

Use of EURO-CORDEX Models for Analyses of the Future Water Resources in Bovilla Catchment

Klodian Zaimi^{1*}, Sergio Fattorelli², Francesca Ramazzina²

¹*Institute of GeoSciences, Energy, Water and Environment, Tirana, Albania;* ²*BETA Studio Srl, Padova, Italy*

Received December 07, 2019; Accepted January 24, 2020

Abstract: Bovilla catchment is part of the Ishëm River. The artificial lake created in 1998 from the Bovilla dam is one of the most important water resources in Albania because is used as the main source from the Tirana Municipality water supply system. About 60% of Bovilla catchment is covered by forest (both broad-leaved and coniferous) and 5% of the area is bare or only barely wooded. Grasslands and pastures cover about 8-9% of the area, while 18% are dedicated to agriculture. Climate change, growing population, unsustainable development, and inappropriate land use threaten to induce or intensify natural hazards' exposure and vulnerability with disastrous consequences for the environment and societies. The performance and the spatial resolution of General Circulation Models (GCMs) have continuously improved in the recent years, but the typical state of the art spatial scale is still too coarse to realistically reproduce present climate and project climate change signals on local scales, especially in the presence of complex orography. In order to provide seasonal and annual water balance with different climate change scenarios for Bovilla catchment, the hydrological rainfall-runoff model HEC-HMS was implemented. In the absence of measured data, the parameters' values of the hydrological model were assigned based on acceptable data ranges from the manual, from literature, and on the expert experience. The parameters have been finalized in order to well match the simulated and observed data.

Keywords: climate change, general circulation models, hydrological model, rainfall-runoff

Introduction

Bovilla catchment is part of the Ishëm River. The artificial lake created in 1998 from the Bovilla dam is one of the most important water resources in Albania because is used as the main source from the Tirana Municipality water supply system. About 60% of Bovilla catchment is covered by forest (both broad-leaved and coniferous) and 5% of the area is bare or only barely wooded. Grasslands and pastures cover about 8-9% of the area, while 18% are dedicated to agriculture. Climate change, growing population, unsustainable development, and inappropriate land use threaten to induce or intensify natural hazards' exposure and vulnerability with disastrous consequences for the environment and societies (Cardona *et al.* 2012). The performance and the spatial resolution of General Circulation Models (GCMs) have continuously improved in the recent years, but the typical state of the art spatial scale is still too coarse to realistically reproduce present climate and project climate change signals on local scales, especially in the presence of complex orography (Scoccimarro *et al.* 2013). In order to provide seasonal and annual water balance with different climate change scenarios for Bovilla catchment, the hydrological rainfall-runoff model HEC-HMS was implemented. In the absence of measured data, the parameters' values of the hydrological model were assigned based on acceptable data ranges from the manual, from literature, and on the expert experience. The parameters have been finalized in order to well match the simulated and observed data.

Materials and Methods

In order to perform analyses of the climate change in Bovilla catchment are needed assessment of the model's bias and application of the bias correction techniques as a preliminary step for simulated weather variables to be corrected. In the present paragraph, the main checks performed to test the quality of the available observations are described, before using them for model bias correction.

*Corresponding: E-Mail: klodianzaimi@yahoo.com; Tel: 00355672155234;

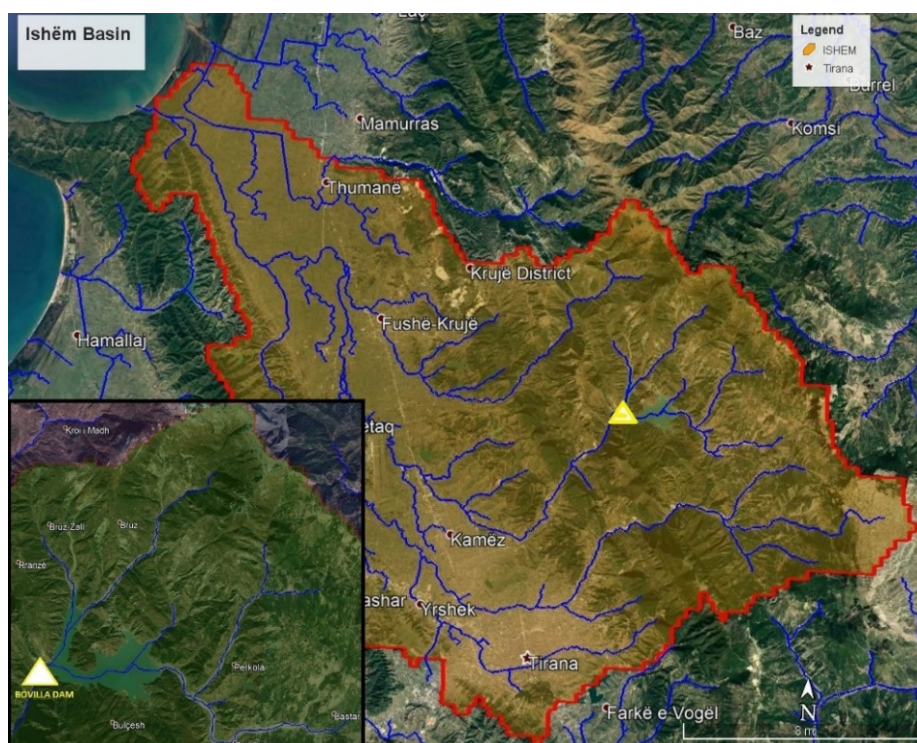


Figure 1 Ishëm river basin and Bovilla catchment

The available observational data are:

Daily precipitation:

period 2002-2011 (stations Shengjergj, Linze, and Dajt Fshat);

period 1960-1990 (station Zallmner);

Daily maximum and minimum temperature:

period 2002-2011 (stations Bulqize, Shengjergj, Linze, Tirana and Dajt Fshat);

period 1960-1990 (station Kruje)

The application of the bias-correction methods based on the observed dataset shorter than 30 years period doesn't permit to completely remove the bias, 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 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 both periods 2002-2011 and 1971-1990, 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. No missing values are detected considering the observed period 1960-1990. The yearly precipitation and maximum and minimum temperature values for the different stations are reported. A high value of the annual maximum and minimum temperature for Tirana 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.

The aim is to define a high-resolution climate projection data for impact analysis on the Bovilla catchment, to be used as input in the hydrological model in order to estimate the impacts on the hydrological process. Selection of the model among those currently available within the EURO-CORDEX project (Coordinated Downscaling Experiment - European Domain) at the maximum resolution (about 12 km) on the Bovilla catchment. The selection highlights the simulations having the best performances in terms of precipitation and temperature (the performances are evaluated using all the weather data available over the area).

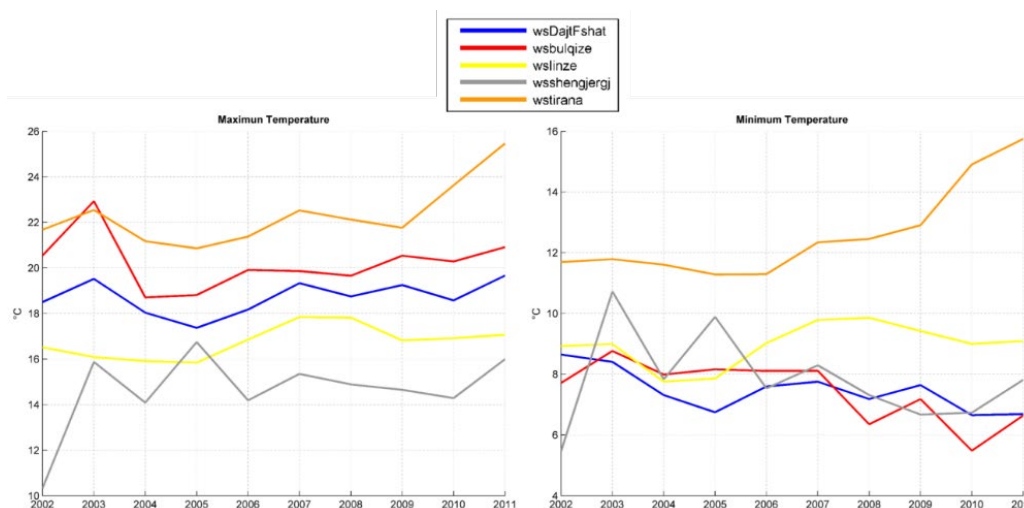


Figure 2 Annual distribution of observational maximum and minimum temperature data for stations, considering the observed period 2002-2011.

Definition of bias-corrected climate data, using the selected model for the 3 periods:

- a. on the period 1981-2010 (historical);
- b. on the period 2011-2100 under IPCC RCP4.5 scenario;
- c. on the period 2011-2100 under IPCC RCP8.5 scenario.

EURO-CORDEX simulations were used at the spatial resolution of 0.11 degrees (about 12 km), forced by different GCM. In particular, the “best” model was selected on the base of a comparison between the observed precipitation and temperature data, available, and all the currently available EURO-CORDEX simulations over the area of interest of the project. After this phase, permitting the selection of the RCM having the lowest bias in the area with respect to the selected variables a bias correction (BC) statistical approach was used (Gudmundsson *et al.* 2012) in order to overcome the existing bias and make these climate data suitable to be input for the hydrological model.

It is worth noting that bias correction performed over a period shorter than 30 years does not allow a whole bias removal, as the observations are available on a time period lower than the one considered necessary by the WMO to represent the climate of the area. Before making the bias correction of the climate data, a completeness test was performed for each case study, in order to ensure that each of them contains a satisfying percentage of valid data (at least 75%). Afterward, the bias correction of the selected model was performed by using 2002-2011 or 1971-1990 as a control period, according to the availability of the observational data. As a further analysis, the annual values of the EURO-CORDEX models for the observed period (2002-2011) were compared with the observed ones.

Generally, the selected model reproduces better the annual trend of the observed values than the other models, especially concerning the annual cumulative precipitation (preptot) and the average annual minimum temperature (tasmin). As expected, the selected bias correction method (QUANT) reduces the error for all three variables.

Results and Discussions

Timespan 2002-2011 and 1971-1990 are respectively assumed as reference period according to with data availability in Figure 3, observed (black line), modeled (blue line) and bias-corrected data (red line) of monthly values respectively for precipitation, maximum temperature, and minimum temperature are displayed for each case study. It is worth noting that, in all cases considered, bias-corrected data (red line) fit very well with observed data (black line). Therefore, the selected bias correction method (QUANT) removes the systematic error of the climate model (blue line) on the control period.

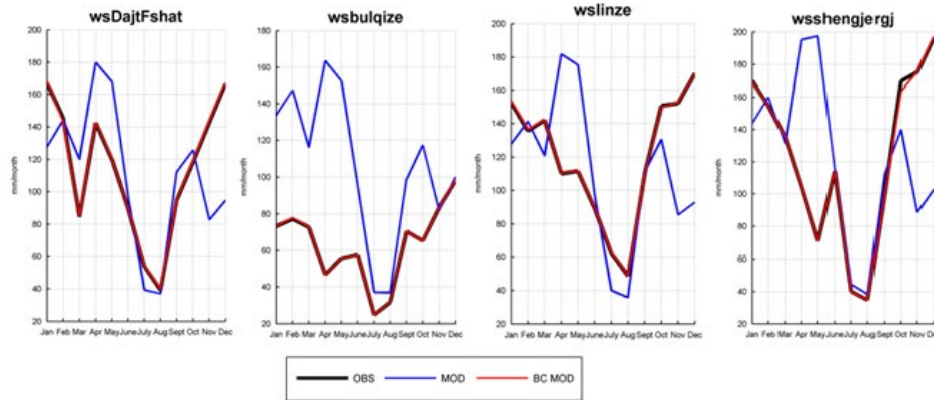


Figure 3 The annual cycle of monthly values for precipitation over the calibration period 2002-2011. Figure 4 shows the comparison between measures and bias-corrected modeled data considering the calibration period 2002-2011.

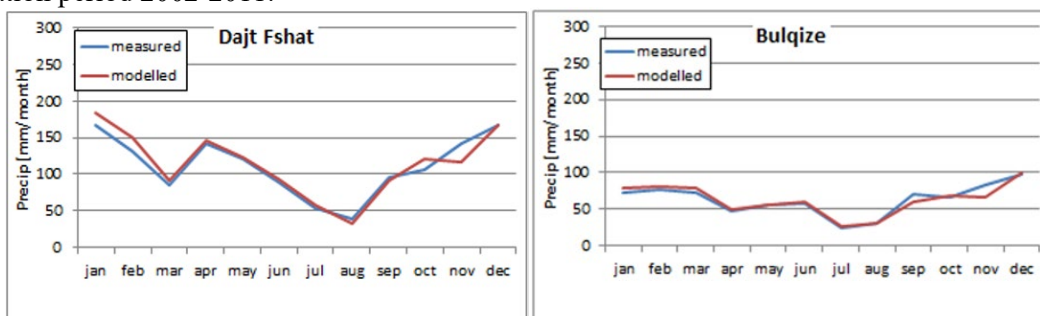


Figure 4 Monthly precipitation in the observed period 2002-2011: comparison between measures and bias-corrected modeled data.

Figure 5 shows the comparison between the datasets 2002-2011 and 1981-2010 of the monthly precipitation obtained from the bias-corrected model.

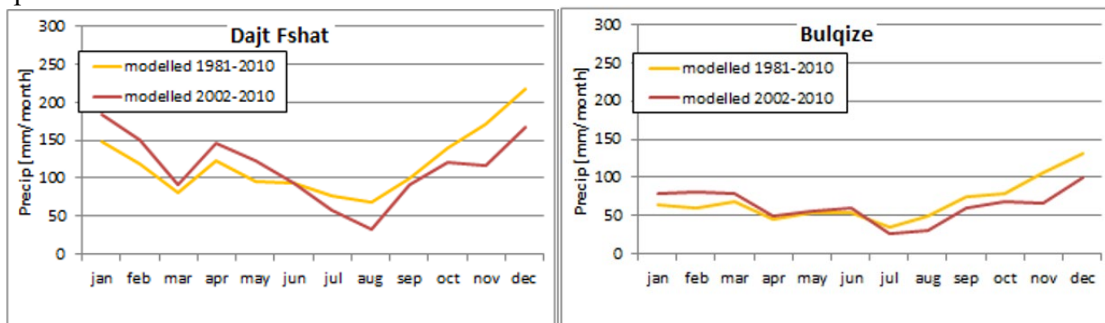


Figure 5 Monthly precipitation from the bias-corrected model: period 2002-2010 (red line) and the period 1981-2010 (orange line).

It is necessary to be aware that one of the problematic aspects related to bias correction methods is that the climate change signal might be altered (Teutschbein & Seibert, 2012).

Therefore, it is important to assess whether the bias correction method can preserve the climate change signal of the selected regional climate model. To this aim, annual time series and trend of observed, modeled and bias-corrected data were evaluated.

These analyses were performed for precipitation calibration for the period 2002-2011 and for calibration period 1971-1990, and for maximum and minimum temperature for calibration period 2002-2011 and for calibration period 1971-1990 under RCP4.5 and RCP8.5 scenarios.

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. Under RCP8.5 trend is generally well preserved for each variable and for each case. Considering the calibration period 1971-1990, under both scenarios, the trend is well preserved by the bias-corrected model for each variable and case considered.

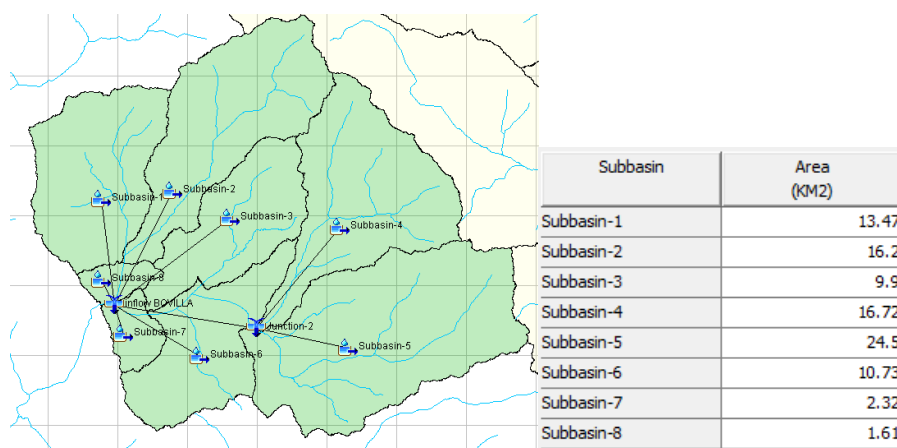


Figure 6 Basin model of Bovilla in HEC HMS.

In general, from the results obtained, the climate change signal is well preserved when the calibration period 1971-1990 is considered because it contains more data, vice versa when the calibration period 2002-2011 is used a slight worst agreement is obtained. All this climatological database needs to be implemented as input data in the hydrological model HEC HMS that is chosen. Bovilla basin was divided into many subbasins in order to better calculate the inflow at the reservoir. Figure 6 shows the basin model of Bovilla in HEC HMS divided into 8 subbasin areas. The lack of water level and discharge data excludes the possibility of the model calibration. So, the model was implemented using parameters suggested in the literature, except for the morphological ones (time lag, slopes, *etc.*) and covers factor USACE (2000). The rainfall and temperature 120-year pattern of the RCP4.5 and RCP8.5 scenarios were entered as input data in the hydrological model HEC HMS for Bovilla. The dataset was divided in the following four 30-year series for computational reasons:

- a. period 1981-2010 (historical);
- b. period 2011-2040;
- c. period 2041-2070;
- d. period 2071-2100.

The results were processed and statistically analyzed with regard to:

- flow peak value and frequency,
- flow-duration curve,
- seasonal water balance,

Figure 7 and Figure 8 show the analysis of the hydrological model results for the Bovilla basin in terms of simulated maximum annual flow (daily values) using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

From the results, it can be observed that:

- there is a slightly increasing trend, more evident for RCP8.5 scenario, of the flow peaks with highest return periods (i.e. 100 years return period);
- Figure 7 shows a 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 105 to 140 m³/s than RCP4.5 scenario results;
- the probability density distribution (Gaussian) of simulated maximum annual flow shows a change in the distribution of medium-high flow peaks: it is that while in the historical period the flows with a peak in the range 45-60 m³/s are more frequent, in the CC scenarios, the flows with a peak in the range 60-75 m³/s become more frequent (Figure 8).

In order to analyze the frequency of flow peaks, the results were firstly split in two 50-year series, one from 2001 to 2050 and one from 2051 to 2100 and ordered increasingly. It can be observed that:

- the runoff calculated using RCP4.5 scenario generates a peak with return period (RP) of 50 years equal to 134 m³/s in 2001-2050, and to 153 m³/s in 2051-2100 (+14%);
- in 2051-2100 the 50-year RP flow peak of the first 50 years is exceeded twice, indicating an increasing trend of the flood's frequency;
- the runoff calculated using RCP8.5 scenario generates a peak with a return period of 50 years equal

to 131 m³/s in 2001-2050, and to 159 m³/s in 2051-2100 (+21%), indicating an increase of the 2001-2050 50-year RP peak frequency;

- both the scenarios, and the RCP8.5 scenario, generate higher maximum annual flows with considering the same return period values.

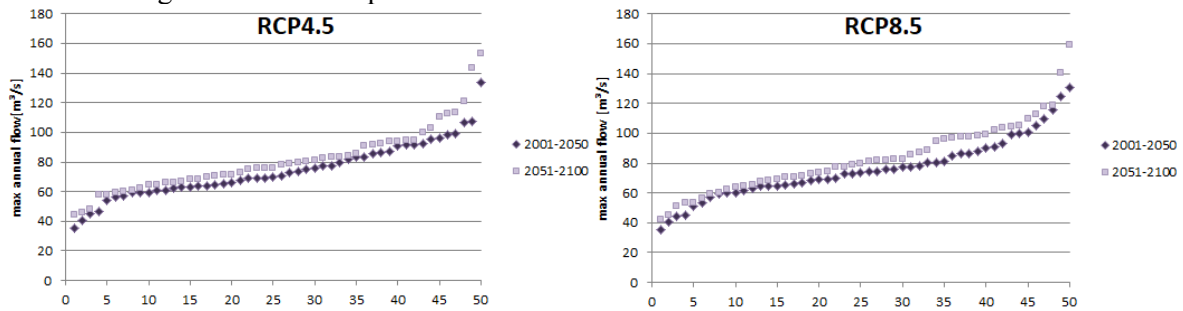


Figure 7 Hydrological model results for Bovilla basin: simulated maximum annual flow covering the periods 2001-2050 and 2051-2100, on a decreasing scale, using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

The same analysis was done with the 30-year periods, including the historical one (1981-2010, 2011-2040, 2041-2070, 2071-2100), and it confirms the increasing term of flood peaks, more regular in case of the RCP8.5 scenario.

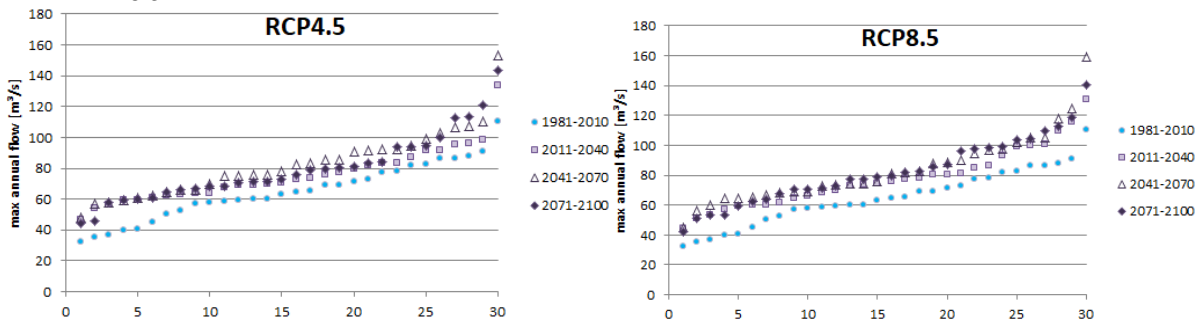


Figure 8 Hydrological model results for Bovilla basin: simulated maximum annual flow covering the 30-year periods 1981-2010, 2011-2040, 2041-2070, 2071-2100, on a decreasing scale, using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios.

The results were processed to calculate the flow-duration curves for the same 30-year periods (1981-2010, 2011-2040, 2041-2070, 2071-2100). The flow duration curves show the torrential regime of the rivers in the Bovilla basin. Figure 9 shows the comparison of the calculated flow-duration curves, in logarithmic scale, using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios respectively. It can be observed that climate change scenarios affect the ordinary flows that decrease over time, more visible in the RCP8.5 scenario case.

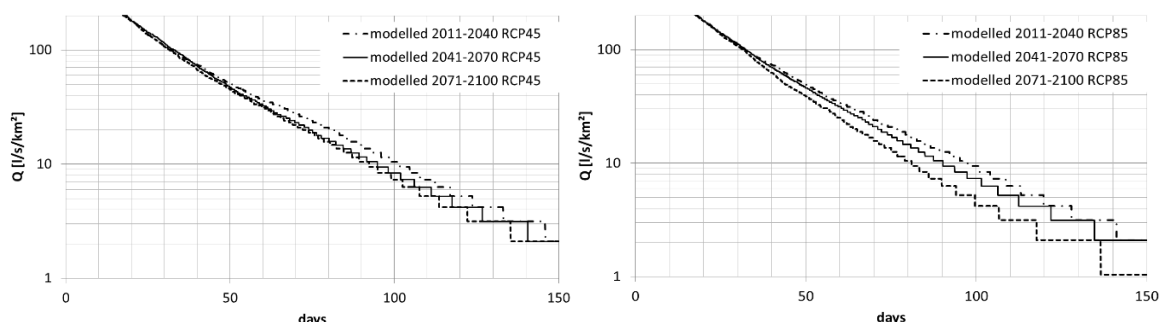


Figure 9 Hydrological model results for Bovilla basin: comparison of the flow-duration curves obtained by the simulation of the 30-year periods 1981-2010, 2011-2040, 2041-2070, 2071-2100, in logarithmic scale, using rainfall and temperature dataset of RCP4.5 and RCP8.5 scenarios. At the bottom: zoom in the range of 0-150 days. The hydrological model results were processed to analyze the seasonal trend.

In this case study, the following simulated daily time-series were considered:

- historical, time series from 1981 to 2010;
- RCP4.5 scenario, time series from 2011 to 2100 (last 30-year period simulated);
- RCP8.5 scenario, time series from 2011 to 2100 (last 30-year period simulated).

The seasonal components were identified using the Seasonal Trend decomposition based on LOESS (STL) method. The results obtained for Bovilla basin in terms of the simulated mean daily flow for RCP4.5 (red line) and RCP8.5 (green line) scenarios compared to the simulated mean daily flow of the historical period (blue line).

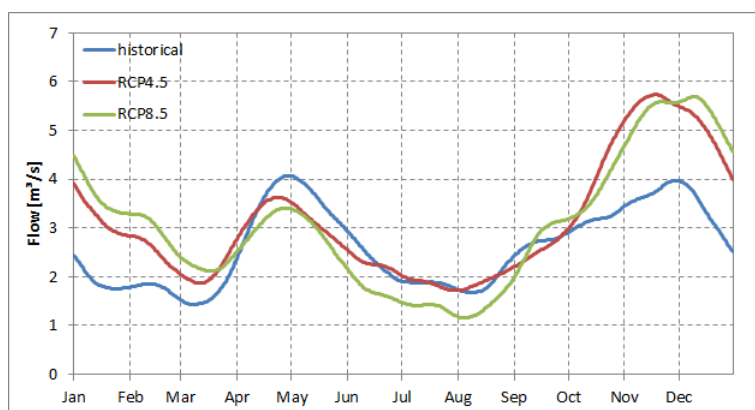


Figure 10 Model results for Bovilla basin: simulated mean daily flow for RCP4.5 and RCP8.5 scenarios

In the CC scenarios, a 20% increase of the annual mean flow is calculated, as compared to the historical period results: the mean flow grows from 2.6 m³/s (historical) to 3.1 and 3.0 m³/s, respectively for RCP4.5 and RCO8.5 scenarios. The climate change scenarios lead to more rainy winter and more droughts in spring and summer:

- considering rainfall events, the more significant variations are expected in November and December, with a 50% increase of monthly mean flow;
- a longer duration of winter rainy period is to be expected, followed by a less rainy spring when a 15% flow reduction for both CC scenarios is to be expected;
- considering the dry period, the RCP4.5 scenario doesn't show any variation for the summer when the RCP8.5 scenario shows a 30% reduction of the expected flow instead.

The increasing rain precipitation to be expected in the CC scenarios allows having a positive water balance that can increase water volume in the reservoir.

Conclusions

The first results of the high-resolution (EUR-11) future climate simulations from EURO-CORDEX were presented in the literature in 2013 (Jacob et al. 2014). 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. The results obtained in this study are consistent with the analysis reported in the mentioned paper. More specifically, under RCP8.5, (Jacob *et al.* 2014) report for large parts of Southern Europe warming of the mean annual temperature of more than 4 °C, for the period 2071-2100 compared to 1971-2000, and of about 4.5°C, over Albania. Similar results for the warming trend are reported in the present work, also if minimum and maximum daily temperature are analyzed and not mean daily temperature. Instead, under the RCP4.5 scenario, the warming for the long-term period (2071-2100) compared with the control period (1971-2000) is in the range [2°C; 2.5°C] over Albania, in agreement with the temperature change found in this work. In terms of precipitation, the paper reports a similar expected pattern between RCP4.5 and RCP8.5; in particular, the ensemble projects, for both scenarios, a substantial steady signal with slight changes in annual precipitation in the range [-5%; 5%]. Similar results, also if in the present work the precipitation results are expressed in mm, are reported. Under RCP4.5, the model project a substantial steady signal, while, under RCP8.5 a slight decrease in annual precipitation is projected. The climate change scenarios lead to more rainy winter and more droughts in spring and summer. The results

obtained for the Bovilla basin in terms of the simulated mean yearly flow are showing a relative increase in the total volume of the water. The monthly distribution is expected to be with a bigger difference from wet to dry season. This means that in term of the water management will be more difficult to use the water in the dry season and also this will be related to higher flood possibility in the wet season.

References

- Cardona O, Aalst M, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty R, Schipper E, Sinh B, (2012) Determinants of risk: Exposure and Vulnerability. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.
- Maraun D, Widmann M, (2018) *Statistical Downscaling and Bias Correction for Climate Research*. Cambridge: Cambridge University Press.
- Ray C, Iphar C, Napoli A, (2016) Methodology for Real-Time Detection of AIS Falsification. Maritime Knowledge Discovery and Anomaly Detection Workshop, Ispra, Italy, pp.74-77. <https://hal-mines-paristech.archives-ouvertes.fr/hal-01421910/document>
- Scoccimarro E, Gualdi, S, Bellucci A, Zampieri M, Navarra A, (2013) *Intense precipitation extremes in a warmer climate: results from CMIP5 models*. pp. 7902-7911.
- Gudmundsson L, Bremnes J, Haugen J, Engen T, (2012) Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations - a comparison of methods. *Hydrology & Earth System Sci.* **9**, 6185-6201.
- Teutschbein C, Seibert J, (2013) Is bias correction of regional climate model (RCM) simulations possible for non-stationary conditions? *Hydrol. Earth Syst. Sci.*, **17**, 5061–5077.
- Jacob D, Petersen J, Eggert B, (2014) EURO-CORDEX: new high-resolution climate change projections for European impact research. *Reg Environ Change* **14**, 563–578.
- USACE (2000). *HEC-HMS hydrologic modeling system user's manual*. Hydrologic Engineering Center, Davis, CA.