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SWAT model analysis of the hydrology of the Niger River Basin: a case study of the Niger Central Hydrological Area, Nigeria

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Abstract: For an improved assessment of water resources, Nigeria is delineated into eight hydrological areas, among which is Niger Central Hydrological Area (NCHA). In this study, we quantified the water resources of NCHA with the use of the Soil and Water Assessment Tool (SWAT). The method includes calibration (1986–1995) and validation (1996-2000) of the SWAT model based on observed river discharges, and performance evaluation of the model (uncertainty analyses) using ‘‘Sequential Uncertainty Fitting Algorithm’’ (SUFI-2). The SWAT-simulated water resource components (blue and green water) were estimated at sub-basins levels and then aggregated to river catchments and local administrative areas. The water components were quantified on spatial and temporal scales. The results of the calibration/validation for most of the discharged data across the watersheds were quite satisfactory and they fall within the calculated prediction uncertainty ranges. For instance, Kaduna had a coefficient of determination (R^2) and Nash–Sutcliffe efficiency (NSE) of 0.74 and 0.72 respectively during calibration and R^2 of 0.72 and NSE of 0.70 during validation falling within *P- factor (R-factor)* of 0.83 (0.92) during calibration and *P- factor (R-factor)* of 0.85 (1.20) during validation. The spatial distribution of the water resources varied greatly across the basin. However, the water components are more available downstream. The patterns of the variability suggest the influence of precipitation, soil properties and land use type. Though the use of a number to denote available freshwater could be misrepresentative, the study provides a guide for effective rain-fed agricultural planning within the basin.

Keywords: Water resources • SWAT model • Niger River Basin • Nigeria

INTRODUCTION

The freshwater resource is a complex system of the environment and its availability at a global scale is essential for the survival of man and the ecosystems. It is a major commodity upon which the growth of the economy, agriculture and industry depends [1]. Paradoxically, this vital resource is the main global challenge facing man at present and all other challenges such as food security, human health, poverty rate, climate change and regional conflicts are intrinsically linked to it [2]. The quantity of freshwater available for man varies from continent to continent and nation to nation with Nigeria (which was ranked low with some other African and Asian countries) having 2.75 in 1000 m^3 per person per year [3]. This low quantity is becoming scarcer due to swift growth in population, improved living standards, industrialisation, and water pollution coupled with climate change [4]. It has been predicted that by the year 2025, Nigeria will be one of the countries in the world that will possibly face conditions of disastrously low freshwater availability [5]. Reduction in the available freshwater will have an impact on water use in sectors like agriculture which uses about 70% of the total water [6]. A threat to agriculture through insufficient freshwater resources is a threat to the nation as over 70% of the nation depends on subsistence agriculture [7, 8]. Hence, there is a need for sustainable water resources management at regional, national or basin scales to mitigate or prevent the impacts of the existing and predicted future water stress [1].

In the assessment and management of water resources, the use of colour has been adopted recently. While four colours (yellow, brown, black and grey) are mostly used in domestic wastewater management, two colours (blue and green) are commonly used in the area of agricultural water management [9]. Though the two terms (blue water and green water) have been defined differently by different authors, there seems to be some level of agreement over the definition. Bluewater (also known as internal renewable water resource) is defined as the combination of surface water and groundwater that can be withdrawn while green water is the precipitation stored in the soil and evapotranspired on cropland [10, 11]. Two concepts can be inferred from the definition of green water, which is storage and evapotranspiration. “Green water storage” is the moisture in the soil while actual evapotranspiration is the “green water flow” which consists of the actual evaporation (the non-productive part) and the actual transpiration (the productive part) [2, 12]. Green water storage is a source of rain-fed agriculture as about 65% of the total

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precipitation on the global scale is returned to the atmosphere through evapotranspiration of plants [13]. It is thus considered a renewable resource due to its potential to create economic return [2]. A better appreciation and management of this renewable freshwater resource is the foundation for life in biotic and freshwater ecosystems [14].

For improved management strategies and implementation of appropriate control measures to the problems of water resources and watersheds, there is a need for a clear understanding of the fundamental watershed processes [15]. In an attempt to understand the processes, water resources scientists and engineers have applied several useful models, the most popular of which are climate and hydrologic models. [2] asserted that hydrological models are better than climate models, particularly at a global scale. While hydrological models are identified with an accurate estimation as regards hydrological processes, climate models are noted for problems of low spatial resolution, poor representation of soil water processes, and, in most instances, lack of calibration against measured discharge. Among the robust hydrological models, the Soil and Water Assessment Tool (SWAT) model has gained more acceptance than some others in terms of freshwater estimates. This is because it is considered free of limitations (such as poor temporal resolution, inconsistent water balance and inability to quantify the model in China using five statistical approaches and the SWAT model. Their result showed there were large variations in the dynamics of the green and blue water flows at the county scale. [2] estimated freshwater availability in the prediction uncertainty) that some are associated with. The reliability of a hydrological model for planning processes lies largely in the ability to curtail the resulting uncertainty in its application within the barest permissible range, through a reliable process of calibration and validation [15]. More so, considering the close nexus between water and food, a model capable of reasonable assessment of water resource availability with high spatial and temporal resolution is crucial for strategic decision-making on food security.

The usage of the SWAT model has been reported across the globe for studies on the hydrology of basins (particularly in the quantification of green and blue water resources) on both spatial and temporal scales. [16] simulated different components of water resources and studied water quality in Europe using a calibrated SWAT model. They found that the calibrated model and results provide adequate information to the European Water Framework Directive and lay the foundation for further assessment of the impact of climate change on water availability and quality. [17] used the model to simulate blue and green water resources in Iran. Their results indicate that irrigation practices have a significant impact on the water balances of the provinces with irrigated agriculture. [18] investigated the dynamics of green and blue water flows and their controlling factors in the Heihe River basin,

West African sub-continent using the Model and found that the uncertainties in model outputs are, in general, within reasonable ranges but larger in sub-basins having features such as dams and wetlands, or sub-basins with inadequate information on climate or land use.

To our understanding based on the available literature, little work has been done on the quantitative assessment of the volumes of the different water components (blue and green water resources) in Nigeria, particularly in our area of study. Though [2] calibrated the SWAT model over West African countries which include Nigeria, the study did not report on volumes of the different water components in Nigeria. Also, the study used the three most frequent soil types as against the dominant soil types used in this study. Thus, this study aims at studying the hydrology of the Niger Central Hydrological area, Nigeria. The specific objectives are: (i) to calibrate and validate the SWAT model in the NCHA of Nigeria with uncertainty analysis, and (ii) to simulate green and blue water resources over the basin.

MATERIALS AND METHODS

Study domain: For better management of water resources, Nigeria is divided into eight hydrological areas which comprise Niger South, Niger Central, Upper Benue, Lower Benue, Niger South, West Littoral, East Littoral and Chad Basin [19]. Niger and Benue hydrological areas are named after the major rivers (River Niger and River Benue) that drained through them. River Niger is the second-largest in Africa which covers an area of 2.27 million km² and delineated a basin (Niger River Basin) through ten West African countries [20]. Out of the active river basin, those within Nigeria account for 44.2% (562,372 km²) of the total basin [21, 22]. The sub-basin of the Niger River Basin (NRB) modelled in this study is the Niger Central Hydrological Area (NCHA), Nigeria (Figure 1). It covers an area of 158,000 km^2 (an area larger than three times the size of some West African countries e.g., Gambia and Guinea-Bissau) and is situated between Latitudes 7.5^o N – 12^o N and Longitudes 3.0^o E – 9.0^o E. The altitude of the area varies from 10 m to 650 m. NCHA extends across the northern and southern parts of Nigeria, reflecting the different climatic, meteorological and hydrological characteristics in the two regions. The climate of the area spans over Tall Grass Savanna agro-ecological zone and some parts of the Rain Forest with high temperatures and humidity [23]. Potential evapotranspiration decreases from the north to the south while the rainfall increases from the north to the south [24]. The area has two distinct seasons (rain and dry seasons). Rain starts in April and ends in October while the dry season lasts from November to March [25]. The average annual rainfall over the area ranges between 700 - 1,500 mm/year depending on the area. It is characterised by diverse land use that includes agricultural lands, wetlands, grassland, forest and urban area. It is an important basin with respect to agricultural food produce and has two (Jebba and Shiroro) of the three major dams in Nigeria fall within it, the third dam (Kanji) is at the inlet into the area [19].

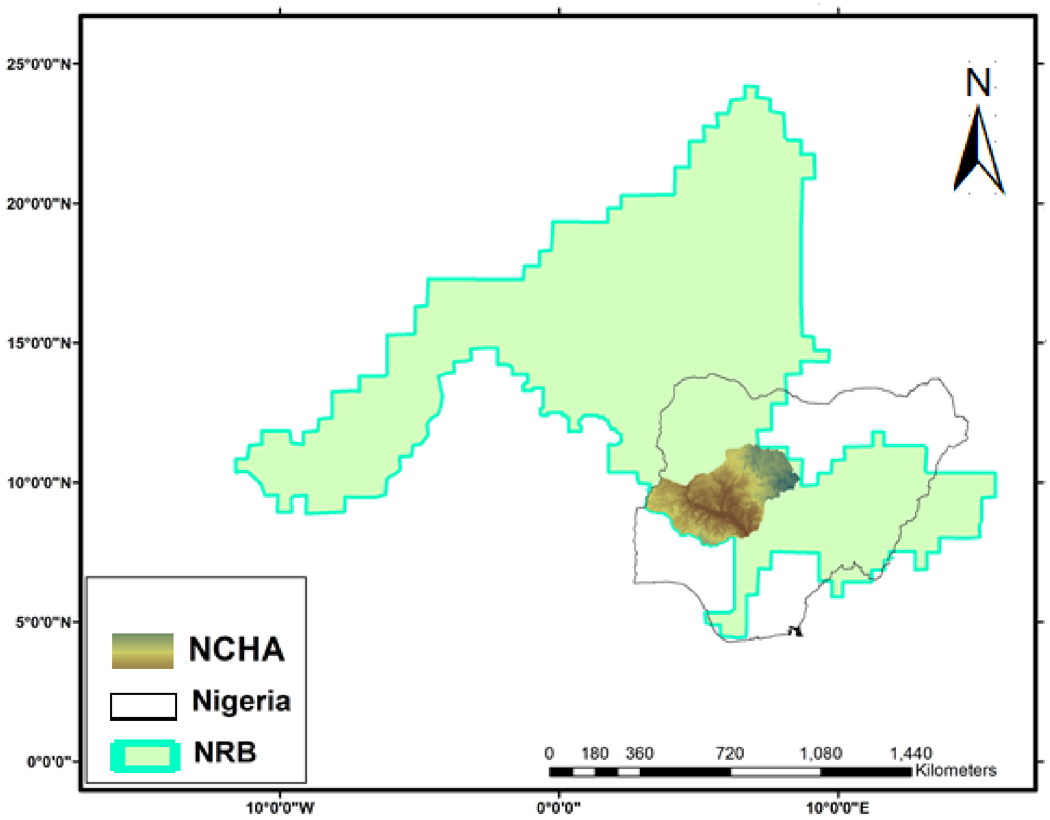


Figure 1: Map showing Niger Central Hydrological Area, Nigeria and Niger River Basin

Data and Methods: To run the SWAT model, the basic data used as input files are digital elevation model (DEM), soils, land use/land cover details and climate data (particularly rainfall and temperature). The data for green and blue water resources analysis were obtained from SWAT simulations. The details of the data and model set-up are presented hereafter.

Data:

A 30 m resolution DEM was downloaded from https://earthexplorer.usgs.gov/. The DEM is from the Shuttle Radar Topography map of the world produced by the Food and Agriculture Organization of the United Mission (SRTM) of the United States National Aeronautics and Space Administration (NASA). It was projected to WGS_1984_UTM; Zone_32 N. Based on the DEM, SWAT on ArcGIS environment allows for the delineation of a basin or watershed. The delineation of the basin allows for the analysis of the hydrologic processes in the sub-basins within the larger basin [26]. This gives room for the extraction of terrain-specific characteristics. The DEM shows the elevation of this basin varies from 10 m to 650 m (Figure 2a).

The soil data used as input for the study was extracted from the harmonised digital soil

Nations. The soil map gives the required physicochemical and hydrological soil parameters (such as soil texture, soil depth, hydrologic soil group (HSG), available water content and organic carbon content) for running the SWAT. The available soil classes are about 33 as shown in Figure 2b. Land use land cover map was created using the Landsat 8 satellite image, downloaded from USGS Earth Explorer. The available classes and percentage coverage are shown in Table 1 and Figure 2c.

For the climate data, a monthly to daily weather convertor (MODAWEC 1.0) otherwise known as MODAWEC stand-alone model was used to generate daily precipitation and temperatures (maximum and minimum) from Climate Research Unit (CRU_TS 4.01) datasets [27]. The CRU provides gridded monthly data with 0.5 by 0.5 latitude and longitude resolution which covers the period 1901-2016 [28]. The CRU datasets used are precipitation, temperatures, and wet days. The choice of CRU datasets was due to the problem of missing data, limitation in data lengths and spatial coverage associated with station data and good correlation of CRU with the available station datasets of the study area [23].

Discharge data for gauged stations (Kaduna, Shiroro, Kachia, Izom, Zungeru, Baro, Agaie and Lokoja) used for calibration and validation of the SWAT model were obtained from the Shiroro hydropower station, Niger State and Kaduna State Water Boards and Nigeria Hydrological Services Agency (NIHSA). The locations of the gauged stations are shown in Figure 2d. Other information obtained at hydropower stations (Jebba and Shiroro) is the details about the reservoirs. Some of the details include the months and years the reservoirs became operational, the values for the storage volume and the reservoir surface area filled to the emergency spillway (see Table 2).

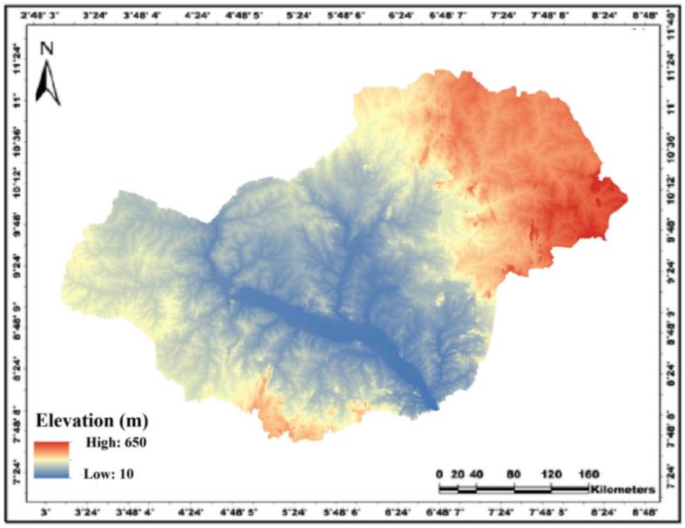


Figure 2a: Elevation of the NCHA

Table 1: Description of land use types and their percent area of coverage

Land use Class	**Code**	**Coverage (%)**
Barren or sparsely vegetated	BSVG	0.13
Cropland/Grassland mosaic	CRGR	60.50
Irrigated crop land and pasture	CRIR	0.15
Forest mixed	FRST	28.23
Grassland	GRAS	0.45
Savanna	SAVA	1.85
Residential	URBN	0.56
Water	WATR	4.08
Wetlands-Mixed	WETL	4.05

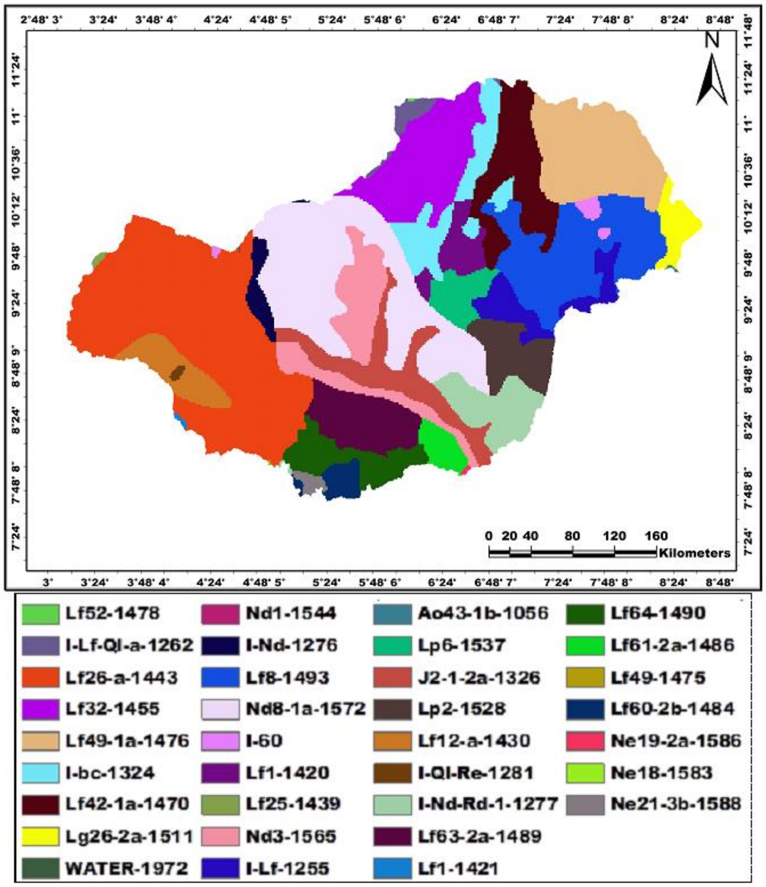


Figure 2b: Available soil type of the NCHA

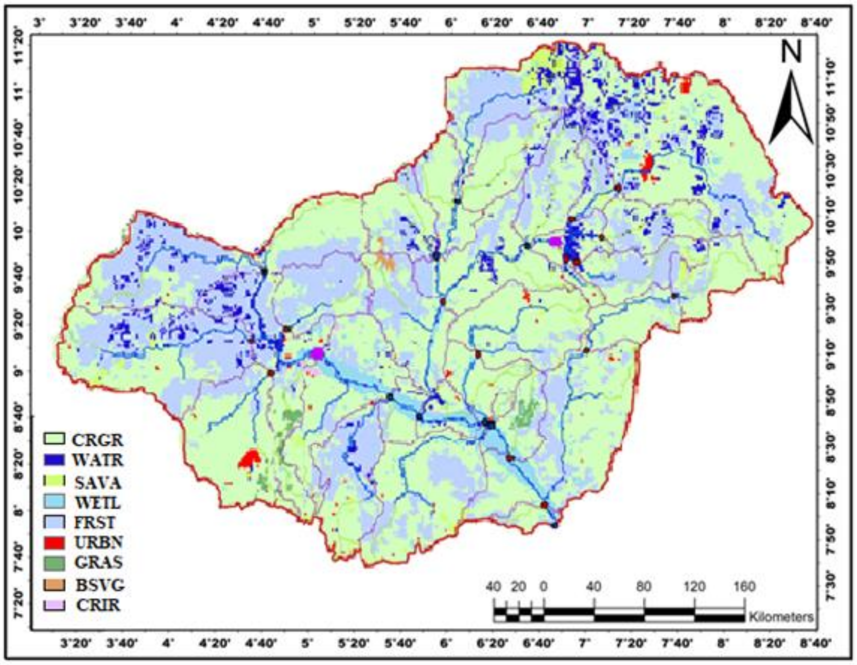


Figure 2c: Land use / Land cover of the NCHA

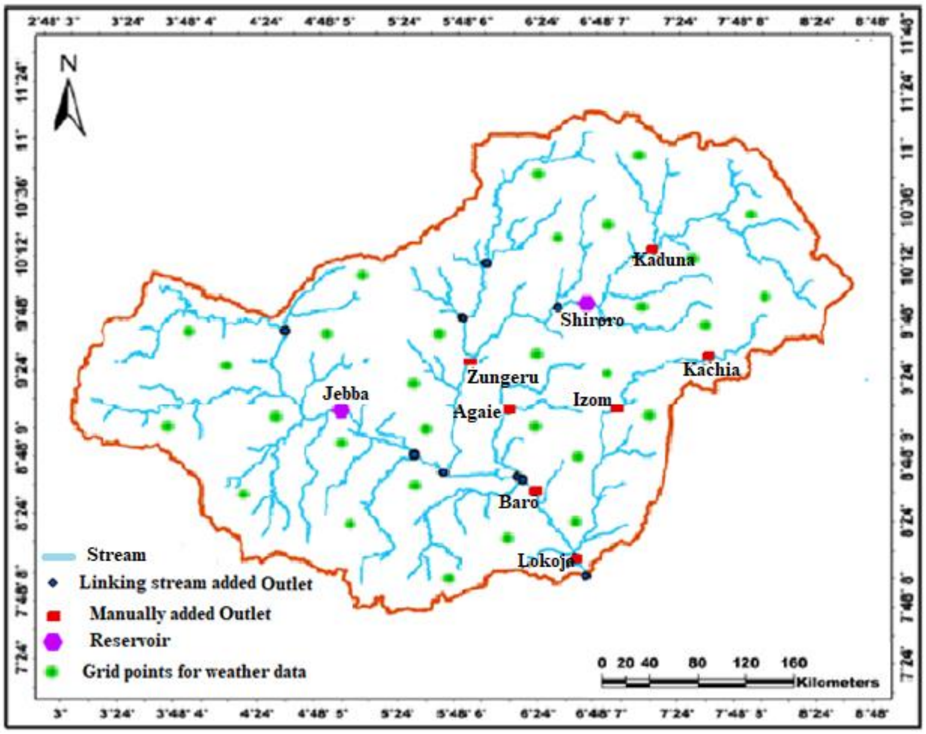


Figure 2d: Gauged station used for the model calibration

Table 2: Some of the Characteristics of the reservoirs which are included in the SWAT model

Name	River	Month	Year	Latitude (°)	Longitude (°)	Surface Area (km^2)	Storage Volume (km^3)
Jebba	Niger	April	1984	9.25	44.75	350	1.00
Shiroro	Kaduna	June	1990	9.97	6.93	320	6.00

Model setup: The parameterisation of the model was done on the ArcGIS interface for SWAT and the procedure for the watershed delineation is as reported in [2]. Some linking streams added to outlets were deleted while two reservoirs and some outlets were added at gauged stations with available streamflow data and a total of 34 sub-basins were delineated. The outlets were added on River Gurara (Kachia and Izom), river Kaduna (Kaduna and Shiroro), river Chanchaga (Agaie) and River Niger (Baro and Lokoja). The stream reaches and the sub-basin geomorphology such as area, elevation distribution, slope, and stream length were automatically parameterized by the interface. To define the hydrologic response unit (HRU), an overlay analysis of the land use, soil and slope distribution was done. This allows for a unique combination of specific soil, land use and slopes to delineate HRUs. Thus, each HRU is treated as a homogeneous block of land use, soil properties and management techniques where the relative impact of vegetation, soil, management, and climate changes is quantified [26]. To have a better simulation, SWAT input was edited using the obtained reservoir information mentioned above. For the few data that are not available, the assumption reported by [2] was used.

It is worth mentioning that Nigeria has nearly sixty (60) large dams, some of which are within the region, but, only Jebba and Shiroro dams with storage volumes greater than 1 km^3 and accessible reservoir data were included in the model. The simulation was then run from 1983-2000, using the first three years as a warm-up period.

Sensitivity, Calibration and Uncertainty Analyses: The SUFI-2 (**S**equential Uncertainty Fitting version 2) algorithm in the SWAT-CUP (SWAT Calibration and Uncertainty Procedure) environment was used for sensitivity, calibration/validation and uncertainty analysis of the SWAT model. The choice of SUFI-2 over other methods (such as Parameter Solution, ParaSol, Bayesian inference methods and Generalized Likelihood Uncertainty Estimation, GLUE) is because SUFI-2 needs fewer simulations to attain a similar level of performance [29, 30]. During a simulation, it can identify the optimal parameter ranges, which are better than absolute parameter values [31]. More so, its ability to simultaneously calibrate model parameters based on data that are spread within a watershed rather than using hydrologic responses from a single watershed outlet is an added advantage [29]. The aforementioned merit of SUFI-2 could be responsible for why it has been widely used in modelling streamflow and other flow parameters in recent years [1, 2, 15, 17].

Sensitivity analysis helps to identify the parameters with the most significant influence on the output of the model. Unlike sensitivity, there exist close nexus between calibration and uncertainty. Calibration is a process of evaluating different features of a model to refine, enhance and build confidence in the model predictions in a way that sound judgment can be made therein while validation is a process of building confidence in the calibrated parameters [32]. The uncertainty analysis is the assessment of uncertainty which arises from errors during the calibration of parameters, input data and errors in the conceptual model [33]. Uncertainty in a modelling work needs to be recognized; else calibration is meaningless and misleading [16].

A number of parameters are available for calibration but it is not feasible to include all. Hence, a need for pre-selection from earlier studies on the SWAT model. The initial ranges of model parameter values were obtained from studies done within West Africa (e.g., [2, 34, 35] (Table 3). The sensitivity and ranking of the pre-selected parameters vary from one watershed to the others as that depends on predominant geomorphologic characteristics. Thus, assessing their sensitivity to the streamflow in the present study area is a prerequisite to their usage for calibration analysis. To determine the sensitive parameters, a global sensitivity analysis approach was used. The approach is relatively fast and considers the sensitivity of one parameter in relation to other parameters under consideration [15]. The statistics used to determine their sensitivity are the *t-value* and *p-value*. The *t*-value indicates the parameter sensitivity of the parameter while the *p-value* indicates the significance of the sensitivity of that parameter indicated by the *t-value*. The larger the *t*-value and the smaller the *p-value*, the more sensitive the parameter [36].

The SUFI-2 algorithm aims at including most of the observed data with the smallest possible uncertainty bands [29]. The algorithms quantify the overall uncertainty for the output using two indices (*P-factor and R-factor*) [14]. *P-factor* is the percentage of observed data bracketed by the model outputs uncertainty, which is quantified as 95% prediction uncertainty (95PPU). In contrast, *R-factor* is the average width of the band divided by the standard deviation of the corresponding measured variable [14]. The range of the *P-factor* varies from 0 to 1, with values close to 1 indicating a very high model performance and efficiency, and *R-factor* also varies in the range of 0–1 [36, 37]. However, a value of > 0.7 is adequate for the *P-factor* when using discharge [16]. Generally, it is preferred to have most of the measured data (plus their uncertainties) bracketed within the *95 PPU* band (*P-factor* tends to 1) while having the narrowest band (*R-factor* tends to 0) [17].

Ten different objective functions are available in SUFI-2 for sensitivity and calibration, but in this study, the two most commonly reported statistics (coefficient of determination, R^2 and Nash–Sutcliffe efficiency, *NSE*) in the SWAT model are used [38]. Both the R^2 and *NSE* give information about the strength of the relationship between the observed and simulated models. While R^2 ranges from 0 to 1, *NSE* ranges from 1 to ∞. Both R^2 and *NSE* have 1 as the best fit [34]. For the model application, streamflow data for the year 1983-2000 were used. The model was calibrated for the year 1986–1995 and validated for 1996–2000. The first three years (1983-1985) were used as warm-up and hence excluded in the analysis. The model performance was classified as satisfactory if R^2 and *NSE* are > 0.5 [39]. The equations for the two objective functions are shown below

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{obs}-Q_{obsm})(Q_{sim}-Q_{simm})\right]^2}{\sum_{i=1}^{n}(Q_{obs}-Q_{obsm})^2\sum_{i=1}^{n}(Q_{sim}-Q_{simm})^2} \quad 1$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs}-Q_{sim})^2}{\sum_{i=1}^{n}(Q_{obs}-Q_{obsm})^2} \quad 2$$

Where R^2 is Coefficient of Determination, *NSE* is Nash-Sutcliffe Efficiency
Where Q_{obs} and Q_{sim} are the respective observed and simulated discharges, while Q_{obsm} and Q_{simm} are the respective means of the observed and simulated discharge

Table 3: SWAT model parameters sensitivity for the calibration

Parameter	**Description**
CN2	SCS runoff curve number for moisture condition II
ALPHA_BNK	Baseflow alpha factor for bank storage
GW_DELAY	Groundwater delay
CH_K2	Channel effective hydraulic conductivity
SOL_AWC	Available water capacity
CH_N2	Manning’s n value for the main channel
ALPHA_BF	Baseflow alpha factor
ESCO	Soil evaporation compensation factor
SOL_K	soil saturated hydraulic conductivity
OV_N	Manning value for overland flow
GW_REVAP	Groundwater “revap” coefficient
GWQMN	Threshold water depth in the shallow aquifer for base flow
MSK_CO2	Calibration coefficient that controls impact of the storage time constant for low flow
RCHRG_DP	Deep aquifer percolation fraction

RESULT AND DISCUSSION

Parameter Sensitivity Analysis: The sensitivity of the parameters was assessed at each of the gauged stations and the ranks were averaged. The nine most sensitive parameters ($p < 0.05$) to the streamflow and their final simulated values as shown by global sensitivity analysis are presented in Table 4. The SCS runoff curve number for moisture condition II (CN2) was ranked as the most sensitive to the streamflow, followed by the baseflow alpha factor for bank storage (ALPHA_BNK). Other sensitive parameters in decreased order of their sensitivity are groundwater delay (GW_DELAY), soil evaporation compensation factor (ESCO), channel effective hydraulic conductivity (CH_K2), available water capacity (SOL_AWC), channel effective hydraulic conductivity (CH_N2), baseflow alpha factor (ALPHA_BF), and groundwater “revap” coefficient (GW_REVAP). The parameters identified as sensitive to streamflow in this study also made the list in other studies within Nigeria and the West Africa region (e.g. [2, 34]). The sensitive parameters are those that represent surface runoff, soil properties, and groundwater recharge, indicating they are the probable dominant sources of the streamflow and thus indicate their significance in the hydrology of the basin.

Table 4: SWAT model parameters sensitivity for the calibration ($p < 0.05$)

Parameter	**Initial parameter range**	**Final parameter range**	**Sensitivity ranking**
CN2	-0.2 - 0.2	-0.17 - 0.12	1
ALPHA_BNK	0.00 - 1.15	0.24 - 0.83	2
GW_DELAY	0 - 100	29 - 40	3
ESCO	0.0 - 1.00	0.19 - 0.74	4
CH_K2	110 - 200	120 - 157	5
SOL_AWC	0.05 - 0.5	0.30 - 0.44	6
CH_N2	0.10 - 0.50	0.35 - 0.43	7
ALPHA_BF	0.00 - 1.00	0.09 - 0.15	8
GW_REVAP	0.02 - 0.30	0.03 - 0.12	9

1 is the most sensitive; 9 is the less sensitive

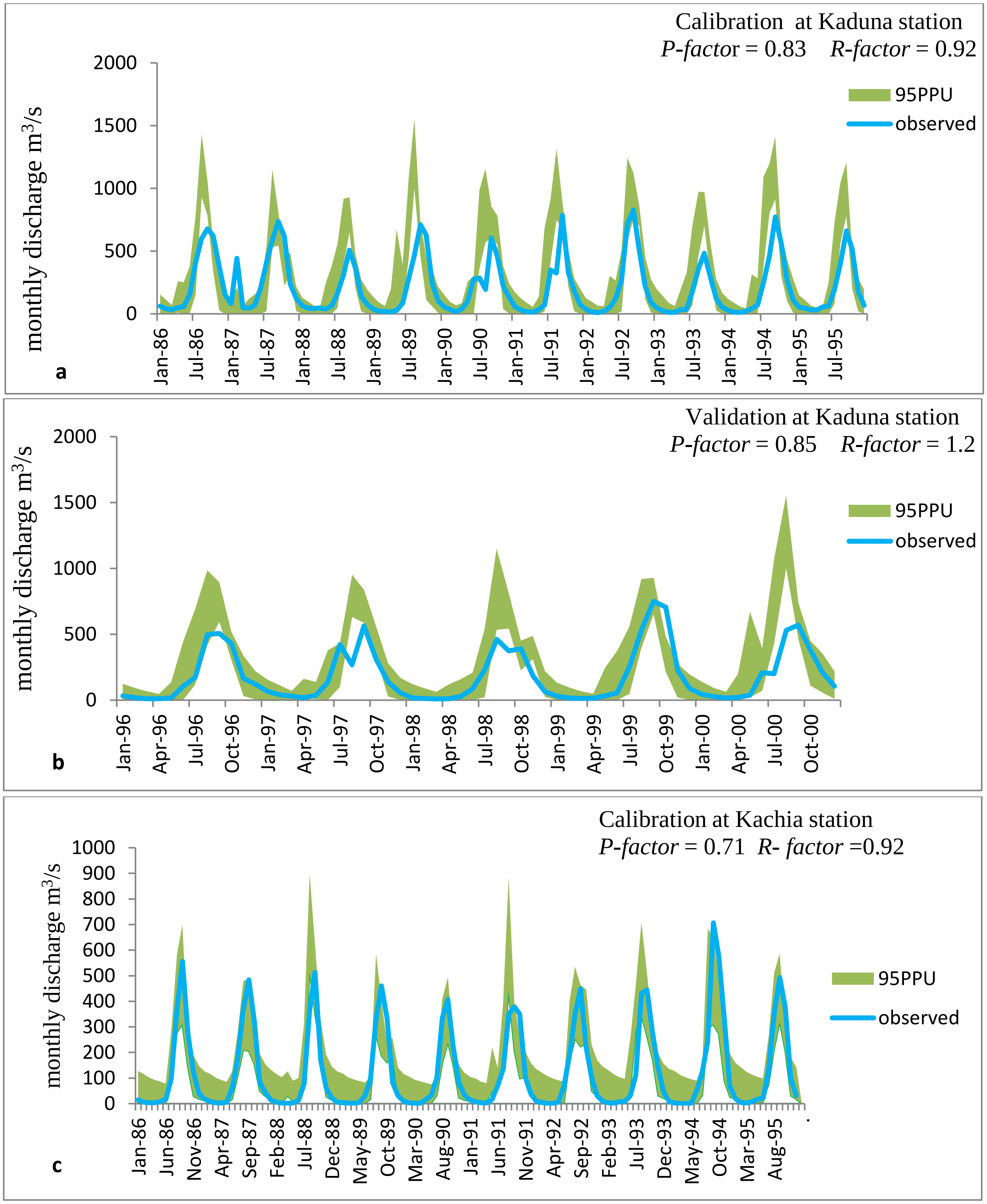
Model calibration and uncertainty analysis:

Uncertainty analysis: The sensitive parameters retained after sensitivity analysis were used for the calibration analysis. The results of the two factors (*R-factor* and *P-factor*) for each station during the calibration and the validation periods are presented in Table 5. The shaded region denotes the *95PPU* (Figure 3). From the obtained values for the two factors considered as the SUFI-2 stopping criteria, it could be deduced that reasonable calibration can be made with the selected parameters and their uncertainty range. On average, most (about 65%) of the observed streamflow data from the seven (7) gauged stations fell within the boundaries of *95PPU* and the average *R-factor* was 1.15. Although, the closer the *R-factor* of a model to 1, the better the model, the adequacy of input and calibrating data could suggest acceptable values [16]. The average *P-factor* value for the entire watershed is reasonable during the calibration and validation period. This indicates that SWAT model uncertainties were within the permissible limits and SUFI-2 can to a large extent capture the model behaviour.

At individual gauged stations, only two stations (Kaduna and Kachia) satisfy strong requirements for the two factors (*P-factor* > 70% *and R-factor* between 0 and 1) during the calibration periods, while none of the stations meet the conditions during validation. However, when two-factor values of each station are subjected to a less strict model quality condition (i.e., *P-factor* > 60% and *R-factor* < 1.3) as applied by [2], three (3) and five (5) stations fulfilled the requirements during the calibration and validation periods respectively. The extent of uncertainty in the model of each station is depicted by the values of the two factors as small *P-factor* and large *R-factor* values represent large uncertainties [17]. The *R-factor* and *P-factor* of the models in this watershed suggest that the calibrated model is reliable for the water resources study of the area

Table 5: Measured monthly streamflow data bracketed by 95PPU and the R-factor

Gauged Station		**Evaluation**	**Statistics**
		P-factor	***R-factor***
Kaduna	Calibration	0.83	0.92
	Validation	0.85	1.20
Zungeru	Calibration	0.49	1.16
	Validation	0.57	0.85
Kachia	Calibration	0.71	0.92
	Validation	0.63	0.68
Izom	Calibration	0.55	1. 38
	Validation	0.61	1.11
Agaie	Calibration	0.65	1.58
	Validation	0.71	1.15
Baro	Calibration	0.61	1.38
	Validation	0.58	1.41
Lokoja	Calibration	0.68	1.24
	Validation	0.64	1.38
NCHA	Calibration	0.65	1.20
	Validation	0.66	1.11


Calibration at Kaduna station
P-factor = 0.83 R-factor = 0.92
95PPU
observed
monthly discharge m³/s
2000
1500
1000
500
0
Jan-86
Jul-86
Jan-87
Jul-87
Jan-88
Jul-88
Jan-89
Jul-89
Jan-90
Jul-90
Jan-91
Jul-91
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
a
Validation at Kaduna station
P-factor = 0.85 R-factor = 1.2
95PPU
observed
monthly discharge m³/s
2000
1500
1000
500
0
Jan-96
Apr-96
Jul-96
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
b
Calibration at Kachia station
P-factor = 0.71 R- factor =0.92
95PPU
observed
monthly discharge m³/s
1000
900
800
700
600
500
400
300
200
100
0
Jan-86
Jun-86
Nov-86
Apr-87
Sep-87
Feb-88
Jul-88
Dec-88
May-89
Oct-89
Mar-90
Aug-90
Jan-91
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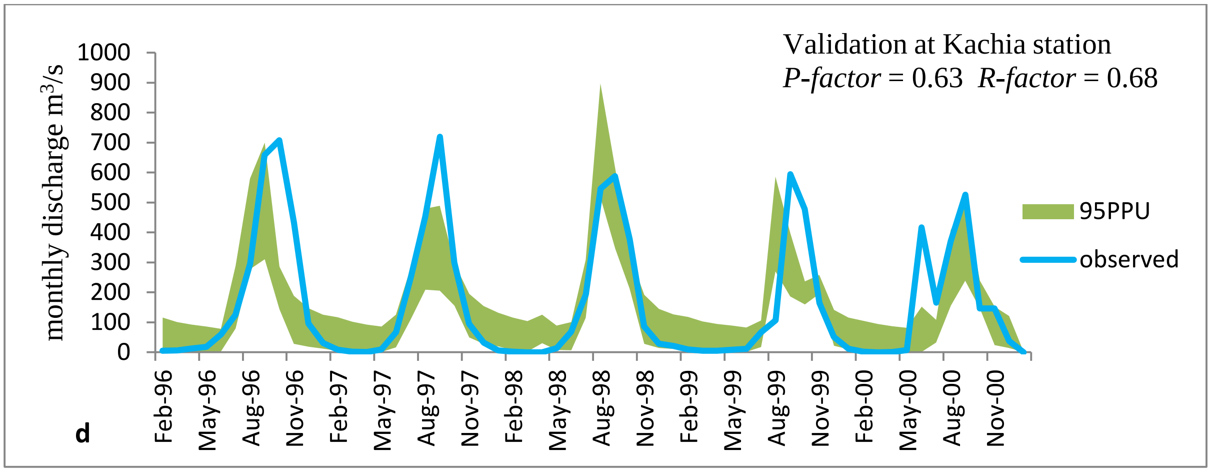


Figure 3: The monthly calibration and validation of the observed and simulated (expressed as 95% prediction uncertainty band) flows for two gauged stations within NCHA

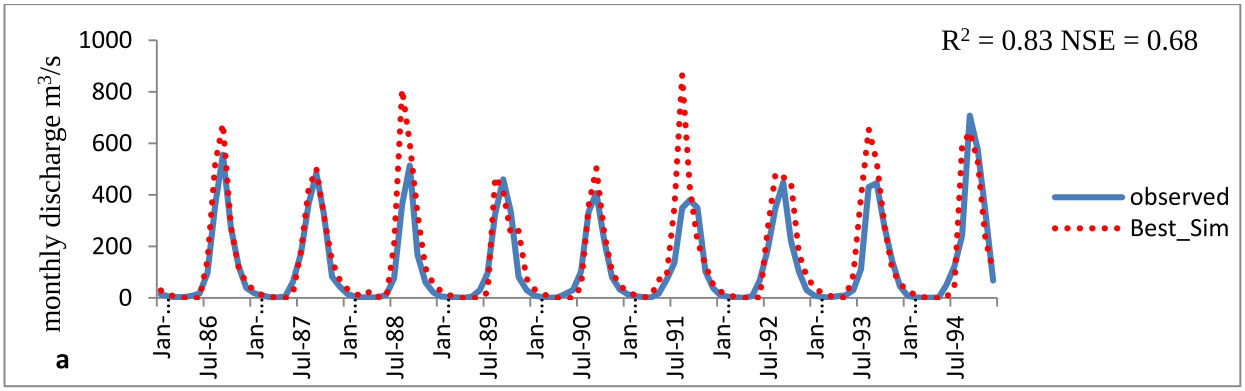
Calibration and validation: The calibration was done using two-thirds of the discharge data while the remaining one-third was used for validation. The statistics of the monthly simulated and the observed streamflow showed good agreement during the calibration and validation periods. Table 6 shows the coefficient of determination (R^2) and Nash- Sutcliffe Efficiency (*NSE*) for the individual gauged station within the study area. The R^2 and *NSE* values of greater than 0.5 (except for the *NSE* value of Zungeru and Agaie during validation) indicate that the models capture well the time series and trends of the streamflow during the calibration and validation periods.

Nevertheless, there were mismatches between the observed and the simulated flow peaks even at stations with high-performance statistical values. While the model recorded excess simulation for some months; it returned a deficit for other months. For reflected through the large *R-factor and* small *P-factor* values; and which could instance, at Kachia, the month of August in the years 1988, 1991 and 1993 were simulated in excess while September 1997 and 1999 were under-simulated (Figure 4). Excess simulations may be attributed to uncertainties in the discharge data used, given that the data were recorded using the error-prone manual method [35]. More so, aggregated monthly data often contained missing daily data. This could be responsible for the non-perfect values of *the P-factor* and *R-factor* of the station as shown under uncertainty analysis. The good performance of the SWAT model in this study is consistent with earlier studies within the lower stream of the Niger River Basin (e.g., [2, 30, 35]. The low *NSE* value of Zungeru (0.43) and Agaie (0.39) stations could be associated with the influence of dam operation, even though; the inclusion of the dam improved the simulation. Other sources of large uncertainty that are

be responsible for poor model calibration in some sub-basins include lack of information on water use and the use of simulated daily precipitation and temperature in driving the SWAT model.

Table 6: Monthly time step calibration and validation performance statistics

Gauged Station		Evaluation Statistics	
		R^2	NSE
Kaduna	Calibration	0.74	0.72
	Validation	0.75	0.70
Zungeru	Calibration	0.65	0.58
	Validation	0.57	0.43
Kachia	Calibration	0.83	0.68
	Validation	0.72	0.70
Izom	Calibration	0.68	0.61
	Validation	0.71	0.57
Agaie	Calibration	0.65	0.39
	Validation	0.74	0.67
Baro	Calibration	0.58	0.53
	Validation	0.61	0.59
Lokoja	Calibration	0.79	0.74
	Validation	0.71	0.68



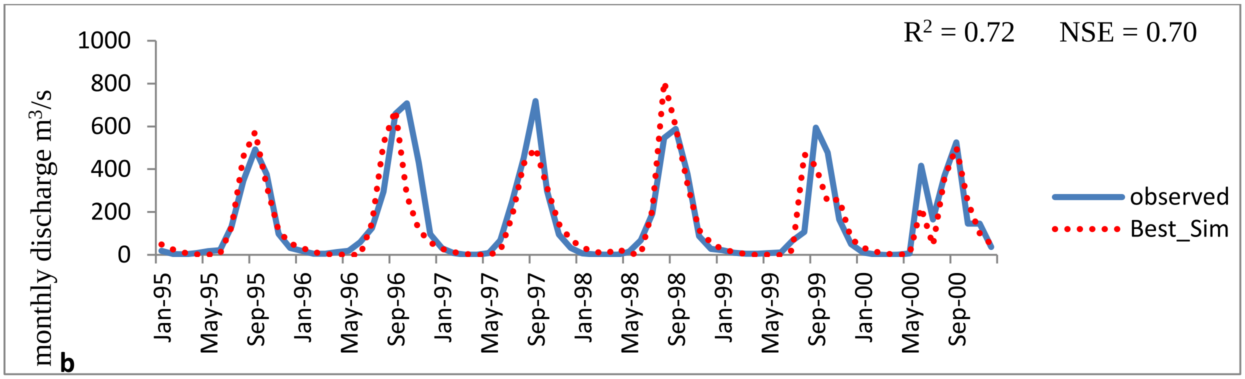


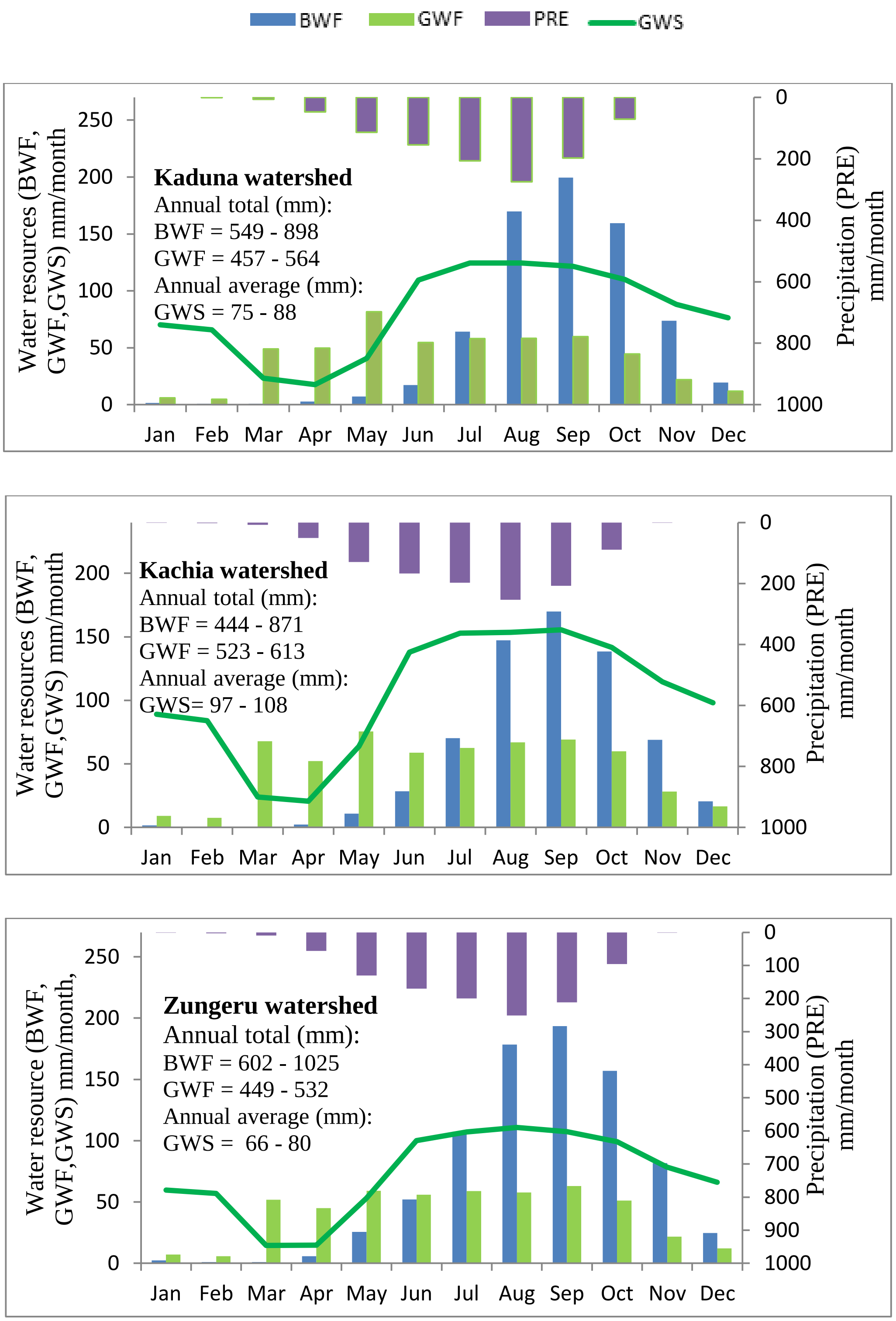
Figure 4 (a) Calibration and (b) validation of monthly simulated and observed flows at the Kachia gauged station

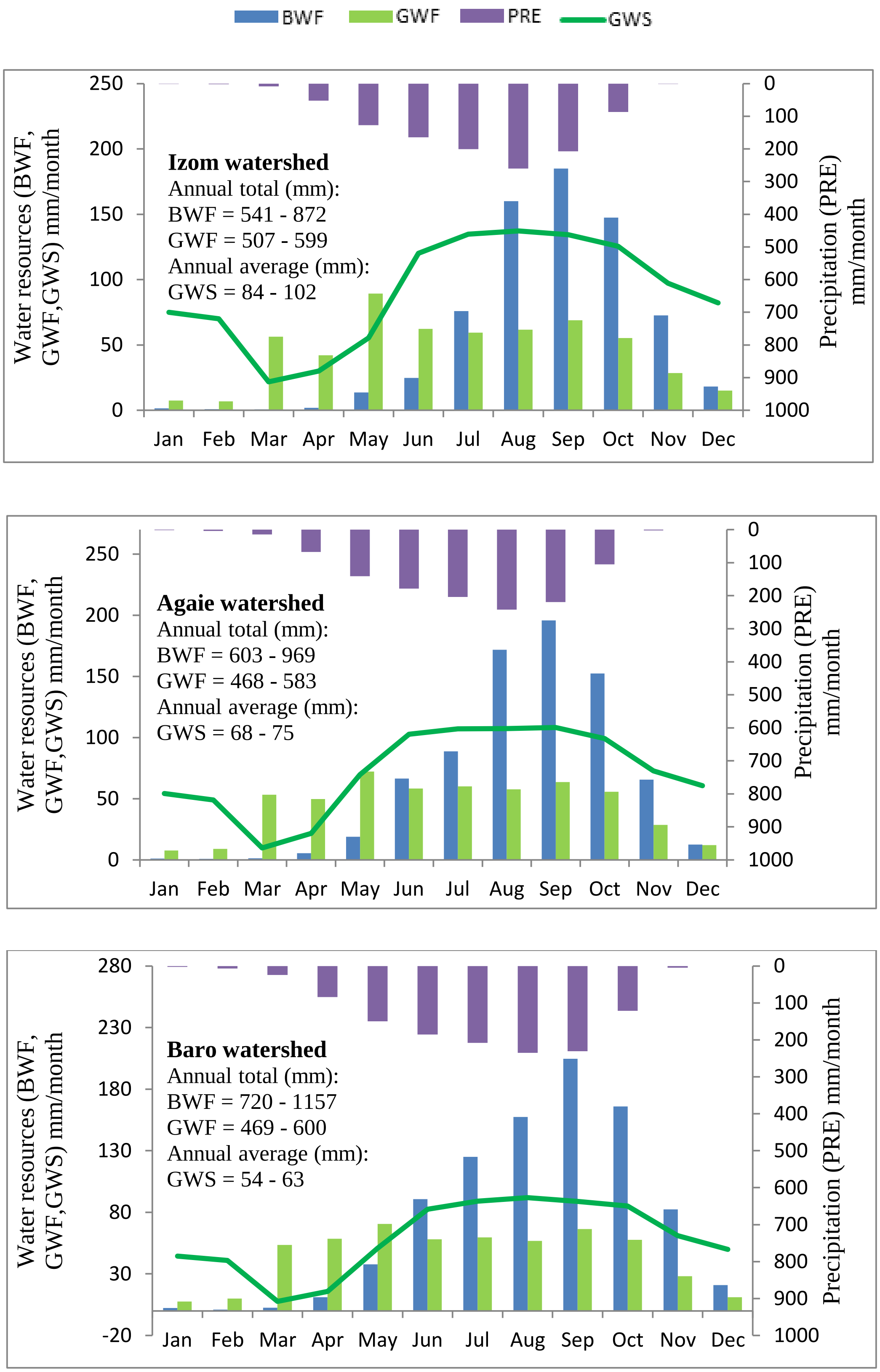
Spatial and temporal Quantification of Water Resources Components: Knowledge of inter- and intra-annual variability of the available water resources (particularly internal renewable water resources) is highly importance for water resources planning. As earlier mentioned, blue water is a combination of surface and groundwater. While some studies take surface runoff as surface water, others used water yield. Though the estimation of both is available on SWAT "Tableout" results, this study adopts water yield as reported in [2] and [17]. The blue water (BWF), green water flow (GWF) and green water storage (GWS) as well as the precipitation (PRE) aggregated at seven sub-basins and the whole watershed are presented in Figure 5 and Figure 6 respectively. The water resources availability on a seasonal basis was also presented and the seasons (dry season, early and late rainy seasons) were defined as mentioned in [23]. The average watershed also shows a similar pattern with blue water as the two sub-basins (Lokoja and Baro) downstream had the highest value. The variability in green water flow was not as pronounced as that of blue water. This could monthly and annual total of blue water availability showed great variability across the sub-basins. The highest annual total values were recorded at Lokoja (709 – 1188 mm) and Baro (720 – 1157 mm) which are situated downstream. This is not unexpected as the largest discharge of River Niger was found downstream and high-water availability downstream has been reported in earlier studies [3, 22, 40]. The highest inter-annual variability was at Zungeru (602 – 1025 mm) suggesting a probable influence of human's activities (such as farming and construction of a dam) on the streamflow. The values (444 – 1188 mm) of internal renewable water resources (blue water, IRWR) reported in this work are within the values (39 – 1357 mm) reported by [2] across eight West African countries.

The monthly green water flow (GWF) otherwise known as actual evapotranspiration (AET) across the

be attributed to the relative stability of land use/land cover as land use types play a vital role in the amount of green water flow [14]. The result is consistent with other studies within Nigeria and West Africa countries [2, 35]. The green water storage (soil moisture) showed a different pattern with the blue and green water flow. Unlike blue and green water flow, where the highest values were obtained downstream, Kachia at the midstream has the highest average annual value that ranged between 97 and 108 mm. Some have attributed this to spatial variation in land use. For instance, the report of [34] claimed that while the amount of blue water available in the White Volta Basin of West Africa decreases with the conversion of grassland and savannah to plantation, the green water storage increases significantly. However, aside from the climate (precipitation and temperature), several factors that are soil-related (such as soil structure and texture, topography and soil depth) could also add to the effects of the vegetation. This agrees with the submission of earlier studies that associate variation in green water storage with the presence of divergent soil textures and properties of varying hydraulic conductivity [41, 42].

Generally, the results suggest that the blue and green water flows largely depend on the precipitation, as the two sub-basins with the highest values of both flows, received the highest amount of rainfall on an annual and monthly basis. In each of the sub-basins in the watershed, the blue water attained its peak in September as against August when precipitation was at maximum. The lag time of a month between the two peaks in all sub-basins further suggests similar watershed characteristics or similar land use types which are reflected in the relatively stable green water flow. Hence, high evapotranspiration in August could be responsible for the delay of the peak of blue water to September. Similar findings have been reported elsewhere [14]. The average seasonal water resources (blue water, green water flow and green water storage) of the whole basin showed that while the blue water resource and green water storage were highest in the late rainy season (JASO), the highest value of green water flow was in the early rainy season (AMJ). This showed the effect of climate (precipitation and temperature) on seasonal and annual water resource availability. High blue water in the late rainy season could be attributed to high green water flow in the early rainy season.


BWF
GWF
PRE
GWS
Kaduna watershed
Annual total (mm):
BWF = 549 - 898
GWF = 457 - 564
Annual average (mm):
GWS = 75 - 88
Water resources (BWF, GWF,GWS) mm/month
Precipitation (PRE) mm/month
0
50
100
150
200
250
0
200
400
600
800
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Kachia watershed
Annual total (mm):
BWF = 444 - 871
GWF = 523 - 613
Annual average (mm):
GWS= 97 - 108
Water resources (BWF, GWF,GWS) mm/month
Precipitation (PRE) mm/month
0
50
100
150
200
0
200
400
600
800
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Zungeru watershed
Annual total (mm):
BWF = 602 - 1025
GWF = 449 - 532
Annual average (mm):
GWS = 66 - 80
Water resource (BWF, GWF,GWS) mm/month,
Precipitation (PRE) mm/month
0
50
100
150
200
250
0
100
200
300
400
500
600
700
800
900
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


BWF
GWF
PRE
GWS
Water resources (BWF, GWF,GWS) mm/month
Precipitation (PRE) mm/month
Izom watershed
Annual total (mm):
BWF = 541 - 872
GWF = 507 - 599
Annual average (mm):
GWS = 84 - 102
0
50
100
150
200
250
0
100
200
300
400
500
600
700
800
900
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Agaie watershed
Annual total (mm):
BWF = 603 - 969
GWF = 468 - 583
Annual average (mm):
GWS = 68 - 75
Baro watershed
Annual total (mm):
BWF = 720 - 1157
GWF = 469 - 600
Annual average (mm):
GWS = 54 - 63
-20
30
80
130
180
230
280

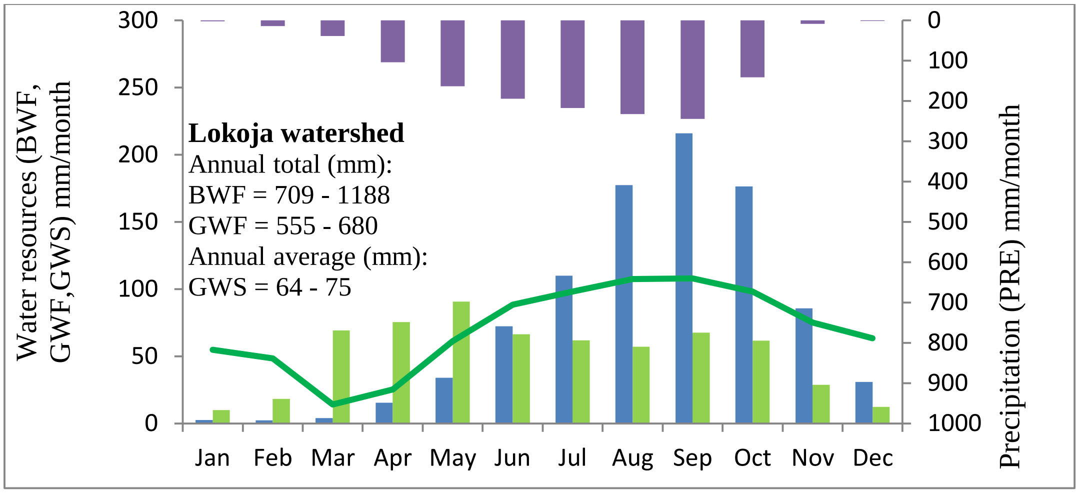
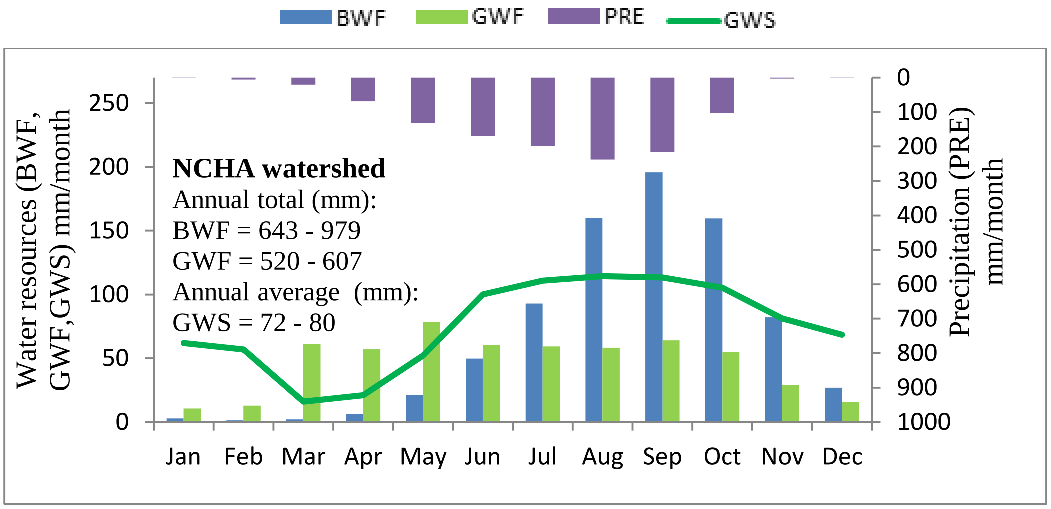


Figure 5 Average (1986-2000) monthly and annual total water resources (Blue water, Green water flow and Green water storage) for seven Sub-basins of NCHA



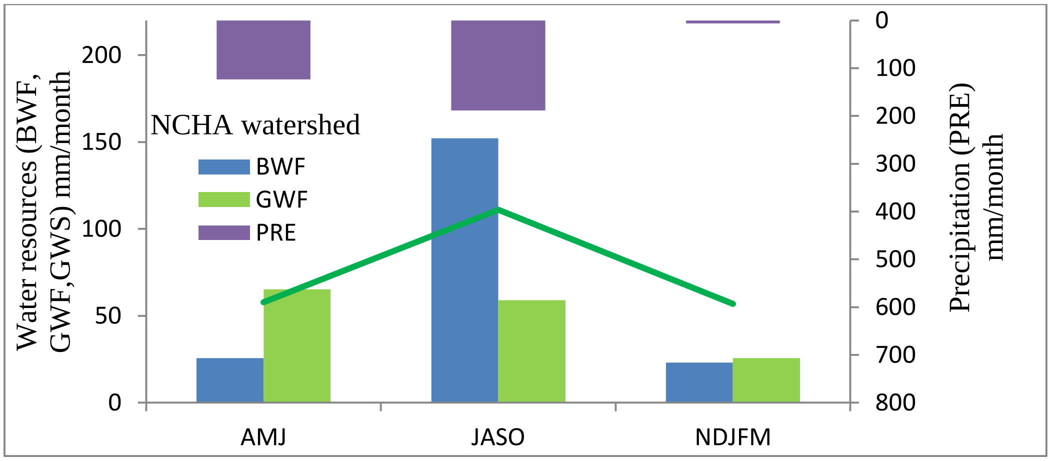


Figure 6 Average (1986-2000) monthly, seasonal and annual water resources (Blue water, Green water flow and Green water storage) of NCHA

Spatial distributions of water resources over NCHA are shown in Figure 7. The average annual precipitation, blue and green water flows are expressed in mm per year while average green water storage is expressed in mm for easy comparison among the sub-basins and with earlier works within West African countries. The distribution of the water resources across the whole watershed showed that though precipitation plays a vital role in water resources components distribution, it is not the sole determinant of their magnitude. The precipitation has the highest value downstream and decreases towards the upstream (SE – NW direction). The blue water distribution showed that the internal renewable water is generally more abundant downstream as compared to upstream. Nevertheless, some areas downstream also lack it. This indicates the role of geology, topology, climate and crop cover on blue water availability as both the surface and groundwater component of blue water depends on them [22, 43]. The report of [44] asserted that change in land use can affect groundwater availability

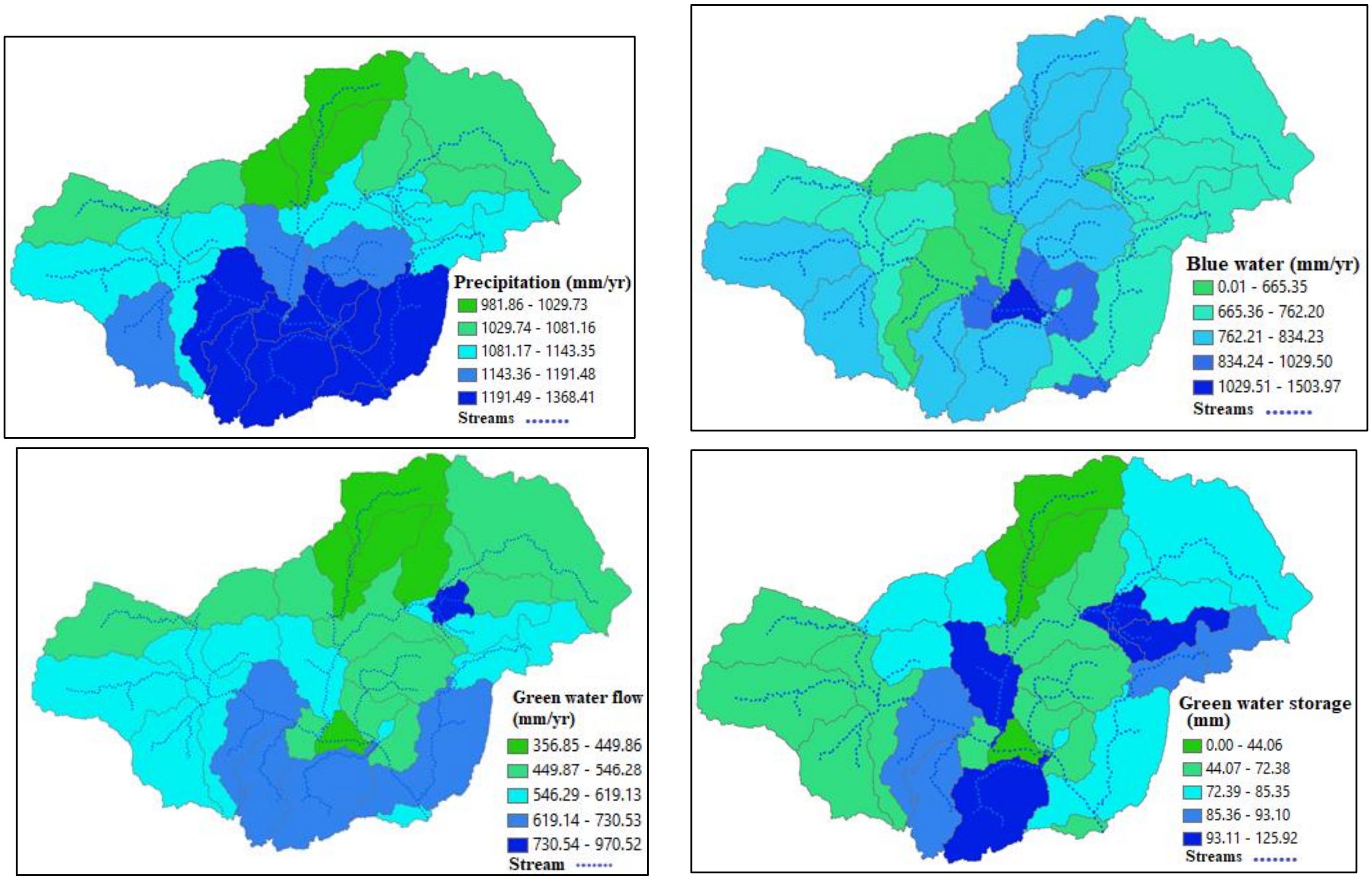


Figure 7: Spatial distribution of average (1986-2000) water resources (annual precipitation, blue water and green water flow; and average green water storage) over NCHA

The orientation of green water flow is closely related to that of precipitation, with an annual decrease in SE-NW direction, except that the highest green water flow is towards the upstream areas around Shiroro dam. However, more sub-basins have sufficient green water flow towards the zone with more forest (Rain Forest agro-ecological) downstream. Earlier studies have shown that the quantity of water flow depends on land use type and the areas with forests are noted for more flows [13]. Unlike the blue and green water flows, the green water storage distribution seems not to follow a particular pattern. There is the availability of water storage in some hydrological regions downstream, midstream and towards upstream. It is worth noting however that the regions that experienced the least amount of rainfall have the lowest green water storage. As earlier mentioned, this indicates the role of watershed characteristics, soil texture and properties in the water storage availability of a region. Considering the importance of rainfall and green water storage in rain-fed agriculture, which is the main occupation of a large percentage of the dwellers of the study area, the southwestern parts of Zungeru down to the southwestern part of Lokoja will be more viable.

The water resource components were aggregated at administrative area levels to have a clear picture of the available quantity in each area. The average annual blue and green water flow and average monthly green water storage for some of the areas are presented in Figures 8a and 8b respectively. The highest blue water flow (1091 mm/year) was found at Edati which is situated downstream. On a general note, blue water flow is higher downstream and its highest value is within the area which recorded the highest rainfall. A similar finding has been reported elsewhere [14]. The highest green water flow (709 mm/year) was at Ilorin East while the lowest (395 mm/year) was at Gusau. Kachia has the highest (103 mm/month) water storage while Mariga has the least (34 mm). This showed some of the areas within NCHA would likely be better for agricultural activities than others as the variable studied play a significant role in crop performance.

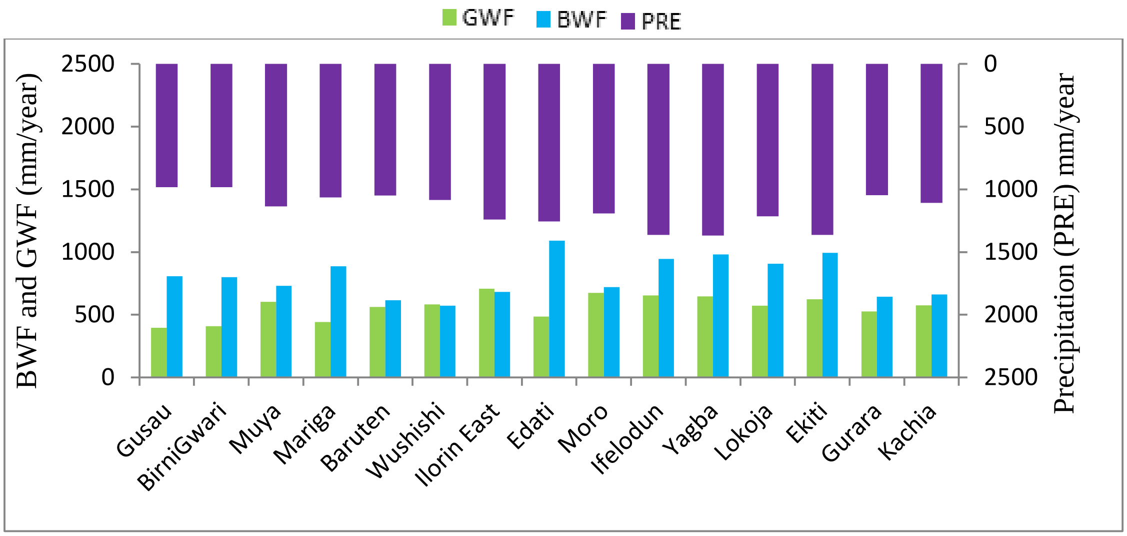


Figure 8(a). Average (1986-2000) annual blue water (internal renewable water resources), green water flow (ET) and precipitation of selected administrative area

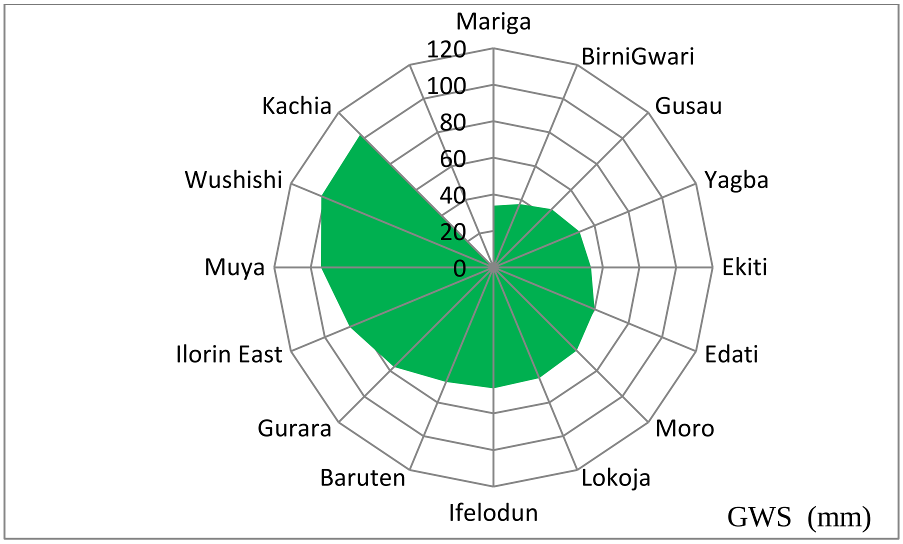


Figure 8(b). Average monthly soil moisture (1986-2000) of selected administrative areas

CONCLUSION

Using the semi-distributed hydrologic model which allows for the integration of hydrological, climate and agricultural processes, this study estimates the water resources availability for NCHA. The SWAT model was successfully calibrated and validated against observed streamflow data taking large dam operations into consideration. Parameter sensitivity and uncertainty analyses were executed to improve the reliability of the model outputs. The calibrated model was used to quantify internal renewable blue water (water yield), green water flow (actual evapotranspiration) and green water storage (soil water) at sub-basins. The water components were then aggregated at the levels of sub-basins, administrative areas and the whole watershed. The probable distribution of the water resource components across the watershed was established. The available freshwater differs from sub-basin to sub-basins and area to area which suggests that quantifying water availability for the whole area as same is error-prone. Bluewater is higher downstream, though some locations at the midstream and upstream have more of it than some downstream. Green water flow and green water storage vary with location; the downstream is generally richer in both than the upstream. This study shows the reliability of the SWAT model for water component prediction in data-scarce regions like Nigeria and provides useful information for further studies on strategic water resources, food security and agricultural planning in NCHA. This study is not free of limitations as the lack of data made difficult calibration of other components of the simulated data (e.g., groundwater and soil moisture). More so, lack of information on water use and artificial structures (e.g., dams), as only the prominent dams have information about the reservoir that could be used to edit the SWAT model.

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REFERENCES

1. Tirupathi, C., Shashidhar, T., Srinivasan, R. (2018) Analysis of rainfall extremes and water yield of Krishn River basin under future climate scenarios Journal of Hydrology: Regional Studies 19, 287–306
2. Schuol, J., Abbaspour, K. C., Srinivasan, R., and Yang, H. (2008) Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic Model Journal of Hydrology 352, 30– 49
3. Shiklomanov, I. A., (2000). Appraisal and Assessments of World Water Resources, Water International, 25(1), 11 –32
4. Prajnya, V.H., Tuppad, P. (2016). Study of hydrologic response of kabini basin using soil and water assessment tool (SWAT). International Journal of Eng. Sci. 6 (8), 2373–2380.
5. Merem, E. C., Twumasi, Y., Wesley, J., Isokpehi, P., Shenge, M. Fageir, S., Crisler, Romorno, C., Hines, A., Hirse, G., Ochai, S., Leggett, S. Nwagboso, E. (2017). Analyzing Water Management Issues Using GIS: The Case of Nigeria Geosciences 7(1): 20-46
6. Masih, I. (2011). Understanding hydrological variability for improved water management in the Semi-arid

Karkheh basin, Iran. Unpublished PhD thesis submitted to Delft University of Technology and of the Academic Board of the UNESCO-IHE Institute for Water Education, the Netherlands, (retrieved June 1, 2016)

7. Shiru, M.S., Shahid S. Alias, N. Chung, E. U. (2018). Trend analysis of droughts during crop growing seasons of Nigeria. Sustainability, 10(3), 871 https://doi.org/10.3390/su10030871
8. Anabaraonye, B. et al. (2019). Educating farmers and fishermen in rural areas in Nigeria on climate change mitigation and adaptation for global sustainability. International Journal of Scientific and Engineering Research, 10(4),1391-1398
9. Sood, A. Sanmugam, P. and Smakhtin, V. (2014) In book: Key concept in water resources management: a review and critical evaluation, 91-102, doi:10.4324/9781315884394
10. Mekonnen, M. M., and Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences 15:1577-1600
11. Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W., and Cramer, W. (2011). Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade. Hydrology and Earth System Sciences 15, 1641-1660
17. model Journal of Hydrology 524 (2015) 733–752
12. Falkenmark, M., Rockstrom, J. (2006). The new blue and green water paradigm: Breaking new ground for water resources planning and management. Journal of Water Resources Planning and Management, ASCE 132 (3), 129–132.
13. Zang, C. and Mao, G. (2019). A Spatial and Temporal Study of the Green and Blue Water Flow Distribution in Typical Ecosystems and its Ecosystem Services Function in an Arid Basin Water, 11, 97, 1-15; doi:10.3390/w11010097
14. Xu, Z., and Zuo, D. (2014) Simulation of blue and green water resources in the Wei River basin, China Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions Proceedings of ICWRS2014, Bologna, Italy, June 2014 (IAHS Publ. 364, 2014). 486-490 doi:10.5194/piahs-364-486-2014
15. Gyamfi, C., Ndambuki, J. M., and Salim, R. W. (2016) Application of SWAT Model to the Olifants Basin: Calibration, Validation and Uncertainty Analysis Journal of Water Resource and Protection, 8, 397-410
16. Abbaspour, K.C., Rouholahnejad, E. Vaghefi, S., Srinivasan, R., Yang, H., Kløve, B. (2015) A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT
18. Faramarzi, M., Abbaspour, K. C. Schulin, R and Yang, H. (2009) Modelling blue and green water

resources availability in Iran, Hydrological Processes 23, 486–501

19. Luo, K. and Tao, F. (2016) Dynamics of green and blue water flows and their controlling factors in Heihe River basin of northwestern China. Hydrology and Earth System Science doi:10.5194/hess-2016-241, 2016
20. Animashaun, I. M. Oguntunde, P.G., Olubanjo, O.O., Akinwumiju, A.S. (2023a) Analysis of variations and trends of temperature over Niger central hydrological area, Nigeria, 1911–2015 Physics and Chemistry of the Earth. https://doi.org/10.1016/j.pce.2023.103445
21. Oguntunde P. G., Lischeid G., Abiodun B. J. (2018). Impacts of climate variability and change on drought characteristics in the Niger River Basin, West Africa. Stochastic Environmental Research Risk Assessment, 32:1017-1034. DOI 10.1007/s00477-017-1484-y
22. Oguntunde, P. G., Abiodun, B. J., Lischeid, G. (2014). A numerical modelling study of the hydroclimatology of Niger River Basin, West Africa, Hydrological Sciences Journal, DOI: 10.1080/02626667.2014.980260
23. Ogilvie, A., Mahé, G., Ward, J., Serpantié, G., Lemoalle, J., Morand, P., Barbier, B., Diop, A. T., Caron, A., Namarra, R., Kaczan, D., Lukasiewicz, A., Paturel, J., Liénou, G., Clanet, J. C. (2010). Water, agriculture and poverty in the Niger River basin, Water International, 35:5, 594-622, DOI: 10.1080/02508060.2010.515545
24. Animashaun, I. M., Oguntunde, P. G., Akinwumiju, A. S., and Olubanjo, O. O. (2020): Rainfall Analysis over Niger Central Hydrological Area, Nigeria: Variability, Trend and Change-point detection, Scientific African https://doi.org/10.1016/j.sciaf.2020.e00419
25. JICA, (2011). The Project for Review and Update of Nigeria National Water Resources Master Plan Inception Report
26. Otache, M. Y., Tyabo, M. A., Animashaun, I. M., Ezekiel, L. P. (2016). Application of Parametric-Based Framework for Regionalisation of Flow Duration Curves. Journal of Geoscience and Environment Protection, 4, 89-99
27. Baker, T. J., and Miller, S. N. (2013) Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. Journal of Hydrology 486 (2013) 100–111
28. Liu J., Williams J.R., Wang X., Yang H. (2009). Using MODAWEC to generate daily weather data for the EPIC model. Environmental
29. Modelling and Software 24 (5): 655-664.
30. Harris I., Jones P. D, Osborn T. J, and Lister D. H. (2014). Updated high-resolution grids of monthly climatic

observations–the CRU TS3.10 Dataset. International Journal of Climatology 34(3):623–642

31. Chien, H., Yeh, P. J.-F, Knouft, J. H. (2013), Modeling the potential impacts of climate change on streamflow in agricultural watersheds of the Midwestern United States Journal of Hydrology 491 (2013) 73–88
32. Animashaun, I. M. Oguntunde, P.G., Olubanjo, O.O., Akinwumiju, A.S. (2023) Assessment of climate change impacts on the hydrological response of a watershed in the savanna region of sub-Saharan Africa Theoretical and Applied Climatology https://doi.org/10.1007/s00704-023-04372-w
33. Bardossy, A., Singh, S. K. (2008). Robust estimation of hydrological model parameters, Hydrology and Earth System Sciences 12 (6), 1273–1283.
34. Abbaspour K. C. Vaghefi, S. A., Srinivasan, R. (2018) A guideline for successful Calibration and Uncertainty Analysis for Soil and Water Assessment: A Review of Paper from the 2016 International SWAT Conference Water 2018, 10 (6) 4-18 doi: 10.3390/w10010006
35. Sayyad, G.**.,** Vasel, L., Besalatpour, A. S., Gharabaghi**,** B., and Golmohammadi, G. (2015) Modeling Blue and Green Water Resources Availability in an Iranian Data Scarce Watershed Using SWAT. Journal of Water Management Modeling C391. doi:10.14796/JWMM.C391
36. Awotwi A., Kumi M, Jansson PE, Yeboah F, Nti I. K. (2015). Predicting Hydrological Response To Climate Change in the White Volta Catchment, West Africa. Journal of Earth Science and Climate Change 6: 249. doi:10.4172/2157-7617.1000249
37. Oloruntade, Ajayi Johnson (2017) Modelling the impacts of climate change on hydrology and water resources in the Niger-South sub-catchment of the Niger River Basin, Nigeria, Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in fulfillment of the Requirements for the Degree of Doctor of Philosophy
38. bbaspour, K. C. (2007), User manual for SWAT-CUP, SWAT calibration and uncertainty analysis programs, 93 pp., Eawag: Swiss Federal Institute of Aquatic Science and Technology, Du¨bendorf, Switzerland. (Available at http:// www.eawag.ch/organisation/abteilungen/siam/software/swat/index_EN
39. Yang, J., Reichert, P. Abbaspour, K.C., Xia, J., Yang, H. (2008). Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China Journal of Hydrology (2008) 358, 1–
40. Gassman, P. W., Sadeghi, A. M, and Srinivasan, R. (2014). Applications of the SWAT Model Special Section: Overview and Insights Journal of Environmental Quality. 43:1–8

41. Moriasi, D.N., Arnold, J.G., van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Transactions- American Society of Agricultural Engineers. 50, 885–900
42. Grijsen, J.G., Brown, C., Tarhule, A., Ghile, Y.B., Taner, Ü., Talbi-Jordan, A., Doffou, H.N., Guero, A.D., Dessouassi, A.Y., Kone, S. and Coulibaly, B. (2013). Climate Risk Assessment for Water Resources Development in the Niger River Basin Part I: Context and Climate Projections http://dx.doi.org/10.5772/56707
43. Korres W. Koyama, C. N., Fiener, P., and Schneider, K. (2009) Analysis of surface soil moisture patterns in agricultural landscape using empirical orthogonal functions. Hydrology and Earth System Science Discussion 6, 5565-5601
44. Gwak, Y. and Kim, S. (2016) Factors affecting soil moisture spatial variability for humid forest hillslope Hydrological processes/ volume 1-15, https://doi.org/10.1002.hyp.11039
45. Hao F.H., Chen L.Q., Liu C.M. & Dai D. (2004). Impact of land use change on runoff and sediment yield. Journal of Soil and Water Conservation 18(3), 5-8.
46. Leduc, C., Favreau, G., and Schroeter, P. (2001). Long-term rise in a Sahelian water-table: the continental terminal in south-west Niger. Journal of Hydrology, 243 (1), 43–54.