Journal of Water Resource and Protection, 2024, 16, 569-583
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Analysing the Potential Impact of Climate Change on the Hydrological Regime of the Upper Benue River Basin (North Cameroon)

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How to cite this paper: Fita, E.D., Ombolo, A., Fotso-Nguemo, T.C., Saïdou, D.B., Daïka, A., Chouto, S. and Mbele, F.A. (2024) Analysing the Potential Impact of Climate Change on the Hydrological Regime of the Upper Benue River Basin (North Cameroon). *Journal of Water Resource and Protection*, **16**, 569-583.
https://doi.org/10.4236/jwarp.2024.168032

Received: June 11, 2024
Accepted: August 9, 2024
Published: August 12, 2024

Abstract

In this study, we analyse the climate variability in the Upper Benue basin and assess its potential impact on the hydrology regime under two different greenhouse gas emission scenarios. The hydrological regime of the basin is more vulnerable to climate variability, especially precipitation and temperature. Observed hydroclimatic data (1950-2015) was analysed using a statistical approach. The potential impact of future climate change on the hydrological regime is quantified using the GR2M model and two climate models: HadGEM2-ES and MIROC5 from CMIP5 under RCP 4.5 and RCP 8.5 greenhouse gas emission scenarios. The main result shows that precipitation varies significantly according to the geographical location and time in the Upper Benue basin. The trend analysis of climatic parameters shows a decrease in annual average precipitation across the study area at a rate of −0.568 mm/year which represents about 37 mm/year over the time 1950-2015 compared to the 1961-1990 reference period. An increase of 0.7˚C in mean temperature and 14% of PET are also observed according to the same reference period. The two climate models predict a warming of the basin of about 2˚C for both RCP 4.5 and 8.5 scenarios and an increase in precipitation between 1% and 10% between 2015 and 2100. Similarly, the average annual flow is projected to increase by about +2% to +10% in the future for both RCP 4.5 and 8.5 scenarios between 2015 and 2100. Therefore, it is primordial to develop adaptation and mitigation measures to manage efficiently the availability of water resources.

Keywords

Climate Variability, Hydrological Modelling, Climate Models, Upper Benue Basin, Northern Cameroon

1. Introduction

Climate change is a very serious threat around the world, and its consequences have an impact on the well-being of populations and their ecosystems. Climate change is the result of an increase in the concentration of greenhouse gases in the atmosphere caused by human activities, leading to global warming [1]. Climatic factors include changes in precipitation, temperature and higher atmospheric CO_2 concentrations according to [2]. As climatic conditions change, we are increasingly seeing more severe and frequent extreme events, including storms, extreme heat, floods, droughts and forest fires [3] [4]. These climatic hazards affect the economic sector both directly and indirectly, making the poorest populations more vulnerable.

Changes affected all climatic zones, notably the Sahelian and arid zone [5]. Several studies over Central and West Africa have shown that water resources are significantly impacted by climate change [5]-[8]. In this area, the availability of water resources is highly dependent on climatic variability and change. Thus, the issue of the impact of climate change on the hydrological regime and further the availability of water resources remains a major concern in the Sahelian regions. Understanding the current hydrological regime of a watershed and its future change is important for water resources management and planning.

The Upper Benue basin is not immune to these phenomena. The Upper Benue catchment is one of the most important basins, which is vital for food security and socio-economic development of this part of Cameroon. This catchment located in the Sudano-Sahelian zone is the main source of water resources in the Upper Benue River. According to [9], the Upper Benue River is fundamental for hydropower generation, fisheries, irrigation, and regulation of the flow during the dry season.

The impact of climate change on water resources has been assessed for several years on many African basins using Global climate models (GCMs) and Regional climate models (RCMs) over past and future periods [4] [8] [10]. The climate model has been applied to predict future streamflow under different scenarios of the development of human activities. Some climate models forecast an increase in precipitation (HadCM3 model), while others show a downward trend (CCLM model) [4]. However, all models are unanimous and agree on global warming [4] [10] [11]. For example, [4] used data from the HadCM3 model and showed that general trends in runoff over the period 1961-2050 are characterised by an increase in runoff in the Wayen basin in Burkina Faso. On the other hand [12] indicated that the integration of GCMs without correction into hydrological models can modify analysis and render the model unrealistic. Ardoin-Bardin [8] described the implications of (GCMs) on the flows of several large river basins in Africa by 2050. The author indicated that northern and southern regions of Africa will experience a significant render decrease in the runoff, while an increase is projected in eastern regions and some semi-arid parts of sub-Saharan Africa.

Several studies have been carried out over the Upper Benue River in order to assess the ability of climate models to simulate the discharge basin [13]-[15]. Mkankam and Kamga [13] evaluated the ability of two climate models HadCM3 and ECHAM4/OPYC3 to reproduce the discharge of the Benue River in Garoua using the Yates hydrological model and predicted an increase in climatics factors. According to the author, precipitation will increase between 4% and 13%, temperature between 1˚C and 3˚C and PET between 4% and 11% by the end of the 21st century. Consequently, the streamflow of the Benue River will increase between 3% to 18%. In their studies, [14] reported that the impact of climate change in the Soudano Sahelian area of Cameroon will be reflected by higher variability of precipitation and temperature and the occurrence of extreme events such as droughts and flows. On the other hand [15] used the HadCM3 climate model to simulate streamflow on the same basin using three hydrological models Yates, GR2M and WBC, and found higher rates of values of streamflow ranging between +14% and +80%. Therefore, all these studies used GCMs and the higher values obtained imply the necessity to correct biases between observed and projected data of climatic factors.

Recently, there has been the return of a wet period accompanied by heavy rainfall [16] [17], which has led to major flooding in the northern regions and more particularly in the upper catchment area of the Benue River, which can have significant impacts on the hydrological regime. It is therefore understandable that one of the major challenges to be taken up by scientists is indeed the most accurate possible assessment of the impacts of climate change on the future flow. The present study aims to assess the potential impact of climate change on the hydrological regime of the upper catchment area of the Benue River using climate models and specifically: 1) simulate monthly discharge using the GR2M model; 2) assess the potential climate change impacts on the future flow.

The rest of the paper is structured as follows: In Section 2, we describe the study area and data. In Section 3, the methodology is presented. In Section 4, the results and the discussions are given. The conclusion is assumed in Section 5.

2. Study Area and Data Description

2.1. Study Area

The Upper Benue River is located in the northern part of Cameroon. It extends between longitudes 11˚47' and 15˚48' East and latitudes 6˚49' and 10˚51' North (**Figure 1**) and administratively covers the Adamawa, North and Far North regions. The surface area of the basin is estimated at 95,626 km^2. This basin presents a diversity of landscapes and a climatic domain that contrasts with the Sahelian zone in the north and wet plateau areas, heavily watered in the south [18]. The climate is characterized by two distinct seasons: the dry season occurring between November and April and a rainy season from April to October with a unimodal pattern distribution of rainfall. The four major rainy months (June to October), concentrated about 65% of annual precipitation. The precipitation of the month of June varies from 40 mm to 240 mm. The precipitations of July, August and September range respectively between 120 - 300 mm, 100 - 320 mm and 70 - 300 mm [17]. The basin has its source in the Adamawa and the Laka Plateau in Chad [18].

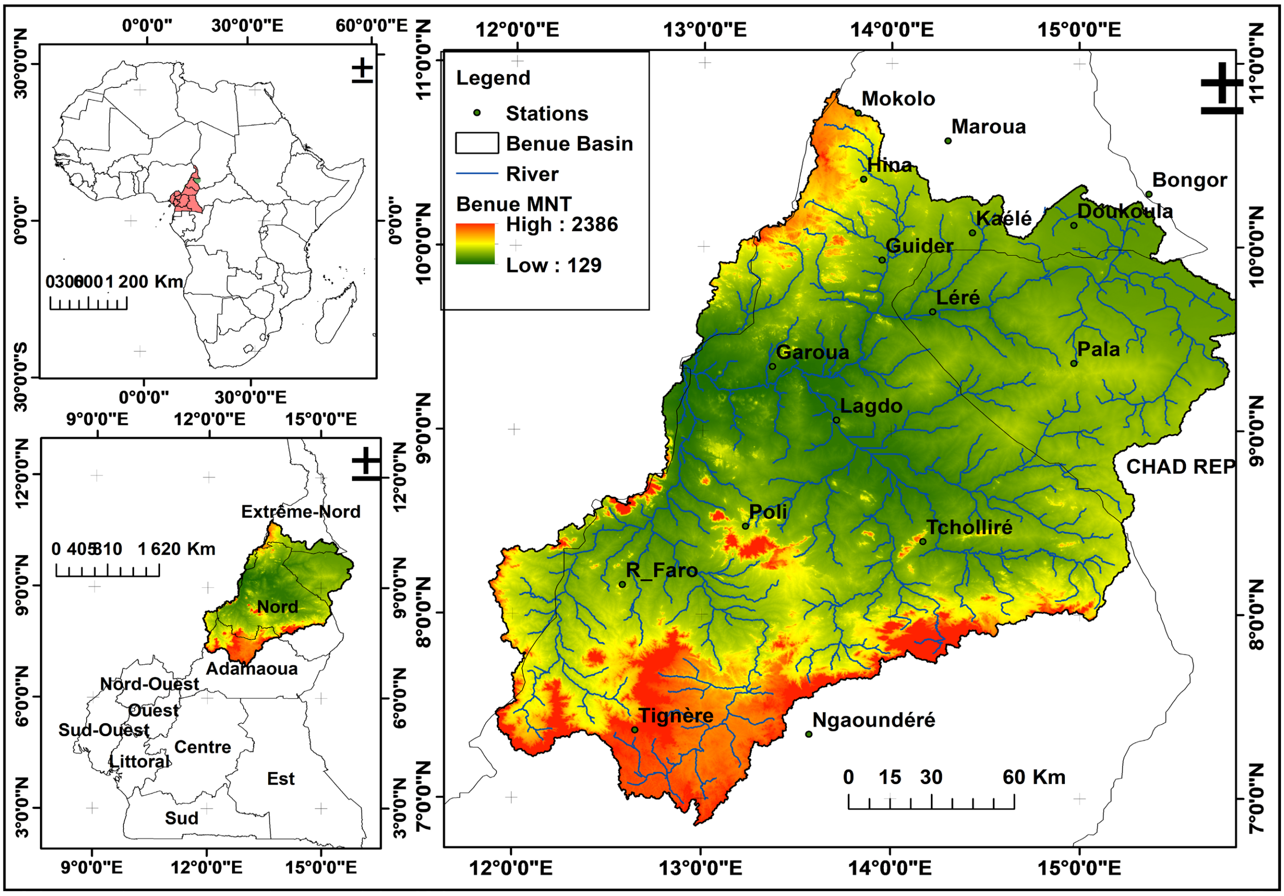


Figure 1. Location map of the upper Benue catchment.

2.2. Data Description

Various data sets have been used in this study: observed data from the historic period (1950-2014) and GCMs data for the future period (2015-2100). Historic hydrological data of Riao (Lagdo) station from 1950 to 1983 provided from [18]. Those from Cameroon's Hydrological Research Centre and from Energy New Organization (ENEO) were used to complete the time series in 2015. In addition, observed climatic data was collected from the Agency for Aerial Navigation Safety in Africa and Madagascar. The climate projection data used are those from MIROC5 and HadGEM2-ES models provided in the framework of phase 5 of the

Coupled Model Intercomparison Project (CMIP5). The MIROC5 known as Model for Interdisciplinary Research on Climate-Earth System, version 5 was developed in Japan by Atmosphere and Ocean Research Institute [19]. The resolution of the model is 1.40 × 1.40 degrees. The Hadley Centre Global Environmental Model HadGEM2-ES has been developed by Met Office Hadley Centre and Instituto Nacional de Pesquisas Espaciais at the resolution of 1.875 × 1.24 degrees. These data range from 2015 to 2100 according to the representative concentration pathways scenarios RCP 4.5 and RCP 8.5. The choice of these two models is dictated not only by their greater and frequent use in assessing the impacts of climate change on water resources, but also by their quality. In addition [12] indicated that these models are amongst the better-performing models in the hydroclimatic studies.

3. Methodology

The methodology used is based on a statistical analysis of hydroclimatic data and hydrological modelling. The homogeneity of the time series has been tested using Pettitt and SNHT tests. Trends were assessed by the Mann-Kendall (MK) test [17]. The Mann-Kendal test searches for a trend in a time series without specifying whether the trend is linear or nonlinear. It is based on the test statistics Z (Equation (1)), which is defined as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{1}$$

The MK statistic *(S)* is defined as the sum of the number of positive differences minus the number of negative differences as Equation (2) follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}(x_j - x_k) \tag{2}$$

$\operatorname{sign}(x_j - x_k)$ is an indicator function (Equation (3)) that results in the values −1, 0, or 1 according to the sign of $x_j - x_k$.

Where $j > k$, the function is calculated as follows:

$$\operatorname{Sign}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \tag{3}$$

The variance Var(*s*) can be computed as Equation (4):

$$\operatorname{Var}(s) = \frac{n(n-1)(2n-1) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18} \tag{4}$$

where *n* is the length of the data set and *t* is the number of data values in a group of determinations.

The GCM's simulation data often include significant biases. For this reason, the empirical Quantile Mapping method has been used to correct biases in temperature and precipitation outputs from GCMs [4] [20]. This method was chosen because it's recognized to better correct the modelled temperature and precipitation output and outperformed the other major methods [12] [21]. The aim of the correction is to adjust the distribution of the monthly time series of the climate model with the distribution of monthly data of observed time series using a function (*k*) "Equation (5)" as:

$$\text{Observed data} = k(\text{GCM}). \tag{5}$$

The hydrological model used to reproduce the hydrology of the basin and to assess the future impact of climate change on the discharge is the GR2M model. GR2M is a conceptual model developed by CEMAGREF (Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts) and adapted by [22]. The inputs were monthly rainfall and potential evapotranspiration (PET) (**Figure 2**).

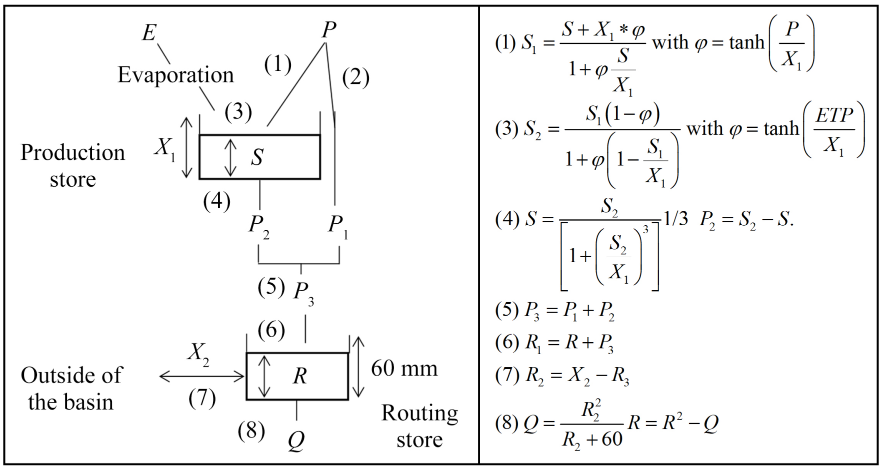


Figure 2. Structure of the GR2M model.

The simulations cover the period 1950-2100. This model has been used in several hydrological modelling studies of the large basins of West and Central Africa [8] [15] [23]. The model was previously calibrated using observed discharge from 1950-1970 and validated over the period 1995-2014. Then the X_1 and X_2 parameters obtained from the calibration were applied to the simulation of the hydrological regime. Model validation is verified by a comparison between the calculated and observed flows through the Nash and Sutcliff criterion (Equation (6)).

$$\text{Nash} = 1 - \frac{\sum\left(Q_{\text{sim}} - Q_{\text{obs}}\right)^2}{\sum\left(Q_{\text{obs}} - \overline{Q_{\text{obs}}}\right)^2} \tag{6}$$

where Q_{sim} is the value of the simulated discharge, Q_{obs} the observed discharge and $\overline{Q_{obs}}$ the mean observed.

The PET has been calculated using the equation of Hargreaves-Samani [24]. This equation (Equation (7)) is reliable and widely used to estimate PET by using daily maximum and minimum temperature, latitude, and daily radiation as follows:

$$\text{PET} = 0.0023\left(T_m + 17.8\right)\left(\sqrt{T_{\max} - T_{\min}}\right)R_a \tag{7}$$

where: R_a = extra-terrestrial radiation (mm/day); $T_{\max}$, $T_{\min}$ and T_m represent respectively maximum minimum and mean temperature.

4. Results and Discussion

4.1. Results

The average annual rainfall for the observed period 1950-2014 varies between 800 mm in the North-East and 1550 mm in the South of the basin located in the Adamawa Plateau with mountain tops rising to over 1000 m. This reflects a gradual increase in mean annual rainfall from the North to the South of the basin (**Figure 3**).

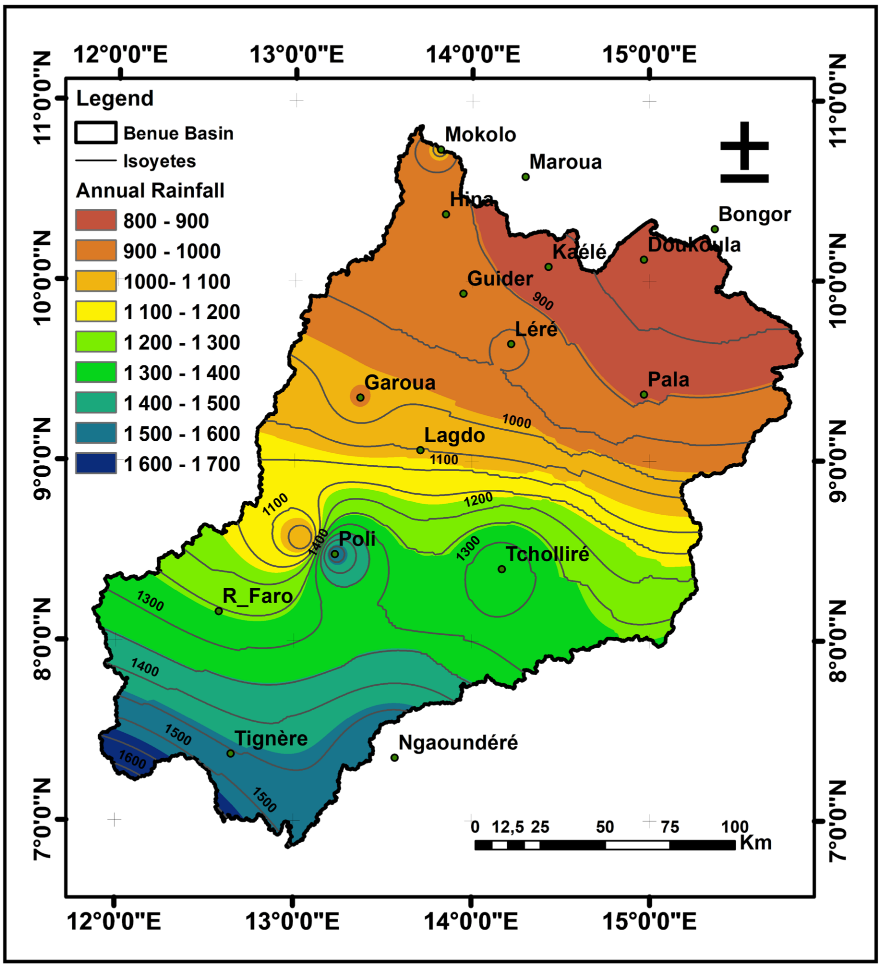


Figure 3. Annual precipitation over the Upper Benue during the period 1950-2015.

The trend analysis of the annual average rainfall series by the MK test reveals the presence of positive and negative trends at the 95% significance level. Annual trends vary between −3 mm/year to +2 mm/year (**Figure 4**). Negative trends are globally observed over the whole basin with strong decreases in rainfall in Pala in Chad Republic located at the northern part of the catchment and Tignere in the southern part of the basin. However, there are increasing trends in the north of the basin, particularly at the stations of Léré, Hina and to some extent at Doukoula. The mean trend across the basin was estimated at −0.568 mm/year, which represents a decrease of 37 mm/year over the observed or historical period from 1950 to 2015. This observation clearly indicates that annual precipitation declined and this trend was most pronounced in the high-altitude zones.

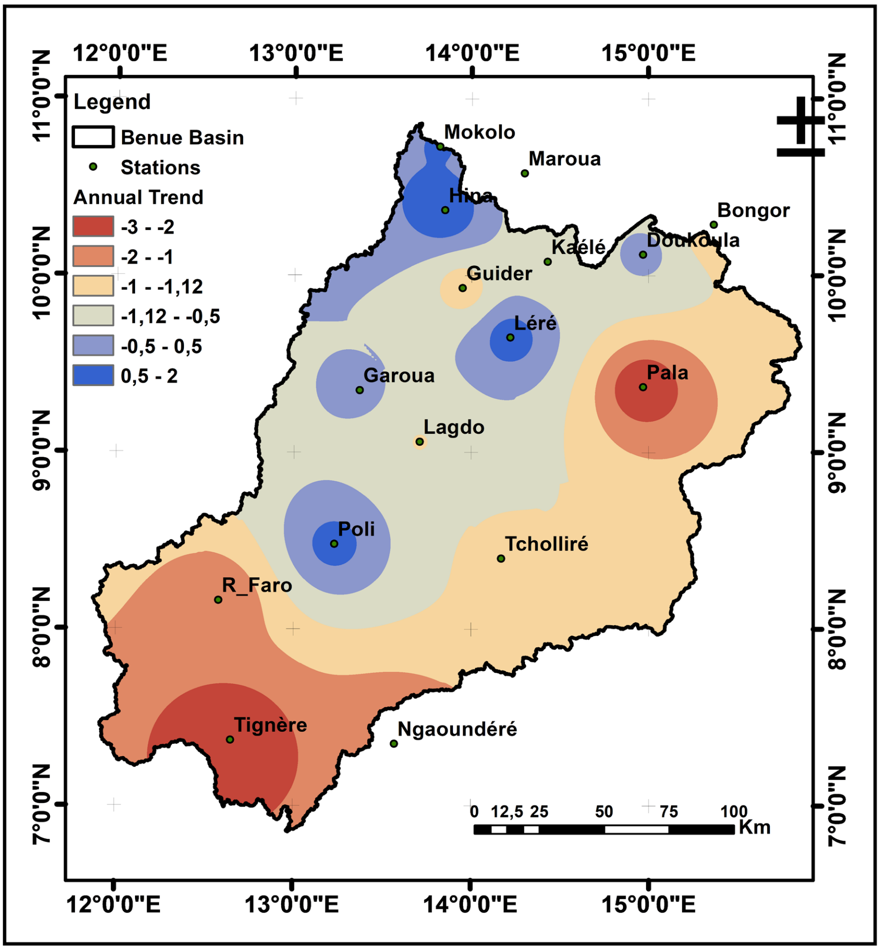
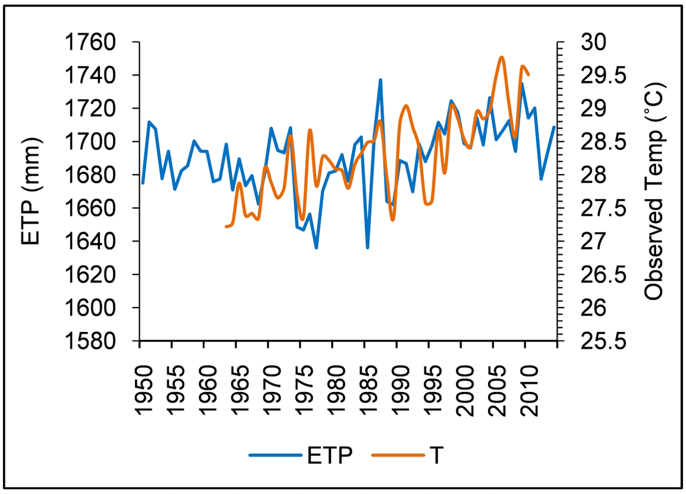
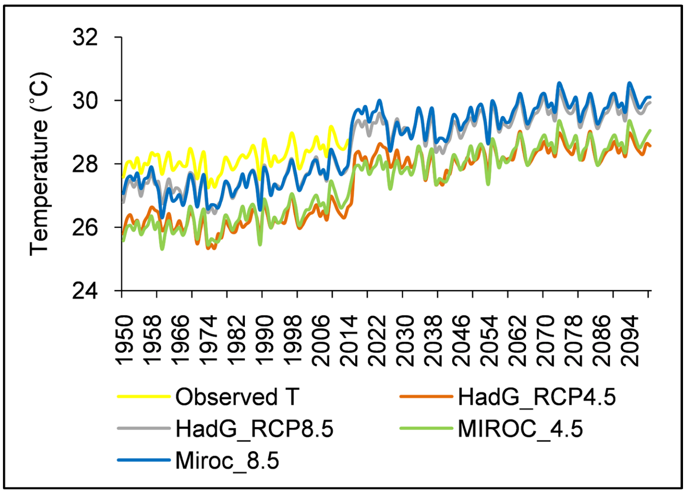


Figure 4. Trends over the Upper Benue during the period 1950-2014 compared to the 1961-1990 reference period.

The analysis of observed temperature and evapotranspiration between 1950 and 2014 shows an increase of 0.7˚C and 14% respectively over the entire catchment area (**Figure 5(a)**) according to the 1961-1990 reference period. For future climate, HadGM2-ES and MIROC5 models project an increase of temperature respectively between 1.9˚C to 2.3˚C under RCP 4.5 and RCP 8.5 by the end of the century (**Figure 5(b)**). Both scenarios predict a warming of about 2˚C. This induces an increase of both precipitation and PET with variation rates of +1% to + 6% and +6% to +10%, respectively.



(a)



(b)

Figure 5. Evolution of historic PET and temperature from 1950 to 2015(a); Evolution of HadGM2-ES and MIROC5 future temperature under RCP 4.5 and RCP 8.5 scenarios from 1960 to 2100 (b).

The GR2M model simulates the observed discharge over the period 1950-1982 and the expected change in flow by the end of the 21st century (2015-2100). The calibration and validation results show that the model reproduces relatively well the observed flow (**Figure 6**). The model is calibrated using 30 years of rainfall and observed discharge. In addition, the low flow is well simulated and the high peak flow corresponding to extreme flow is underestimated. The Nash value obtained ranges between 0.87 and 0.91. Despite the good quality of the simulated flow, the model failed to reproduce some extreme flow observed during a wet year such as 1961 and 2012.

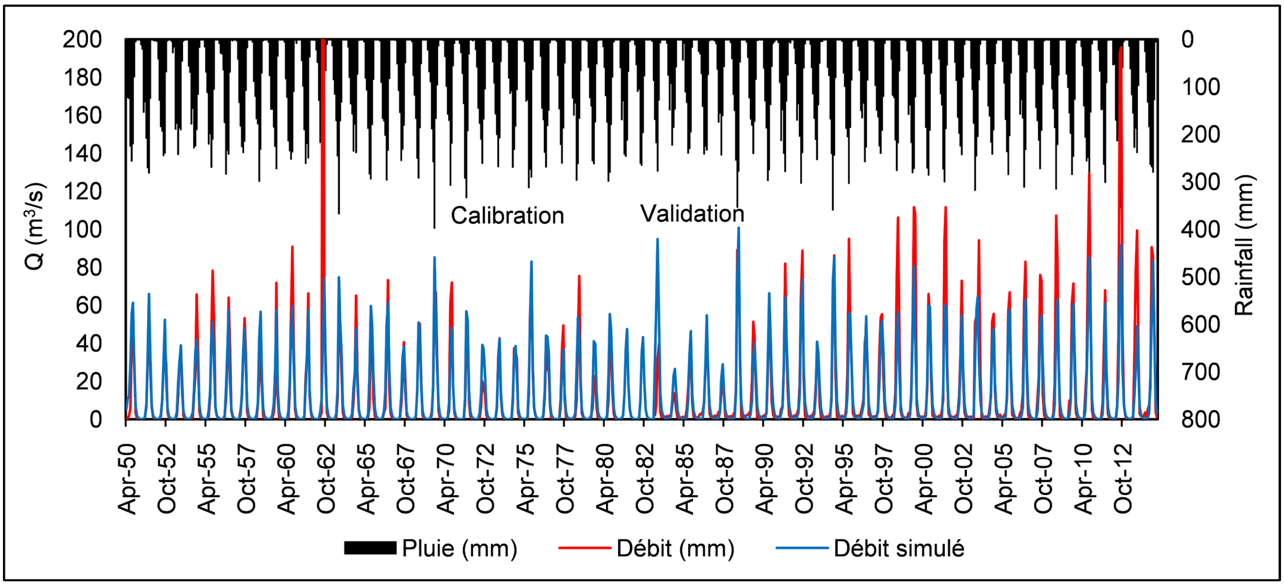
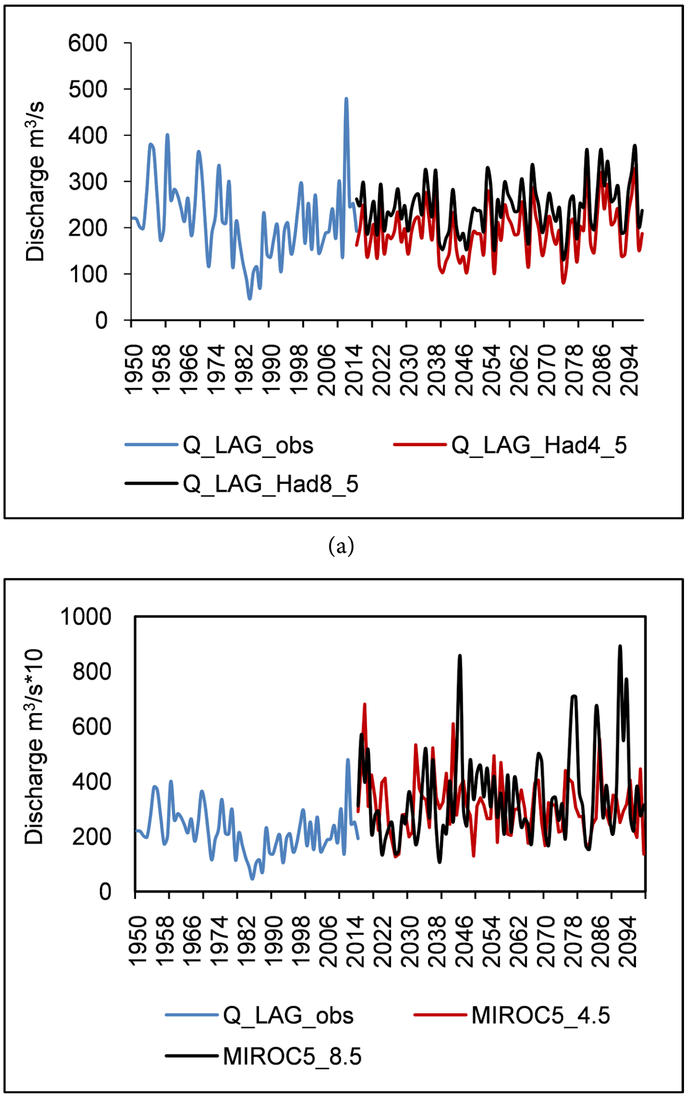


Figure 6. Comparison of observed and simulated discharge at Lagdo during the 1950-2015 period.

The simulation outputs obtained RCM with the GR2M model under both RCP 4.5 and RCP 8.5 scenarios indicate an increase in mean annual flows in the range between +2% and +10% by 2100 (**Figure 7**). The HadGM2-ES model predicts a significant increase in surface flows of about 2% at Lagdo under RCP 4.5 scenario, while it increases by 3% under RCP 8.5 scenario (**Figure 7(a)** and **Figure 7(b)**).

Thus, the increase in surface runoff that began in the early 1990s will intensify until 2050 under RCP 4.5 scenario. On the other hand, the trend will be reversed from 2050 onwards and runoff will decrease by 2% until 2100. The simulated flows increased by 9.6% compared to the 1961-1990 reference period recommended by [25] and by 6% compared to the period 1950-2014, despite the current decreasing trend in flows indicated by observed field data. The HadGM2-ES model predicts a significant decrease in surface flows of 2% at Lagdo under RCP 4.5 scenario, while it increases by 1% under RCP 8.5 scenario compared to the 1961-1990 reference period (**Figure 7(a)**). Thus, the increase in surface runoff that began in the early 1990s will intensify until 2050 under RCP 4.5 scenario.

Similarly, the MIROC5 climate model predicts significant increases by 10% under RCP 8.5 scenario (**Figure 7(b)**) while it decreases to 2% at Lagdo under RCP 4.5 scenario. The increase in surface runoff that began in the early 1990s will intensify until 2050 under RCP 8.5 scenario. By subdividing the evolution of flows by period, we note a slight increase of 0.8% in flows by 2020; a regression of about 5% by 2050 and an increase of 6% by 2100 compared to the 1961-1990 reference period. On the other hand, comparing the rate of change of observed and simulated flows concerning the 1950-2014 baseline period flows will decrease by about 9% by 2050 and increase to 3% by 2100. On the other hand, the trend by RCP 4.5 scenario will be reversed from 2050 onwards and runoff will decrease by 2% until 2100.



(a)

(b)

Figure 7. Observed and simulated discharge on the Benue River at Lagdo station with HaDGEM2-ES (a) and MIROC5 models (b) in the period 2015-2100.

4.2. Discussion

The results obtained in this study follow the conclusion of the work carried out on large basins over Africa [8] [16] [26]-[28]. The orographic effects of the Poli and Mandara Mountains, which block the circulation of the monsoon and cause heavy rainfall in mountainous areas [15] [26], can explain the uneven distribution of rainfall. Moreover, all studies carried out over northern Cameroon are unanimous on the decrease in rainfall from south to north [15] [23] [26]. In addition, the study of [7] [16] on the Lake Chad basin also reports a downward trend in rainfall. This decrease was accompanied by an increase in temperature of about 0.7˚C and a 14% in the Benue basin. This upward trend in climatic parameters under climate change conditions has also been demonstrated by other authors over Benin [4] [8] and Burkina Faso [27]. The RCMs used predicts significant warming of the basin for both RCP 4.5 and 8.5 scenarios. This result is linked with previous studies in other regions of Africa and the world [29] [30]. Similarly, [25] has indicated that the global average temperature has warmed by between 0.7˚C and 1.06˚C between 1980 and 2012 over some regions of Africa. The GR2M model used in this study indicated that the model was able to reproduce the present flow according to the value of Nash criteria but underestimated the extreme flow. Moreover [15] and [30] reported the adequate performance of the GR2M model in the Rheraya catchment and some basins in Cameroon. Projected runoff indicated an increase of flows between +2% and +10% depending on the considered scenario and time reference used. This means that the increase in rainfall, temperature and PET will lead to an increase in river discharge. Sighomnou [15] finds significantly higher rates ranging between +14% and +80% on the runoff of rivers in North Cameroon. In response to increases of 4% and 13% in rainfall and 1˚C to 3˚C in temperature, [13] showed that Benue River will experience a change in flow of -3% to +18% by the end of the 21st century and [31] suggested that the decreasing of annual precipitation in the same basin will lead a decrease of stream flow up to 51% in the future. This flow value remains higher than the values obtained in this study. Higher values of +19% to +23% and 17% to 25% respectively have been found by [8] on the Chari and Logone rivers. However, the different values noted by each author can be related to the strong uncertainties due to the choice of climate models, scenarios and hydrological models [30]. For [29] GR2M is most sensitive to the PET formula in that climate model. On the other hand, the increase of flow in the future suggests the beneficial effects of climate change on the availability of water resources in the basin. However, [32] [33] expressed reservations and indicated that an increase in annual river flows is not necessarily beneficial but may instead lead to stronger and more frequent floods.

5. Conclusion

This study tries to analyse climate variability and assess the potential impact of future climate change using hydrological modelling on the Upper Benue River. A conceptual model GR2M was used to simulate the monthly runoff in the Lagdo station and to provide future change on the runoff under two regional climate models. The results obtained illustrate a regressive spatiotemporal dynamic of mean annual rainfall estimated at 10%, *i.e.* 37 mm/year; an increase of 0.7˚C in mean temperature and 14% in PET. The HadGM2-ES and MIRO5 climate models under the RCP 4.5 and RCP 8.5 scenarios predict a warming of the basin of about 2˚C and an increase in precipitation of between 2% and 10% by 2100. The calibration and the validation results show that the model reproduces relatively well the observed flow according to the value of **Nash**. The Annual average runoff is projected to increase to about 10% in the future for both RCP 4.5 and 8.5 scenarios; this induces an important implication for the availability of water resources in the Upper Benue catchment.

Acknowledgements

The authors like to acknowledge the Cameroonian Ministry of Higher Education through research funding program.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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