Chapter

Future Climate Change Impacts on River Discharge Seasonality for Selected West African River Basins

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Abstract

The changing climate is a concern to sustainable water resources. This study examined climate change impacts on river discharge seasonality in two West African river basins; the Niger river basin and the Hadejia-Jama'are Komadugu-Yobe Basin (HJKYB). The basins have their gauges located within Nigeria and cover the major climatic settings. Here, we set up and validated the hyper resolution global hydrological model PCR-GLOBWB for these rivers. Time series plots as well five performance evaluation metrics such as Kling–Gupta efficiency (KGE),); the ratio of RMSE-observations standard deviation (RSR); per cent bias (PBIAS); the Nash–Sutcliffe Efficiency criteria (NSE); and, the coefficient of determination (r2), were employed to verify the PCR-GLOBWB simulation capability. The validation results showed from satisfactory to very good on individual rivers as specified by PBIAS (−25 to 0.8), NSE (from 0.6 to 0.8), RSR (from 0.62 to 0.4), r2 (from 0.62 to 0.88), and KGE (from 0.69 to 0.88) respectively. The impact assessment was performed by driving the model with climate projections from five global climate models for the representative concentration pathways (RCPs) 4.5 and 8.5. We examined the median and range of expected changes in seasonal discharge in the far future (2070–2099). Our results show that the impacts of climate change cause a reduction in discharge volume at the beginning of the high flow period and an increase in discharge towards the ending of the high flow period relative to the historical period across the selected rivers. In the Niger river basin, at the Lokoja gauge, projected decreases added up to 512 m3/s under RCP 4.5 (June to July) and 3652 m3/s under RCP 8.5 (June to August). The three chosen gauges at the HJKYB also showed similar impacts. At the Gashua gauge, discharge volume increased by 371 m3/s (RCP8.5) and 191 m3/s (RCP4.5) from August to November. At the Bunga gauge, a reduction/increase of -91 m3/s/+84 m3/s (RCP 8.5) and -40 m3/s/+31 m3/s/(RCP 4.5) from June to July/August to October was simulated. While at the Wudil gauge, a reduction/increase in discharge volumes of −39/+133 m3/s (RCP8.5) and −40/133 m3/s (RCP 4.5) from June to August/September to December is projected. This decrease is explained by a delayed start of the rainy season. In all four rivers, projected river discharge seasonality is amplified under the high-end emission scenario (RCP8.5). This finding supports the potential advantages of reduced greenhouse gas emissions for the seasonal river discharge regime. Our study is anticipated to provide useful information to policymakers and river basin development authorities, leading to improved water management schemes within the context of changing climate and increasing need for agricultural expansion.

Keywords: west African rivers, seasonality, climate change, PCR-GLOBWB, river discharge

1. Introduction

Many regions worldwide have experienced modifications in their hydrological regimes due to changing global climate [1]. The changing climate significantly impacts the availability and quantity of water in individual river basins and, on a global scale, has long been an international concern [2]. Freshwater availability in West Africa is paramount to economic development and social well-being [3]. In most West African countries, agriculture is the crucial sector supporting about 60% of the region's population [4]. Agriculture production in Nigeria and other West African countries depends majorly on water availability. Most importantly, wetlands watersheds contribute in diverse ways to the livelihoods of millions of people in this region [5, 6]. However, due to climate change, West Africa is already experiencing sea-level rise with severe coastline erosion, increased temperatures, unpredictable rainfall, dwindling water resources and many more. Accordingly, it is critical to examine future consequences of climate change on river discharge seasonality for a more explicit and quantitative understanding of the available water for various functions. Knowledge about river discharge seasonality is necessary for understanding important interannual hydrological dynamics [7].

There exist intricate interactions between streamflow and other climate variables (e.g. precipitation, temperature, and evapotranspiration) in a catchment [8, 9]. Therefore, the effects of climate change on streamflow across a given region are often assessed using hydrological models forced with global climate models [10]. Many studies that have examined climate change impacts on discharge seasonality globally can be found in the literature. Dettinger and Diaz [11]; explored on a global scale, the seasonality and variability of streamflow. They concluded that local seasonal cycles of necessary climatic inputs influence streamflow seasonality. On a regional scale, Aich et al. [12] compared the impacts of climate change on streamflow regimes in four large African river basins and found visible impacts of climate change on high and low flows and mean discharges. Eisner et al. [13] investigated climate change impacts on streamflow seasonality, over eleven large river basins, using an ensemble of hydrological and climate models. They found an increasing/decreasing tendency for high and low flows in many of the basins. Hirpa et al. [14] estimated the response of future streamflow in the greater Horn of Africa, using a distributed hydrological model driven by an ensemble of climate models. The study found a reduction in streamflow in the major rivers in Ethiopia and increasing streamflow projections in the equatorial zone towards ending of the century. WaleWorqlul et al. [15] found that climate change would significantly influence the hydrology of two subbasins in the upper Nile in Ethiopia. Li and Jin [16] in their study also found increasing streamflow variability attributed to increasing rainfall variability in the Jing River of China. Ficklin et al. [17], in their study, projected an arid-conditions by the 2080s for many subbasins in the Upper Colorado River Basin of the southwestern United States when they investigated the impacts of Climate Change on Streamflow and hydrology of the basin. Vano et al. [18] identified seasons susceptible to future climate change in the Pacific Northwest using the Variable Infiltration Capacity hydrology mode forced with an ensemble of ten global climate models. These studies and many others all show that climate change plays an increasingly important role in river discharge seasonal flow; hence, it is crucial to know how the climate changes would affect seasonal variations of a basin's streamflow.

The vulnerability of most West African countries to climate change originates from high reliance on climate-based economic activities and large populations in coastal urban areas [19]. Climate change may undoubtedly modify the river flow regime of most West African basins. It may cause a temporary increase of flow in some places or reduce river flows in other areas [20]. Few studies have addressed climate change impacts on the seasonal river discharge regime in West Africa, especially over Nigeria. Ayeni et al. [20] assessed the impacts of climate changes on three basins of southwestern Nigeria for the period (1961–2007), using the Pitman rainfall-runoff model forced with CSIRO Mark3.5, MIROC3.2-medres and UKMO-HadCM3 GCMs. Ndulue and Mbajiorgu [21] quantified the hydrological changes due to climate impacts and land use in the Upper Ebonyi river watershed, south-eastern Nigeria, for the present period (1985–2014) and the future period (2020–2030 and 2040–2050), using the SWAT forced with the CSIRO-Mk3–6-0 climate model.

The availability of observation data has limited research in this region; the majority of the river basins are ungauged [21]. Also, studies in west African tend to be fragmentary [22], as they use different; climate models; bias correction approach, emission pathways; meteorological forcings; period considered (future and historical). Furthermore, as water availability is critical to economic and social well-being, it is vital to understand the relationship between climate change and streamflow and how it will affect streamflow to establish appropriate adaptation policies. These reasons, coupled with the region's high vulnerability, have made it crucial to provide reliable future projections for river discharge seasonality.

This study, therefore, aims to assess the climate change impacts on far-future river discharge seasonality. We used the PCR-GLOBWB model, forced with five consistent climate models, considering two future emission scenarios (RCP4.5 and RCP 8.5). This study is anticipated to provide useful information to policymakers and river basin development authorities, leading to the improvement of water management within the context of climate change. Our study will also help concerned river basin authorities to improve water management and future socio-economic development for river basins in Nigeria.

2. Study area

Two river basins, with at least five consecutive hydrological years record, over the period 1958–2015 were selected. River selection are from Global Runoff Data Center (GRDC)'s [23] available collection of West African basins. Gauges of the rivers are located in North-central and North-east (**Figure 1**) of Nigeria. Besides, the location of the gauges covers the vast tropical savannah climatic region, which covers most of the country (west to centre Nigeria) and the Arid climatic region found in the North [24]. Climate change impacts in Nigeria has been identified as disastrous due to the country's vulnerability and deficient coping capability [25]. The consequences are evidenced in rising temperature, variable precipitation, sea-level rise and flooding, desertification and drought, altered water resources, and biodiversity loss [26]. Moreover, the ecological system, agricultural systems, and livelihoods that these basins support are susceptible to the reality of climate change. The selected basins are briefly described in **Table 1**.

The Niger river basin: is the longest catchment in West Africa. The Niger watershed stretches over an expanse of terrain that spans ten west African countries, covering an area of around 2,156,000 km^2, with nearly 1,270,000 km^2 hydrologically active [27]. The Niger river comprises of different hydrographic regions uniquely identified by drainage and hydrological characteristics. The Guinea highland is the river source, flowing to the Sahara into Mali through the Inner Delta. From

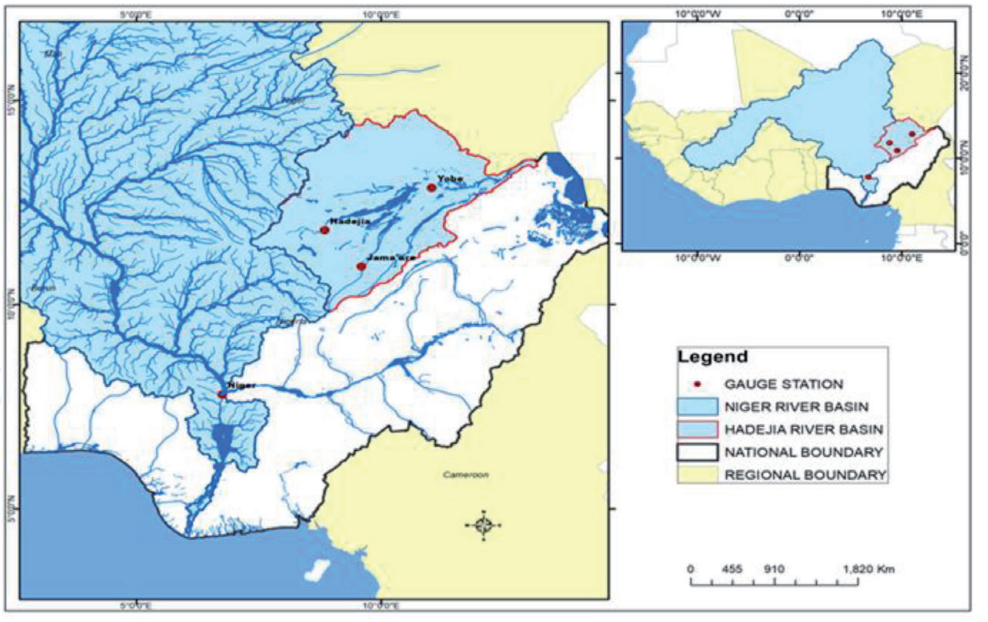

Figure 1.
Study area map.

River Basin	Niger	Hadejia-Jama'are Komadugu-Yobe Basin		
River name	Niger	Hadejia	Jama'are	Yobe
Gauge station	Lokoja	Wudil	Bunga	Gashua
Area (km^2)	2,156,000	16,380	7977	62,150
GRDC number	1,834,101	1,837,410	1,837,255	1,837,107
Annual precipitation (1971–2000) (mm)	1403	950	909	414
Mean temperature (1971–2000) (°C)	26.7	25.9	25.7	27.9
Koppen-Geiger climate classification	Tropical Savannah (Aw)	Tropical Savannah (Aw)	Tropical Savannah (Aw)	Arid Steppe hot (Bsh)

Table 1.
Description of selected rivers and gauges.

the Inner Delta, it flows southeast, and join with its major tributary, River Benue and eventually enters the Atlantic Ocean by the Niger Delta within Nigeria [28]. 28.3% (424,500 km2), of the hydrologically active basin falls within Nigeria (the lower Niger) and stretches over 20 of the country's 36 states. Within Nigeria, the Niger river constitutes two major rivers (the Niger and Benue) and more than half of its major rivers. Approximately 60% of the Nigerian population lives in the basin area. 71% of over 100 million people inhabiting the Niger basin live in Nigeria [28]. Agriculture, particularly rain-fed agriculture, supports most of the inhabitants' livelihood and is therefore susceptible to impacts of climate variability. The gauging station on the Niger river in this study is Lokoja at the confluence of the river Niger and Benue.

The Hadejia-Jama'are Komadugu-Yobe Basin (HJKYB) is a combined basin of the Komadugu-Yobe river and the Hadejia-Jama'are River System located in the north-east part of Nigeria. The Hadejia and Jama'are river are the two main rivers of this basin that meet at the Hadejia Nguru Wetlands (HNW) to form the Komadugu-Yobe Basin [29]. The Hadejia river has its source in the Kano highlands, while the Jama'are river rises from the Jos plateau in Nigeria. The combined catchment of the

HJKYB discharges into Lake Chad, and it is the major recharge into the lake from Nigeria. The HJKYB is one of the essential basins in Nigeria that support over 15 million people, which mostly rely on agriculture, fishing, livestock rearing, and water supply [30] for their livelihoods. An essential part of the HJKYB is the HNW which was the pride and joy of the north-eastern part of Nigeria for many years. The research site on the HJKYB is at the Gashua gauge station on the Komadugu-Yobe River, Bunga gauging station on the Jama'are River, and the Wudil on the Hadejia river.

2.1 Methods

2.1.1 The PCRaster global water balance model

The PCR-GLOBWB is a large scale hydrological model, which incorporates human activities into hydrology [31]. Global simulation of hydrology is daily and at a spatial resolution of 5 arcmin (0.08^o at the equator). In this study, our focus is on river basins in West Africa, specifically for gauging stations located within Nigeria. The PCR-GLOBWB simulates water stored in two top soil layers S_1 and S_2; one bottom groundwater reservoir S_3 for each grid cell and time step. The model also simulates; water movement between the atmosphere and layer of topsoil (precipitation, evaporation, transpiration, and snowmelt); among the soil; in between the soil and the active layer of groundwater and estimates interception by canopy and snow storage. Distinct land cover types (forest, grassland, irrigated paddy field, irrigated non-paddy field, and open water), soil types, and elevation are considered to determine sub-grid variability. The Improved ARNO scheme is used in the model to estimate the fraction of the area of saturated soil [32]. Precipitation can be intercepted, evaporated, or infiltrated into the soil layers. The excess surface runoff (Q_{dr}), second soil layer (interflow) runoff (Q_{sf}), and groundwater (baseflow) runoff (Q_{bf}) make up the runoff from each cell. To obtain the river discharge (Qchannel), Specific runoff from each cell is gathered and then routed through the drainage network following the travel-time solution of [33]. At each time step, the model simulates (i) livestock, household irrigation and industrial water demand, (ii) water withdrawn from surface water, groundwater and desalinisation. For this work, we adopted the guideline of standard parameterisation of [31] of PCR-GLOBWB, which is based on available global datasets.

2.2 Data

2.2.1 Forcing datasets

Datasets, as described in [34], is followed and repeated in this study. The meteorological datasets required to drive the model are precipitation, temperature, and reference potential evapotranspiration. We obtained these data from the CRU TS 3.2 [34]. These data were processed by interpolating station observation past time-series to a global grid resolution of 0.5^0. Due to the daily resolution of PCR-GLOBWB, the monthly CRU TS 3.2 data were downscaled to daily resolution with ERA 40 (1958–1978, [35]) and ERA-Interim (1979–2015, [36]). ERA 40 and ERA-I had been spatially downscaled from their initial spatial resolutions of 1.2^o and 0.7° to 0.5° in the resampling scheme of the European Centre for Medium-Range Weather Forecasts (ECMWF). This downscaling was done by first allotting the larger values ERA40 and ERA-I to the middle of the cells and then interpolating spatially to the higher resolution of 0.5°. Firstly, downscaling of precipitation was done by temporarily assigning a threshold of 0.1 mm day^{-1} to the daily time series of ERA, thereby estimating the number of days with rain and eliminating the drizzle effect. The rainfall quantity below this threshold was proportionally allocated to the rainy days. Thereafter, CRU monthly precipitation was reproduced by multiplicative scaling of the daily rainfall totals. Also, monthly reference potential evaporation, estimated from the CRU dataset with Penman-Monteith, was scaled using multiplicative scaling and down-scaled to daily data using a daily temperature-based ET product derived from daily ERA temperatures. An additive scaling method was used for air temperature (see [31] for more details). For this work, standard parameterisation guideline, as provided in [31], was adopted. We used available global datasets, including vegetation, geological information, and soil properties, to parameterise the model and simulate discharge at daily time steps over the selected river basins (from 1958 to 2015). Monthly averages were used to report the output from the Model.

2.2.2 Discharge data

Streamflow observation data for the selected river basins were retrieved from the Global Runoff Data Centre (GRDC) [23] to compare with the hydrological model simulated discharge.

2.2.3 Climate scenarios

We used the output of GCMs from the first phase of the ISI-MIP [37], which has five GCMs from the CMIP5 archive. GCMs from the CMIP5 archive [38]. In the framework of the ISIMIP, five GCMs simulations were bi-linearly downscaled spatially to a 0.5° × 0.5° grid for the period of 1950–2099 [39]. The five GCMs are GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M. The GCMs were selected because of their wide application for modelling, predicting climate extremes, and investigating physical climate processes over West Africa [12, 40–42]. Again, the availability of ensemble member bias-corrected using an established approach to facilitate climate change impact assessments [43], guided our selection.

2.3 Validation

Station records from GRDC for the majority of the rivers in West Africa have missing values. Validation of PCR-GLOBWB for the selected river systems was limited to four gauging stations, where we could get a minimum of 5 hydrological years. Five performance evaluation metrics were used to evaluate discharge simulated at the selected gauging stations [44, 45]. These statistics are the Kling–Gupta efficiency (KGE); the Nash–Sutcliffe Efficiency criteria (NSE); the coefficient of determination (r2) per cent bias (PBIAS); and the ratio of RMSE-observations standard deviation (RSR). The performance ratings for quantitative statistics are presented in **Table 2**.

2.4 Method of analyses

For the analyses, we used discharge climatologies, i.e. long-term average monthly river discharge of each river. Projected daily discharge from five climate models was averaged to monthly climatologies and analysed for two periods, the reference (1971–2000) and the far-future period (2070–2099). Absolute changes between Reference and far future conditions was computed for each climate model historical (1971–2000).

Performance Ratings	r^2	NSE	RSR	PBIAS	KGE
Very good	$0.75 < r^2 \leq 1$	0.75 < NSE ≤	0 ≤ RSR ≤ 0.5	PBIAS < ±10	0.9 ≤ KGE ≤ 1
Good	$0.65 < r^2 \leq 0.75$	0.65< NSE ≤ 0.75	0.5 < RSR ≤ 0.6	±10 ≤ PBIAS < ±15	0.75 ≤ KGE < 0.9
Satisfactory	$0.5 < r^2 \leq 0.65$	0.5< NSE ≤0.65	0.6 < RSR ≤ 0.7	±15 ≤ PBIAS < ±25	0.5 ≤ KGE < 0.75
Unsatisfactory	$r^2 \leq 0.5$	NSE ≤ 0.5	RSR > 0.7	PBIAS ≥ ±25	KGE < 0.5

Table 2.
Overview of monthly performance ratings [45].

2.5 Seasonality index (SI)

The seasonality of river discharge volumes shows the extent of variation in monthly discharge magnitude throughout the year. In this study, we used SI, developed by [46]. SI is the summation of the absolute changes of the monthly river discharge volumes from the mean monthly discharge, divided by the total annual river discharge of a given year. It is given as:

$$SI = \frac{\sum_{n=1}^{12} X_n - \frac{R}{12}}{R} \tag{1}$$

where X_n is the mean discharge of the nth month, and R is the mean annual discharge. SI varies from zero (all months having equal discharge distribution) to 1.83 (the discharge occurs in one month). A seasonal pattern in the discharge regime is established when SI is 0.6 and above. A region with high SI would be susceptible to drought because a high SI value in an area translates to the high variability of water resources and the shortage with respect to time. The classification of the degree of SI values is presented in **Table 3**.

2.6 Results

2.6.1 PCR-GLOBWB validation

PCR-GLOBWB models' validation results in terms of five metrics are presented in **Table 4** and **Figure 2** for the gauges. Overall, the performance of the PCR-GLOBWB on the monthly time step for validation periods was satisfactory. As seen in **Figure 2**, the hydrographs monthly flow pattern was well reproduced, close agreement in discharge distribution is seen in accord with performance statistics. The PCR-GLOBWB model performance was adequate in all basins, displaying very good to satisfactory values, established on ratings detailed in [44, 45]. **Table 5** sums up the five performance metrics values obtained for validation periods in each study basin. Concerning KGE values, the best model fit was found for the Hadejia (0.88) and Yobe (0.87) basins. The Niger, Hadejia, and Yobe river have very good NSE (0.8, 0.79, and 0.79), RSR (0.4, 0.45, and 0.4), and r^2 (0.88, 0.79, and 0.82) values, while Jamaare has satisfactory values (NSE = 0.6, RSR = 0.62, r^2 = 0.62). The highest PBIAS values reaching −18 to −25% were obtained in the Niger and Jamaare river. The PCR-GLOBWB model mostly reproduced well the flow dynamics of the

Seasonality Index	Regime
< 0.19	Very equable (discharge equally spread all over moths)
0.20–0.39	Equable, but with a definite wetter period
0.40–0.59	Rather seasonal with a short drier period
0.60–0.79	Seasonal
0.80–0.99	Marked seasonal with a long dry period
1.00–1.19	Most discharge in < 3 months
>1.20	Extreme discharge, with almost all discharges in 1–2 months

Table 3.
Classification of seasonality index (SI).

River	Validation period	KGE	NSE	R^2	RSR	PBIAS %
Niger	1979–1989	0.73	0.8	0.88	0.4	–25
Jama'are	1966–1975	0.69	0.6	0.62	0.62	–18
Yobe	1978–1983	0.87	0.79	0.82	0.4	6.68
Hadejia	1982–1989	0.88	0.79	0.79	0.45	0.8

Table 4.
Model's validation performance for the river basins.

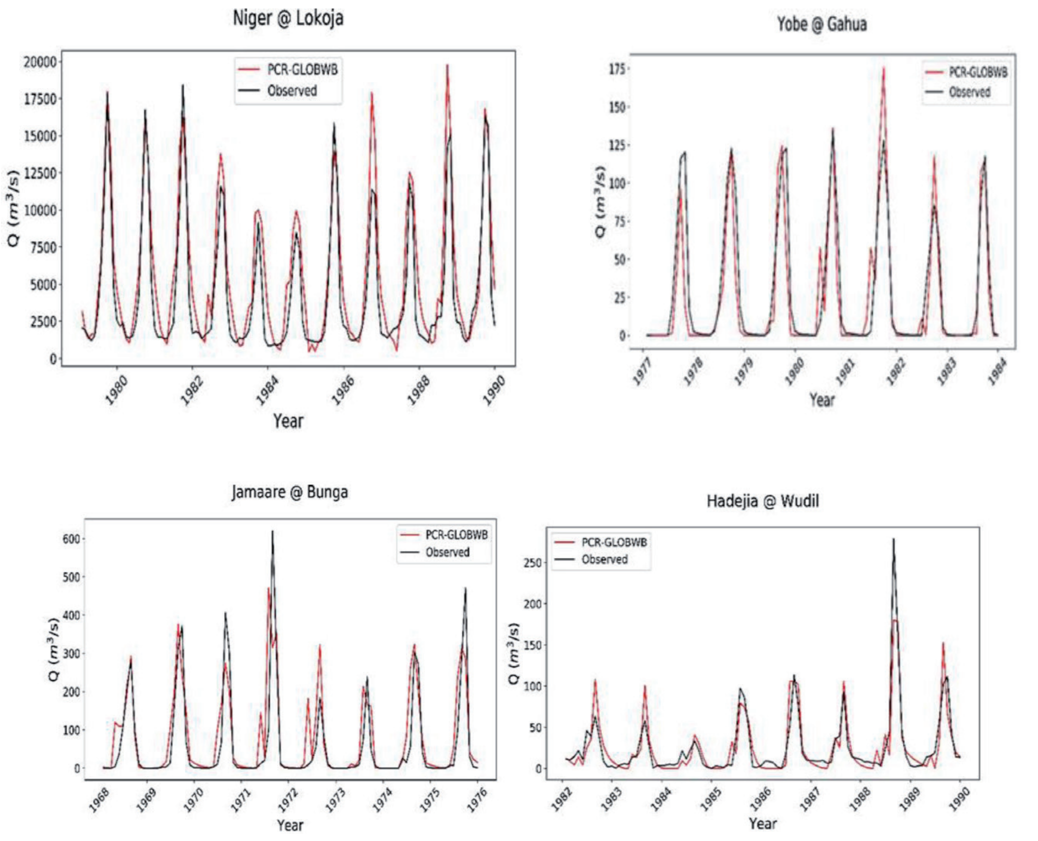

Figure 2.
Hydrographs for the different validation period of the four rivers (a) Niger (b) Yobe (c) Jamaare (d) Hadejia. Red line is PCR-GLOBWB and Black line is Observed.

	Reference-period	RCP4.5	RCP8.5
Niger	0.56 (0.51–0.59)	0.58 (0.48–0.62)	0.61 (0.45–0.63)
Yobe	1.05 (1.03–1.18)	1.09 (0.97–1.30)	1.03 (0.98–1.30)
Jamaare	1.07 (1.04–1.09)	1.14 (0.97–1.22)	1.12 (0.96–1.25)
Hadejia	0.89 (0.85–0.91)	0.86 (0.68–0.92)	0.87 (0.69–0.93)

Table 5.
Seasonality index (SI) of climate models median discharge climatologies for reference and projected far-future periods under RC4.6 and RCP8.5. Minimum and maximum values of the climate models' combinations are shown in brackets.

observed but displayed some disparity. Peak values overestimation was also seen in most cases for the river basins. The overestimation of flow can be attributed to the CRU TS 32.1, forcing input data. CRU Precipitation across Africa is of low quality due to sparse CRU stations and limited data assimilated during the reanalysis of ERA-40 [47]. As a result, of the temporal and spatial disparity in station density, the datasets are subjected to uncertainties; this uncertainty explains the overestimation of the stations' hydrographs. However, CRU TS 3.2 is a preferred data as it based on observation. Using another meteorological dataset may reduce the overestimation, but at the cost of the temporal variability, because no other datasets cover a long period of 1958–2015.

2.6.2 Historical discharge representation

Simulated discharge of the PCR-GLOBWB driven with five climate models was compared with CRU observed discharge to check the model's performance for the reference period (**Figure 3**). **Figure 3** shows the agreement between CRU observed discharge and the climate models is good for the Niger and Hadejia, yet there are some differences in representing high flow periods. For the Yobe and Jamaare rivers,

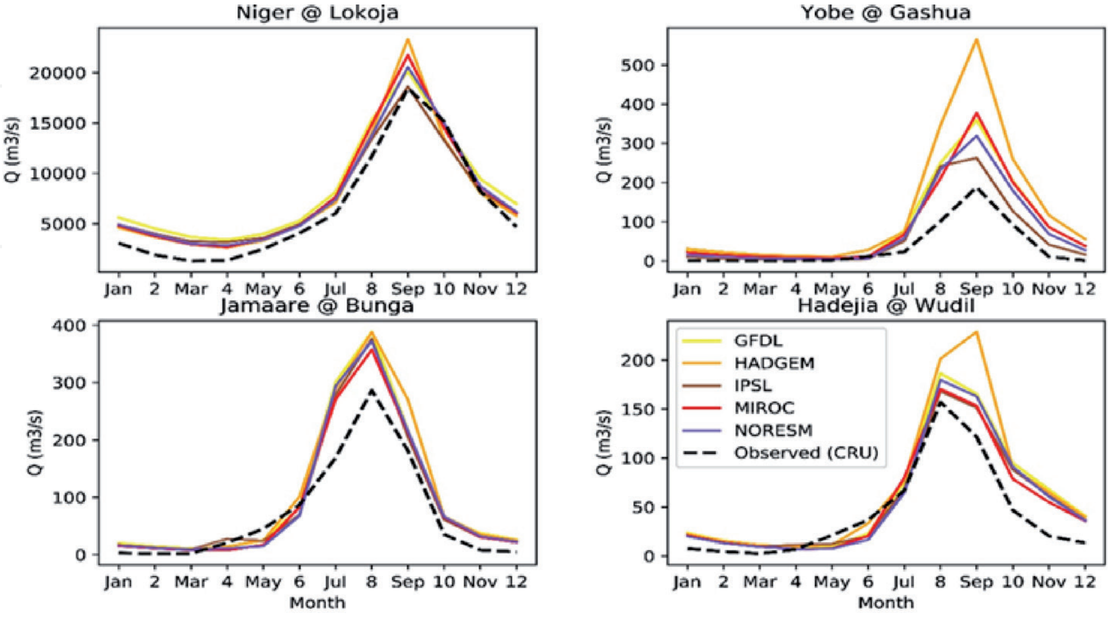

Figure 3.
The long-term mean annual dynamics of river discharge simulated with PCR-GLOBWB driven by the five climate models outputs over the reference period 1971–2000 for the four case study rivers.

the seasonal pattern of observed discharge dynamics was well captured; however, the results differ more distinctly in the representation of high flow periods. Nonetheless, these results are still agreeable, considering the small absolute numbers of discharge in these basins.

2.6.3 Evaluation of climate trends in the basins

Figure 4 presents the seasonal dynamics of precipitation and **Figure 5** of temperature for the reference and far future periods as illustrated by the median under RCP4.5 and RCP8.5 scenarios. Increasing temperature is projected in all study basins all year round under both scenarios, plus higher increases under the RCP8.5 compared to the RCP4.5. The highest increase in temperature is observed for the

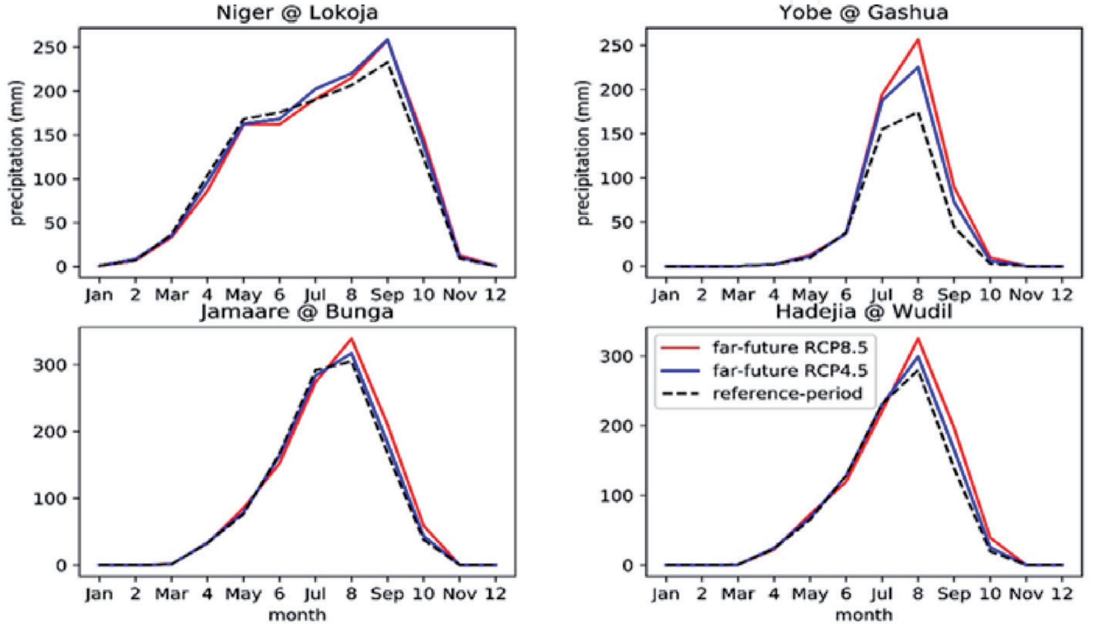

Figure 4.
Long-term monthly precipitation for the reference and far-future time slices as indicated by the climate models median of the climate projections under RCP 4.5 and RCP 8.5.

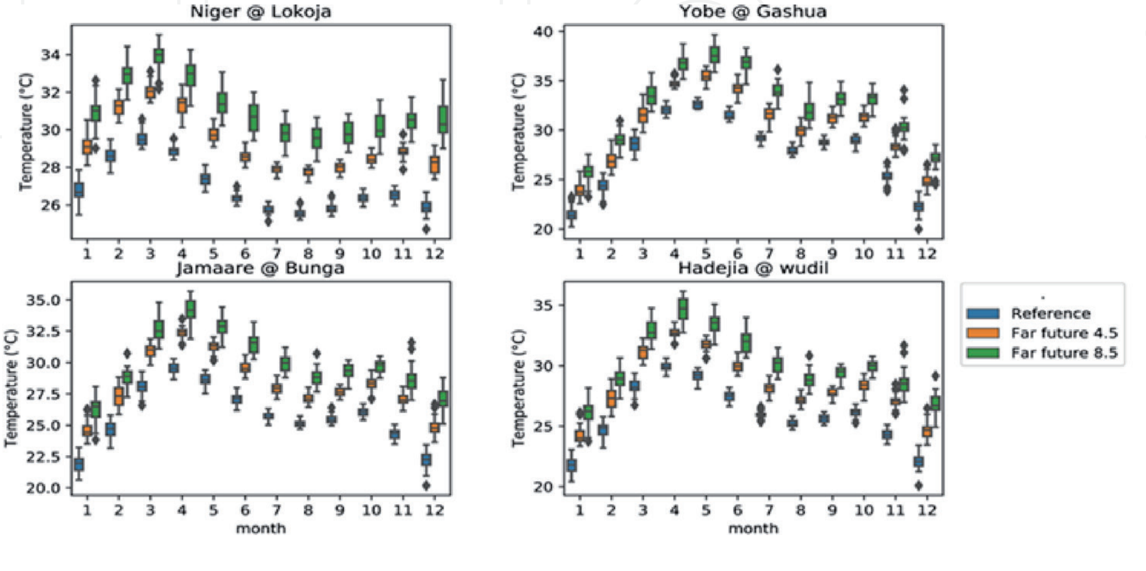

Figure 5.
Long-term monthly temperature for the reference and far-future time slices as indicated by the climate models median of the climate projections under RCP 4.5 and RCP 8.5.

Yobe River, reaching about 38°C in the month of may (RCP 8.5). Considering the precipitation dynamics in the Lokoja gauge of the Niger River located in central Nigeria, a moderate decrease at the beginning of the rainy season (from March to July), under both RCPs, is observed. Additionally, increasing precipitation is projected in Niger from July to November. A similar trend of a moderate reduction in rainfall at the start of the rainy season (June–July) is also observed for the Jama'are and Hadejia rivers. At the same time, an eventual increase is seen from July to November in the latter part of the year. The increase is from July to October in the Yobe, Jamaare, and Hadejia under both scenarios. Increasing precipitation is projected from June to November at Gashua (Yobe river). Biasutti [48] discovered decreasing rainfall in the start months (June–July) and increased rainfall in the end months (September–October), signifying a delay of the rainy season in West Africa. Refs. [49–51] also found a late beginning of the rainy season across Sahelian Africa because of a decrease in precipitation in July and August.

2.6.4 The seasonality index

As explained previously, we quantified climate change impacts on the monthly concentration and seasonal variation of discharge volumes. **Table 5** presents the SI of the five GCMs median considering the reference period climate and far-future climate under RCP4.5 and RCP8.5. As seen from the table, variations in SI between reference-period and end-century regimes are overall small. Over the Niger basin, the annual discharge volume under the RCP8.5 is seasonal compared with the reference period. For the Yobe and Jamaare rivers, the future annual river discharge volumes would be concentrated in less than three months. Annual SI over the HJKYRB river for the reference and Far-future period shows similar seasonal variability regimes of marked seasonality with a long dry period. The two basins generally receive most of the precipitation during the wet season; therefore, annual discharge occurs during the high-flow period.

2.6.5 Climate change impacts on seasonal discharge variation

Multi-model median monthly river discharge climatologies for the reference and far-future conditions under scenarios are presented in **Figure 6**.

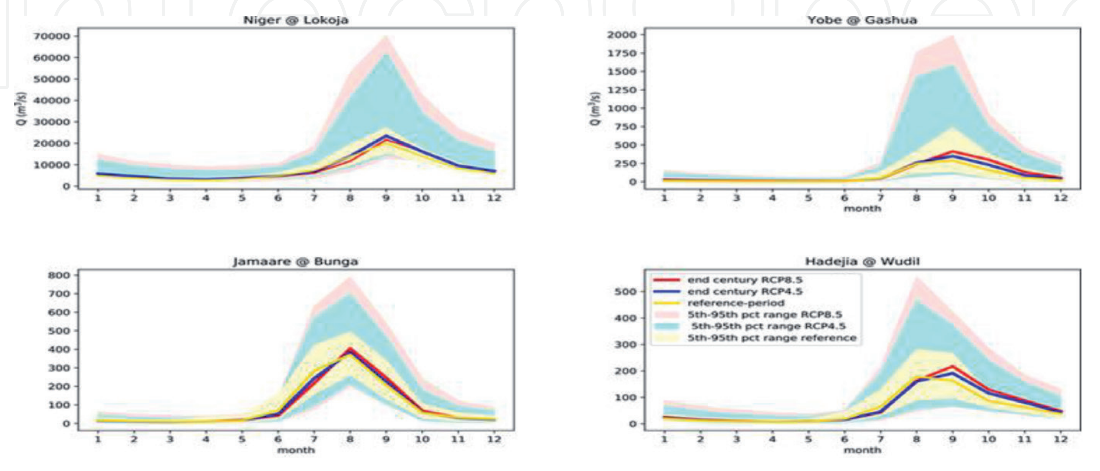

Figure 6.
Monthly streamflow climatologies projected for reference (1971–2000) and far-future (2070–2099) periods. The solid lines represent the ensemble median of all climate models combinations, while the colours represent the range from the 5th to 95th percentile.

2.6.5.1 Niger Basin at the Lokoja gauge station

The multi-model median reveals a reduction in the river discharge at the start of the high flow period. Total projected decreases added up to 512 m^3/s under RCP 4.5 (June to July) and 3652 m^3/s under RCP 8.5 from June to August. The most reduction in discharge volume (2101 m^3/s) occurs in August under RCP8.5, corresponding to about 58% of the total decrease for the three months. Eisner et al. [13] showed that under RCP8.5, the Niger basin shows declining discharge at the onset of the rainy season, with the highest loss 37 per cent occurring in August. When looking under the RCP 4.5 (**Figure 6**), discharge volume is expected to increase from August. The most significant increase under the moderate end scenario is shown in September and October, which considerably adds up to about +5565 m3/s (+52%) volume to the total increase in discharge volume. **Figures 7** and **8** show that MIROC-ESM-CHEM hydrological simulation under both scenarios results in considerable volume increases all through the year caused by a related rise in precipitation, particularly towards the end of the rain period (August to September). **Figures 7** and **8** also reveal that the other four hydrological simulations show contrasting change direction (decrease and increase) notably from August to November based on the individual climate model. The conflicting trend of change of each climate model cancels out in the multi-model median.

2.6.5.2 Hadejia-Jama'are Komadugu-Yobe Basin (HJKYB)

2.6.5.2.1 Yobe river at Gashua gauge station

Precipitation pattern influences river discharge seasonality in the Yobe river. Although the broad seasonal change signal at the Gashua gauge is unaltered by climate change, the climate models median show, considerable increases in river discharge volumes from August to November (**Figure 6**). Discharge volume increased by + 371 m^3/s under RCP8.5 and + 191 m^3/s under RCP4.5 for the four-month period, amounting to about +87% (RCP4.5) and +90% (RCP4.5) of the total increased volumes. Generally, this increase in discharge arises from two climate models (**Figures 7** and **8**): the MIROC-ESM-CHEM and HADGEM-ES result in increased precipitation in the rainy season (July to October).

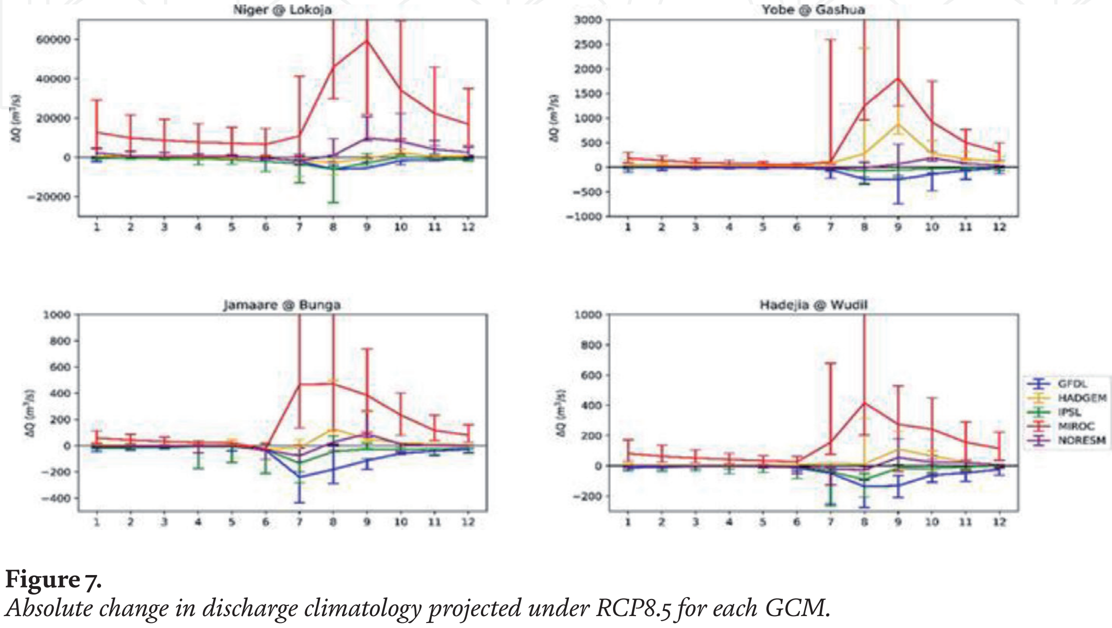

Figure 7.
Absolute change in discharge climatology projected under RCP8.5 for each GCM.

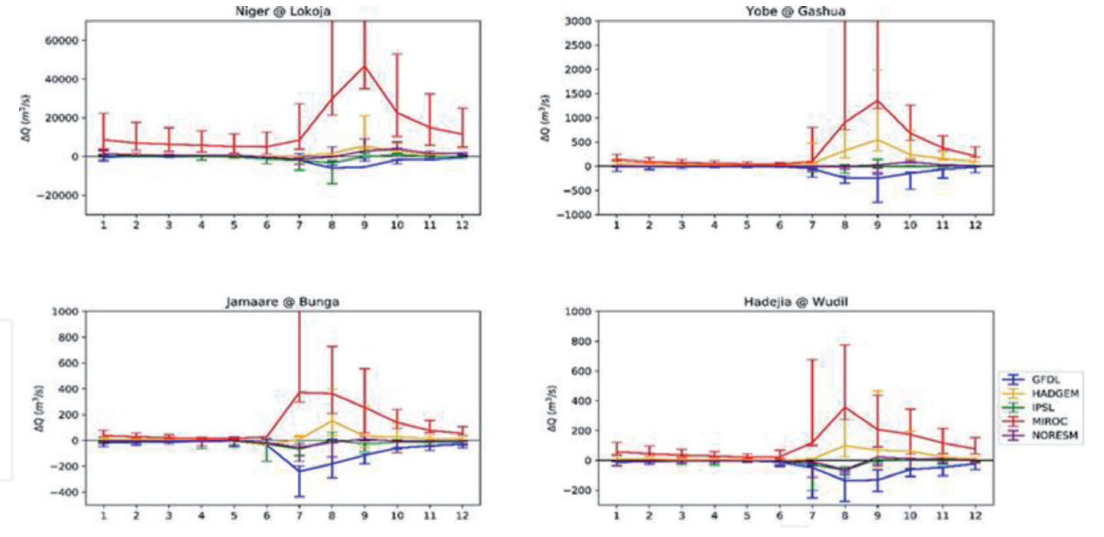

Figure 8.
Absolute change in discharge climatology projected under RCP4.5 for each GCM.

Hydrological projections of NORESM and IPSL-CM5A-LR show minor changes from the reference period, while the GFDL decreases the discharge volume (**Figures** 7 and **8**).

2.6.5.2.2 Jamaare river at the Bunga gauge station

The precipitation change pattern mainly influences the Jamaare river discharge regime. **Figure 6** reveals a one-month shift and decreases in discharge volumes from May to July at the start of the high flow season under both scenarios. The expected decrease in precipitation amounts explains this decrease in discharge volume (**Figure 4**). Under the RCP8.5, a reduction of 32 mm in precipitation for June to July translates to a reduction of -91 m^3/s (−24%). For the moderate end scenario, a decrease of 11 mm in precipitation results in decreasing discharge volume of -40 ms/s (−14%). An increase in discharge volume is shown from August to October in the latter part of the year. Projected increases in discharge volumes from August–October amount to +84 m^3/s (+13%) under RCP8.5 and +31 $m^3/3$ (+4%) for RCP4.5. In absolute terms, under both RCPs, (in **Figures** 7 and **8**), discharge response of the high flow season (June to October) is conflicting, having projected decreasing and increasing trend dependent on the GCM.

2.6.5.2.3 Hadejia river at Wudil gauge station

The hydrograph for the Hadejia river presents the peak monthly streamflow shifting from August to September for two scenarios (**Figure 6**). This shift is likely linked to a delayed start of precipitation. The climate model median projects a reduction in discharge volumes from June to August amounting to −39 m3/s (−15%) under RCP8.5 and −40 m3/s (−15%) under RCP 4.5. An increase in river discharge volumes is shown from September to December under both RCPs, which is related to increasing precipitation. For the RCP 8.5, the cumulative increase of discharge volume is from September to December amounts to 133 m3/s (38%) for RCP8.5 and 80 m3/s (23%) for RCP4.5. When considering the individual GCMs, Three out of the five climate models show increasing volumes in discharge in the peak flow period for RCP8.5 (**Figure 8**). The largest increase is found for MIROC (**Figures** 7 and **8**); however, the signal of change depends on the Individual model.

In all four rivers, hydrological simulations of the MIROC climate model reveal the highest discharge compared to the other four climate models in all cases.

2.7 Discussion

The evaluation of climate change's hydrological consequences often necessitates using a hydrological model forced with GCMs under various emission scenarios [52]. This study established the use of the PCR-GLOBWB model for two West African river basins; the Niger river basin and the Hadejia-Jama'are Komadugu-Yobe Basin (HJKYB). The monthly streamflow simulation results of the gauge stations of the two river basins were validated against observed discharge (GRDC) using five performance evaluation metrics were. The output of GCMs from the first phase of the ISI-MIP was adopted to investigate the response of streamflow seasonality to climate change. The PCR-GLOBWB was shown to be very applicable over the two basins. Its PBIAS, NSE, RSR, r^2 and KGE values ranged from −25 to 0.8, 0.6 to 0.8, 0.62 to 0.4, 0.62–0.88, and 0.69 to 0.88, respectively, which were within the acceptable limits [45], as shown in **Table 2**.

According to the results of the multi-model median regarding climate change, climate change impacted the temporal pattern of future river discharge in the river basins. The late start of the rainy season concluded in this work has been reported by previous studies [13, 48–50, 53]. Streamflow of the three rivers in combined HJKYB, the Yobe, Jamaare and the Hadejia, is controlled by precipitation. Genthon et al. [54] reported the climatic influence on discharge in this basin. Across the two basins, our findings indicate that climate change exacerbates the seasonality pattern already present. The basins influenced by precipitation exhibit a continuous increase in streamflow volumes during the later part of the high-flow season. In the Niger basin, climate change significantly affects the volume of streamflow seasonality (indicated by SI). In the four rivers, projected river discharge seasonality is amplified under the high-end emission scenario (RCP8.5); our findings support decisions on the potential advantages of reduced greenhouse gas emissions for the streamflow dynamics. It must be stressed that our analysis focused exclusively on the effects of climate change on streamflow regimes. Population expansion and economic development envisaged for the future are expected to raise human demand for water resources, potentially intensifying their interference with the streamflow regime. The consequences of these could outweigh the climatic changes examined in this study.

3. Conclusions

This study assessed of climate change impacts on the seasonal river discharge in two rivers in West Africa, including the Niger, and the Hadejia-Jama'are Komadugu-Yobe Basin (HJKYB). For this analysis, we set up and validated the PCR-GLOBWB model at the selected gauging stations of each river basin. Climate change impacts on river discharge seasonality were examined with five bias-corrected GCMs, collected from the "ISIMIP" project framework. The PCR-GLOBWB model validation performance was satisfactory in its performance for all statistics at each of the basins (**Table 5**). The five bias-corrected GCMs were then used to force PCR-GLOBWB in the reference and far-future period. Based on our results, Climate change will influence the seasonal regime of discharge of the selected rivers, i.e., the timing and the magnitude of flows. The findings of this study reveal that there are little differences in SI between the present and the far-future. However, climate change will affect the temporal seasonality pattern. At the gauges of the Niger, Yobe, and Jamaare rivers, decreasing discharge volumes when the high-flow period begins (typically May–July) is expected in the far future. This is explained by the delayed start of the raining season. All four rivers steadily project increasing river discharge at the end of the high-flow season (typically August–November) during the peak-flow period. In this basins, increased precipitation amounts result in a projected increase in discharge volumes.

Adequate storage has to be made for the increased high-flow season; otherwise, water scarcity may disturb agricultural production regardless of the overall increases in annual water availability. Even though increased discharge volumes can be considered advantageous to agricultural productivity, this can only be achievable when there are provisions to store excess flow for later use. When there are no/sufficient existent storage structures, much of the additional flow is lost. Increased high flow may destroy croplands through flooding. Increased discharge volumes could lead to floods and destroy crops over a vast expanse of land. Excess water could reduce plant development, delay farm operations, make the soil soggy and unworkable. The projected increased discharge for the HJRB could help revive the currently shrinking Lake Chad basin. The findings of this study show that climate change will significantly impact the hydrological regimes of the two basins examined, with significant consequences for water resource planning and management. Finally, the methods used in this study may prove helpful for future research examining the effects of climate change on the hydrology of different regions.

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Conflict of interest

The authors declare no conflict of interest.

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