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ESTIMATION OF WATER STRESS IN GUINEA AND SUDANO-SAHELIAN ECOLOGICAL ZONES OF NIGERIA UNDER CLIMATE CHANGE AND POPULATION GROWTH

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ABSTRACT

Climate change and population growth are seen to be the major factors that will shape the pattern of per capita water up to the end of 21st century. The study aimed to project water stress condition in Guinea and Sudano-Sahelian ecological zones of Nigeria under the impacts of climate change and population growth. Firstly, annual water yield was generated using KNMI climate explorer for (2019-2048), (2049-2078) and (2079-2100) under three CO2 emission trajectories. Secondly, population was projected using the Nigeria's average growth rate of 2.6%. Thirdly, the per capita water was analysed based on water stress index. Mann-Kendal statistical test was used to analyses trends in water stress at 0.05 significant levels. Result demonstrated that the Guinea and Sudano-Sahelian ecological zones of Nigeria will experience significant positive trend in water stress with respect to climate change impact for mid and long-term periods whereas no significant trend under the short-term projection. However, regional trend analysis under the influence of population growth at constant climate observed that there were significant positive trends in water stress for the three projected periods. More so, the same positive trends were obtained under the combined impacts of climate change and population growth in Guinea and Sudano-Sahelian ecological zones of Nigeria. This implies that future water scarcity is imminent and will primarily cause by population growth and secondarily by climate change in the area. The results can act as guidelines for strategic planning for adaptive and mitigation measures to water stress as envisaged by the projection.

Contribution/Originality: This study is one of very few studies which have investigated regional impacts of climate change and population growth on water stress in Guinea and Sudano-Sahelian ecological zones of Nigeria.

1. INTRODUCTION

Water resources are sources of water that are useful or potentially useful to humans [1]. This includes groundwater, rivers, streams, lakes, reservoirs, basins and runoffs. It is important because it is needed for life to exist. Many uses of water include agricultural, industrial, domestic, recreational and environmental activities. Virtually all of these human uses require fresh water. Felix, et al. [2] asserted that sustainable management of water resources is a function of hydrologic cycle; of which water resources and the hydrologic cycle have very important link with climate change. Umesh and Pouyan [3] stated that effect of climate change on water resources is because of the water and water quality changes that are caused by climate factors (mainly includes rainfall and temperature changes).

The twin issues of climate change and water resources management have received global, regional and local attention. It is widely regarded as the most essential of natural resources; yet freshwater systems are directly threatened by human activities and stand to be further affected by anthropogenic climate change [4]. The imperative of the forgoing has been highlighted by their inclusion in Sustainable Development Goals (SDGs) which is a road map between years (2016-2030). Sustainable development itself is an approach that uses the earth's resources in such a way that future generations' needs are not compromised. In other words, sustainable development seeks a balance among economic growth, social well-being and environmental protection. Mohamed [5] posited that the 2030 agenda for sustainable development is an ambitious agenda framed around 17 Sustainable Development Goals (SDGs).

Nigeria's surface water resources is estimated at to be about 267 billion m^3/annum while its groundwater resource is estimated at about 52 billion $m^3$of groundwater potential. Statistics on the actual amount of groundwater utilization is, however, not available. What is most commonly known is that groundwater resources (which come in the form of boreholes and hand dug wells) have become the most important sources of public and private water in urban and rural areas which attract wide and minimally regulated exploitation [6]. Despite the huge water resources, water resources development has not been able to keep pace with the phenomenal population growth [7]. With rising population, water resources represent a major prerequisite and driver of socio-economic development. Economic sectors that water caters for include domestic, agriculture and fisheries, industry, recreation, municipality including waste/effluent disposal, and water transportation. It also plays a prominent role in power and energy generation: hydroelectric power generation's share of total power production has decreased from over 70 % in 2004 to the present proportion of about 40% [8]. Yet, at the same time, population and economic growth have led to ever more demands on the resources. The quantity and quality of Nigeria's water resources are affected by the coupling of the human factors and climate change. The spatial distribution of rainfall, climate pattern and hyrdogeological units from the coastal areas to the Sahel regions of Nigeria provide a framework for the identification of the threats in terms of quantity and quality.

Guinea and Sudano-Sahelian ecological zones of Nigeria covered about 79% of the entire landmass of Nigeria. It is inhabited by over 50% of the country's 167 million people [9] sparsely distributed across 79% of the country's total landmass. It is home to over two-third of the Nigeria's 250 ethnic groups [10]. However, the water resources in this area have been threatened by the persistent impact of climate change [11]. This is noticeable from the occurrence of drought to the continuous decrease in the quality and quantity of water due to reduced river flows and reservoir storage, lowering of water tables, drying up of aquifers and wetlands [12]. Lake Chad for example has shrinked from its initial 25,000km^2 in 1960s to 1350km^2 in 2005 [10]. Streams in these zones which hitherto were perennial have now become seasonal such that water can only be found in them during the wet seasons with little or no water in dry seasons. It is with this background that the current study aimed to project water stress condition in Guinea and Sudano-Sahelian ecological zones of Nigeria under the combined impacts of climate change and population growth.

2. MATERIALS AND METHODS

The study area lies between Longitudes 3°E to 15°E of the Greenwich meridian and Latitudes 8°N to 14°N of the equator Figure 1. The area covers the Guinea and Sudano-Sahelian Ecological Zones of Nigeria. It is bordered to the north by Niger Republic, to the east by Republic of Cameroun, to the south by the tropical rainforest and to the west by Benin Republic. The two predominant air masses that influence the weather and climate of these zones are Tropical Continental (cT) air mass and Tropical Maritime air mass (mT) [13]. The former is dry and dusty which originates from Sahara Desert, while the latter is dense and moist which originates from Atlantic Ocean. The rainfall distribution shows a mean of 1120 mm but attain 1500 mm around the plateau area. The temperature shows a mean annual of 24°C to 30°C.

To assess the relative performance of the simulation data against observation data, the root mean square error (RMSE), mean absolute error (MAE) and Nash-Sutcliffe coefficient of efficiency (NSE) were computed. This are expressed mathematically in Equation 1, 2, and 3 respectively [14-16].

It is as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{n}} \tag{1}$$

$$\text{MAE} = \frac{\sum_{i=1}^{n}|(SIM_i - OBS_i)|}{n} \tag{2}$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}{\sum_{i=1}^{n}(OBS_i - \overline{OBS_i})^2} \tag{3}$$

Where

SIM and OBS refer to 'simulated or predicted data'.

n is the total number of pairs of simulated and observed data.

i is the ith value of the simulated and observed data.

$\overline{OBS}$ is the mean value of the observed data.

RMSE evaluates the average error magnitude between simulated and observed data. MAE measures the average magnitude of errors in a set of predictions but less sensitive to extreme values than RMSE. NSE was used to quantify how well the plot of observed versus simulated data fits the 1:1 line. For a perfect model, NSE is 1.

Water stress analysis was carried out in three steps. Firstly, annual water yield (annual differences between rainfall and potential evapotranspiration) was generated using a web based application of Royal Netherland Meteorological Institute Known as KNMI Climate Explorer (https://climexp.knmi.nl). Many climate change studies have been undertaken using data from this source [17-19]. It comprises of observed and simulated rainfall and evaporation data. The observed data are that of Climate Research Unit (CRU TS 4.2) and the simulated data are that of CMIP5 both found in the KNMI database. The coordinates of each of the three basins were used to derive the average annual water yield Table 1, and Figure 1. The water yield scenario projections were generated for three future periods namely near-term (2019-2048), mid-term (2049-2078) and long-term (2079-2100) using the multi-model ensemble mean of CMIP5 GCMs under three CO_2 emission trajectories (RCPs 2.6, 4.5 and 8.5) with reference to the 1959-1988 baseline condition. In the second step, population of each of the basin was projected for three future periods namely near term (2019-2048), mid-term (2049-2078) and long-term (2079-2100) using the Nigeria average population growth rate of 2.6% as declared in 2006 population census. In the third step, the information generated from step one and two above were used to analyse the per capita water in each of the three basin based on the most commonly used indicator of water stress known as the Falkenmark indicator' or 'water stress index' Table 2. It is the most commonly used measures of water stress [3, 20-22]. This method defines water scarcity in terms of the total water resources that are available to the population of an area; measuring scarcity as the amount of renewable freshwater that is available for each person each year.

Table-1. Location and size of the study area.

Ecological Zones	River Basin	Latitude (°N)	Longitude (°E)	Area (KM²)	Elevation (m a.s.l.)
Guinea	Kainji Lake Basin (KLB)	9° 51' - 10° 11'	4° 34' - 4° 36'	1,300	142
Sudan	Sokoto - Rima Basin (SRB)	10° 12' 12° 25'	3° 44' - 8° 14'	135,000	300
Sahel	Komadugu - Yobe Basin (KYB)	12° 88' - 13° 31'	7° 90' 11° 56'	84,138	294

Source: Lapidez [23]; Ahmed, et al. [24].

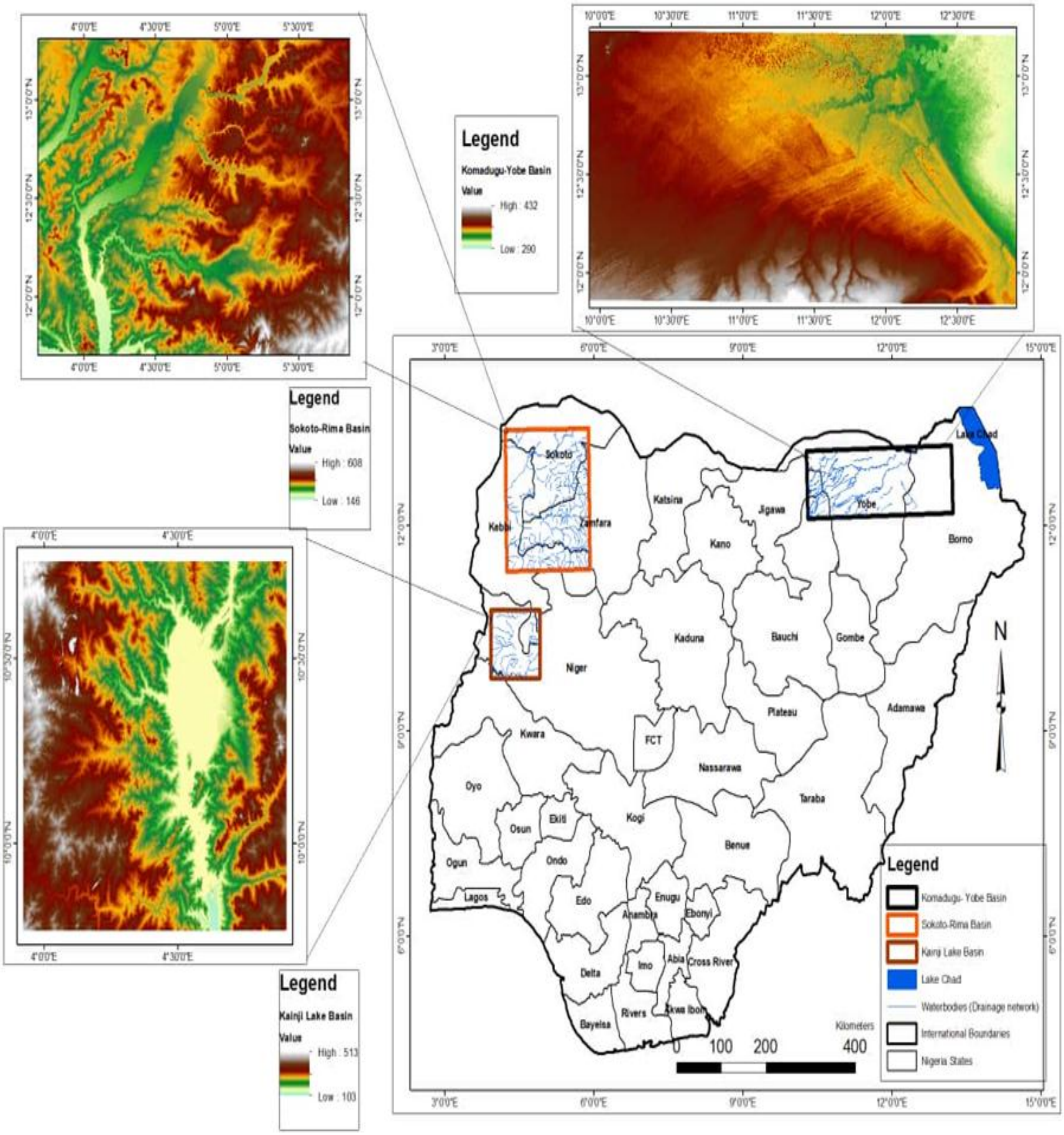

Figure-1. The study area.

This was done in three ways namely: water stress condition under climate change at constant population, water stress condition under population growth at constant climate, and water stress condition under the combined influence of climate change and population growth. This is expressed mathematically in Equation 4. It is computed as:

$$WSI = \frac{AWY \times TLA}{TP} \tag{4}$$

Where

WSI: Water Stress Index.

AWY: Annual water yield.

TLA: Total land area.

TP: Total population.

Table-2. Classification of water stress level.

WSI (CM/capita/year)	Stress Level
> 1,700	No Stress
1,000 - 1,700	Stress
500 - 1,000	Scarcity
< 500	Absolute Scarcity

Source: Falkenmark (1989) cited in Taikan and Quiocho [25].

However, population projection can be computed as follows:

$$P_T = P_O e^{k\Delta t} \tag{5}$$

Where:

P_T: Population at time T.

P_O: Population at time zero or initial population.

k : Growth rate.

Δt: Elapsed time in years from time zero.

To achieve part of objective, Mann-Kendall test [26, 27] was applied to detect the monotonic trends in projected water stress time series. The Mann-Kendall statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series [28-30]. This is expressed mathematically in Equation 6, 7 and 8, thus, calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \text{sign}\left(x_j - x_k\right) \tag{6}$$

$$\text{VAR}(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{7}$$

Where:

n = the number of data points.

t_i = the number of ties for the i value.

m = the number of tied values (a tied group is a set of sample data having the same value).

$$Z_s = \begin{Bmatrix} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 \qquad if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{Bmatrix} \tag{8}$$

A positive value of Z_s indicates increasing trends while negative $Z_s$value reflects decreasing trends, while 0 values indicate no trends. Testing trends was done at specific α significant level. When $|Z_s| > Z_{1-}{}^{\alpha}/_2$, the null hypothesis is rejected and a significant trend exists in the time series.$Z_{1-}{}^{\alpha}/_2$ is obtained from the standard normal distribution table. In this study, significance levels of α=0.05 was used. Nahlah, et al. [30] stated that at the 5% significance level, the null hypothesis of no trend is rejected if $|Z_s|$ > 1.96 and conclude that there is significant trend in the time series.

In order to assess trends at a regional scale, the regional MK test was employed as used by Mohammed, et al. [21]; Michael, et al. [31] to quantitatively combine results of the MK test for individual locations and to evaluate the regional trends. In the regional MK test, the S_r of regional data is expressed mathematically in Equation 9, 10 and 11 as follows:

$$S_r = \sum_{i=1}^{n} S_i \tag{9}$$

Where

S_r is Kendall's S for the "ith" location in a region with m locations within the region. If S_r is estimated using independent identically distributed data, $S_r$is approximately normally distributed for large m with mean equal to 0 and the variance as noted below.

$$Var(S_r) = \sum_{i=1}^{n} Var = \sigma^2 \tag{10}$$

$$Z_r = \begin{Bmatrix} \frac{S_r-1}{\sigma} for S_r > 0 \\ 0 \qquad for S_r = 0 \\ \frac{S_r+1}{\sigma} for S_r < 0 \end{Bmatrix} \tag{11}$$

To determine whether to reject or not the null hypothesis of no trend, the test statistics Z_r is assessed against the critical value Zcrit corresponding to the specific significance level α of the test. For the two-tailed test, the critical value is defined as $\Phi^{-1}(1 - \alpha/2)$, where Φ is cumulative distribution function of standard normal distribution (Helsel and Hirsch 2002; cited in Michael, et al. [31]. The null hypothesis is rejected and the trend is considered significant statistically if the value of $|Z_r| \geq$ Zcrit.

3. RESULTS AND DISCUSSION

3.1. Evaluation of Models Performance for Evaporation and Rainfall

The veracity of the CMIP5 multi-model ensemble mean simulation compared with observed rainfall and evaporation in the Guinea and Sudano-Sahelian ecological zones of Nigeria were evaluated using statistical matrices. The matrices are root mean square error (RMSE), Mean Absolute Error (MAE) and Nash-Sutcliffe Efficiency (NSE) Table 3. These statistical tests have been frequently used to quantify the significant differences between the observed and simulated hydro-meteorological time series [14, 32]. The results indicate that Sokoto – Rima Basin (SRB) has the highest error between the simulated and observed dry season evaporation given as RMSE (1.55) and MAE (1.45) while Kainji Lake Basin (KLB) has the least error given as RMSE (1.14) and MAE (1.05).

Table-3. Evaluation matrices between observed and simulated evaporation and rainfall.

	Kainji Lake Basin (KLB)			Sokoto-Rima Basin (SRB)			Komadugu-Yobe Basin (KYB)		
Evaporation	**RMSE**	**MAE**	**NSE**	**RMSE**	**MAE**	**NSE**	**RMSE**	**MAE**	**NSE**
Seasonal Dry	1.14	1.05	0.94	1.55	1.45	0.86	1.14	1.10	0.89
Seasonal Wet	0.60	0.55	0.98	0.57	0.55	0.98	0.65	0.55	0.98
Annual	0.86	0.70	0.97	0.72	0.60	0.98	0.72	0.60	0.98
Rainfall									
Seasonal Dry	0.32	0.30	0.99	0.17	0.16	0.99	0.13	0.12	1.0
Seasonal Wet	1.29	1.05	0.94	0.78	0.60	0.98	0.96	0.95	0.96
Annual	0.49	0.35	0.99	0.50	0.40	0.98	0.50	0.50	0.98

As for NSE, KLB has the highest value (0.94) followed by Komadugu – Yobe Basin (KYB) (0.89) and then SRB (0.86). This implies that the CMIP5 multi-model ensemble mean is better able to reproduce the dry season evaporation in KLB than in the KYB and SRB. Wet season evaporation in KYB has the highest error between the simulated and observed given as RMSE (0.65) and MAE (0.55) while SRB has the least error given as RMSE (0.57) and MAE (0.55). As for NSE, all the three basins have the same value given as (0.98). This implies that the CMIP5 multi-model ensemble mean reproduce the same wet season evaporation across the three basins. There is also variation in the ability of the CMIP5 multi-model ensemble mean to reproduce the annual evaporation across the three basins. KLB has the highest error between the simulated and observed annual evaporation given as RMSE (0.86) and MAE (0.70) while KYB and SRB have the same least error given as RMSE (0.72) and MAE (0.60). As for NSE, KYB and SRB have the same value (0.98) and the least is KLB (0.97). This entails that the CMIP5 multi-model ensemble mean is better able to reproduce the annual evaporation in KYB and SRB compared to KLB.

Dry season rainfall in KLB has the highest error between the simulated and observed given as RMSE (0.32) and MAE (0.30) while KYB has the least error given as RMSE (0.13) and MAE (0.12). As for NSE, KYB has the highest value (1.0) denoting perfect replication of dry season rainfall in the basin. KLB and SRB have the least NSE value (0.99). This confirms that the CMIP5 multi-model ensemble mean is better able to reproduce the dry season rainfall in KYB than in KLB and SRB. Furthermore, wet season rainfall across these basins reveal that KLB has the highest error between the simulated and observed given as RMSE (1.29) and MAE (1.05) while SRB has the least error given as RMSE (0.78) and MAE (0.60). As for NSE, SRB has the highest value (0.98) followed by KYB (0.96). This implies that the CMIP5 multi-model ensemble mean is better able to reproduce the wet season rainfall in SRB than in the KYB and KLB. Moreso, there is variation in the ability of the CMIP5 multi-model ensemble mean to reproduce the annual rainfall across the three basins. SRB and KYB have the highest error between the simulated and observed as obtainable fromRMSE (0.50) and MAE (0.40) while KLB has the least error given as RMSE (0.49) and MAE (0.35). This means that the CMIP5 multi-model ensemble mean is better able to reprecate the annual rainfall in KLB than in KYB and SRB.

On a general note, despite the variations in the ability of the CMIP5 multi-model ensemble mean to reproduce dry and wet season temperatures and rainfall across the three basins, the errors between the observed and simulated are within the acceptable threshold. The error mergins for temperature (0.57 - 1.55) and rainfall (0.13 - 1.29) are in tandem with (1.78 - 2.10) reported by Vera and Díaz [33] for South America and also consistent with those found in most regions of the world Kumar, et al. [34]. NSE of (0.8) threshold is in the range of 'very good values' as recommended by Moriasi *et al.* (2007) cited in Miguel, et al. [35] for general performance ratings. Thus, we can conclude that these CMIP5 multi-model ensemble mean is good at simulating the rainfall and temperature in Guinea and Sudano-Sahelian ecological zones of Nigeria.

3.2. Water Stress under Climate Change with Constant Population

Climate change and population growth are seen to be the major factors that will shape the pattern of per capita water up to the end of 21 century. The projected changes under climate change at constant population growth over KLB, SRB and KYB are shown in Table 4.

Table-4. Water stress under climate change with constant population in KLB, SRB and KYB.

Basin	Year	Population (Millions)	TWA (MCM/year)	Per Capita WA(CM/year)	Falkenmark Index		
					Rcp2.6	Rcp4.5	Rcp8.5
KLB	1991-2005	172,835	13700	79266	No Stress	No Stress	No Stress
	2006-2018	172,835	12,250	70876	No Stress	No Stress	No Stress
	2019-2048	172,835	11,500	66537	No Stress	No Stress	No Stress
	2049-2078	172,835	10,850	62776	No Stress	No Stress	No Stress
	2079-2100	172,835	9,610	55602	No Stress	No Stress	No Stress
SRB	1991-2005	16,100,000	1,789	111	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2006-2018	16,100,000	1,336	82	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2019-2048	16,100,000	1,092	67	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2049-2078	16,100,000	823	51	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2079-2100	16,100,000	693	43	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
KYB	1991-2005	18,400,000	4,182	227	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2006-2018	18,400,000	3,845	208	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2019-2048	18,400,000	3,328	180	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2049-2078	18,400,000	3,164	171	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2079-2100	18,400,000	2,852	155	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity

Note: Total Water Availability (TWA), Per Capita Water Availability (PCWA), Million Cubic Metre (MCM).

The per capita water across KLB, SRB and KYB collectively referred to as Guinea and Sudano-Sahelian ecological zones of Nigeria reveals a space and time differentials. Based on 2006 population census, which stand at 172.8 thousand for KLB, the total available water was 13.7 BCM/year and the per capita water was 79,266 CM/year which reveals that there was no water stress with respect to the three CO_2 emission pathways namely RCP2.6, RCP4.5 and RCP8.5. Conversely, SRB population under the same period stood at 16.1 million with total available water of 1.8 BCM/year and the per capita water of 111 CM/year. The emission trajectories for lower scenario as well as highest scenario indicate that there is absolute scarcity of water in this basin Table 4. As for the KYB, it had a population of 18.4 million under the same time with total water availability of 4.2 BCM/year and per capita water of 227 CM/year. At 2018, the population projection based on 2006 census of 2.6% growth rate, the total population of KLB was 212.3 thousand with total water availability was 12.25 BCM/year and per capita water was 70876 CM/year which means there was no water stress in the basin. However, the situation at SRB during the same time shows a total water availability of 1.34 BCM and per capita water of 88CM/year which is far below the minimum per capita water of 500 CM/year and indicate that the basin is in condition of absolute scarcity. Similarly, the condition over KYB at the same period confirms that total water availability stood at 3.8 BCM/year and per capita water of 208 CM/year. This also indicates condition of absolute scarcity in KYB but the magnitude is less compare to condition over SRB.

By near-term (2019-2048) at constant population, projected total available water will be 11.5 BCM/year and per capita water will be 66,537 CM/year over the KLB which indicate absence of water stress under the three CO_2 emission scenarios. The condition changes over the SRB with total water availability of 1.1 BCM/year and per capita water of 67CM/year. All the three RCPs show condition of absolute scarcity over the SRB. At KYB, the total available water will stand at 3.4 BCM/year and per capita water will be 180 CM/year. This also indicates absolute scarcity of water in this basin under the lower and highest emission trajectories. During mid-term projection (2049-2078), KLB total water availability will decrease to 10.85 BCM/year and per capita water is put at 62,776 CM/year. The CO_2 emission under the three RCPs indicates that there will be no water stress over this basin Table 4. However, the situation over SRB during the same period put total available water at 823MCM/year and per capita water at 51 CM/year. Also, the emission trajectories of the three RCPs reveal that absolute scarcity of water will prevail over this basin.

Table-5. Mann–Kendall trend analysis of projected water stress for KLB, SRB and KYB.

Climatic Period	Water Stress											
	Climate Change			Population Growth			Combined Impacts			Regional Trend		
RCP8.5												
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	1.96*	1.30	2.48*	2.35*	1.82	2.39*	2.31*	1.93*	0.36	2.86*
2049-2078	1.06	2.31*	2.67*	0.89	2.39*	1.94*	0.19	2.63*	2.53*	2.05*	2.75*	2.31*
2079-2100	0.82	2.61*	1.98*	0.56	2.05*	2.64*	0.33	2.24*	2.51*	2.48*	2.33*	2.38*
RCP4.5												
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	2.36*	1.30	1.98*	2.35*	1.82	2.39*	2.31*	1.97*	2.36	2.86*
2049-2078	1.06	2.31*	1.97*	0.89	2.39*	2.74*	0.19	2.63*	2.53*	2.05*	1.95*	2.31*
2079-2100	0.82	2.61*	2.08*	1.56	2.05*	2.64*	0.33	2.24*	2.51*	1.94*	2.33*	2.38*
RCP2.6												
	KLB	SRB	KYB	KLB	SRB	KYB	KLB	SRB	KYB	CC	PG	CI
2019-2048	0.67	2.62*	2.36*	1.30	1.98*	2.35*	1.82	2.39*	2.31*	1.93*	0.36	2.86*
2049-2078	1.06	2.31*	2.67*	0.89	2.39*	1.94*	0.19	2.63*	2.53*	2.05*	2.75*	2.31*
2079-2100	0.82	2.61*	2.88*	2.56	2.05*	2.64*	0.33	2.24*	2.51*	1.92*	2.33*	2.38*

Note: *= Statistically significant trends at the 0.05 significance level.

More so, the situation over KYB is not much different from that obtainable over SRB just that the magnitude is less with total available water of 3.2 BCM/year and per capita water stand at 171 CM/year. Just like over SRB, the lower and higher emission scenarios indicate absolute water scarcity in KYB. From the forgoing it is evident that climate change will amplify water stress condition due mainly from decreasing rainfall with corresponding increasing temperature. This is in agreement with Lapidez [23] that projected for the future three periods (2006–2030, 2031–2055, and 2056–2080) an increase in water deficiency in all seasons for parts of the Philippines due to a projected increase in temperature and decrease in precipitation. That the decrease in water availability will increase water stress in the basin, further threatening water security for different sectors. Pervez and Henebry [28] in Bangladesh, Ahmed, et al. [24] in Morroco, Bozkurt, et al. [36] in Chile, Didovets, et al. [37] in China.

Long-term projection (2079-2100) of per capita water over KLB reveals that total water availability of 9.6 BCM/year and per capita water stand at 55, 60 CM/year. The condition with respect to RCP2.6, RCP4.5 and RCP8.5 indicate no water stress. SRB condition under this time period projected total water availability of 693 MCM/year and per capita water of 43 CM/year with all the three CO_2 emission pathways portraying water condition of the basin to be under absolute scarcity. Furthermore, projected water condition over KYB at this time period shows that total available water will be 2.9 BCM/year and per capita water of 155 CM/year Table 4. Representative concentration pathways of 2.6, 4.5 and 8.5 indicate absolute water scarcity. In addition, per capita water availability over KLB, SRB and KYB during the short, mid and long-term projections was subjected to Mann-Kendal trend analysis tested at 0.05 significant levels. Trend analysis at individual basin confirms that at KLB there is no positive trend in water stress but at SRB and KYB there is significant positive trend in water stress for all three RCPs and the projection periods. This will no doubt affect the domestic water usage and agricultural potentials which predominantly is the major occupation of people within these basins. Regional trend of all the three basins as a whole, indicate that absolute water scarcity is alarming in the entire Guinea and Sudano-Sahelian ecological zones of Nigeria with respect to all the three emission scenarios as well as across the projection time periods. These upward trends were tested at 0.05 significant levels were all found to be significant Table 5. This is in tandem with Gebre and Ludwig [38] that reported around 2010, the southern and eastern rims of Mediterranean basin were experiencing high to severe water stress. By the 2050 horizon, this stress could increase over the whole Mediterranean basin, notably because of a 30–50% decline in freshwater resources as a result of climate change. In addition, under a business-as-usual water-use scenario, total water withdrawals were projected to double on the southern and eastern rims. That the worrying trend indicate the need to develop mitigation scenarios. Similarly, Pengpeng, et al. [39] stated that in China, estimates of 368 million people (nearly one third of the total population) were affected by severe water stress annually during the historical period (1979-2008), while future projections indicate that more than 600 million people (43% of the total) might be affected by severe water stress, and half of China's land area would be exposed to stress. Besides, aggravating water stress conditions could be partly attributed to the elevated future water withdrawals.

3.3. Water Stress under Population Growth with Constant Climate

Table 6 shows projected changes in per capita water under population growth at constant climate over KLB, SRB and KYB in Guinea and Sudano-Sahelian ecological zones of Nigeria. At KLB during the 2005, the population was 172,835 thousand with total water availability of 13.7 BCM/year and per capita water of 79,266 CM/year. This means there was no water stress in this basin based on the Falkenmark index which indicates minimum per capita water of 500 CM/year. This means there was no water stress in this basin based on the Falkenmark index which indicates minimum per capita water of 500 CM/year. However, the situation over SRB during this period shows that the population was 16.1 million with total water availability of 1.8 BCM/year and per capita water of 111 CM/year. The per capita water according to Falkenmark index indicates that the basin was in absolute scarcity. Similar situation is obtainable over KYB though, with less magnitude. The population stood at 18.4 million with total available water of 4.2 BCM/year and per capita water of 227 CM/year. By2018 based on projected population, water stress has already intensified in Guinea and Sudano-Sahelian ecological zones of Nigeria as represented by KLB, SRB and KYB. The population was projected to be 212.2 thousand, 21.9.

Table-6. Water stress under population growth with constant climate in KLB, SRB and KYB.

Basin	Year	Population (Millions)	TWA (MCM/year)	Per Capita WA(CM/year)	Falkenmark Index
KLB	1991-2005	172,835	13,700	79266	No Stress
	2006-2018	212,231	13,700	70677	No Stress
	2019-2048	446,768	13,700	33574	No Stress
	2049-2078	940,492	13,700	15949	No Stress
	2079-2100	1,571,456	13,700	9545	No Stress
SRB	1991-2005	16,100,000	1,789	111	Absolute Scarcity
	2006-2018	21,907,569	1,789	82	Absolute Scarcity
	2019-2048	46,117,701	1,789	39	Absolute Scarcity
	2049-2078	97,082,535	1,789	18	Absolute Scarcity
	2079-2100	162,213,996	1,789	11	Absolute Scarcity
KYB	1991-2005	18,400,000	4,182	227	Absolute Scarcity
	2006-2018	25,037,222	4,182	167	Absolute Scarcity
	2019-2048	52,705,944	4,182	79	Absolute Scarcity
	2049-2078	110,951,469	4,182	38	Absolute Scarcity
	2079-2100	185, 387, 424	4,182	23	Absolute Scarcity

Note: Total Water Availability (TWA), Per Capita Water Availability (PCWA), Million Cubic Metre (MCM).

Million, and 25.1 million for KLB, SRB and KYB respectively. While per capita water for KLB stand at 70,677 CM/year, for SRB is 82 CM/year and KYB is 167 CM/year. This is an indication that water stress is imminent over SRB and KYB but no stress over KLB. For near term projection (2019-2048), population is projected to be 446.7 thousand over KLB with per capita water of 33,574 CM/year indicating no stress. While over SRB, population will be 46.2 million with per capita water of 39 CM/year indicating absolute scarcity. Estimation over KYB reveals population of 52.8 million with per capita water of 79 CM/year portraying the basin to be under absolute scarcity condition Table 6. This means that underground water will be highly exploited to augment the shortages from the surface water. Gneneyougo, et al. [40] reported similar situation in the Bandama Basin, Côte D'ivoire.

By mid-term projection (2049-2078), population of KLB will be 940.5 thousand with per capita water of 15,949 CM/year indicating no water stress. SRB population stands at 97.1 million with per capita water of 18 CM/year, while KYB population will be 111.0 million with per capita water of 38 CM/year. Still at KLB there is no water stress but the situation over SRB and KYB will be absolute water scarcity with a little variation. During the long-term projection (2079-2100), it is estimated that population over KLB will be 1.6 million with per capita water of 9,545 CM/year. While SRB will have population of 162.3 million with per capita water of 11 CM/year. As for KYB, population will be 185.4 million with per capita water of 23 CM/year. These figures are indications that Guinea and Sudano-Sahelian ecological zones already stressed water condition will intensified toward the end of the century. This is in agreement with Coffel, et al. [41] that regional water scarcity will continue to be a chronic issue for the Upper Nile from population growth alone, but runoff deficits during future hot and dry years will amplify this effect, leaving an additional 5-15% of the future population facing water scarcity. That adaptation and climate resilient water management policies informed by an understanding of compound extremes will be essential to manage these risks.

3.4. Water Stress under Climate Change and Population Growth

Per capita water under the combined influence of climate change and population growth is projected for near, mid and long-term period Table 7. The 2018 projected population based on 2.6% growth rate reveals that, KLB stood at 212.3 thousand with total water availability of 12.2 BCM/year under the impact of climate change gives a corresponding per capita water of 57,720 CM/year. This value according to Falkinmark index indicates that the basin is not in water stress condition at this time. However, the situation over SRB shows population of 22.0 million and total water available under climate change to be 1.4 BCM. The per capita water stood at 60 CM/year, an indication that the basin is under absolute scarcity of water condition. Similar condition is obtainable over KYB with population of 25.1 million and total available water of 3.9 BCM/year give per capita water of 154 CM/year. This is also less than the minimum of 500CM/year.

By near-term projection (2019-2048), water stress condition would have deteriorated especially over SRB and KYB given the existing situation at 2018 coupled by the ever increasing population growth and CO2 emission. These combined influences reveal that per capita water over KLB will be 25,740 CM/year, a condition of no water stress. SRB condition under the same influence stands at per capita water of 24 CM/year. This positive trend of water stress is significant at 0.05 significant levels for all the three RCPs. While KYB will have a per capita water of 79 CM/year with also significant positive trend of water stress with respect to lower and highest emission pathways. At mid-term projection (2049-2078) per capita water over KLB decreases to 11,536 CM/year but still not under water stress condition. Trend analysis of water stress at 0.05 significant levels indicates no significant positive trend for RCP2.6, RCP4.5 andRCP8.5 CO_2 emissions Table 5. But at SRB, per capita water decreases to 8 CM/year. A condition of absolute water scarcity and found to be significant at 0.05 significant levels with respect to the three emission scenarios. In KYB per capita water will decreases to 29 CM/year though higher than in SRB. The trend analysis shows that the positive trend of water stress is still significant at 0.05 levels for all the three emission trajectories.

Table-7. Water Stress under Combined Impacts in KLB, SRB and KYB.

Basin	Year	Population (Millions)	TWA (MCM/year)	Per Capita WA(CM/year)	Falkenmark Index		
					Rcp2.6	Rcp4.5	Rcp8.5
KLB	1991-2005	172,835	13700	79266	No Stress	No Stress	No Stress
	2006-2018	212,231	12,250	57720	No Stress	No Stress	No Stress
	2019-2048	446,768	11,500	25740	No Stress	No Stress	No Stress
	2049-2078	940,492	10,850	11536	No Stress	No Stress	No Stress
	2079-2100	1,571,456	9,610	6115	No Stress	No Stress	No Stress
SRB	1991-2005	16,100,000	1,789	111	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2006-2018	21,907,569	1,336	60	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2019-2048	46,117,701	1,092	24	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2049-2078	97,082,535	823	8	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2079-2100	162,213,996	693	4	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
KYB	1991-2005	18,400,000	4,182	227	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2006-2018	25,037,222	3,845	154	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2019-2048	52,705,944	3,328	63	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2049-2078	110,951,469	3,164	29	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity
	2079-2100	185,387,424	2,852	15	Absolute Scarcity	Absolute Scarcity	Absolute Scarcity

Note: Total Water Availability (TWA), Per Capita Water Availability (PCWA), Million Cubic Metre (MCM).

During the long-term (2079-2100), estimated per capita water of KLB would have decreases to 6,115 CM/year but no significant positive trend of water stress with regard to RCP2.6, RCP4.5 and RCP8.5. However, SRB per capita water would stand at 4 CM/year. This indeed portray a serious danger because the surface water condition of this basin at this time cannot meet the basic domestic need of the population, talk less of the agriculture water need which is highly demanded. Similar situation exist over KYB though with lesser magnitude comparable to SRB. Per capita water would be 15 CM/year in KYB. This value also indicates deficiency of the surface water to meet the domestic and agricultural water need of the people in this basin. The decline in per capita water was subjected to trend analysis at 0.05 significant levels. Analysis shows a significant positive trend in water stress condition.

The per capita water of KLB, SRB and KYB were unified as one region that is Guinea and Sudano-Sahelian ecological zones of Nigeria. Regional trend analysis shows that the entire region will experience significant upward trend in water stress with respect to climate change impact for mid and long term periods where as no significant trend under the short term projection. Trends were tested at 0.05 significant levels. However, regional trend under the influence of population growth at constant climate observed that there is significant upward trend in water stress for the three projected periods Table 6. More so, the same upward trend is obtained under the combined impacts of climate change and population growth for the short, mid and long term projection in Guinea and Sudano-Sahelian ecological zones of Nigeria. The implication of this finding is that surface water resources cannot meet the ever increasing water demand for various uses. Hence, serious exploitation of underground water. This is in agreement with Hosea, et al. [42] that confirmed similar trends in water availability in Kenya where as much as climate change impacts the recharge rate, the impact is dwarfed by the effect of demand driven chiefly by population growth. Further, effective volume of freshwater in the aquifer is expected to be exhausted, that is, be reduced to the zero level between 2022–2027 for the RCP 2.6 scenario and 2023–2028 for the RCP 8.5. Also, Kara [43] reported similar trend Turkey. Guoyong, et al. [44] reported climate change will alter the hydrological regimes of rivers in USA. This will create additional challenges for water resources which are already stressed due to extensive anthropogenic activities. Therefore, the impacts of the projected climate change have to be understood and incorporated into the regional water management strategies to ensure sustainable approach in governing the water systems.

4. CONCLUSIONS

Changes under climate change and population growth suggest that regional trend of all the three basins as a whole, indicate that absolute water scarcity is alarming in the entire Guinea and Sudano-Sahelian ecological zones of Nigeria with respect to all the three emission scenarios as well as across the projection time periods. These upward trends tested at 0.05 significant levels were all found to be significant. Conversely, under population growth at constant climate, the population was projected to be 212.2 thousand, 21.9 million, and 25.1 million for KLB, SRB and KYB respectively. While per capita water for KLB stand at 70,677 CM/year, for SRB is 82 CM/year and KYB is 167 CM/year. This is an indication that water stress is imminent over SRB and KYB but no stress over KLB. This implies that future water scarcity will by primarily caused by population growth and only secondarily by climate change in Guinea and Sudano-Sahelian ecological zones of Nigeria. The results can act as guidelines for strategic planning for adaptive and mitigation measures to water stress as envisaged by the projection. This will also forms a baseline for future research in Guinea and Sudano-Sahelian ecological zones and Nigeria in general.

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