CLIMATE CHANGE IMPACTS ON ULZA DAM LIFESPAN

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ABSTRACT

Ulza Dam is one of the oldest hydropower infrastructures in Albania. The water capacity of the reservoir has been reduced because of the accumulation of the sediments coming from Mat River. The bathymetric measurements and river sediment transport are used for quantifying the water storage change up to nowadays. Analyzing the future climate change impact in the sediment transport from the river is very important for understanding the Ulza Dam lifespan. In order to analyze the sediment regime in the future, the climate change projection from the EURO-CORDEX has been downscaled for Mat River catchment and used as input for the HEC-HMS hydrological model considering also the erosion and sediment module. The hydrological model was also calibrated with the MUSLE parameters, and it reproduces the average value of the total sediment transport. The analysis of climate change impact on erosion and sediment transported at the reservoirs was done considering the mean annual load for the different 30-year simulated periods related to values from the historical period 1981-2010. Considering the impacts of climate change, the mean annual sediment siltation could increase for RCP4.5 and RCP8.5 scenarios. Over this hypothesis, the remaining lifespan can be reduced drastically in both scenarios. Different land-use scenarios were analyzed to evaluate the impact of erosion and, because the current land use scenario doesn't produce any impact on the hydrological process, but only effects at a small scale, two hypothetical scenarios were defined at large scale and applied for Mat River catchment. Extensive management of land use and reforestation produce a positive effect on the hydrological process and reducing the erosion rate. The change of land use significantly counteracts the negative effects of climate change by 15% and a 24% reduction in the case of these land-use scenarios.

Keywords: *climate change, hydrological model, sediments, land-use, catchment*

INTRODUCTION

Ulza dam was built between 1952 and 1958 in the Mat river. The dam and the hydro-power plant are situated next to the village Ulza and are in the vicinity of the town of Burrel in Albania. The dam is of concrete-gravitational type with a height of 64.2 m and length of the crown of 260 m. The total volume of the reservoir (in the period when it was built) was 240×10^6 m^3, and the volume of the body of the dam is 260 000 m^3. The average annual inflow of water in the reservoir is 1170×10^6

m³. The altitude of the crown of the dam is 131.7 m a.s.l. The maximal water level of the reservoir is 129.5 m and the maximal operative level is one meter lower, 128.5 m. The minimal operational water level is 117 m. The weir is on the altitude of 109.0 m a.s.l. with a maximal discharge capacity of 2160 m³/s. The maximal discharge of Mat river for the Ulza dam cross-section is 1200 m³/s [1]. The reservoir "Ulza" has a primarily energetic function, but also it has several secondary functions like fishing, tourism, local-climatic and other functions. Because of this, the reservoir "Ulza" is of grave importance not only for the region but also for the whole country. Ulza catchment is a sub-basin of the Mati river basin about 70 km from Tirana, covering almost the entire Mat district of the Diber region. The total area of the Ulza catchment is 1224 km². The surrounding mountains forming the watershed are over 2000 m a.s.l., with the highest peak of 2245 m a.s.l. The length of the main tributary, the Mat River, is about 68 km. The average slope of the river is around 0.3% in the valley from Klos to Ulza and around 4% in the mountain area. The following Figure 1 shows the hypsometric curve of the Ulza catchment. It can be observed that the catchment can be considered in his late maturity stage according to Scheidegger's definition [2].

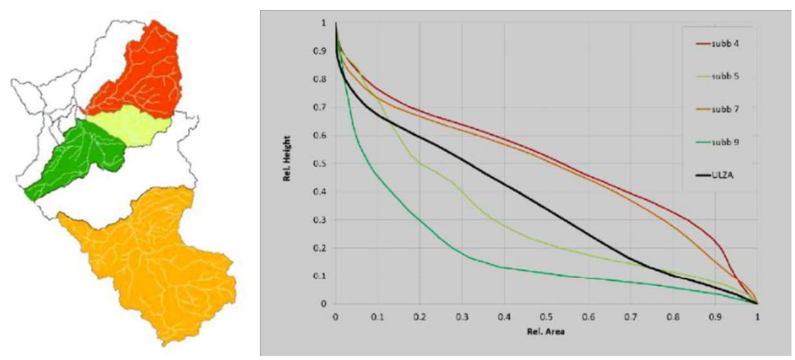

Figure 1 – Hypsometric curves of some sub-basins: sub-basins n.5 and 9 (green) are in the old age, sub-basins 4 and 7 (red, orange) are in the maturity age.

The geologic formations in the Ulza catchment belong mainly to highly consolidated magmatic (effusive, ultrabasic, etc.) rocks, that bordering the basin in the upper and the central part. The lower part of the Mat River is composed of brown soils rich in humus. The soils are characterized by low reaction and limited fertility. Erosion and land degradation are some of the main problems in the watershed, leading to downstream problems on landslides and flooding. About 70% of the Ulza basin is covered by forest (both broad-leaved and coniferous) and less than 3% of the area is bare or only barely wooded. Grasslands and pastures cover about 14% of the area, while 12% are dedicated to agriculture. The analysis of the available CORINE Land Cover maps from 2000, 2006 and 2012 and of the data collected for this study shows that there's not been an evident evolution in land use during the last years. It can be observed that from 2000 to the present days there are no significant changes in land cover (less than 0.1% for some land use classes). This situation doesn't affect the hydrological cycle at the basin scale and as a consequence, there is no significant change in sediment transport. The water level data from Shoshaj hydrological station have been converted to discharges data, for the HEC-HMS hydrological model calibration, together with the calculated (from Ulza dam operator) inflow to the Ulza reservoir.

MATERIALS AND METHODS

For the simulations, the dataset (temperature and precipitation) used is the 30 years weather data originated from bias-corrected EURO-CORDEX, the European branch of the international CORDEX initiative, which is a program sponsored by the World Climate Research Program. This dataset represents also the basis of what was used in the climate change analysis, whose aim is to provide high-resolution climate projection data for impact analysis on the Ulza catchment area with the use of bias-corrected climate data for the 3 periods:

a. on the period 1981-2010 (historical data);

b. on the period 2011-2100 under IPCC RCP4.5 scenario;

c. on the period 2011-2100 under IPCC RCP8.5 scenario.

Assessment of the models' bias and application of the bias correction techniques require, as a fundamental preliminary step, the availability of good-quality long time series of observations for the simulated meteorological variables to be corrected. Daily precipitation and daily maximum and minimum temperature for the period 2002-2011 (stations Macukull, Kurbnesh, Bulqize, Shengjergj, Fshat-Klos, and Burrel). Based on this concept, the observed data was validated through a basic integrity test and a test for the identification of anomalous values. On the basis of these tests, the initial dataset was reduced. The “best” model was selected on the basis of a comparison between the available observed precipitation and temperature data and all the currently available EURO-CORDEX simulations over the area of interest. A preliminary evaluation based on the HEC-HMS hydrological model was conducted for the period 2002-2011. The model was calibrated based on the water level data at Ulza dam, elaborated to obtain the flow data, based on the storage capacity. Shoshaj hydrological station discharge data was used for the calculation of the total sediment transport, equal to 1254 t/year/km². The HEC-HMS hydrological model has also been calibrated with the MUSLE parameters, and it reproduces the average value of the total sediment transport. Total sediment transport simulated at Ulza reservoir shown in Figure 2, is calculated to be 1266 t/year/km². The model works transporting the sediment that reaches the reservoirs during main hydrological events. With this method, the calibration was achieved, and the model can be used for future analysis. The model runs also for the 30 years period 1981 – 2010, whose meteorological data were obtained from the bias-corrected EURO-CORDEX model. During the 30 years period, the average precipitation trend is characterized by higher rainfall amounts, that produce a greater value of sediment at the reservoirs, equal to 1472 t/year/km² for Ulza dam. These numbers are used in the comparison of different scenarios. As anticipated, the land-use scenario with a simple projection of the current trend doesn’t present any significant changes with reference to soil conservation and water balance. In order to verify a significant impact, different assumptions must be done as important land-use changes have been considered in order to analyze the impacted run-off and erosion. Different scenarios can be introduced in order to define any action plans for reducing erosion in the dam reservoir.

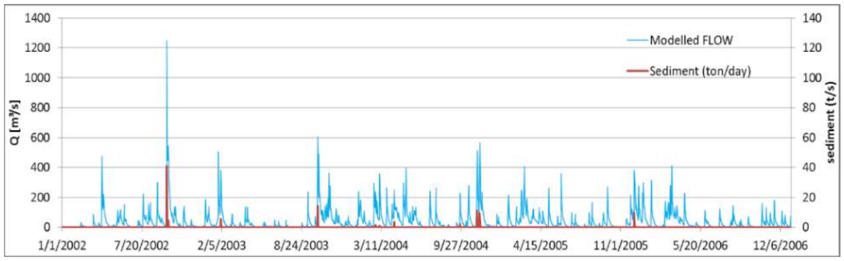

Figure 2 – Model results for Ulza reservoir, simulated water flow, and sediment load.

RESULTS AND DISCUSSION

In general, from the results obtained, the climate change signal is well preserved when the calibration contains more data. Given the objective of the present hydrological study, it is important to note that the total annual precipitation presents a fairly constant trend, lightly decreasing in the case of the IPCC RCP85 scenario for the annual precipitation trend for Fshat-Klos meteorological station. The maximum daily precipitation in the simulated period presents an increasing trend (+20%) both in RCP45 and RCP85 shown in Figure 3 for Fshat-Klos meteorological station. Considering the calibration period 2002-2011, under RCP4.5 the trend is properly preserved by bias-corrected model for temperature variables, while for precipitation slight differences in trend values are recorded for Burrel station. Under RCP8.5 trend is generally well preserved for each variable and for each case.

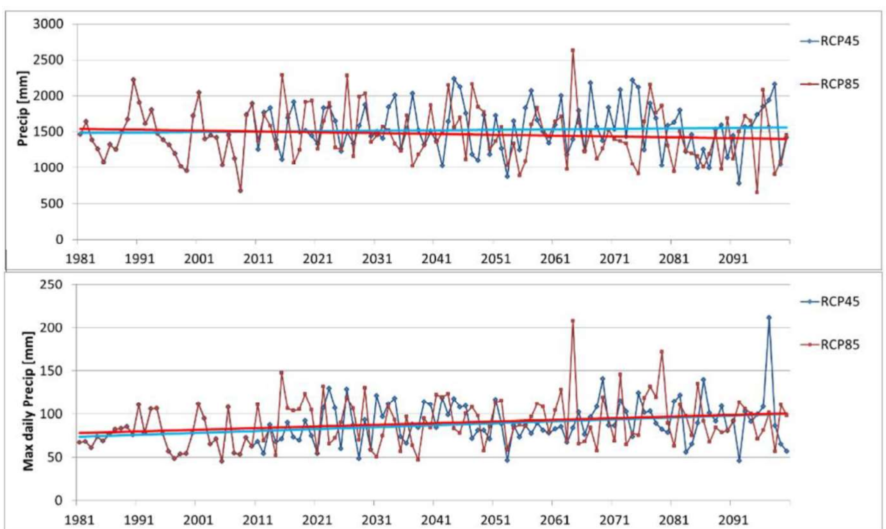

Figure 3 – Annual and Maximum daily Precipitation at Fshat-Klos meteorological station in the IPCC RCP4.5 scenario (blue line) and IPCC RCP8.5 scenario (red line).

The first results of the high-resolution (EUR-11) future climate simulations from EURO-CORDEX were presented in the literature in 2013. The analysis carried out was directed towards regional climatic changes in Europe, addressing the differences between mean changes in annual mean temperature and total precipitation for the IPCC RCP4.5 and RCP8.5 scenarios [3]. In HEC-HMS the physical watershed 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. The model components used to simulate the hydrological process are including precipitation and temperature data [4]. The Modified USLE method (Williams, 1975) was adapted from the original Universal Soil Loss Equation, based on precipitation intensity [5]. The MUSLE equation changed the formulation to calculate erosion from surface runoff instead of precipitation. Ulza basin was divided into many sub-basins in order to better calculate the inflow at the reservoir. MUSLE parameters were attributed based on the analysis carried out in GIS environment, to identify the critical areas. The following Figure 4 shows the analysis of the hydrological model results for Ulza catchment in terms of simulated maximum annual flow (daily values) using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

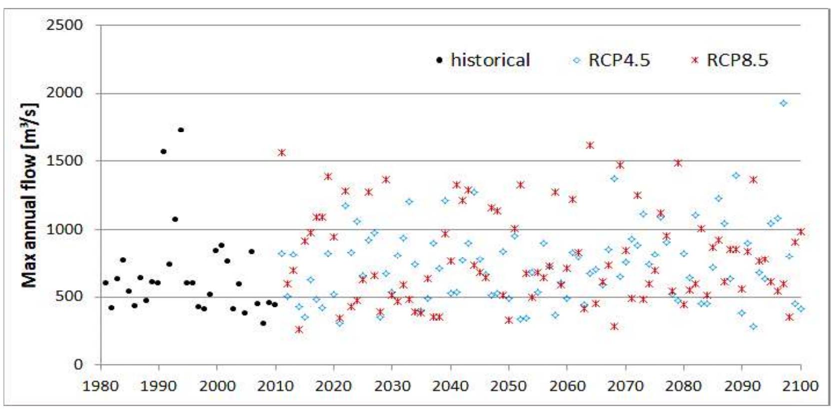

Figure 4 – Hydrological model results for Ulza basin: simulated maximum annual flow using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

It can be observed that there is a slight variation of the highest flow peaks caused by extreme events (i.e. 100 years return period) and the simulated maximum annual flow series present a slightly increasing trend both for RCP4.5 and RCP8.5 scenarios. The probability density distribution (Gaussian) of simulated maximum annual flow (Figure 5) shows a small different behaviour of the two CC scenarios in terms of flow peaks mean value. The RCP8.5 scenario results show more flow peaks in the range from 1200 to 1800 m^3/s than RCP4.5 scenario results. The distribution of medium-high flow peaks is more frequent in the CC scenarios for the range 400-600 m^3/s in comparison with the historical period. The flows with a peak in the range of 600-800 m^3/s become also more frequent. From the CC scenarios, a 19% increase of the annual mean flow is calculated, as compared to the historical period results. The mean flow grows from 40.4 m^3/s (historical) to 48.0 m^3/s and 48.1 m^3/s, respectively for RCP4.5 and RCO8.5 scenarios. The climate change scenarios lead to more rainy winter and more droughts in summer. Considering rainfall events, the more significant variations are expected in November and December, with a 50% increase in monthly mean flow. Considering the dry period, the more significant variations are expected from June to August, with a 37% and 30% decrease of monthly mean flow respectively in RCP8.5 ad RCP4.5 mean flow. The mean daily flow data were used to evaluate the changes in the retention basin in terms of volume and water balance. To define the mean daily water demand taken for multi-purpose use from the reservoir, with the same procedure above description for inflow data, has been analyzed the daily average discharge from Ulza reservoir from 1981 to nowadays. From the complete list of data has been removed the contribution from the spillway.

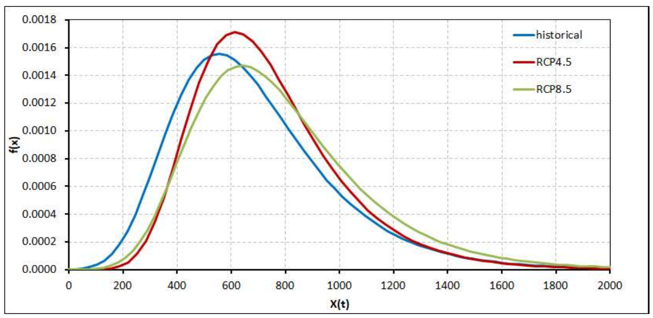

Figure 5 – Hydrological model results for Ulza basin: probability density distribution (Gaussian) of simulated maximum annual flow using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

The analysis of climate change impact on erosion and sediment transported at the reservoirs was done considering the mean annual load for the different 30-year simulated periods. Figure 6 shows the relative value of the sediment load at the reservoir in relation to the first 30-year simulated period (1981-2010), the sediment load is closely related to the rainfall-runoff events and their distribution. RCP4.5 scenario would lead up to 1.25 the current sediment load while the RCP8.5 scenario would lead up to 1.30 the current sediment load in the last 30-year simulated period.

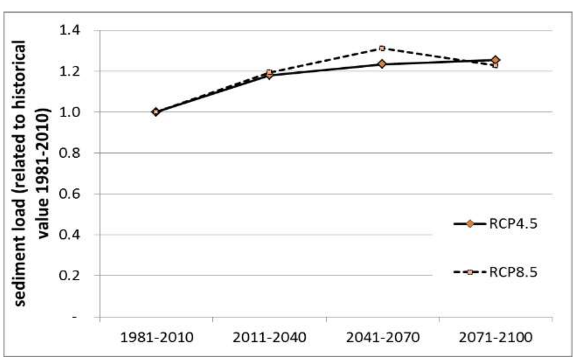

Figure 6 – Model results for Ulza basin: simulated sediment load at the reservoir for RCP4.5 and RCP8.5 scenarios (values are related to historical value 1981-2010)

The current total specific average annual sediment inflow has been evaluated to be about 1214 t/y, km². Considering an average bulk density of bottom sediment of 1,20 t/m³ and trapping efficiency of the reservoir of 83%, the current mean annual sediment siltation in the reservoir could be evaluated in 1052000 m³/y. The current reservoir total storage volume has been evaluated to be 177 Million m³. The remaining lifespan, until complete filling of the reservoir, in the same hypothesis, could be evaluated in about 168 years from nowadays. Considering climate change scenarios, the mean annual sediment siltation could increase to 1315000 m³/y for the RCP4.5 scenario and to 1370000 m³/y for the RCP8.5 scenario. Over this hypothesis, the remaining lifespan would reduce to 134 or 119 years respectively. The present paragraph describes the combined effects of climate change and hypothetical land-use scenarios for 2071-2100. As described above, many different land-use scenarios were analyzed in order to evaluate the impact in terms of erosion and, because the projected current land-use scenario produces only impact at a small scale on the hydrological process. The two hypothetical scenarios were defined on a large scale. In order to verify the combined effect of climate change and land-use scenarios, the simulations listed in Table 1 were modeled.

Table 1 – Simulations modeled to analyze the combined effect of climate change and land-use scenarios for 2071-2100.

CC scenario	**Land-use scenario**
RCP4.5	S2: all land not currently under forest is reforested, with the exclusion of urban areas
RCP4.5	S3: all land classified as US3 (tree crops), US4 (agricultural land), US5 (bare soil) are converted to US2 Land use Index
RCP4.5	S4: all land classified as US4 (agricultural land), US5 (bare soil) are converted to US3 Land use Index
RCP4.5	S5: deterioration of the current situation, with a 20% decrease of currently forested areas
RCP8.5	S2: all land not currently under forest is reforested, with the exclusion of urban areas
RCP8.5	S3: all land classified as US3 (tree crops), US4 (agricultural land), US5 (bare soil) are converted to US2 Land use Index
RCP8.5	S4: all land classified as US4 (agricultural land), US5 (bare soil) are converted to US3 Land use Index
RCP8.5	S5: deterioration of the current situation, with a 20% decrease of currently forested areas

Extensive management of land use and reforestation produce a positive effect on the hydrological process and reducing the erosion rate. The change of land use in Scenario S2 significantly counteracts the negative effects of climate change (15% and 25% reduction for Ulza dam). In particular, the positive effect would balance the climate change impact (Figure 7), controlling the erosion phenomena and extending the lifespan of the Ulza reservoir.

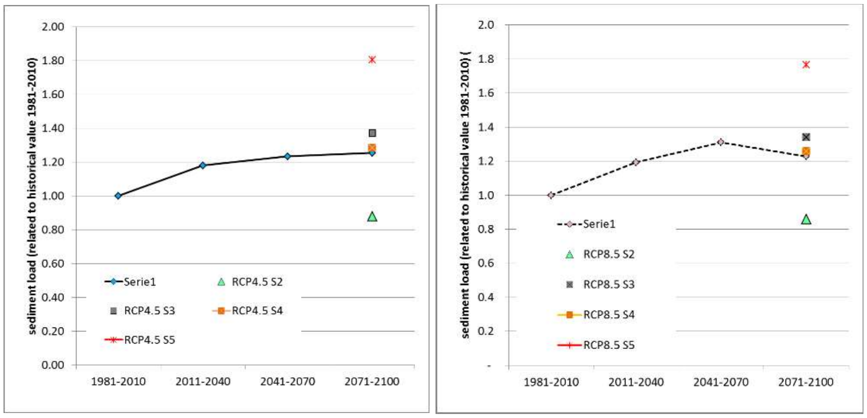

Figure 7 – Model results for Ulza reservoir for the period 2071-2100: simulated sediment load for RCP4.5 (left) and RCP8.5 (right) scenarios with different land-use scenarios (current, S2, S3, S4, S5).

CONCLUSION

Ulza dam is one of the most important hydropower plants in Albania. The capacity of the reservoir is reduced from the time of construction in the middle of the past century. The Climate Change scenario was selected on the base of a comparison between the available observed precipitation and temperature data and the available EURO-CORDEX simulations over the area of interest. The effect of climate change in water regime has increased the siltation of the total sediments in the Ulza reservoir. The climate changes current land-use scenario produces only impact at a small scale on the hydrological process. For this reason, two hypothetical scenarios were defined on a large scale together with climate change. The current reservoir total storage volume has been evaluated to be 177 Million m³. The remaining lifespan, until complete filling of the reservoir with the present trend, is about 168 years from nowadays. Considering the two climate change scenarios, the remaining lifespan would reduce to 134 or 119 years respectively. The study shows that land-use is very important in the future of the Ulza reservoir. The change of land-use in Scenario S2 significantly counteracts the negative effects of climate change (15% and 25% reduction for Ulza dam). The negative impacts of climate change in the reservoir capacity can be reduced drastically with the application of the best practices of the land-use in this catchment.

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