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Climate Change

Assessment of climate change impacts on Kossou power dam inflows (White Bandama River, Côte d'Ivoire)

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Hydropower generation is tributary by inflows of reservoir. Changes in inflows can result lead to changes in hydropower generation. In Côte d'Ivoire, energy production is largely due to hydropower dam and so the climate change is a challenge for the entire hydropower sector. This work aims to assess future climatic variability and its impacts on reservoir inflows of Kossou Dam. Historical climate data from 10 stations were used. The future climate data were produced by CLMcom-CCLM4.8 using the boundary conditions of three GCMs (CNRM-CERFACS-CNRM; ICHEC-EC-EARTH; MPI-M-MPI-ESM-LR). Simulation results for future climate under RCP 4.5 and RCP 8.5 scenarios indicate that the annual temperature may increase around 5% and the rainfall may decrease by 15 to 25 % in the future. Under RCP scenario, the inflows of Kossou dam may increase according ICHEC and MPI projections. On the other side, the CNRM indicated indicates a decrease.

INTRODUCTION

The impacts of climate change on watershed hydrology are of great interest to water resource managers and hydropower shareholder (Bates *et al*., 2008; Onwuemele Andrew, 2018). Sub-Saharan Africa is considered the most vulnerable to the impacts of climate change because of its high dependence on agriculture and natural resources, warmer baseline climates, low precipitation, and limited ability to adapt (Hassan and Nhemachena, 2008; Gezu Tadesse and Moges Dereje, 2018; Akintonde *et al*. 2019; Ume Chukwuma Otum *et al*. 2019). Indeed, the drought that affected West African countries after the end of the 1960s is known as one of the most undisputed and largest recent climate changes recognized by the climate research community (Dai and al., 2004; Gichangi and Gatheru, 2018; Momodou Badjie *et al*. 2019). Rainfall is one of the most usable weather parameters that allow determining climate variability, particularly in West Africa (Kouadio *et al*., 2011; Fitsum Bekele *et al*. 2017; Magreth S Bushesha, 2018). In West Africa, a significantly decrease in annual rainfall (Tarhule and Woo, 1997, Nicholson *et al*., 2000; Le Barbé *et al*., 2002; Goula *et al*., 2006; Le Lay and Galle, 2005) and in the number of rainy days, at the inter-annual scale, has been observed (Houndénou and Hernandez, 1998; Barbé *et al*., 2002) after 1970. This rainfall deficit resulted in a decrease in flows some streams in West African (Aka *et al*., 1996; Servat *et al*., 1997; Fanta *et al*., 2001). According to Madiodio *et al*. (2004), the annual average stream flow has decreased from 20% to 60% since the 1970s in West Africa. However, according to Riede *et al*. (2016), it is very likely that precipitation has decreased between 1950 and 2010 with a recovery over the last 20 years. Thus; West Africa is characterized by a climatic variability marked by alternating dry and wet periods. These dry and wet periods have raised many questions about the impact of these climatic sequences on the flows Rivers used by the hydro-electric dams. Indeed, the potential for hydroelectric generation is very dependent of runoff from watersheds. Thus, the runoff-rainfall processes will affect hydro-electric dam severe by changes in climatic parameters given. A reduction in rainfall by 10% gives a 25 to 50% loss in hydropower generation. As a result of temperature increase of a few degrees, a severe impact of higher evapotranspiration on hydropower might result in a substantial decrease in generated electricity (Pilesjo and Sameer, 2016). In general, increases in climate variability will lead to a lower energy security (Advait, 2014). Most sub-Saharan African countries are dependent on hydropower, and many have already suffered drought-induced energy shortfalls particularly in Côte d'Ivoire during 1983. Indeed, during this year of drought, a lowering of the water level has been observed in the Kossou dam built in 1972 by Côte d'Ivoire. This situation led to a decrease in hydropower production. Other hydro-electric dams (Ayamé 1, Ayamé 2, Taabo, Buyo (1980) and Fayé) were also affected by the meteorological drought. Thus, the climate is key factor an in hydropower generation. Likewise, the runoff which is dependent on rainfall is the key resource for hydropower generation. The challenge then is what will be the impact of climate change on hydropower generation across the future trends on the flows river in

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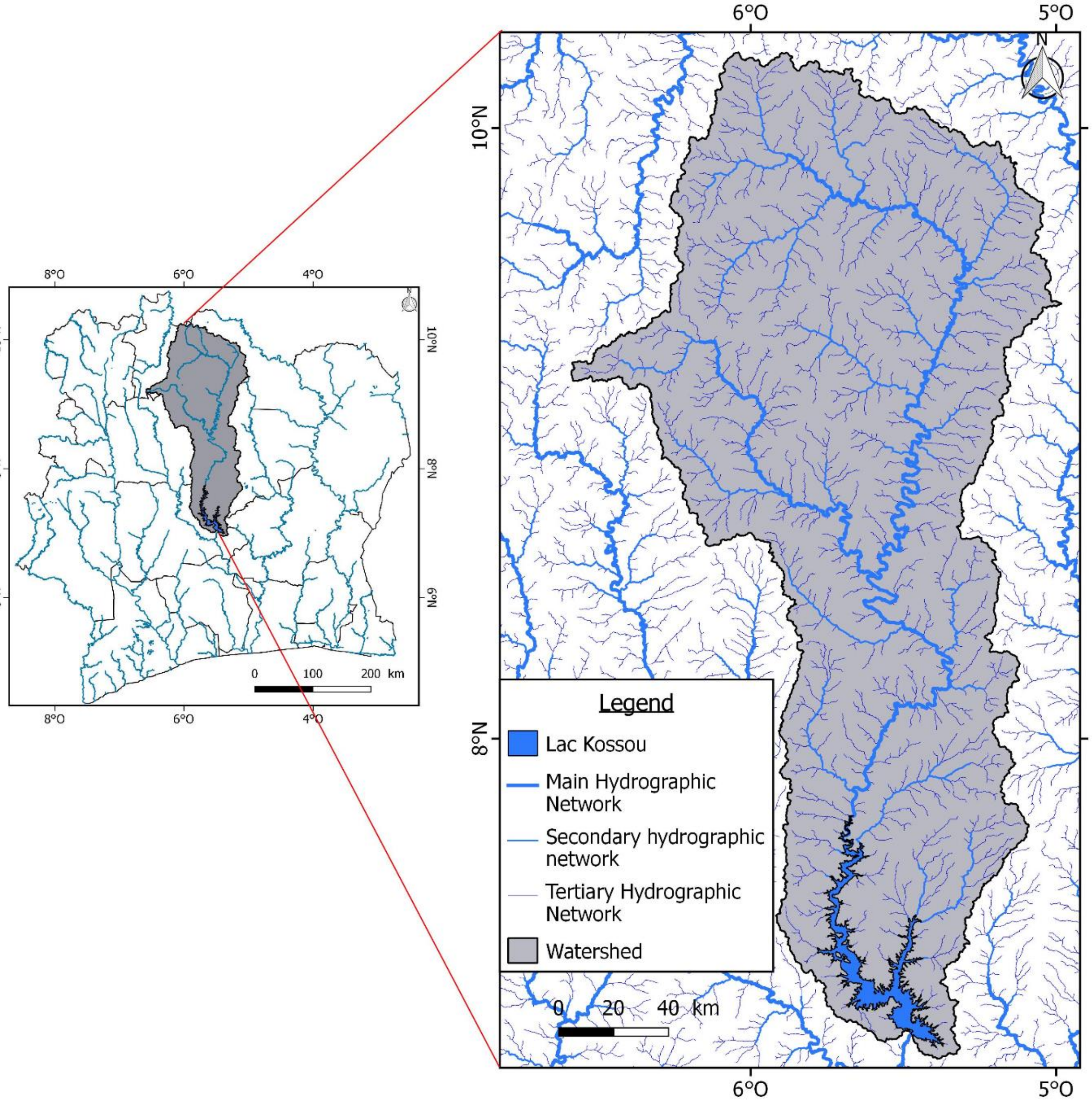


Figure 1 Geographical location of study area

Côte d'Ivoire. This study aims to provide an assessment of the impact of climate change on stream flows of White Bandama river and consequently on the hydro power generation of Kossou.

Study area and Data set

Study Area

Kossou power dam is located on the white Bandama River and it was built between 1969 and 1972 (Figure 1). Add electric production, this dam is also used for irrigation of agricultural land and fishing activities. Currently, the dam lake covers an average area of 900 km². The White Bandama River which supplies water to Lake Kossou is a tributary of Bandama River which is one of the four major rivers of the country. Its source is located north of Côte d'Ivoire near Boundiali town at an altitude of 480 m. The white Bandama watershed is under the dry sub-tropical climate (north) and equatorial climate (south). First climate regime is characterized by an annual rainfall ranges from 1,000 mm to 1,250 mm with average annual temperature of 26.7°C. In the second climate regime, annual rainfall varies between 1000 and 1300with average annual temperature of 25.5°C. Topography of the study area show that the altitudes range from 200 to 408 meters above sea level. The vegetation in the white Bandama basin consists of grassy and shrubby savannah.

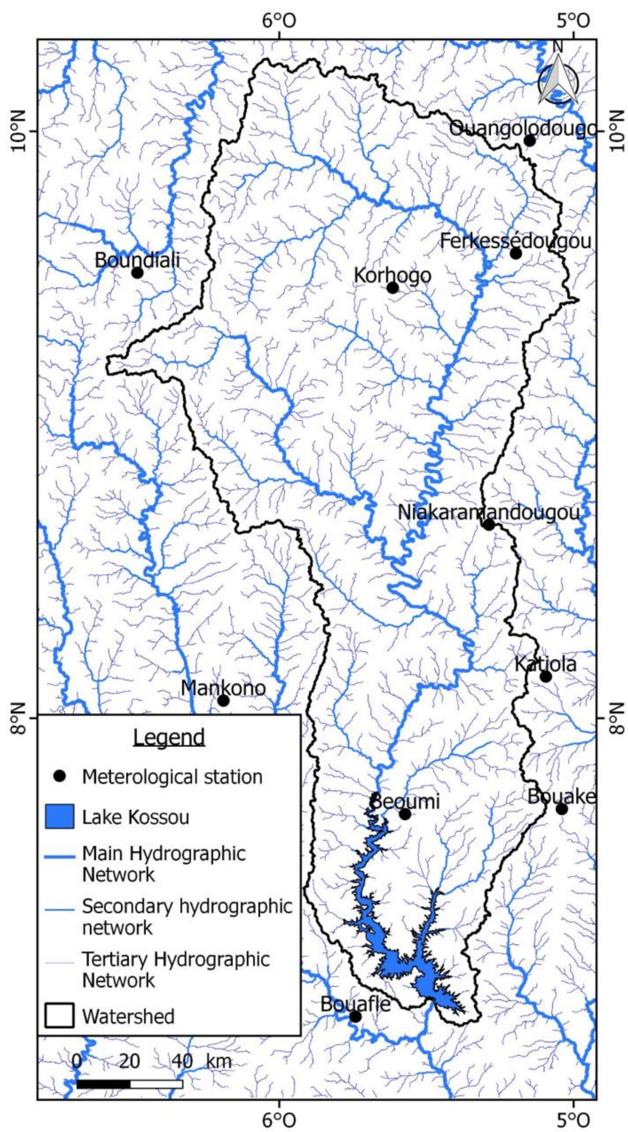
Dataset

Climate data

The climate data used in this study are the historical meteorological and projected future climate Data. The climatic parameters used are the monthly potential evapotranspiration, rainfall and temperature. For this study, twelve meteorological stations from 1970 to 2000 were selected to provide a good spatial coverage of basin (Figure 2). The historical data were collected from the National Department of Meteorology of Côte d'Ivoire. For projected climate data, an ensemble of three RCM-GCM datasets have been selected and the simulations results were performed in the framework of the CORDEX-Africa project (Table 1). The future climate data were produced by one regional climate model (CLMcom-CCLM4.8/ CCLM Climate Limited-area Modelling Community, Germany) using the boundary conditions of three GCMs (CNRM-CERFACS-CNRM; ICHEC-EC-EARTH; MPI-M-MPI-ESM-

Table 1 Bias of climate simulations of regional models for temperature and rainfall over the reference period (1971-2000)

Variables climatic	Bias of climate simulations (%)		
	CNRM	ICHEC	MPI
Rainfall	-40,1	-18,0	-15,0
Temperature	-2,6	-5,1	-2,1



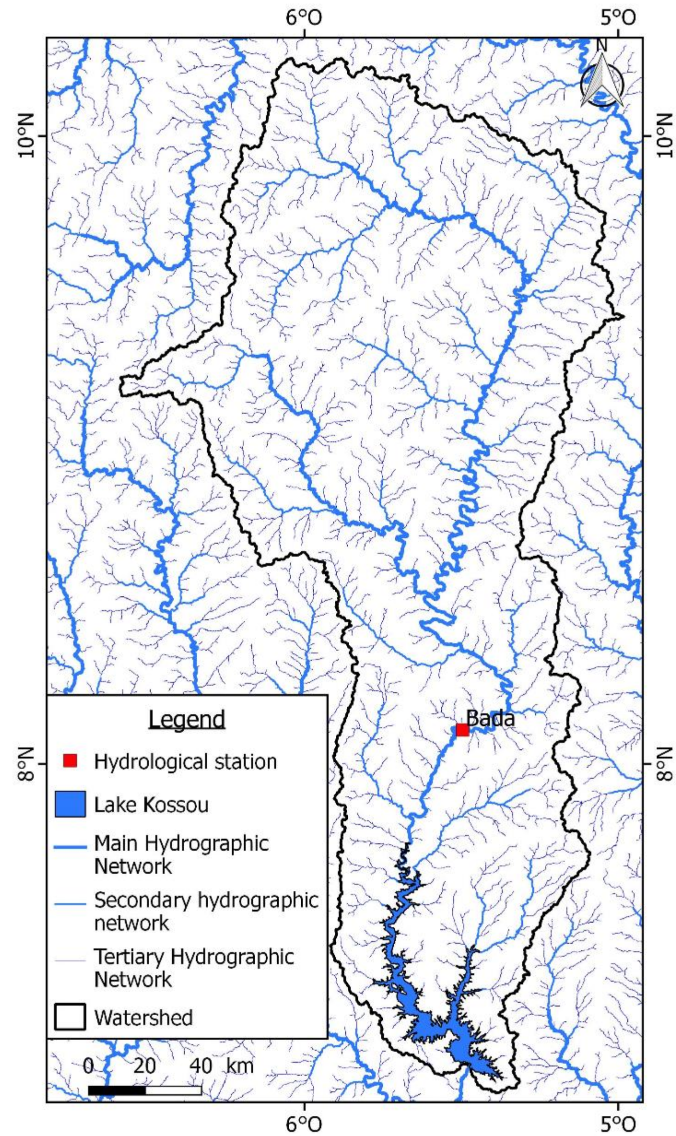


Figure 2 Network of meteorological station used in this study; **Figure 3** Hydrological station used in this study

LR). Dynamical downscaling is one of the techniques that transfer information from GCMs to finer scales by applying a higher-resolution regional climate model (RCM) over a limited area with initial and boundary conditions taken from a driving GCM. The emission scenarios RCP 4.5 and RCP 8.5 were used in this study. The simulated data (temperature and precipitation) range from 1970 to 2000 for the historical runs and from 2021 to 2040 for the RCPs. The baseline period is 1970-2000 due to the availability of the historical meteorological data.

Historical hydrological data

The hydrological data were collected from the hydrological division of Côte d'Ivoire. These hydrological data include mean monthly flow at Bada station on white Bandama river with drainage area of 26200 km² (Figure 3). The monthly flows observed at Bada gauge from 1954-2000.

METHODOLOGY

Bias-correction method for climate simulations

One prerequisite step of most climate change impact studies is the post processing of RCM-GCM outputs across bias correction. This step is significant influence on the hydrologic response of catchment. The approach based on the Linear scaling (LS) of precipitation and temperature used in this study. This method aims to perfectly match the monthly mean of corrected values with that of observed ones (Lenderink *et al*., 2007). It operates with monthly correction values based on the differences between observed and raw data (raw RCM simulated data in this case). Precipitation is typically corrected with a multiplier and temperature with an additive term on a monthly basis (Fang *et al*., 2015):

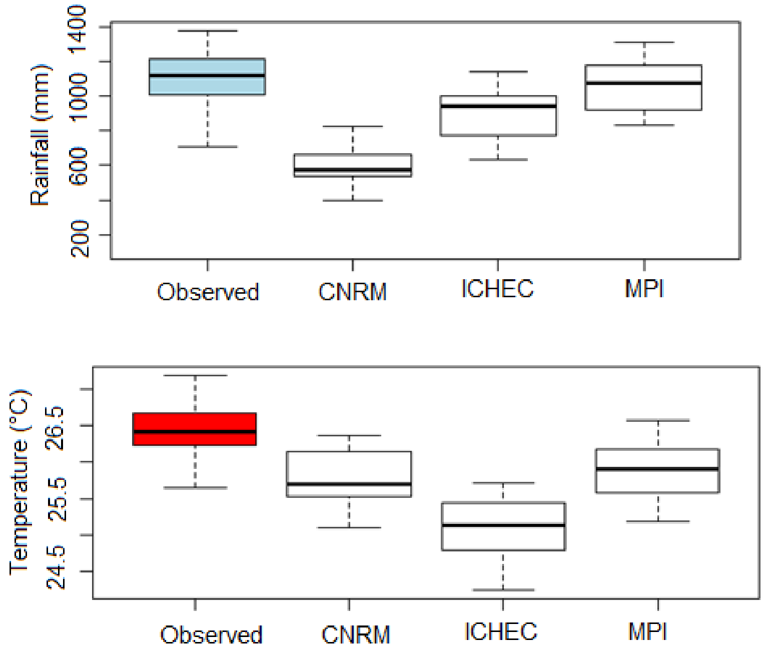


Figure 4 Comparison of observed and simulated climate data over the reference period (1970-2000).

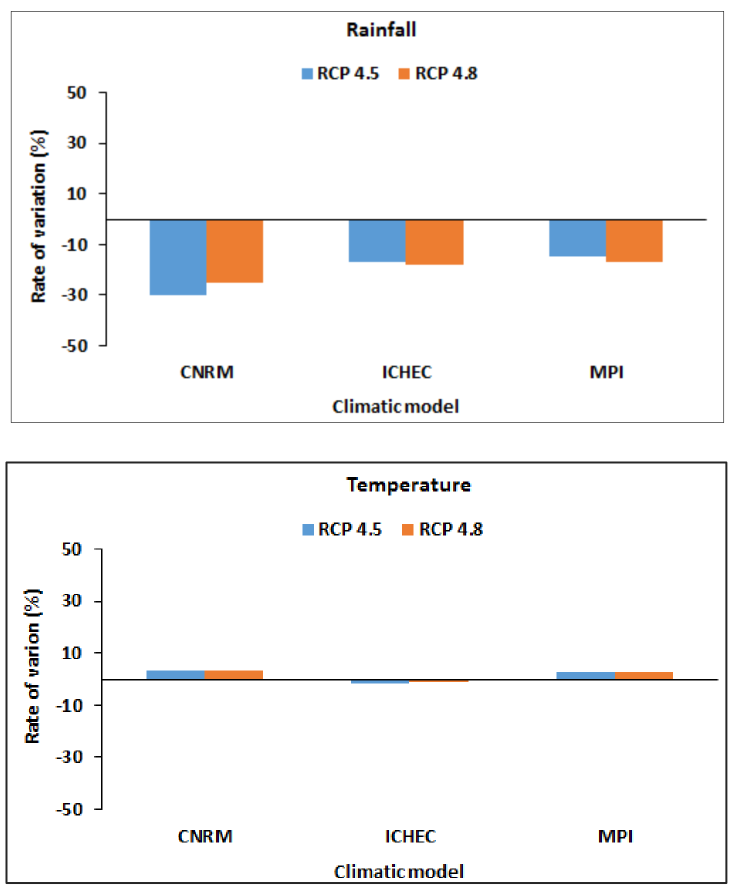


Figure 5 Change rates of mean rainfall, and temperature on White Bandama basin for the three climatic model under the RCP 4.5 and RCP 8.5 emissions scenarios.

$$P_{cor,m,d} = P_{raw,m,d} \times \frac{\mu\left(P_{obs,m}\right)}{\mu\left(P_{raw,m}\right)}$$

$$T_{cor,m,d} = T_{raw,m,d} + \mu\left(\mathrm{T}_{\mathrm{obs,m}}\right) - \mu\left(T_{raw,m}\right)$$

Where $P_{cor,m,d}$ and $T_{corm,\,d}$ are corrected precipitation and temperature on the d^{th} day of m^{th} month and $P_{raw,m,d}$ and $T_{raw,m,d}$ are the raw precipitation and temperature on the *d* the day of *m* the month. μ represents the expectation operator (e.g., μ ($P_{obs,\,m}$) represents the mean value of observed precipitation at given month *m*).

Hydrologic simulations

The aim of the hydrological modelling is to estimate the effects of climate change on rivers inflows at Bada station of White Bandama River. The GR2M hydrologic model (Génie Rural à 2 parameters au pas de temps Mensuel) developed by Makhlouf and Michel (1994) was used to simulate inflow into the Kossou Reservoir based on the observed and projected meteorological forcing. This conceptual hydrological model is a spatially lumped and a monthly time-step and its widely used for hydrological modeling of river basins in Sub-Saharan Africa (Niel *et al*., 2003; Mahé *et al*., 2005; Kouakou *et al*., 2012; Ibrahim *et al*., 2015; Soro *et al*., 2017; Coulibaly *et al*., 2018). The full description of the GR2M model is given by Mouelhi *et al*. (2006). In the study, a summarized description of model is presented. In its operation, the model describes each river basin as having two reservoirs, a soil reservoir denoted as S that controls the production function with a maximal capacity X1 (mm; the first free parameter of the model) and a routing reservoir denoted as R that controls the transfer function with a capacity of 60 mm. The implementation of the model consists of the determination of the two parameters X1 and X2 during a calibration period and then a validation where the representativeness of the two parameters is evaluated (different with the calibration period (Ibrahim *et al*., 2015). GR2M is calibrated and validated through the Nash efficiency criterion (Nash, 1970). For optimization and assessment criteria of model, it is necessary generate a set of parameters (X1 and X2) of model for the calibration period (1975-1983). The parameters corresponding to the best Nash value is then considered as models parameters. These parameters are then applied to the validation period (1984-1992). In this study, the criteria to assess efficiency of the GR2M model both on the calibration and validation periods is the standard NSE calculated on raw discharge. The Nash-Sutcliffe efficiency coefficient (NSE) is given in the following equation:

$$NSE = 100 \times (1 - \left[\frac{\sum_{i=1}^{n}\left(F_i^{obs} - F_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(F_i^{obs} - F_i^{mean}\right)^2}\right])$$

where F_i^{obs} is the observed flows for month *i*, F_i^{sim} is the simulated flows for month *i*, and F_i^{mean} is the mean observed flows over the given period.

RESULTS AND DISCUSSION

Performance of the regional climatic model

The biases on simulations of the regional climate model are setby comparison of the simulated historical data with the observations of the same period at the local scale (Table 1). Moreover, the figure 4 shows, using box plots, the historical rainfall and temperatures observed and simulated by regional climate models over the period 1970-2000. Overall, the regional CLMcom-CCLM4.8 model underestimates rainfall and temperature in the study area (Table 1). The works of Akinsanola *et al*. (2015) showed that RCMS simulate West Africa climate in satisfactory way despite the fact that they exhibit systematic biases. Recently, Akinsanola and Ogunjobi (2017), have that indicated that the RCMs performance is highly variable among different sub-regions as well as for different seasons, implying that no single model is best at all time.

Changes in climatic forcing

The per cent changes in monthly rainfall based on ground-based observations and projected simulation from the HadGEM2-ES model are presented in the Figure 5. The climate models used indicate that a decrease trend of rainfall over the watershed. The magnitude of this decrease varies according to the climate model and the emission scenarios of greenhouse gases. Thus, under the RCP 4.5 scenario, the CNRM model shows a decrease of about 30% compared to the reference period. As for the MPI model, it indicates a rate of change of 15% compared to the reference period. This same decrease trend is also indicated by climate models under Scenario 8.5. These trends are confirmed by works of Coulibaly *et al*. (2018) in Sassandra watershed (Côte d'Ivoire). In West Africa, several authors (Mbaye *et al*., 2015; Soro *et al*., 2018) have indicated future decrease trends in rainfall under RCP 4.5 and RCP 8.5.

At the temperature level, the climate models used indicate contrasting trends. Indeed, the CNRM and MPI models indicate an increase in average temperature over the White Bandama watershed. In the Bandama watershed, Soro *et al*. (2018) shows that annual temperature may increase under RCP 4.5 and RCP 8.5. On the other side, the ICHEC model indicates a slight decrease in average temperatures. This situation could be related to the ICHEC model ability to correctly reproduce climate variables in this area.

Hydrologic model validation

Calibration is the process of choosing the best sets of model parameters, by automatically adjusting their numerical values to better mimic the response observed at the outlet. In this work, the GR2M model calibration was performed for the period 1975-1983. For this period, the best Nash performance coefficient is order to 79.8% (Table 2). The GR2M model validation was done using 1984-1992 period with the Nash coefficients greater than 70%. Simulated and observed runoffs for calibration and validation periods are presented in Figure 6. There is a generally good fitness.

Inflows changes based on climate scenarios

Effects of climate on monthly inflows

Figure 7 shows the evolution of the monthly inflows for the baseline period (1976-1995) and also for the 2040 horizon. The climate model outputs were used as input to the hydrologic model to simulate projections of monthly inflows at the Bada station. Under scenarios RCP 4.5 and RCP 8.5, the three climate models predict an increase in average monthly inflows over the reference period. This increase does not affect

Table 2 Calibration and validation period with Nash Criteria Value from hydrological model

river	Station	calibration		validation	
		period	Nash Criteria Value (%)	period	Nash Criteria Value (%)
White Bandama	Bada	1975-1983	79,8	1984-1992	73

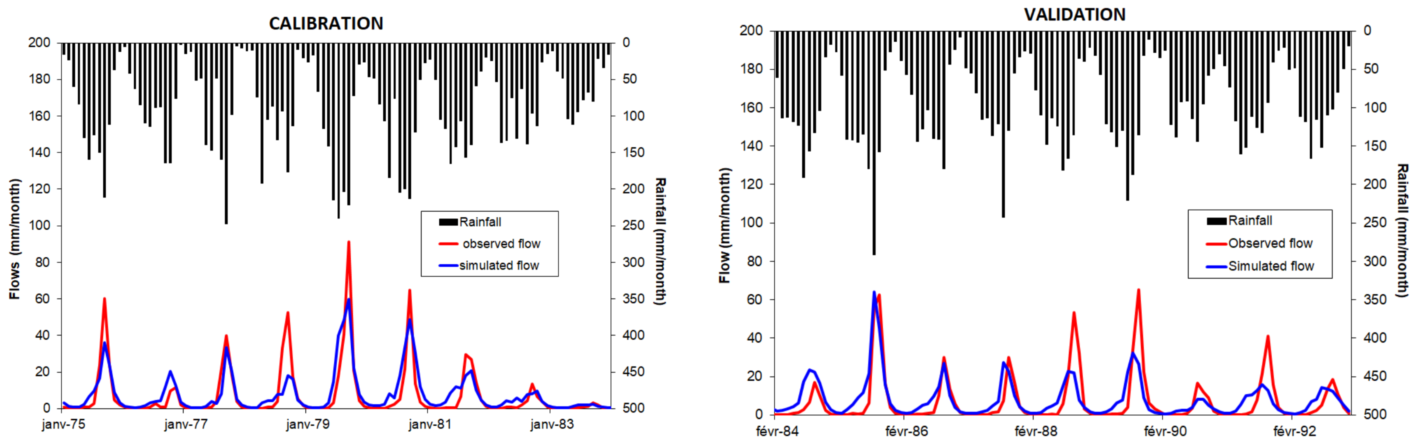


Figure 6 Comparison of observed and simulated hydrographs at Bada station on White Bandama River

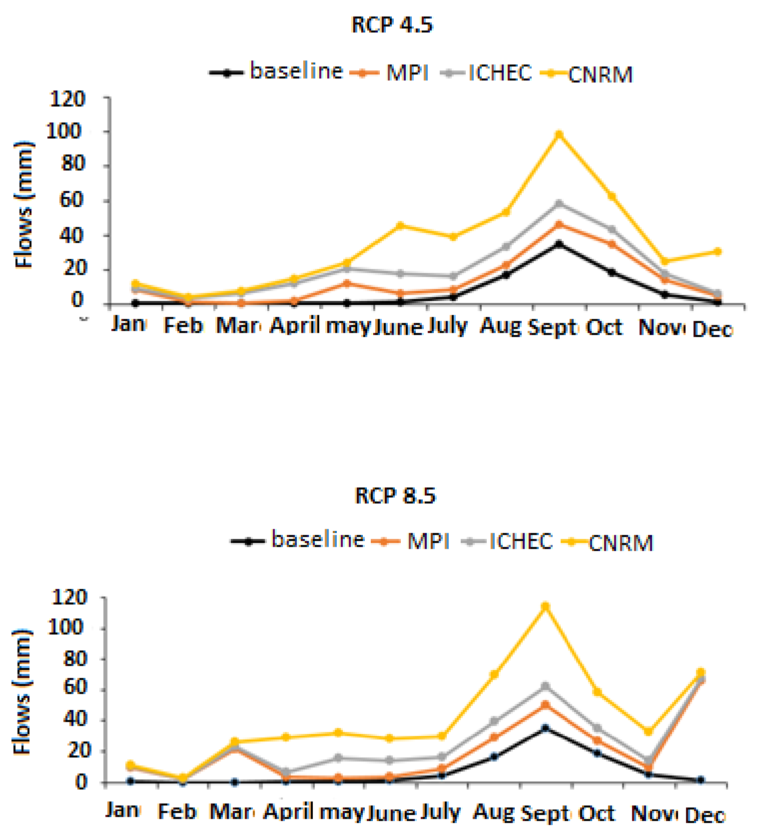


Figure 7 Evolution of inflows by 2040 compared to the 1976-1995 baseline period

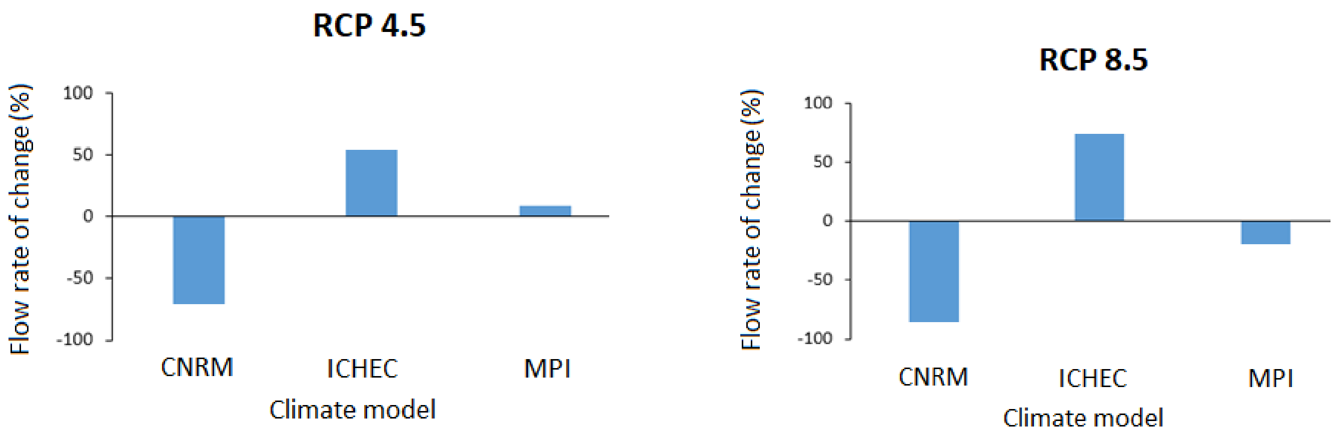


Figure 8 Change in annual flows by 2040 compared to the 1976-1995 baseline period

the seasonal distribution of flows. These results confirmed the analysis of Soro *et al*. (2018) in the Bandama watershed concerning the trends of future runoff under RCP scenario.

Effects of climate on annual inflows

Figure 8 shows the evolution of the annual inflows for the 1976-1995 reference period and for the 2040 horizon. Overall, the results are different in terms of climate models and also scenarios. Under Scenario 4.5, two models predict an increase with varying proportions of average inflows at the Kossou reservoir. For the RCP 8.5 scenario, climate forcings indicate a decrease in mean annual flows with the CNRM and MPI models. For the ICHEC model, it indicates an increase in average annual flows. However, the work of Ardoin *et al*. (2009) indicates a downward trend in runoff that could reach 38 % in the watersheds on the Sassandra catchment (Côte d'Ivoire).

CONCLUSION

This study aims essentially to show the impacts of climate change on the inflows of the Kossou power dam by 2021-2040 because it participates in the energy production of Côte d'Ivoire. Thus, the outputs (precipitation and temperatures) of CNRM, ICHEC and MPI climate models under RCP 4.5 and RCP 8.5 are used as inputs to the hydrological model GR2M to simulate water inflow by 2021-2040. Overall, the study showed that that the temperature may increase and the rainfall may decrease in the future. Under RCP4.5 and RCP 8.5 the inflows of Kossou may increase. These results highlight the large uncertainties associated with the impacts of climate change on water resources through global model hydrological.

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Author Contributions
Gneneyougo Emile SORO developed the ideas; N'Da Jocelyne Maryse Christine AMICHIATCHI contributed to the realization the map and the data processing. Gneneyougo E. SORO analyzed data and wrote the paper with inputs from William Francis KOUASSI and Tié A. GOULA BI.

Conflicts of Interest
The authors declare no conflict of interest.

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