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Research Paper

Conducting Hydrological Modelling in Mat River

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Abstract: Ulza Lake catchment is part of the Mat River basin and has a hilly and partially mountainous watershed. From the hydrographic point of view, it is distinguished for a dense network of watercourses, especially in the middle and lower part where ultrabasic formations are dominant. In order to analyse seasonal and annual water balance for Ulza Lake watershed, the HEC HMS hydrological rainfall-runoff model has been implemented in the Mat river. The hydrological model used as input daily hydrometeorological observed data for precipitation, discharge, and temperature in the period 2002-2011. The method used for transform was SCS Unit hydrograph and for the routing was used Muskingum Kinge. The observed meteorological data was validated through a basic integrity test for the identification of anomalous values. Ulza Lake catchment has been divided into 13 sub-basins in order to better calculate the inflow. The hydrological historical data in the period 2002-2011 was used for calibrating the model. HEC HMS result data series for Ulza Lake were processed and plotted using different methods.

Keywords: *hydrological model, water balance, discharge, rainfall-runoff, inflow*

Introduction

According to the geographical classification of Albania, the Mat River watershed belongs to the North Central Highland. The Mati River originates from Mount Kaptinës and has a hilly and partially mountainous watershed. The upper part of the Mati River watershed extends from the southern side of the Dhoksit Mountain and from Kaptinës Martaneshit to Klos. The Mat River watershed is bordered on the east and southeast by the Drini I Zi River basin, on the south and southwest by the Ishëm River Basin and on the north by the Fan River Basin. From the hydrographic point of view, it is distinguished for a dense network of watercourses, especially in the middle and lower part where ultrabasic formations are dominant. The watercourses that flow into the Mat River mention the Zalli i Liçonës, the Bejnit stream, and the Lusës (Kurdarise) stream from the right flowing stream, while the left flank mentions the Dishës, Xibri, Darsi and Batrës streams (IHM, 1984). The basin relief is hilly, and the valley height varies from 50 m to 700-800 meters. Elevations from 200 to 400 meters are predominate. The smallest heights are in the west while the highest is east of the basin. Mat river valley lies between 125-200 meters and 200-400 meters. According to the climate classification of Albania, the study area is part of the Northern Hilly Mediterranean climate zone. The average annual temperatures vary between 11ºC and 14 ºC, while the absolute minimum varies from -7ºC to -9ºC and in cold winters from -13 -C to -17ºC. The average temperature of January due to the relief forms is in the range of 2-4 ºC. Ice days vary between relief forms between 30 and 40 days and occur from November to March but can also be observed from October to mid-April. The annual rainfall varies from 1200mm to 1400mm which is approximately what is the average of the territory of Albania. Snow is mostly observed during November-March (IHM, 1985). The average maximum layer of snow reaches 15 to 30 cm. Ulza lake catchment basin is vulnerable to climate change hazards, particularly droughts and floods. Human pressure has adversely affected natural ecosystems causing significant erosion and sediment transport to the lake. A hydrological model, validated and calibrated, has been built to estimate the water resources for the Ulza Lake watershed.

The surrounding of Ulza lake watersheds is composed of different ecosystems (forests, lake ecosystem, water sources and rivers, pastures and agricultural land). The ecosystems provide services such as the natural cycles of nutrients, soil formation, and primary production, but are under considerable human pressure. They play an important role in carbon sequestration, water quality, biodiversity values, etc. Direct services are also provided, such as drinking water, firewood, medicinal plants, soil protection, fish, etc.

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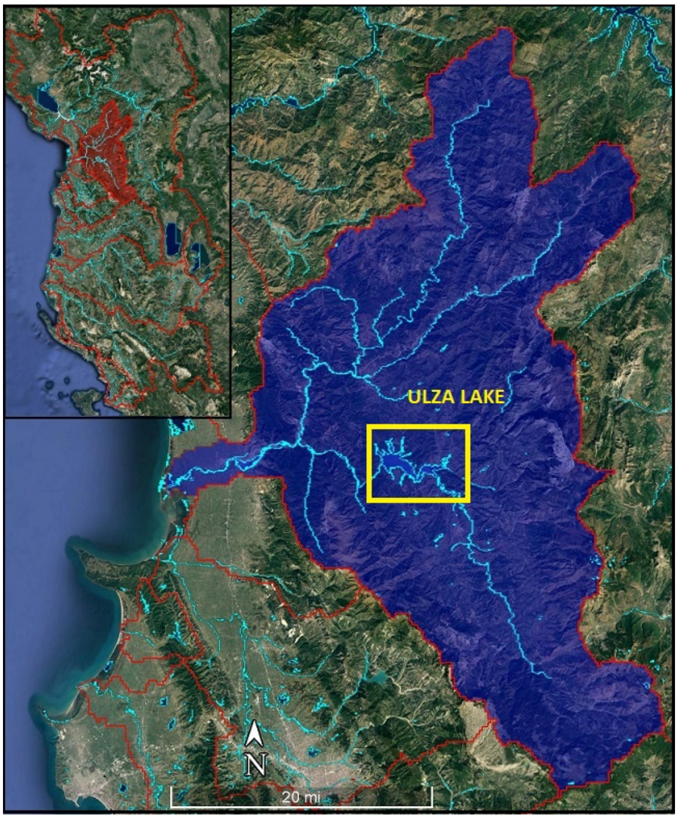


Figure 1. Mati river catchment and Ulza Lake

Materials and Methods

The hydrological conditions of the Mat River watershed in Ulza lake, depending primarily on climate, topography, geology, hydrology, soil type, and vegetation. In the study area, a series of streams and streams flow into the Mat River. From the Vasha Bridge to the Shoshaj Bridge, over the Mat River, the streams flow mainly from the left bank. As we said above, the hydrography of the Mat River consists of many streams, that characterize the terrain's orography. In the dry season of the year, most of the streams are dry, while in winter they have torrential flows. During the maximum discharges, they descend to the lower area Klos, Sucit, and Plezhës fields, eroding the banks of their valleys. Rainfall and snow are the main sources of water accumulation in the Mat River watershed. The average rainfall ranges from 1200 to 1400 mm per year, but in the upper parts of the basin, the rainfall has reached 2500-2700 mm in some years (IHM, 1985). About 82% of the annual precipitation falls in the colder year and 14% falls in the warmer year. In June, which is an intermediary month, falls 4% of the precipitation. The water supply of the Mat River and its tributaries in the warm season of the year is made of groundwater coming from limestone formations such as the case of the Benit stream flowing into the right bank of the Mat River in the town of Klos (IHM, 1984).

Table 1 Average monthly and annual temperatures

Stations /Months	1	2	3	4	5	6	7	8	9	10	11	12	Average
Fshat Klos	6	6.2	8.3	11.7	16	13	23	23	19	13	10	6.1	12.9
Bize	3.2	-2.4	0.2	4.5	10	12.5	16.4	14.3	12	6.7	2.9	-1.4	5.9
Lena Martanesh	1	2.3	4	8.4	13.9	16.6	19.1	19.1	15.6	10.8	6.8	2.6	10
Burrel	5.5	5.9	8.3	11.7	16.1	20.3	22.7	23	19	12.7	9.5	6.2	13.4
Kurbnesh	0.4	2	4.6	8.9	13.5	17.4	19.9	20	16.6	11.4	7.1	3	10.4

In this river, three hydrological stations in Shoshaj, Klos, and Darsi stream have been operating. For the purpose of the study, the water flow analysis of the Mat River at the Shoshaj site was initially conducted. It is noted that the catchment area of the Mat River at the Shoshaj site is 646 km^2 (IHM, 1984). While at the entrance to Ulza Lake it reaches 704 km^2. At the Ulza hydropower dam, the catchment area is 1186 km^2, which in addition to the lake itself (16 km^2) includes a series of important watercourses such as the Uraka River (257.6 km^2), the Kurvaj River (61 km^2), the stream of Shuterise, etc. From the Ulza Dam to the Shkopet Dam the watershed extension is relatively small and the total area up to the Shkopet Dam reaches 1243 km^2.

Table 2 Average monthly and annual precipitation

Stations /Months	1	2	3	4	5	6	7	8	9	10	11	12	Annual
Burrel	142	130	116	107	86	60	42	47	78	113	161	159	1240
Fshat Klos	159	154	128	115	108	73	47	70	95	118	185	181	1430
Bize	191	170	153	147	137	79	50	67	134	185	240	194	1750
Q. Bulqize	130	136	108	104	84	68	38	60	60	100	172	173	1230
Martanesh	178	161	140	132	117	79	43	51	88	141	226	196	1550
Kurbnesh	129	124	138	131	97	62	76	101	136	136	189	170	1500

Table 3 Monthly average discharges in Shoshaj hydrological station

Station	1	2	3	4	5	6	7	8	9	10	11	12	Annual discharge
Mati Shoshaj	36.9	37.5	36.8	38.8	30.8	15.4	7.3	5.2	6.9	10.7	29.8	40	24.7

In order to provide seasonal and annual water balance for Ulza Lake watersheds, the hydrological rainfall-runoff model has been implemented. The software chosen was the open-source HEC-HMS of the US Army Corps of Engineers (USACE), which is designed to simulate the complete hydrologic processes of dendritic watershed systems, including the erosion and sediment transport. The Hydrologic Modeling System (HEC-HMS) is one of the most widely used simulation tools developed by the U. S. Army Corps of Engineers Hydrologic Engineering Center (HEC) and is designed to simulate the rainfall-runoff processes of the drainage basin. A soil moisture accounting algorithm has been used to evaluate the performance of the HEC-HMS model for many river basins. The software includes many hydrological analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including snowmelt, soil moisture accounting, and evapotranspiration. Advanced capabilities are also provided for gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark). Supplemental analysis tools are provided for model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion and sediment transport, and water quality USACE (2018). The software features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the user seamless movement between the different parts of the software. Simulation results are stored in HEC-DSS (Data Storage System) and can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing, and includes procedures necessary for continuous simulation including evapotranspiration, snowmelt, and soil moisture accounting USACE (2018).

Results and Discussions

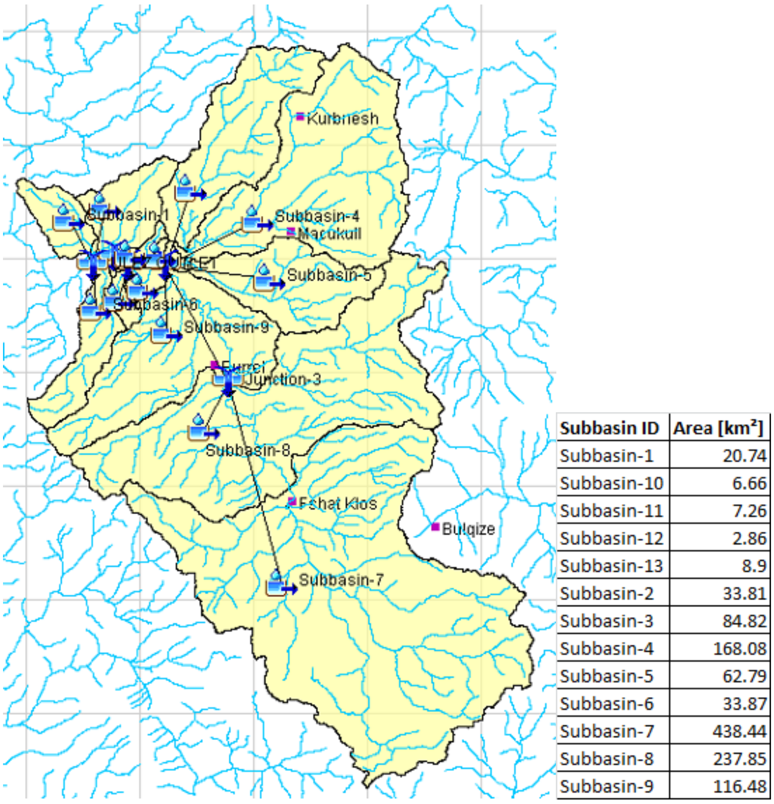
The physical watershed for Ulza Lake is represented in the basin model. Hydrologic elements are added and connected to one another to model the real-world flow of water in a natural watershed. In this study case the elements used to describe the watersheds are:

a. Sub-basin used to represent the physical watershed with given precipitation.
b. The outflow from the sub-basin element is calculated by subtracting precipitation losses, calculating surface runoff, and adding base-flow.
c. Reach used to convey streamflow in the basin model.
d. Inflow to the reach can come from one or many upstream elements.
e. Outflow from the reach is calculated by accounting or translation and attenuation.
f. Channel losses can optionally be included in the routing.
g. Junction used to combine streamflow from elements located upstream of the junction.
h. Reservoir used to model the detention and attenuation of a hydrograph caused by a reservoir.

Table 4 The mathematical models used in Ulza Lake catchment

Sub-basin	Surface	Simple
	Loss rate	Soil moisture accounting
	Transform	SCS Unit hydrograph
	Baseflow	Recession
Reach	Routing	Muskingum Kinge

Most hydrologic elements require parameter data so that the program can model the hydrologic processes represented by the element. The soil moisture accounting loss method uses three layers (soil, groundwater 1 and groundwater 2) to represent the dynamics of water movement in the soil and should be used with the canopy and surface methods. The soil layer will dry out between precipitation events as the canopy extracts soil water. The surface layer holds precipitation and allows it to infiltrate after the rain has stopped. Infiltration is generally reduced if no surface method is selected. The soil layer is subdivided into tension storage and gravity storage. Groundwater layers are not designed to represent aquifer processes but are used for representing shallow interflow processes (USACE 2018).



Subbasin ID	Area [km²]
Subbasin-1	20.74
Subbasin-10	6.66
Subbasin-11	7.26
Subbasin-12	2.86
Subbasin-13	8.9
Subbasin-2	33.81
Subbasin-3	84.82
Subbasin-4	168.08
Subbasin-5	62.79
Subbasin-6	33.87
Subbasin-7	438.44
Subbasin-8	237.85
Subbasin-9	116.48

Figure 2. Mat Basin model for Ulza Lake in HEC-HMS hydrological model

The initial condition of the soil is specified as the percentage of the soil that is full of water at the beginning of the simulation. It was assigned equal to 85% from calibration. It affects only the very first period of the simulation. The maximum infiltration rate sets the upper bound on infiltration from the surface storage into the soil: it has been set equal to 10 mm/hr (sandy soils). The percentage of the sub-basin which is subject to direct runoff (Impervious) was assigned equal to 30% from calibration. Soil storage represents the total storage available in the soil layer. Tension storage specifies the amount of water storage in the soil that does not drain under the effects of gravity. Percolation from the soil layer will occur whenever the current soil storage exceeds the tension storage. Water in tension storage is only removed by evapotranspiration. Tension storage must be less than soil storage. The soil percolation sets the upper bound of percolation from the soil storage into the upper groundwater. Groundwater 1 storage represents the total storage in the upper groundwater layer USACE (2000). The groundwater 1 percolation rate sets the upper bound of percolation from the upper groundwater to the lower groundwater. The groundwater 1 coefficient is used as the time lag on a linear reservoir for transforming water in storage to become lateral outflow. The lateral outflow is available to become base flow.

Similarly, for Groundwater layer 2, not used in this model. Parameters have been set based on the manual's range and calibration results. The available meteorological observational data for the daily precipitation and daily maximum and minimum temperature in the period 2002-2011 are meteorological stations: Macukull, Kurbnesh, Bulqize, Shengjergj, Fshat-Klos, and Burrel. It is important to underline that the application of the bias correction methods based on observed dataset shorter than 30 years period doesn't permit to completely remove the bias (Maraun and Widmann, 2018), in particular for what concerns the values in the tails of the distributions. Based on this concept, the observed data was validated through a basic integrity test and a test for the identification of anomalous values (Ray et al., 2016). On the base of these tests, the initial dataset was reduced. However, the completeness test over the whole period considered was passed (at least 75% of data are available) for the period 2002-2011 for each variable and station examined. This preliminary phase is essential for the evaluation of the bias and the following bias correction application. In order to verify how many observational data are not available, the percentage per year of the missing data for each station is calculated for each variable considering the observed period 2002-2011. The most different behavior can be noted for the Shengjergj station in 2002, where a very low value of the annual precipitation is reported; however, this can be explained with the very low number of data available during this year (missing data are about 79%) Furthermore, the generally low value of the annual precipitation for Bulquize and Burrel stations depends on the presence, in the observed data, of long periods of absence of precipitation. Also, the maximum and minimum temperature is characterized by a low annual value for the Shengjergj station in 2002 with respect to the other stations due to the presence of about 81% of missing data (from January to the middle of October) during this year. Moreover, for the same reason, a high value of the annual maximum and minimum temperature for Kurbnesh station in 2010 and above all in 2011 with respect to the other stations is reported. In fact, in those years, both variables are characterized respectively by about 25% of missing data (generally in February, November, and December) in 2010 and 28% of missing data (from January to the middle of April) in 2011.

Definition of the initial storage and cover factor in Ulza Lake

CORINE Land Use classes have been grouped in 8 families to which has been assigned a unique initial storage value (sum of canopy and surface storage) and cover factor value, based on literature data and calibration results. Ulza Lake catchment has been divided into many sub-basins in order to better calculate the inflow at the reservoir. The following Table 5 summarizes the main parameters adopted for each sub-basin, following the calibration of the model. Considering the simulated time period, the daily time step of the input data (precipitation, temperature) compared to the time of concentration of the flow (less than 1 day), the element reach is not included in the model because it would not influence the result but only extend the time of the simulation.

The hydrological historical data in the period 2002-2011 from Shoshaj station and data measured from Ulza hydropower operator was used for calibrating the model. Figure 3 shows the model calibration results for Ulza Lake, comparing the simulated water flow and measured water flow at the lake (recalculated from the available data). HEC-HMS result data series were processed and plotted using different methods (temporal distribution, aggregated distribution, probability density distribution, etc.). The following Figure 3, and Table 6 show the analysis of the hydrological model results for Ulza Lake in terms of simulated annual flow (daily values) using rainfall and temperature dataset.

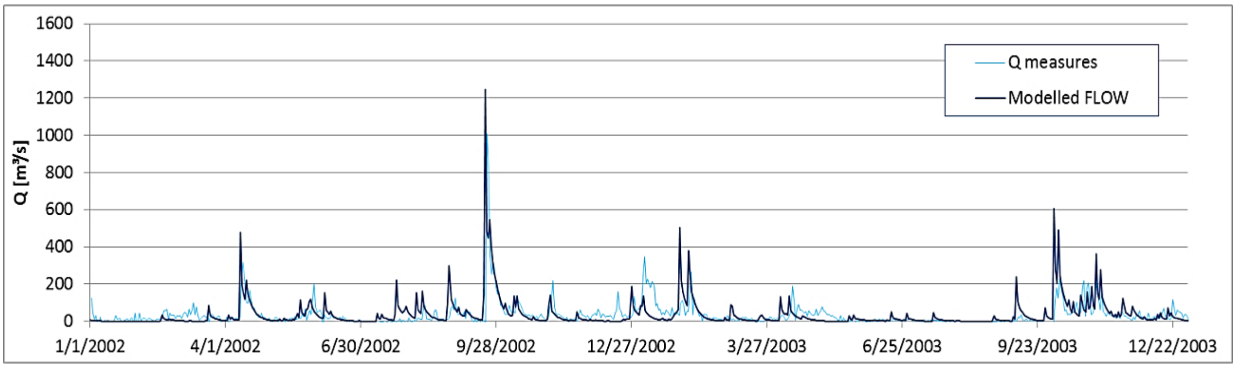


Figure 3. Model results for Ulza Lake (simulated water flow and measured water flow at the reservoir)

Table 5. Main parameters adopted for each sub-basin of Ulza Model, based on the model's calibration.

Component/Sub-basins		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Canopy	Max. Storage (mm)	6.50	5.75	6.09	6.15	5.54	6.80	6.20	5.93	5.03	5.95	4.01	2.19	3.62
Surface	Initial storage	2	2	2	2	2	2	2	2	2	2	2	2	2
Transform SCS	Lag time	74	121	143	136	107	110	176	137	130	50	69	50	118
Soil Moisture Accounting loss	Soil [%]	85	85	85	85	85	85	85	85	85	85	85	85	85
	Ground water	95	95	95	95	95	95	95	95	95	95	95	95	95
	Max infiltration	7	7	7	7	7	7	7	7	7	7	7	7	7
	Impervious	5	5	5	5	5	5	5	5	5	5	5	5	5
	Soil storage	350	350	350	350	350	350	350	350	350	350	350	350	350
	Tension storage	330	330	330	330	330	330	330	330	330	330	330	330	330
	Soil percolation	3	3	3	3	3	3	3	3	3	3	3	3	3
	Ground water store.	350	350	350	350	350	350	350	350	350	350	350	350	350
	Ground water perc.	1	1	1	1	1	1	1	1	1	1	1	1	1
	Ground water coef.	240	240	240	240	240	240	240	240	240	240	240	240	240
Baseflow recession	Recession constant	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Ratio to Peak	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Figure 6 Results for yearly water balance in Ulza Lake

Years	**Annual Discharge Measured m^3/sec**	**Annual Discharge simulated with HEC-HSM m^3/sec**	**Difference %**
2002	34.79	37.2	2.29
2003	32.57	34.1	1.41
2004	54.67	53.5	-1.19
2005	48.47	52.1	3.39
2006	28.33	30.2	1.99
2007	27.14	26.9	-0.39
2008	33.54	35.3	2.40
2009	61.64	66.7	5.45
2010	83.22	87.5	3.70
2011	21.35	20.2	-2.44

Conclusions

The hydrological conditions of the Mat River watershed in Ulza Lake are very important for the hydropower sector and the management of the water resources. In order to provide seasonal and annual water balance for Ulza Lake watersheds, the HEC-HSM hydrological rainfall-runoff model has been implemented. The hydrometeorological qualitative dataset is very important for the application of hydrological modeling in Mat River. The density of the watercourses with the change of the topography from 200 to 2000 meters above the sea level creates difficulties in the distribution of the hydrometeorological information in the catchment. Extending in time the database with the recent period 20012-20019 will improve the model results. Some type of testing has been performed to improve the database. In some sub-basins, there is the need of having more information especially from the water users because of the agriculture some part of the discharge is stored in small reservoirs in the wet season and used in the period from May to October. The calibration and verification procedure of the hydrological model has very good results in most parts of the sub-basins.

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