface of a lake is formed by a pan evaporation, a pluviometer, a thermometer, an anemometer and a psychrometer (Figure 3), all of them being located on a raft (in the middle of the lake). In Romania the water evaporation is measured by using a Russian GGI-3000 pan, with a surface of 3000 $cm^{2,}$ and a depth of 60 cm. The measurements are performed daily at 7 am and 7 pm during the period without ice at the surface of water, respectively from April to November. The daily evaporation is obtained by summing the values measured over a 24-hour period.

Figure 3. Pan evaporation and pluviometer on the raft at the surface of Izvorul Muntelui reservoir (left) and the raft location near the dam on Fântânele reservoir (right)

The hydrological measurements are made at the gauging stations located upstream and downstream the reservoirs. They record surface inflow and outflow and water level. The volume and the area of the reservoirs were extracted from the volumetric and area curves included in the hydrological studies of lakes, provided by Jiu Water Basin Administration and Siret Water Administration. In this paper we used monthly data series of evaporation and other climatic parameters (precipitations, air temperature, and relative humidity) from April to November, between 1961 and 2012. All the data were collected by the Romanian National Institute of Hydrology and Water Management. For the first part of the study, concerning the analysis of the most important particularities of evaporation from the surface of the analyzed lakes, the approach was based on: i) simple linear regression, in order to identify the relationships between evaporation and others climatic parameters; ii) statistical tests, like the nonparametric Mann-Kendall test for detecting the evaporation trend, and Pettitt as well as the Lee and Heghinian tests for identifying the change points in the evaporation datasets.–In the second part of the study, we estimated the hydrological budget of the reservoirs Fântânele and Izvorul Muntelui, by using the water balance equation, proposed by Sokolov *et al.* in 1974:

$$P + Q_{SI} + Q_{UI} - E - Q_{SO} - Q_{UO} - A_S - \eta = 0,$$

where: P = precipitation (rainfall and snow) (m^3/s); Q_{SI} = surface water inflow into the water body from outside (m^3/s); Q_{UI} = subsurface water inflow into the water body from outside (m^3/s); Q_{SO} = surface outflow from the water body (m^3/s); Q_{UO} = subsurface outflow from the water body (m^3/s); E = water evaporation (m^3/s).

3 RESULTS AND DISCUSSIONS

3.1 The variation of water evaporation

The mean annual evaporation measured on the Fântânele reservoir from 1961 to 2012 was 655.0 mm, with a maximum evaporation of 869.2 mm/year registered in 1962 and a minimum one of 482.8 mm/year in 1991 (Figure 4). During the same period, on Izvorul Muntelui reservoir, the evaporation varied from 777.5 mm/year (in 1962) to 371.9 mm/year (in 2009), having a mean value of 597.6 mm (Figure 4).

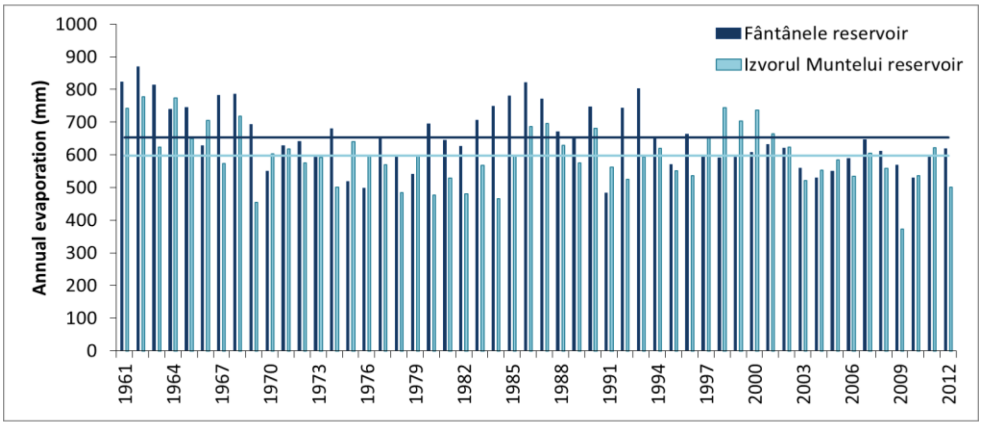
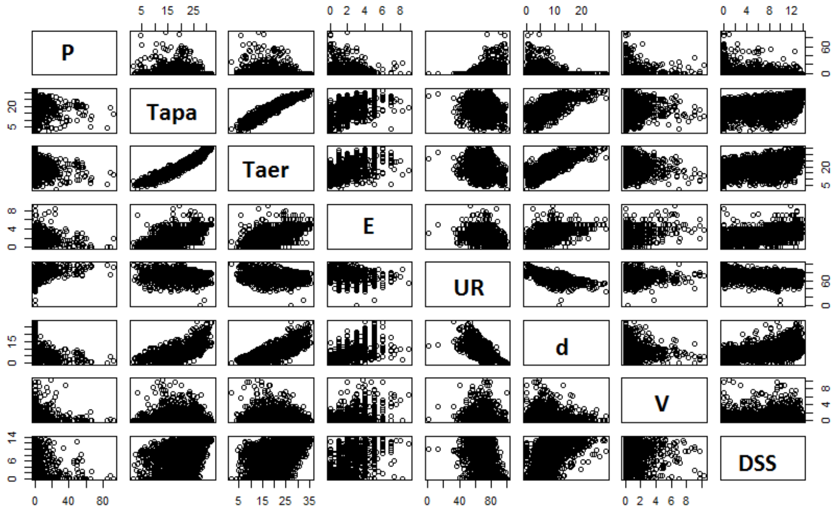


Figure 4. Variation of the annual evaporation and average multiannual evaporation on Fântânele and Izvorul Muntelui reservoirs (1991-2012) (data source: NIHWM)

In general. the temporal and spatial variability of evaporation is strongly related to some climatic parameters like air temperature, relative humidity, sunshine duration, wind speed (Allen et al., 1998; Dąbrowski, 2007; Al Domany et al., 2013; Stan et al., 2016). According to the coefficient correlation base on Pearson statistical test, the evaporation on the surface of Fântânele reservoir is strongly dependent of air temperature and sunshine duration (Figure 5). Regarding the relation between the climatic parameters and the evaporation rate on Izvorul Muntelui reservoir, the Pearson correlation coefficients indicate that evaporation process depends especially on air humidity and rainfall, as limiting factors.



where: P – precipitations (mm), Tapa – water temperature (ºC), Taer – air temperature (ºC), E – evaporation (mm), UR – realtive humidity (%), d – humidity deficient (mb), V – wind speed (m/s), DSS – sunshine duration (hours)

Figure 5. Relation between evaporation and some climatic and hydrological parameters measured on Fântânele reservoir

In order to analyze the temporal variation of evaporation of those two reservoirs, statistical tests were used to identify trends and changes in data series. The Mann-Kendall test identified for Fântânele reservoir a general negative trend of the evaporation, with a significance level of 0.001, while at the monthly level (in June, July or September) the significance degree range between 0.05 – 0.1. For Izvorul Muntelui reservoir, a declining trend also has been identified, significant at 0.05. By applying the Pettitt and Lee and Heghinian statistical tests on the time series between 1961 and 2012, the evaporation appeared to have registered change points during the 70s and 90s for Fântânele reservoir (Table 2). In the case of the Izvorul Muntelui reservoir, the Pettitt test identified no changes; only the Lee and Heghinina test has marked a change into the evaporation data set in 1966 (Table 2).

Table 2. Years of changes identified in the evaporation data series (1961-2012) for Fântânele and Izvorul Muntelui reservoirs by applying Pettitt and Lee and Heghinian statistical tests

Reservoir	**Change point (years and values)**			
	Pettitt test			**Lee and Heghinian test (year)**
	Year of change	Average evaporation before (mm)	Average evaporation after (mm)	
Fântânele	1994	686.0	592.9	1968
Izvorul Muntelui	No change point identified			1966

3.2 Hydrological balance of the Fântânele reservoir

The hydrological balance of the Fântânele reservoir was analyzed during 1991-2012. This reservoir is a small one, having a surface of 3.25 km^2, being fed by precipitation, groundwater and input flow. The average water volume in the analyzed period was of 4.5 mil. m^3, with maximum values greater than 8.0 mil. m^3 in 2005 and 2006 (according to the volumetric curve, data source: Jiu Water Basin Administration), due to the high precipitation (>1000 mm/year).

The pluviometric regime of Fântânele reservoir is characteristic for the southwestern part of the Romanian Plain, where the precipitation is generally low and concentrated in spring and at the beginning of summer (Figure 6). During the period 1991-2012 the annual amount of precipitation varied from 250 mm/year to 1000 mm/year, the multiannual average being of 453.2 mm (Figure 6).

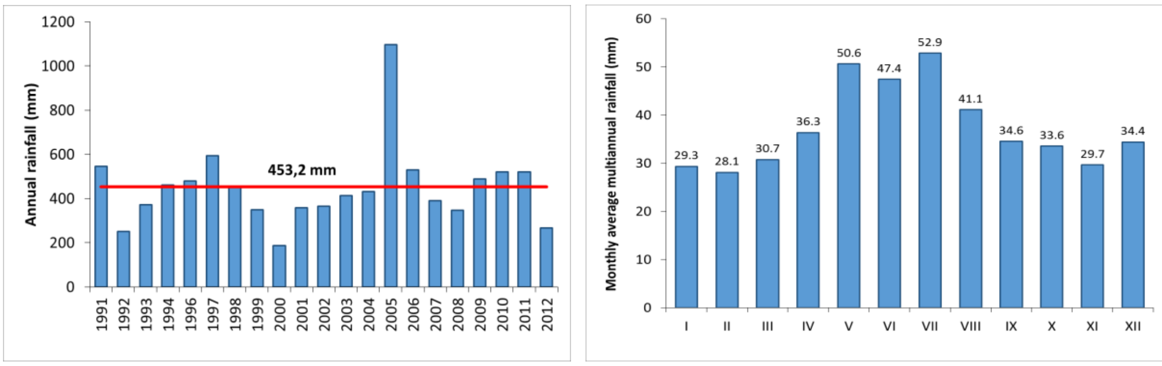


Figure 6. Variation of the annual (left) and monthly (right) precipitation for Fântânele reservoir (1991-2012) (data source: NIHWM)

The average multiannual evaporation for the period 1991-2012 reached 607 mm (Figure 7), ranging from 483 mm/year (1991) to 800 mm/year (1993). The decrease of annual evaporation reported after 2010 was caused by the reduction of the period of evapometric measurements from April-November, to April-September. At Fântânele reservoir the monthly evaporation (Figure 7) exceeds the precipitation.

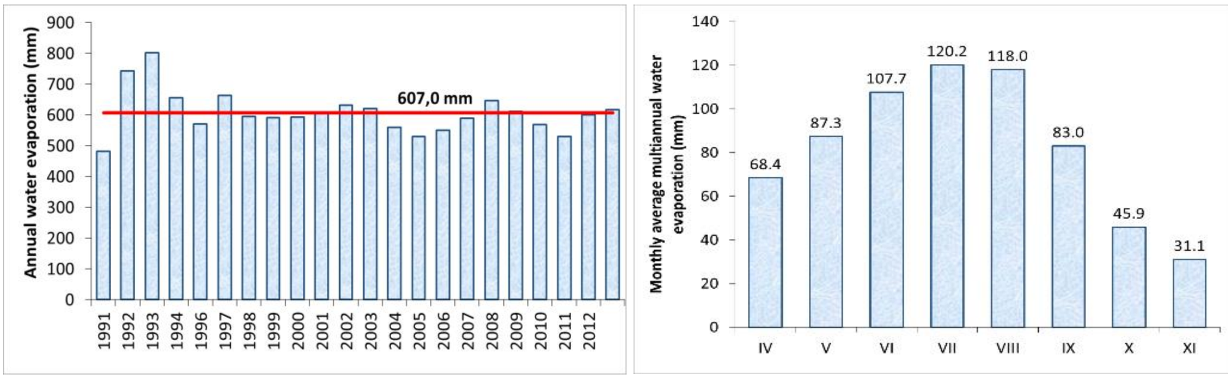


Figure 7. The annual (left) and monthly (right) variation of evaporation on Fântânele reservoir (1991-2012) (data source: NIHWM)

Due to the increasing in air and water temperature during the summer months (June, July and August), the evaporation process is intensifying, so the water losses are getting greater and can exceed 3,0 mil. m^3 (Table 3). For Fântânele reservoir, the relief and the climate characteristics (plain, high aridity) favor the intensification of the evaporation, which reaches values of more than 8 mm/day, and generates losses of up to 0.12 mil.m^3/day.

Concerning the input components of the hydrological balance they are represented by the inflows from Desnăţui and Terpeziţa rivers, and from the water drainage on the intern basin surfaces, as well as by the atmospheric precipitation.

Table 3. Monthly and annual values (mil. m^3) of the hydrological balance components for Fântânele reservoir (1991-2012) (source: NIHWM)

Parameters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annually
Rainfall	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	1,3
Tributary rivers	2.0	3.1	2.8	1.1	1.0	0.6	0.7	1.0	0.5	0.6	0.7	1.6	15,2
Interbasin flow	0.7	1.1	1.0	0.4	0.3	0.2	0.2	0.4	0.2	0.2	0.3	0.6	5,7
Water pipe	3.4	3.6	5.3	2.3	1.7	1.9	2.0	2.7	3.3	3.4	3.1	3.6	29,0
Evaporation			1.1	2.1	2.8	3.3	3.9	3.6	2.4	1.3	0.6		19,1
Difference inflows-outflows	-1	0.7	-2	-2	-3.0	-4.3	-4.8	-4.7	-4.8	-3	-2	-1	-26

The output components include the flow through the water pipe used for the irrigation and the evaporation losses. The largest part of the entrances comes from the rivers (15.2 mil. m^3 annually), followed by the flow provided from inter basin areas (5.7 mil. m^3), and then from precipitation (1.3 mil. m^3) (Table 3). The losses due to water pipeline annually reach 28.0 mil. m^3, and by evaporation 19.1 mil. m^3 (about 40% of the lake losses during a year).

The annual balance for the Fântânele reservoir is deficient, caused by the drainage or by the water demanded for crops irrigations (downstream of the dam), but also by the intense evaporation during the summer months (Figure 8).

At monthly level, we found that the hydrological balance is positive only in February (month with winter phenomena), and for the rest of the year the balance is negative, especially during the summer and autumn months (Figure 8).

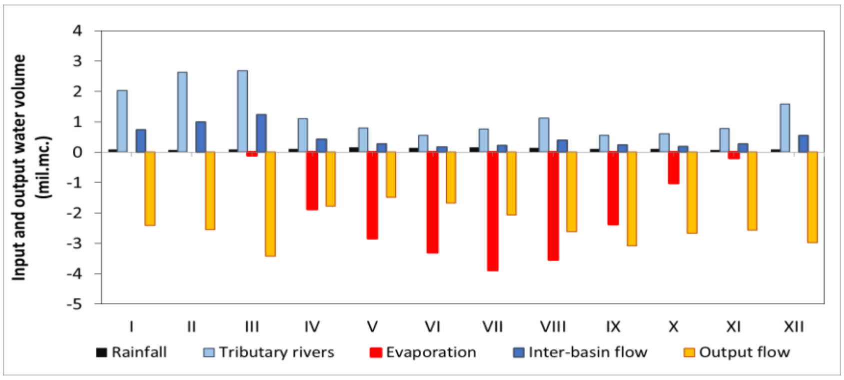


Figure 8. Monthly variation of water balance components for Fântânele reservoir (1991-2012) (data source: NIHWM)

3.3. Hydrological balance of Izvorul Muntelui reservoir

During the period 1991-2012, the mean water volume stored in the Izvorul Muntelui reservoir was 760 mil. m^3, while the annual surface area of the lake varies between 2200 ha and 2750 ha (according to the volumetric curve, data source: Siret Water Basin Administration). The annual rainfall varied between 430 mm/year (2006) and 1150 mm/year (2011), with a multiannual average of 716.8 mm (Figure 9). At monthly level, the highest rainfall (above 115 mm/month) was recorded in summer (June and July), and the lowest ones in winter (below 20 mm/month) (Figure 9). In general, the precipitation is not only a major component of the water balance, but it also drives the other elements of the hydrological budget into the lake, respectively the input flows.

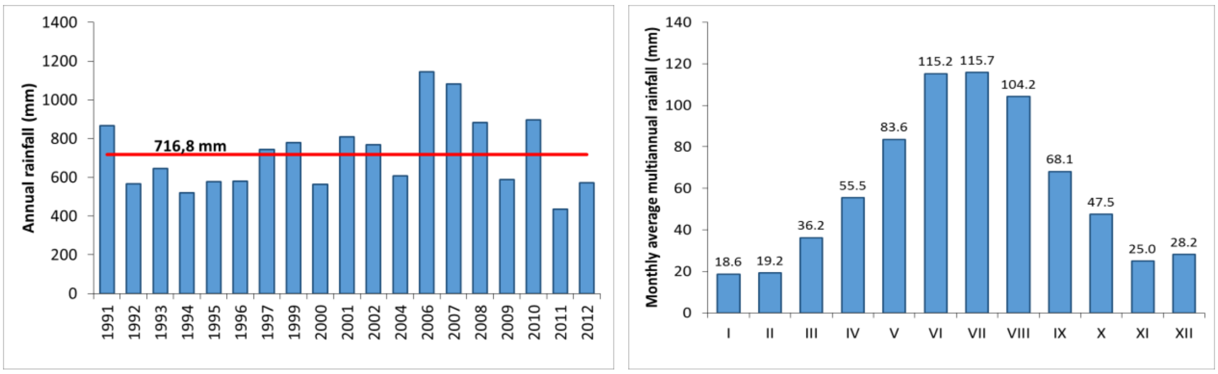


Figure 9. Variation of the annual (left) and monthly (right) precipitation for Izvorul Muntelui reservoir (1991-2012) (data source: NIHWM)

Regarding the evaporation, the multiannual average value is 586.0 mm/year, while the highest values exceed 740 mm/year (Figure 10) during the years with favorable climatic conditions (high temperature and low precipitations). In summer, the maximum evaporation cannot reach the amounts of precipitation caused by the wind influence, named föhn (Gâştescu, 1963), that is why Izvorul Muntelui reservoir can be considering a lake with excess humidity.

For the Izvorul Muntelui reservoir, the input components of the water balance between 1991 and 2012 are: the precipitation (93.1 mil. m^3/year), the inflow from the tributary rivers Bistrita, Bistricioara, Schitu, Bolatau, Bicaz and from the headrace Tasca (~1800 mil. m^3), and those provide from the drainage on the slope across the basin (121.8 mil. m^3) (Table 4).

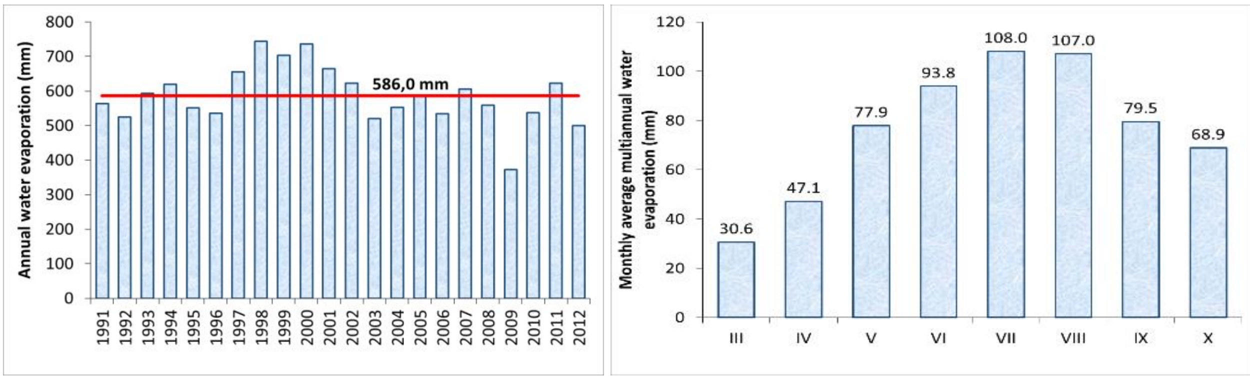


Figure 10. The annual (left) and monthly (right) variation of evaporation on Izvorul Muntelui reservoir (1991-2012) (data source: NIHWM)

Regarding the outputs, they were being represented by the evaporation and the river discharges. The losses by the outflow summarized ~1812 mil. m^3 (Table 4), being represented by the turbine water discharged (1611.6 mil. m^3), and also water evaporation at the surface of lake, the last one representing around 1.5% of the hydrological balance. The highest values of water flow entering the lake is registered in spring (Table 4), especially in May (323.1 mil. m^3), and this could be correlated with the precipitation and the snowmelt. The high temperatures during the summer period have intensified the evaporation, so the water losses caused by this one is higher in June, July and August (more than 3.2 mil. m^3/month), but they are insufficient to significantly change the hydrological balance of the Izvorul Muntelui reservoir.

Table 4. Monthly and annual values (mil. m^3) of the hydrological balance components for Izvorul Muntelui reservoir (1991-2012) (data source: NIHWM)

Parameters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annually
Precipitation	2.7	2.9	3.6	6.5	8.9	13.2	17.1	15.0	8.4	6.4	3.9	4.5	93.1
Tributary rivers	64.9	63.6	123.0	255.0	323.1	196.1	191.6	175.5	141.6	100.6	91.5	83.5	1809.8
Drainage on the slope across the basin	5.4	4.9	10.1	12.1	11.2	14.1	15.2	15.7	12.4	8.4	6.8	5.5	121.8
Turbine output	146.5	140.1	104.4	72.9	105.9	119.7	147.5	174.1	146.3	155.5	152.3	146.3	1611.6
Evaporation	0.0	0.0	0.2	1.4	2.5	3.2	3.8	3.5	2.6	2.1	1.4	0.0	20.8
Differences inflows-outflows	-73.5	-68.6	32.2	199.2	234.7	100.5	72.6	28.5	13.5	-42.3	-51.5	-52.8	32.7

The hydrological balance of the Izvorul Muntelui reservoir during the period 1991-2012 was excessive, especially during the years 1992, 1994-2002, 2004-2007 and 2009, due to the contribution of the tributary rivers, the headrace and the greater quantities of precipitation (Figure 11). By analyzing the hydrological balance at the monthly level, we can conclude that it is positive during the period with high precipitation, respectively in spring and the beginning of summer, and negative during the autumn and winter, when the turbine output is double then in other months. In December it is the biggest negative water deficit, due to the reduction of the inflow. The biggest positive error, which signified a high excess of water into the reservoir, was found in April and May, and it is related snow melting and higher precipitation (Figure 11).

4 CONCLUSION

The analysis based on direct measurements of water evaporation and other climatic parameters (air temperature, relative humidity, wind speed and precipitations) during 1961-2012 indicates the amount of water evaporated from the surface of Fântânele reservoir of 655 mm/year, with the maximum value in July (120 mm). Meanwhile for Izvorul Muntelui reservoir, the mean evaporation was lower, 597 mm/year, due to the influence of mountainous climate.

Thus, for the Fântânele reservoir, located in the south-west of the country, in a plain region, the annual water balance is negative, while for Izvorul Muntelui reservoir located in a mountains area, with significant water inputs from the tributaries, and inter-basin areas, the balance is generally positive. The evaporation has recorded high values in the case of Fântânele reservoir (more than 40% of the output components of the hydrological balance), especially during the summer months. In the case of Izvorul

Muntelui reservoir, this process counted only 1% in the water balance equation. The analysis of the impact of evaporation on water volumes of a reservoir, based on direct measurements in a well-developed network of evapometric stations, could bring valuable data useful for adapting the management of water resources stored in reservoirs to current environmental and climate changing conditions.

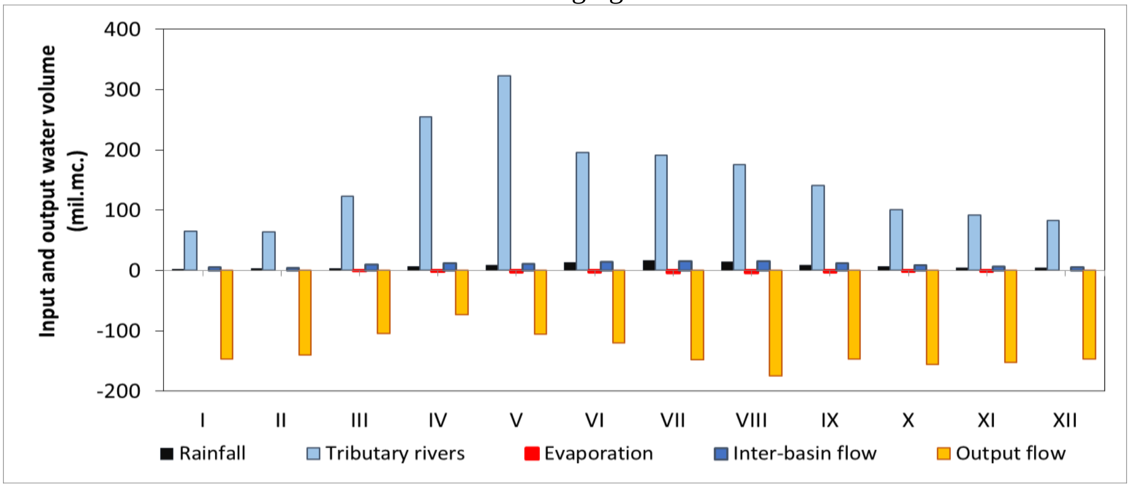


Figure 11. Monthly variation of the hydrological balance components of the Izvorul Muntelui reservoir (1991-2012) (data source: NIHWM)

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