Statistical Downscaling and Inflows Projections of an Arid Watershed Study Case: Hassan Addakhil Dam the Way Forward

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Abstract: This study aims to assess future inflows of Hassan Addakhil dam in front of hydroclimatic variation under climate change. The Coupled Model Intercomparison Project Phase 5 (CMIP5) precipitation data was downscaled for Foum Tilicht and Foum Zaabel rain gauge stations at a daily time-scale, using SDSM software considering the baseline period 1983-2012. Future precipitation projections over the period 2013-2100, were generated for three Representative Concentration Pathway, namely RCP 2.6, RCP4.5 and RCP8.5. Besides, the future hydrologic projection was conducted through HEC-HMS. The results show that the sum of precipitations would increase for Foum Zaabel compared to the reference period by 14% for RCP2.6, 11% for 4.5%, and 14% for RCP8.5 in the 2050s. For the 2080s these changes would move to 11%, 14%, and 15% for RCP2.6, RCP4.5, and RCP 8.5 respectively. Concerning Foum Tilicht, this increase is estimated at 22%, 19%, and 20% for RCP 2.6 and RCP4.5 and RCP8.5 in the 2050s, whereas in the 2080s it's around 21% for and 22%. The Future projection of the Hassan Addakhil dam inflow, under RCP 2.6, RCP 4.5 and RCP 8.5, shows that the maximum and the minimum inflow is likely to occur during October and July respectively.

1 INTRODUCTION

The anthropogenic factor increased significantly the greenhouse emissions, which, unfortunately, accentuated global warming (IPCC, 2014). Climate change has led to the heterogeneity of the spatial and temporal distribution of precipitation, shifting of rainfall trend, snowmelt conditions change and increasing of extreme event frequency (Trenberth, 2011). Indeed, the hydro-climatic condition tends to change in the sense that some areas will experience increasing precipitation while other areas will experience an opposite trend (IPCC, 2014; Kaito et al., 2000).

Therefore, Climate change is considered as the principal trigger for precipitation heterogeneity in terms of variation of its magnitude, frequency, and intensity; which can lead to a socio-economic and environmental crisis (Dong, 2020; Sillmann et al., 2013; Sisco et al., 2017).

Along with climate change, water demands (irrigation, public supply, industry…) are continuously increasing, which would put more pressure on water resources (Karmaoui et al., 2020). Consequently, the increase in water demand and the spatiotemporal heterogeneity in hydro-climatic conditions will certainly affect dams performance (Okkan & Kirdemir, 2018). Dam is a hydraulic structure often used to meet multiple purposes comprising: drinking water, irrigation, hydropower, flood mitigation and environmental streamflow requirements (L. Zhang, 2000). Indeed, more than 47000 dams are constructed worldwide (Shah & Kumar, 2008). Due to the spatiotemporal variability of precipitation, and the increasing demands and the severity of the extreme events, dam policy becomes a tool for guaranteeing water security as a concept

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combining water availability, water accessibility, water safety and quality, and water management (Gain, 2016). Morocco is one of the countries highly concerned by water security problems. To avoid water shortages, Morocco has adopted a dam policy since 1960's and has implemented more than 140 dams to meet drinking water demand and enhance agriculture investments. However, climate change and extreme events affect directly sustainable management of these reservoirs. Several studies over the world have assessed the behaviour of dams under climate change. Ehsani et al., 2017 used neural network algorithm to assess the dam's behaviour under climate change and to optimize releases to meet downstream demands. Yang et al., 2019 investigated the impact of dam's construction under climate change on hydroecological behaviour and natural hazard risk. The results showed that the construction of the dam helps to overcome drought conditions and mitigate flood risks. Yang et al., 2019 assessed streamflow variation due to climate change and dams construction using the Global Environmental Flow Calculator while the dam's management was conducted through HEC-ResSim. The results showed that the multi-functional dams can enhance the performance of streamflow regularization. Okkan & Kirdemir, 2018 investigated the evolution of the projected crop water demands, hydro-meteorological changes, and dam performance under climate change. Z. Zhang et al., 2015 assessed the streamflow variability response to climate change in a coastal Chinese watershed, using the ecohydrological analysis and environmental flow factor. The results showed that a cascade dam's development can mitigate the effect of climate change on hydrologic behaviour. Raje & Mujumdar, 2010 evaluated the performance of a significant reservoir in India under climate scenarios by employing alternative operating policy. Raje & Mujumdar, 2010 investigated the response of multipurpose reservoirs to climate change.

In terms of climate change assessment, Global climate models (GCM) and the Regional climate models (RCM) are the primary sources for studying historical trends for precipitation and predict likely future rainfall (Chokkavarapu & Ravibabu, 2019). A set of available GCMs for climate change projection, namely the Coupled Model Intercomparison Project Phase 5 (CMIP5), basically used for the fifth IPCC Assessment Report (Lutz et al., 2016), was presented by (Chokkavarapu & Ravibabu, 2019). Furthermore, to explore the future climate change variation and its impact, four representative concentration pathways have been set: RCP2.6 as a mitigation scenario (Vuuren et al., 2011), RCP4.5/RCP6 as medium stabilization scenarios and RCP8.5 as a pessimistic scenario. These scenarios were performed for the CMIP5 to predict future global change (Taylo et al., 2012; Xin et al., 2013). However, the spatial resolution of GCM and RCM are respectively between [250Km, 600 km] and [30Km, 90Km] (Chokkavarapu & Ravibabu, 2019). Hence, the GCM and RCM are too coarse to assess local environmental factors (Chokkavarapu & Ravibabu, 2019; Diallo et al., 2012; Zeng et al., 2016). To overcome the GCM and RCM data uncertainty, global and regional precipitation data are downscaled at a finer scale resolution (IPCC, 2014). Downscaling coarse precipitation data aims to assess the likely future rainfall data with less uncertainty. The most used methods in this sense are: delta/ratio, stochastic downscaling, statistical downscaling, and dynamic downscaling (Chokkavarapu & Ravibabu, 2019). Statistical downscaling has the advantage to be less computationally demanding, cheaper and more convenient for users. Among the developed tools in this sense, the Statistical Downscaling Model SDSM, which has been efficiently used by several researchers to downscale GCM coarse data. Indeed, (Y. Zhang et al., 2016) used SDSM to downscale GCM products, based on CanESM2 predictors over the Xin River Basin. S. Samadi et al (Samadi et al., 2011) used SDSM for downscaling HadCM3 Global Circulation Model data based on NCEP/NCAR reanalysis, over Iran for a baseline period between 1964 and 2001. M. M. Gulacha et al (Gulacha & Mulungu, 2017) generated climate change scenarios for precipitation and temperature using SDSM in Wami-Rivu river basin Tanzania. The SDSM was used to downscale HadCM3 under A1 and A2 scenarios. Tukimat et al., 2019 analyzed the accuracy of projected precipitation at ungauged rainfall stations using SDSM and CanESM2 projected data under RCP4.5 and RCP 8.5.

In this study, we used the second-generation Canadian Earth System Model (CanESM2) developed in the fifth version of Coupled Model Intercomparison Project (CMIP5) in the Statistical Downscaling Model (SDSM) software to downscale precipitations in Ziz watershed controlled by Hassan Addakhil reservoir . These projections were used afterwards in assessing future inflows of Hassan-Addakhil dam in front of hydroclimatic variation under climate change. The measured precipitation recorded for Foum Zaabel, and Foum tilicht rain gauge stations in this watershed were used in SDSM for calibration and validation considering 1983-2012 as a baseline period and (2035-2064) ,(2065-2094) as future periods to compare with. After successful calibration and validation of historical data compared to the modeled one, projected precipitations for the two future horizons 2050 and 2080, were modeled in HEC-HMS to generate future inflows of Hassan Addakhil dam.

2 MATERIALS AND METHODS

2.1 Study Area

The study is carried out for the watershed of Hassan Addakhil dam (Figure 1), located in the southeastern of Morocco.

The measured precipitation data for Foum tilicht and Foum Zaabel rain gauge stations, located upstream the dam, were provided by the Hydraulic Basin Agency of Ziz-Guir-Rheriss. The daily maximum rainfall data were provided over the period 1983-2012 (the most available data) of the rain stations of Foum Zaabel and Foum Tillicht. Over the period ranging from 1983-2012, the station of Foum Zaabel registered a maximum and minimum daily precipitation of 64 mm and 0 mm respectively, with a mean and standard deviation respectively of 0.41mm and 2.57. On other hand, the station of Foum Tilicht is characterized by a maximum and minimum average daily precipitation of 50.2 mm and 0 mm respectively, with a mean and standard deviation respectively of 0.33mm and 1.90.

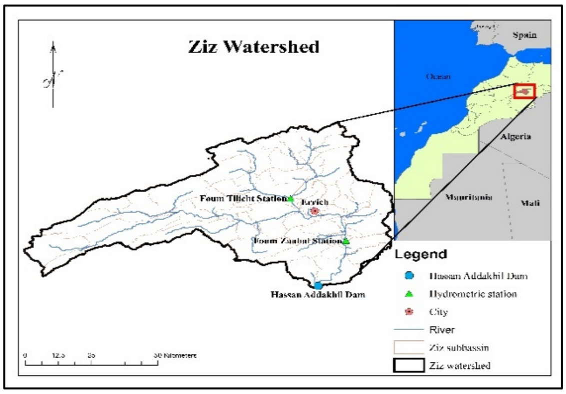

Figure 1: Ziz watershed Location

2.2 Climatic Data and Downscaling

In this study, the second-generation Canadian Earth System Model (CanESM2) integrated in the Coupled Model Intercomparison Project Phase 5 (CMIP5) was used to investigate future changes in Ziz watershed in terms of precipitation under different representative concentration pathway (RCPs). Indeed, CanESM2, which was developed by the Canadian Centre for Climate Modelling and Analysis (CCCma) of Environment and Climate Change Canada is freely available in the portal: http://climate-scenarios.canada.ca/?page=pred-canesm2. 26 atmospheric variables (predictors) from the National Centre for Environmental Prediction (NCEP) reanalysis were used during calibration and validation (1983-2005), while CanESM2 predictors data (of a spatial resolution of 2.81°) were used for projections under the intermediate and pessimistic scenarios RCP4.5 and RCP8.5 (2013-2100).

The downscaling steps were conducted in SDSM software developed by (Wilby et al., 2002). This software enables reducing the uncertainty of GCMs at a local region using statistical downscaling leading to climate change scenarios at a daily time-scale. SDSM model is based on multiple regression and stochastic weather models. For the correlation between independent variables and the dependent variable, SDSM uses empirical statistical techniques. Indeed, the predictor variables provide daily data at the large-scale atmosphere and the predictand describes the conditions of local climatic conditions. A stochastic algorithm is used to calibrate the predicted precipitations to fit the observed ones in the best way. (Pervez & Henebry, 2014). Based on the GCM independent variables, the stochastic weather generator algorithm is also carried out for precipitation prediction. (Figure 2)

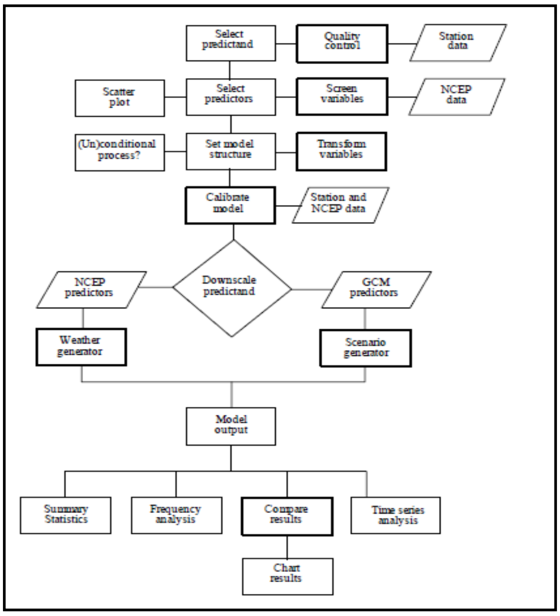

Figure 2: Climate scenario generation using SDSM (Wilby & Dawson, 2007)

2.3 Hydrological Modeling

The goal of the current phase is to estimate the future inflows of Hassan Addakhil dam under climate change scenarios. The projected future hydrologic inflows resulted from modelling projected precipitations using HEC-HMS software. Several scenarios have been modelled. Indeed, two future horizons were considered for each RCP, which has led to six future inflows series. HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) is a hydrology software developed by engineers from the United States Army (U.S. Army Corps of Engineers). The hydrologic model is based on the Soil Conservation Curve Number method (SCS-CN) (USDA, 1986). Besides, the Hydrological model has been calibrated and validated for the study are of the present paper by (Elhassnaoui et al., 2019).

3 RESULTS AND DISCUSSION

3.1 Screening of Predictors

Precipitation over the period 1983-2012 was taken as a baseline period. Quality control was first undertaken in SDSM to check the total number of observed values as well as of missing values. Following this, “Screen variables” is a primary step that allows identifying more sensible predictors to the available daily measured data. Correlation analysis and scatter plots lead to finding the most suitable parameters for building calibration relationships. More correlated parameters correspond to low P-value with higher Partial r. Three predictors were found more sensible for Foum Zaabel and two for Foum Tillicht (Table 1).

Table 1: Selected predictors for the two rain gauge stations

Station	Screened predictors
Foum Zaabel	• Ncepp850gl • Nceps850gl • Ncepp1zghl
Foum Tillicht	• Ncepp1zghl • Ncepp8_vgl

3.2 Calibration and Validation in SDSM

Calibrating observed precipitation using the selected predictors consist of developing relationships between predictor variables and predictand variables. This process, which has been conducted for the period 1983-2005, led to satisfactory results, where R-square R^2 ranges from 0.73 to 0.82. Indeed, Comparison between observed series and generated ones using weather generator indicated approximate values. (Figure 3)

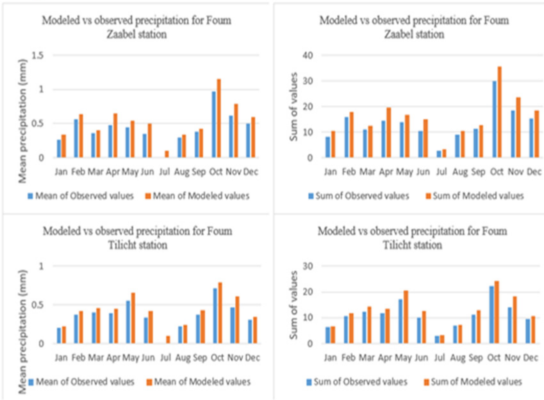

Figure 3: Graphical comparison between observed and modeled precipitation (1983-2005) (upper part for Foum Zaabel and lower part for Foum Tillicht station)

3.3 Scenario Generator: Climate Projections

Precipitation has been downscaled using outputs from CanESM2 for the three RCPs: 2.6, 4.5, and 8.5. Projections have been then compared to the chosen baseline period 1983-2012. Two horizons of projections are studied: 2050 (2035-2064) and 2080 (2065-2094).

Projections for the two stations showed different changes. For Foum Zaabel, mean precipitation would tend to decrease in the 2050s from November to March with a percentage ranging from -5% to-39% for RCP 2.6, -1% to -42% for RCP 4.5 and -7% to -45% for RCP 8.5. This period would know the same trend in the 2080s with decrease between -2% and -34% for RCP 2.6, -6% and -41% for RCP 4.5, -11% to -56% for RCP 8.5. In parallel with that, mean precipitation projections for the period from April to October tend to increase. This can be explained by extreme events and summer storms that would be intensified in the area due to climate change. Months of June and October showed the highest increase, as shown in the tables below. The sum of monthly values for Foum Zaabel was in line with mean values changes. (Table 2, Table 3 and Figure 4)

Table 2: Future variation of monthly mean precipitation at Foum Zaabel station

Station Foum Zaabel	% of change	RCP 2.6		RCP 4.5		RCP 8.5	
"Mean value."		2050	2080	2050	2080	2050	2080
Jan		-37%	-27%	-39%	-33%	-30%	-44%
Feb		-5%	-14%	-19%	-9%	-8%	-18%
Mar		-5%	-2%	-10%	-10%	2%	-17%
Apr		46%	39%	46%	49%	39%	52%
May		35%	34%	44%	24%	51%	34%
Jun		60%	58%	63%	69%	79%	69%
Jul		12%	11%	13%	11%	11%	0%
Aug		4%	-1%	0%	-3%	6%	-7%
Sep		13%	4%	2%	4%	2%	-4%
Oct		51%	38%	41%	53%	42%	88%
Nov		-39%	-34%	-42%	-41%	-45%	-56%
Dec		-14%	-4%	-1%	-6%	-7%	-11%

Table 3: Future variation of monthly sum of precipitation at Foum Zaabel station

Station Foum Zaabel	% of change	RCP 2.6		RCP 4.5		RCP 8.5	
"Sum value"		2050	2080	2050	2080	2050	2080
Jan		-37%	-27%	-39%	-33%	-30%	-44%
Feb		-6%	-15%	-20%	-10%	-9%	-19%
Mar		-5%	-2%	-10%	-10%	2%	-17%
Apr		46%	39%	46%	49%	39%	52%
May		35%	34%	44%	24%	51%	34%
Jun		60%	58%	63%	69%	79%	69%
Jul		27%	19%	38%	15%	15%	6%
Aug		4%	-1%	0%	-3%	6%	-7%
Sep		13%	4%	2%	4%	2%	-4%
Oct		51%	38%	41%	53%	42%	88%
Nov		-39%	-34%	-42%	-41%	-45%	-56%
Dec		-14%	-4%	-1%	-6%	-7%	-11%

On the contrary, Foum Tilicht station showed fewer trends to decrease and more ones to increase. Indeed, except February, April and December, other months were characterized generally by rising mean and sum precipitation values. The highest rises were remarked in March and October.

Overall, projections indicated that the sum of precipitations would increase for Foum Zaabel compared to the reference period by 14% for RCP2.6, 11% for 4.5%, and 14% for RCP8.5 in the 2050s. For the 2080s these changes would move to 11%, 14%, and 15% for RCP2.6, RCP4.5, and RCP 8.5 respectively. Concerning Foum Tilicht, this increase is estimated at 22%, 19%, and 20% for the 2050s, whereas in the 2080s it's around 21% for RCP 2.6 and RCP4.5 and 22% for RCP8.5. (Table 4, Table 5 and Figure 5)

Table 4: Future variation of monthly mean precipitation at Foum Tilicht station

Station Foum Tilicht	% of change	RCP 2.6		RCP 4.5		RCP 8.5	
"Mean value"		2050	2080	2050	2080	2050	2080
Jan		41%	49%	29%	43%	35%	43%
Feb		-1%	-7%	-8%	-11%	-3%	1%
Mar		68%	71%	72%	69%	68%	61%
Apr		-12%	-18%	-16%	-25%	-17%	-11%
May		32%	29%	30%	31%	36%	32%
Jun		14%	22%	21%	23%	15%	21%
Jul		11%	11%	12%	11%	12%	13%
Aug		2%	11%	-5%	15%	1%	3%
Sep		19%	17%	24%	18%	15%	18%
Oct		28%	30%	30%	32%	24%	31%
Nov		71%	57%	50%	71%	62%	53%
Dec		-10%	-10%	-14%	-9%	-13%	-4%

Table 5: Future variation of monthly sum of precipitation at Foum Tilicht station

Station Foum Tilicht	% of change	RCP 2.6		RCP 4.5		RCP 8.5	
"Sum value"		2050	2080	2050	2080	2050	2080
Jan		41%	49%	29%	43%	35%	43%
Feb		-1%	-7%	-8%	-11%	-3%	1%
Mar		68%	71%	72%	69%	68%	61%
Apr		-12%	-18%	-16%	-25%	-17%	-11%
May		32%	29%	30%	31%	36%	32%
Jun		14%	22%	21%	23%	15%	21%
Jul		15%	12%	21%	10%	22%	31%
Aug		2%	11%	-5%	15%	1%	3%
Sep		19%	17%	24%	18%	15%	18%
Oct		28%	30%	30%	32%	24%	31%
Nov		71%	57%	50%	71%	62%	53%
Dec		-10%	-10%	-14%	-9%	-13%	-4%

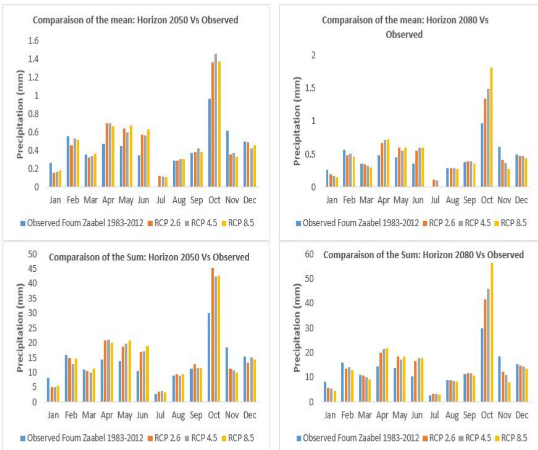

Figure 4: Future variation of monthly mean and sum of precipitation at Foum Zaabel station under RCP 2.6, RCP 4.5 and RCP 8.5

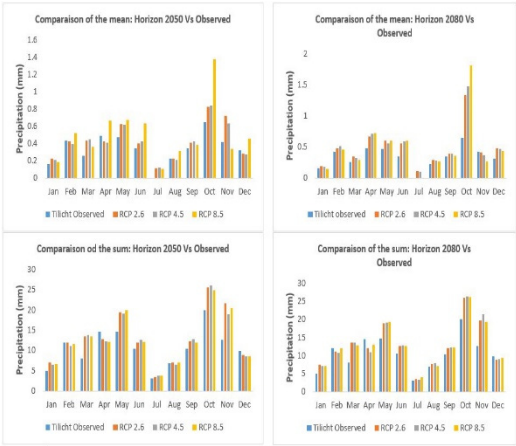

Figure 5: Future variation of monthly mean and sum precipitation at Foum Tilicht station under RCP 2.6, RCP 4.5 and RCP 8.5

3.4 Hydrological Modeling: Climate Projections

The Future projection of the Hassan Addakhil dam inflow, under RCP 2.6, RCP 4.5 and RCP 8.5 for the 2050 horizon, shows that the maximum inflow is likely to occur during October. The average monthly dam inflow during October is 1442 m^3/s for RCP 2.6, 1359 m^3/s for RCP 4.5 and 1367 m^3/s for RCP 8.5. In the other hand the minimum monthly dam inflow, for the 2050 horizon, is likely to occur during July. The average dam inflow during July is 216 m^3/s for RCP 2.6, 222 m^3/s for RCP 4.5 and 211 m^3/s for RCP 8.5. For the 2080 horizon, the monthly maximum inflow is likely to occur during October, for RCP 2.6 and RCP 4.5, however the simulation under RCP 8.5 shows that the monthly maximum inflow will occur during September. The average monthly dam inflow during October is 1107 m^3/s for RCP 2.6. In other hand the average dam monthly inflow during September is 1224 m^3/s for RCP 8.5. Furthermore, the minimum monthly dam inflow, for the 2050 horizon, is likely to occur during July. The average monthly dam inflow during July is 274 m^3/s for RCP 2.6, 260 m^3/s for RCP 4.5 and 256 m^3/s for RCP 8.5.

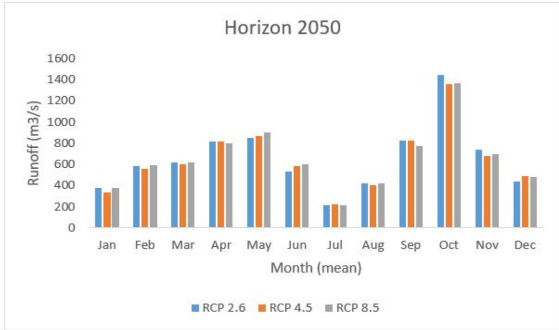

Figure 6: The Future projection of the Hassan Addakhil dam inflow, under RCP 2.6, RCP 4.5 and RCP 8.5 for the 2050 horizon

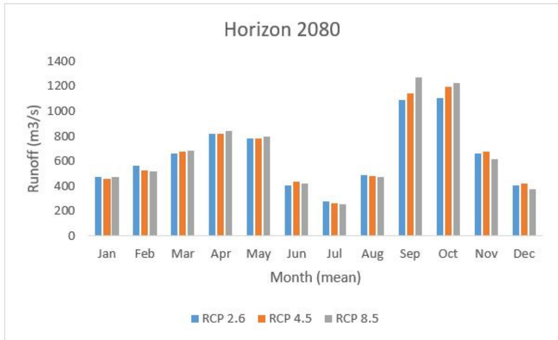

Figure 7: The Future projection of the Hassan Addakhil dam inflow, under RCP 2.6, RCP 4.5 and RCP 8.5 for the 2080 horizon

4 CONCLUSIONS

Daily rainfall data for Foum Tilicht and Foum Zaabel rain gauge stations were provided by the hydraulic agency of Ziz-Guir-Rheriss for the period 1983-2012. The Coupled Model Intercomparison Project Phase 5 (CMIP5) precipitation data was downscaled for these stations at a daily time-scale, using CanESM2 data in SDSM software. Future precipitation projections over the period 2013-2100, were generated for three Representative Concentration Pathway, namely RCP2.6, RCP4.5 and RCP8.5 and compared with the baseline period 1983-2012. HEC-HMS was then used considering these projected precipitations to evaluate future inflows of Hassan-Addakhil dam. Trends towards increase were more remarked for the two stations compared to months with decreasing precipitations. As an overall assessment of the sum precipitation, Foum Zaabel showed a trend to increase around 14% for the three RCP while Foum Tilicht precipitation would tend to increase up to 20%. This could be interpreted by the likely tendency to floods because of climate change effects. Afterwards, Future inflows of the Hassan Addakhil dam were assessed in HEC-HMS, for the three scenarios RCP 2.6, RCP 4.5 and RCP 8.5 which has showed that the maximum and minimum inflow are likely to occur during October and July respectively.

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