Climatic Variability and Estimation of Supplementary Irrigation Water Needs of Selected Food Crops in the Sokoto-Rima River Basin, Nigeria

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ABSTRACT

The study investigated the effects of rainfall and temperature variability on crop water requirements of selected food crops in the Sokoto-Rima River Basin, Northwest of Nigeria. Rainfall and temperature datasets were obtained from the Climatic Research Unit (CRU) TS 3.21 of the University of East Anglia, Norwich, for a period of 70 years (1943-2012). The suitability of CRU datasets were verified by correlating the datasets with measured rainfall data of Yelwa synoptic station, from the Nigerian Meteorological Agency. Selected food crops were used for estimating supplementary irrigation water needs in the River basin. Results of Mann-Kendal, Spearman's Rho and linear regression tests showed strong evidence of increasing annual temperature and potential evapotranspiration with corresponding decrease in rainfall amounts, especially in the northern parts of the basin which houses big irrigation projects and dams such as the Goronyo Irrigation and the Bakolori Dam and Bakolori Irrigation Project. This will impact on the water availability within the basin, through reduction in surface and ground water supply for ongoing irrigation and other water resources projects. Water requirements for selected crops were modeled to ascertain crop sensitivity to climatic variability which will aid in the design of supplementary irrigation water needs models. Results showed that even in the rainfall months, supplementary irrigation of varying quantity is required to complement rainfall, most especially, in the northeast of the basin. Surprisingly, the month of May which marks commencement of rainfall, recorded the highest water need and this has implication for agriculture yields in the region.

Keywords: Climatic variability, Supplementary irrigation, Food crops, Rainfall, Temperature

1.0. Introduction

The Sokoto-Rima River Basin is located in the Sudano-Sahelian belt of Nigeria, and has a population of more than 15 million (NPC, 2006). Of this population, 75% depends on rain-fed agriculture for the sustenance of livelihood and food security according to FAO (2018). Climate variability and change has triggered research into the future of water resources and its sustainability under the current situation of climatic uncertainty. Already, it has been reported that the belt is faced with serious environmental challenges arising from aridity in response to climate change, rainfall variability and repeated drought, linked to intensified anthropogenic and natural processes (IPCC, 2007; Bello, 2010; AbdulKadir *et al.*, 2013).

Researchers have also confirmed an increasing rate of desertification in the region (Zhao *et al.*, 2005; Huang and Siegert, 2006; Susana and Kelley, 2006; Sonia *et al.*, 2007; Sivakumar, 2007; Hanafi and Jauffret, 2008). These are threats to agricultural productivity, food security and sustainability of rural livelihood in the region, where subsistent farmers are dominant. Water deficit in the region since the wake of global warming is not expected to improve in the future (Abaje *et al.*, 2011). More importantly, taking into account the population growth and the expected negative effect of climate change on rain pattern in extreme northern Nigeria, the Sokoto-Rima River basin will most likely be faced with the problem of allocating adequate water for agriculture to maintain food security. The major crops involved in food security in the Sokoto-Rima River basin are: wheat, maize, rice, millet,

beans, guinea corn, tomato, cabbage, carrot, onion. The sensitivity of these crops to climate change has been classified by Allen *et al.* (1998) as ranging from medium to high in the face of hydrological stress.

Moreover, since agriculture in the basin is essentially rain-fed, changes in climatic variables in particular rainfall and temperature will adversely affect farming operations. For example, Adelana *et al.* (2003) found that infrequent and short period of rainfall (< 60 raining days) in most part of the basin prevent the development of agriculture and restrict crop production in a year to only one planting season per year. This has led to repeated crop failures and declining yields which have led to decrease in the income of farmers and the associated problems of food shortage, malnutrition and general impoverishment of local inhabitants (Ekpoh, 1999; Mortimore and Adams, 2001).

In order to meet the food security of the teeming population of the Sokoto-Rima River Basin, who are mostly subsistent farmers, there is need for scientific quantification of the effect of climate change on crop production. Evapotranspiration, crop factor and water requirements of popularly cultivated crops in the region need to be ascertained. Management of water based on evapotranspiration in river basins has become a developing trend in arid and semi-arid areas (Qin *et al.*, 2009). Evapotranspiration is widely used in guiding agricultural irrigation schedule through the quantitative estimation of the crop water requirement in order to achieve water saving and agricultural yield increase (Dingman, 2002). Previous studies that attempted to examine impacts of climate change on agricultural production in many developing countries concentrated only on general analyses of potential impacts of climate change on crops production, food security and animal husbandry (Odjugo, 2001; Adejuwon, 2006a; Adejuwon, 2007b; Adefolalu, 2007; Jagtap, 2007; Nwafor, 2007). Not much has so far been done in quantifying the effects of climatic variability on crops and on developing supplementary irrigation schedule to guide farmers during long dry spell in rainy season in many developing countries and therefore forms the basis for this study.

2.0. Materials and Methods

2.1. Study area

The study area is located in Northwestern Nigeria and lies largely in the far North of Sudano-Sahel of West Africa in the zone of Savanna-type vegetation belt generally classified as semi-arid (Sombroek and Zonneveld, 1971). It lies between Latitudes 12° and 14° N and Longitudes 5° and 7°E. The basin is underlain by a sequence of inter-bedded semi-consolidated gravels, sands, clays and some limestone and ironstone of cretaceous to quaternary age resting on pre-Cambrian basement complex rocks which outcrop extensively to the east and south of Zamfara State as well as to the south of Kebbi State (Sombroek and Zonneveld, 1971). The Sokoto basin is a semi-arid region marked by distinct weather conditions-the wet and dry seasons. Rainfall is highly seasonal and usually starts from May or June of each year and lasts till September or early October depending on the rainfall pattern for that year. There is a marked seasonal variation in temperature and diurnal range of temperature. Daily maximum temperature of the basin is between 36°C-40°C. During the harmattan season, daily minimum temperature may fall below 18°C. Between February and April which is the peak of heat, temperature reaches the highest of 44°C. In the extreme north, the shrubby and thorny vegetation of the Sahel zone is the dominant vegetation type.

2.2. Data collection and analysis

Precipitation and temperature datasets available on high-resolution (0.5 x 0.5 degree) grids from the Climatic Research Unit (CRU) TS 3.21 of the University of East Anglia, Norwich, United Kingdom (New *et al.*, 2000; Mitchell and Jones, 2005) were used in this study and is available at <http://www.cru.uea.ac.uk/>. Data were collected for a period of 70 years for Bunza and Dakingari, Southwest of the basin, Gulma and Augi, North West, Goronyo and Galadi, North East and Maje and Dan-Dume South East for the period 1943-2012. Quality control of CRU datasets has been discussed in detail in New *et al.* (2000). In addition, the suitability of CRU datasets were verified by correlating the rainfall data from this source with measured rainfall data from Yelwa synoptic station, Nigerian Meteorological Agency, for the period 1950-2012. Only points from the CRU dataset that yielded positive relation with NIMET point-gauged data were used in the study (Tables 1 and 2).

Figure 1: Sokoto River basin

(Source: Adopted from Ita, 1993)

Table 1: Result of correlation of rainfall data from CRU data set with measured data from NIMET (Yelwa Station)

Data Point	Multiple R	R Square	Adjusted R Square	Standard Error
Bunza	0.97	0.94	0.93	14.8
Dakingari	0.96	0.92	0.91	17.2
Gulma	0.97	0.95	0.95	13.5
Augi	0.98	0.96	0.96	12.1
Goronyo	0.95	0.90	0.89	29.7
Galadi	0.96	0.92	0.92	26.1
Maje	0.97	0.95	0.94	16.7
Dan-dume	0.97	0.94	0.93	18.8

Correlation was performed on monthly basis

Table 2: Result of correlation of temperature (°C) data from CRU data set with measured data from NIMET (Yelwa Station)

Data Point	Multiple R	R Square	Adjusted R Square	Standard Error
Bunza	0.96	0.92	0.91	0.6
Dakingari	0.98	0.96	0.96	0.42
Gulma	0.93	0.87	0.85	0.83
Augi	0.92	0.86	0.85	0.8
Goronyo	0.82	0.67	0.64	1.32
Galadi	0.86	0.74	0.72	1.17
Maje	0.97	0.95	0.94	0.50
Dan-dume	0.88	0.77	0.75	1.66

Correlation was performed on monthly basis

2.3. Data analysis

Analysis of data was achieved using the excel analysis toolPak. The Thornthwaite water balance computer software version 1.10, developed by the United States Geological Survey Department was used for computing the components of water balance. The choice of this model is based on the nature of physical processes that interact to produce the phenomena under investigation (i.e. temperature rainfall relationship), availability of the required model components/data and wide applicability of the model for hydrological impact of climate change assessment. Although studies have shown, the

Penman (1948) equation is considered to be the most accurate and has widespread application (Ayoade, 1983; Anyadike, 1987), unfortunately, the model requires a lot of input data which are not readily available in most developing countries for example where net radiation data and soil heat flux. Monthly potential evapotranspiration (PET) was estimated from mean monthly temperature (T). In this study, PET was calculated using the Hamon equation (Hamon, 1961) shown in Equation 1.

$$PET_{Hamon} = 13.97 \times d \times D_2 \times W_t \quad (1)$$

where:

PET_{Hamon} PET in millimeters per month,
 d Number of days in a month,
 D_2 Mean monthly hours of daylight in units of 12 hrs, and
 W_t Saturated water vapor density term, in grams per cubic meter, calculated using Equation 2:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100} \quad (2)$$

where:

T Mean monthly temperature in degrees Celsius (Hamon, 1961)

2.4. Estimating monthly supplementary irrigation water for selected food crops

Monthly supplementary irrigation water need of selected crops was calculated by subtracting the effective rainfall from the crop water need. The crop water need is expressed in mm water layer per time unit, in this case mm/month. If the rainfall is sufficient to provide the water needs of the crops, irrigation is not required. To ascertain if monthly supplementary irrigation is required for any of the selected crops within the Sokoto-Rima River Basin, the model designed by Allen *et al.* (1998) for estimating supplementary irrigation need was used. The equation is given by:

$$IR = ET_{crop} - P_e \text{ mm month} - 1 \quad (3)$$

where:

IR Supplementary irrigation in mm;
 ET_{crop} Consumptive water need (mm); and
 P_e Effective rainfall (mm)

ET_{crop} is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally. It is determined as:

$$ET_{crop} = ET_o \times K_c \quad (4)$$

where:

ET_o Reference crop evapotranspiration (mm d^{-1}) and also represents an index of climatic demand,
 K_c Varies predominately with the specific crop characteristics and only to a limited extent with climate.

This relationship enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies (FAO, 1986). Values of ET_o were determined using the modified Thornthwaite model (McCabe and Markstrom, 2007).

The K_c is a dimensionless crop coefficient. It is the ratio of the crop ET_c to the reference ET_o , and represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These are crop height, albedo, canopy resistance and evaporation from soil, especially exposed soil (Allen *et al.*, 1994). Because of the sparseness of data on crop coefficient in

developing countries, empirical estimates are usually employed and the most common is the FAO estimates (FAO, 1986) (Table 3). The K_c values are estimated under a standard climatic condition. This condition has been defined as crops grown in large fields under non-limiting agronomic and soil water conditions (FAO, 2002).

Table 3: Estimated values of crop factor (K_c) for various crops under a standard climatic condition and growth stages

Crop	Total growing period (days)	Initial stage K_c	Crop dev. Stage K_c	Mid-season stage K_c	Late season stage K_c
Maize (grain)	125-180	0.40	0.80	1.15	0.70
Groundnut	130-140	0.45	0.75	1.05	0.70
Tomato	135-180	0.45	0.75	1.15	0.80
Cabbage	120-140	0.45	0.75	1.05	0.90
Carrot	100-150	0.45	0.75	1.05	0.90
Green Bean	75-90	0.35	0.70	1.10	0.30
Onion (dry)	150-210	0.50	0.75	1.05	0.85
Melon	120-160	0.45	0.75	1.00	0.75
Millet	105-140	0.35	0.70	1.10	0.65
Sorghum	120-130	0.35	0.75	1.10	0.65
Soybean	135-150	0.35	0.75	1.10	0.60
Cucumber	105-130	0.45	0.70	0.90	0.75
Pepper	120-210	0.35	0.70	1.05	0.90
Bean (dry)	95-110	0.35	0.70	1.10	0.30
Potato	105-145	0.45	0.75	1.15	0.85

Source: FAO Irrigation and Drainage Paper, No. 24 (1986)

To determine the monthly water requirement per crop, K_c values for that crop for various stages of growth were averaged.

2.5. Trend analysis

Trend analysis of annual rainfall and temperature distributions were determined using a Trend/change detection software (TREND) version 1.0.2 developed by the Cooperative Research Centre for Catchment Hydrology's (CRCCH) Climate Variability Program, in Australia. The scientific development and testing of the software have been carried out at University of Melbourne and Griffith University (Chiew and Siriwardena 2005). TREND is widely adopted by researchers and considered as robust in detecting trends and changes in climatic time series data (Mu *et al.*, 2007; Ma *et al.*, 2008; Zhang and Lu, 2009).

3.0. Results and Discussion

3.1. Temporal trends in rainfall in the Southwest of the Sokoto-Rima basin

Annual trend of rainfall, southwest of the Sokoto-Rima River Basin is presented in Figure 2. The first three (3) decades from mid-1940, 1950, and 1960 were generally observed to be wet decades. This rising trend was interrupted by a break at the start of 1970 before another rise above rainfall mean value of 827.3 mm in 2000. There was a continuous downward trend in rainfall from 1970. Lowest rainfall was observed in 1973 with annual rainfall of 464.6 mm. Other years of much low rains are 1982 (529.2 mm), 1987 (391.2 mm) and 1987 (568.6 mm). Highest rainfall of amount 1096.6 mm was recorded in 1957. Other years of very high rainfall amounts were 1978 and 1946 with rainfall values of 1090.6 mm and 1087.2 mm respectively. An average rainfall of 927.7 mm was recorded in wet years (36 years in which rainfall was above mean value). In the dry years' episode (34 years), rainfall amounts were below the average (721.1 mm). Figure 3 shows the annual trend of rainfall, NW of Sokoto-Rima River basin (1943-2012).

Figure 2: Annual trend of rainfall, SW of Sokoto-Rima River basin (1943-2012)

Figure 3: Annual trend of rainfall, NW of Sokoto-Rima River basin (1943-2012)

3.2. Trend of rainfall, NW of Sokoto-Rima River basin

In the Northwest of the Sokoto-Rima River basin, wettest years were seen clustered between 1950, and 1960 as well as part of mid 1940s (Figure 4). This rising trend was interrupted by breaks around the start of 1970 when rainfall predominantly decreased below a mean value of 722.3 mm. There was a continuous downward trend in rainfall from 1970 which extended into 2000 with very weak sign of recovery in 2010. This is similar to the result obtained for China (Junliang *et al.*, 2016). Lowest rain year was 1973 with rainfall amount of 384.4 mm. Other years of significantly low rains were 1982 (385.8 mm) and 1987 (385.8 mm). Maximum rainfall amount of 1044.7 mm was recorded in 1946. Other years of high rainfall amounts were 1978 and 1952 with rainfall values of 1012.6 mm and 1007.1 mm respectively. An average rainfall of 841.3 mm was recorded in wet years (34) years in which rainfall was above the mean value. In the dry years episode (36 years), rainfall amount was as low as 609.9 mm on the average. These values obtained were found to be higher than those of the upper East region of Ghana as reported in Abdul-Rahaman *et al.* (2016).

Figure 4: Annual trend of rainfall, NE of Sokoto-Rima River basin (1943-2012)

3.3. Trend of rainfall, NE of Sokoto-Rima River basin

In the Northeast of the basin, rainfall pattern varied widely as shown Figure 5. Wet rainfall episode was observed to cluster around mid-1940s, 1950s and 1960s. From 1970s, there was however, a downward trend below the mean value of 580.5 mm which continued into 2010 with an occasional few years in which rainfall was above the mean value. The lowest rainfall in the Northeast of the basin was observed in 1982 with annual rainfall of 310.6 mm. Other years of very low rains were 1973 (338.3 mm) and 1985 (353.6 mm). Highest rainfall of amount 837 mm was recorded in 1954. An average rainfall of 689.6 mm was recorded in wet years (35 years in which rainfall was above mean value of 580.5 mm). In the dry years' episodes (35 years) in which rainfall amounts were low, the average rainfall amount was 471.5 mm.

Figure 5: Annual trend of rainfall, SE of Sokoto-Rima River basin (1943-2012)

3.4. Trend of rainfall, SE of Sokoto-Rima River basin (1943-2012)

Unlike the patterns observed in some parts of the basin, there was a gradual decrease in the rainfall amount in the Southeast of the basin. The wettest years were however around 1940s, 1950s, 1960s and part of 1970s before an interruption in the start of 1980. In 1990 and 2010, there was evidence of recovery though rainfall distribution varied around mean value of 955.3 mm (Figure 5). Lowest rain year was 1983 with rainfall amount of 668.8 mm. Other years of very low rains were 1973 (734.9 mm) and 1990 (740.1 mm). Highest rainfall of amount 1307 mm was recorded in 1954. Other years of very high rainfall amounts were 1946 and 1962 with rainfall values of 1284.6 mm and 1270.6 mm respectively. An average rainfall of 1076.7 mm was recorded in wet years (34 years in which rainfall was above mean value of 955.3 mm). In the dry years episode (36 years) in which rainfall amounts were below average, the average rainfall amount was 840.7 mm.

From Figures 2-5 trends in annual rainfall distribution over Sokoto Rima River basin is best described as experiencing moderate downward trend across 1940-2012. However, for locations in the extreme north of the basin declining annual rainfall amounts seem to be more pronounced when compared to distributions in the southern part of the basin. This is expected as rainfall amount in Nigeria decreases from the coastal south (south of the moisture that produces rain) to the north due to effect of continentality. Similarly, the decrease in rainfall amount for most locations in northwest and northeast of the study area may also be due to increased distance from the zone of influence of topography and the orography as well as in accordance with the general trend in rainfall distribution in Nigeria (Oguntunde *et al.*, 2011). Declining rainfall amount is an important limiting factor for rain-fed crop production. The observed decreasing rainfall amount in the extreme northern parts of the basin will exacerbate the ongoing impacts of climate change and variability, with serious implications for sustainable socio-economic lives, including decline in agricultural activities, drought, migration, health problems, farmer-herdmen crises. Also, pests attack and development of crop diseases, withering and desiccation of crops have been linked to reducing annual rainfall amount (Thompson and Amos, 2010; Obi, 2010; Aondoakaa, 2012; Singh *et al.*, 2014). For example, Obi (2010) reported evidence of reducing pesticide sensitivity due to decreasing precipitation. His study added that pest population may increase across the northern Nigeria and threaten food production. NEMA (2010) has reported the outbreak of pests and diseases due to meteorological drought condition in part of Borno State. Pests and diseases reduce crop yield, quality and value. Since the basin houses big irrigation projects and dams such as the Goronyo Irrigation and the Bakolori Dam and Bakolori Irrigation Project, north of the basin, the observed decrease in annual rainfall trend with corresponding increase in temperature will impact on the water availability of the basin, through reduction in surface and ground water supply for ongoing irrigation and other water resources projects as a result of rapid moisture loss by evaporation and evapotranspiration.

3.5. Temperature trend in the Southwestern part of Sokoto-Rima River basin

In Figure 6, temperature varied widely around mean value of 28.7°C in the southwestern part of the Sokoto-Rima River basin. Temperature was generally below mean value from 1940 to 1970s. This was however interrupted from 1980 and most parts of 2000 and 2010 when there were more years of higher temperature value than the mean. There was a general rising trend in temperature was observed. Lowest temperature was obtained in 1961 with value of 27.7°C. Other years of very low temperature were 1971 (27.8°C), 1965 (27.9°C) and 1975 (27.9°C). Highest temperature of 29.8°C was recorded in 2009, followed by 2011 and 1973 with temperature values of 29.6°C. Northwest of the basin, there was more cluster of temperature below mean value of 28.8°C (Figure 6). Temperature was generally below mean value from 1940 to 1970s with very few years in which temperature was above the mean. From 1980 down to 2010, temperature varied remarkable around the mean line, although there was a cluster of temperature above mean line in 1980. Lowest temperature was observed in 1961 with temperature value of 27.8°C. Other years with very low temperature were 1965 (27.9°C) and 1975 (27.1°C). Highest temperature of 29.9°C was recorded in 2009, followed by 2010 with value of 29.8°C.

Figure 6: Annual trend of temperature, SW of Sokoto-Rima River basin (1943-2012)

Figure 7: Annual trend of temperature, NW of Sokoto-Rima River basin (1943-2012)

3.6. Temperature trend in the Northwest and Northeast

In Figure 8, the annual pattern of temperature in the northeastern part of the Sokoto-Rima River basin is presented. Temperature was generally above mean value of 28.3°C from mid-1940 to the 1970s. This was however interrupted from 1980 and most parts of 2000 and 2010 when there were more years in which temperature values were above the mean. A gradual rising trend in temperature was however observed. Lowest temperature was observed in 1961 with temperature value of 27°C. Other years of very low temperature were 1963 (27.01°C) and 1977 (27.5°C). Highest temperature of 29.4°C was recorded in 1943.

Figure 8: Annual trend of temperature, NE of Sokoto-Rima River basin (1943-2012)

In the Southeast of the basin, there was more cluster of temperature below the mean value of 26.2°C (Figure 8). Temperature was generally below mean value from the start of 1950 which extended into 1970. In 1980, however, temperature pattern assumed a rising pattern down to 2010. There were however few years in between, which temperature values were above the mean line. Lowest temperature was observed in 1961 with value of 25.2°C. Other years with very low temperature were 1989 (25.5°C) and 1975 (25.6°C). Highest temperature of 27.1°C was recorded in 2009, followed by 2010 with value of 27.0°C. Figure 9 shows the annual trend of temperature, SE of Sokoto-Rima River basin (1943-2012).

Figure 9: Annual trend of temperature, SE of Sokoto-Rima River basin (1943-2012)

Upward trends in the annual temperature tend to be more pronounced unlike rainfall pattern even though the values coefficients of determination ranges from 0.3-0.45. Rising temperature has been implicated as a direct consequences of global warming. If the present trends in the emission of GHGs through anthropogenic activities continues there is high probability of sharp rise in temperature with

corresponding decline in rainfall amounts in the region. The observed trends may also point to the fact that uncertainty in climatic variables is a major environmental concern in the basin as there are evidence of rainfall recovery in between extreme or near-extreme climate drought condition. Steady rise in annual temperature pattern has been linked to climate change (IPCC, 2007; Bello, 2010). Thus, the rising annual temperature trend across the basin as shown in this study is an indication of changing climate while the rapid fluctuation around mean value for some locations, south of the basin is an indication of unstable temperature condition. Both climate change and unstable climatic conditions have negative implications for social and economic development within the basin as both phenomenon have the tendency to trigger hydro-meteorological droughts. As temperature rises, crops will lose water rapidly through transpiration thereby increasing crop water need. High potential evapotranspiration (PET) is usually observed during high temperature condition (Audu *et al.*, 2013). Thus, higher value of PET, means increased moisture loss, leading to deficit water balance which is unfavourable to crops. When plant water deficit is not met on time, it causes contingent drought. Crops growing under low soil moisture, yield little and poor quality seeds. As reported by Obi (2010), while increase in temperature is expected to elongate the growing season in temperate regions, such increase within the tropics is expected to decimate agricultural output by aggravating soil evaporation rate and invariably drought. Ayoade (1983) has also observed that excessive heat destroys the plant protoplasm and also decreases the reproductive capacities of animals. Increasing temperature weakens plants and their leaves wither easily hence poor photosynthesis (Audu *et al.*, 2013). Other studies have established that rising temperature will result in reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise; reduced sugar content, bad coloration, and reduced storage stability in fruits; increase of weeds, blights, and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances (Kim, 2009). Apart from crops, animals also die in large number during prolonged drought as a result of heat stress, dehydration and attack by drought induced diseases.

3.7. Temporal trend of climatic variables over the Sokoto-Rima River basin

Table 4 shows statistical trend patterns of climatic variables over the Sokoto -Rima River basin. Rainfall in SW of the Sokoto-Rima River basin showed evidence of decreasing rainfall. Trend results of rainfall were -2.12 (Mann-Kendall), -2.19 (Spearman's Rho) and -2.18 (linear regression). Trend was detected in rainfall time series at $\alpha < 0.05$. Temperature pattern showed evidence of increasing trends for the entire basin. Results of temperature trend were 5.14 (Mann-Kendall), 4.85 (Spearman's Rho) and 6.15 (linear regression). Trend in time series of temperature distribution was detected at $\alpha < 0.01$. Potential evapotranspiration showed evidence of increasing trend with results of 5.46 (Mann-Kendall), 5.18 (Spearman's Rho) and 6.69 (linear regression) at $\alpha < 0.01$.

Northwest of the Sokoto-Rima River basin downward trend results of rainfall was -1.98 (Mann-Kendall), -1.954 (Spearman's Rho) and -2.03 (linear regression) at $\alpha < 0.05$ for all the three tests. Temperature showed evidence of increasing trend in the following order; 4.94 (Mann-Kendall), 4.65 (Spearman's Rho) and 5.71 (linear regression). Downward trend in time series of temperature distribution was detected at $\alpha < 0.01$ for all the three tests. Potential evapotranspiration showed evidence of increasing trend with trend results of 5.56 (Mann-Kendall), 5.16 (Spearman's Rho) and 6.55 (linear regression) at $\alpha < 0.01$.

Rainfall in the north-east of the Sokoto-Rima River basin presented evidence of decreasing trend as follows Mann-Kendall (-3.01), Spearman's Rho (-3.086) and linear regression (-3.56). Temperature pattern showed evidence of increasing trend with the following results; 5.74 (Mann-Kendall), 5.31 (Spearman's Rho) and 6.68 (linear regression). Potential evapotranspiration also showed evidence of increasing trend with trend results of 5.98 (Mann-Kendall), 5.64 (Spearman's Rho) and 7.59 (linear regression). Upward trend was found at $\alpha < 0.01$.

Trend results of rainfall southeast of the Sokoto-Rima River basin were -1.78 (Mann-Kendall), -1.81 (Spearman's Rho) and -2.08 (linear regression). Results of Mann-Kendall and Spearman's rho present possible evidence of decreasing trend in rainfall pattern. Temperature pattern showed evidence of increasing trend. Results of temperature trend were 4.89 (Mann-Kendall), 4.67 (Spearman's Rho) and 5.83 (linear regression). Potential evapotranspiration distribution showed evidence of increasing trend with trend results of 5.52 (Mann-Kendall), 5.18 (Spearman's Rho) and 6.61 (linear regression). Results of the statistical trends buttressed earlier observations of increasing temperature, PET with

evidence of declining rainfall. Although changes in annual rainfall distribution are not as pronounced as pattern observed for temperature, the results are indication of changing climate in the basin. In addition to aforementioned direct impacts on crops, there is serious concern in the region concerning desertification. According to Thompson and Amos (2010), desertification is the insidious cause of the decline in Nigeria's agricultural productivity which has taken hold of 35% of previously cultivable land in eleven (10) northern states. Similarly, Ayuba and Dami (2011) pointed out that Nigeria is losing an estimated land of 351, 000sq.km to desert representing 38% of its total landmass, which corresponds to the landmass of the desert – threatened frontline states of the country (Bauchi, Gombe, Borno, Yobe, Jigawa, Kano, Katsina, Zamfara, Sokoto and Kebbi States). Regrettably, these states are known for grains (guinea corn, millet, maize, groundnut, beans onions, cucumber etc.) production in the country and now seriously affected by desertification thereby bringing a decline in agricultural produce and causing food insecurity (Audu, *et al.*, 2013). Soils become more loosed and less fertile when encroached by desertification. This threatens farming and affects food production.

Table 4: Trend pattern of climatic variables over the Sokoto-Rima River basin

Climatic station	Time series	Mann-Kendal	Significance level	Spearman's Rho	Significance level	Linear Regression	Significance level
	1943-2012	z-test		z-test		t-test	
SW	Rainfall (mm)	-2.12	$\alpha < 0.05$	-2.19	$\alpha < 0.05$	-2.18	$\alpha < 0.05$
	Temp ($^{\circ}\text{C}$)	5.14	$\alpha < 0.01$	4.85	$\alpha < 0.01$	6.15	$\alpha < 0.01$
	PET(mm)	5.46	$\alpha < 0.01$	5.18	$\alpha < 0.01$	6.67	$\alpha < 0.01$
NW	Rainfall (mm)	-1.98	$\alpha < 0.05$	-1.954	$\alpha < 0.10$	-2.03	$\alpha < 0.05$
	Temp ($^{\circ}\text{C}$)	4.94	$\alpha < 0.01$	4.65	$\alpha < 0.01$	5.71	$\alpha < 0.01$
	PET(mm)	5.56	$\alpha < 0.01$	5.16	$\alpha < 0.01$	6.55	$\alpha < 0.01$
NE	Rainfall (mm)	-3.01	$\alpha < 0.01$	-3.086	$\alpha < 0.01$	-3.56	$\alpha < 0.01$
	Temp ($^{\circ}\text{C}$)	5.74	$\alpha < 0.05$	5.31	$\alpha < 0.05$	6.68	$\alpha < 0.05$
	PET(mm)	5.98	$\alpha < 0.01$	5.64	$\alpha < 0.01$	7.59	$\alpha < 0.01$
SE	Rainfall (mm)	-1.78	$\alpha < 0.10$	-1.81	$\alpha < 0.10$	-2.08	$\alpha < 0.05$
	Temp ($^{\circ}\text{C}$)	4.89	$\alpha < 0.01$	4.67	$\alpha < 0.01$	5.83	$\alpha < 0.01$
	PET(mm)	5.52	$\alpha < 0.01$	5.18	$\alpha < 0.01$	6.61	$\alpha < 0.01$

3.8. Monthly supplementary irrigation needs of selected crops in the Southwestern part of the basin

Supplementary irrigation needs of selected crops in the southwestern part of the basin are presented in Tables 5a-5d. Monthly supplementary irrigation needs of maize (grain) was 100.6 mm in May, 52.9 mm in June, -8.4 mm in July, -59.8 mm in August and -1.6 mm in September. The negative value of supplementary irrigation need in July, August and September show rainfall is at the peak and maize does not require supplementary irrigation. Similarly, supplementary irrigation is not required for the months of April and October as April rainfall is not considered to be effective enough to commence farming. Thus the month of April a full irrigation may be required. In October which marks the cessation of rainfall in the basin, full irrigation is required. Supplementary irrigation needs for groundnut for the months of May, June, July, August and September were 97.1 mm, 49.9 mm, -11.1 mm, -62.1 mm and -3.9 mm respectively. Tomato, cabbage and carrot require supplementary irrigation needs of 105.9 mm, 57.4 mm, -4.3 mm, -56.1 mm and 1.9 mm for the months of May, June, July, August and September respectively. Monthly supplementary irrigation requirement in onion (dry) cultivation were estimated as 100.6 mm in May, 52.9 mm in June, -8.4 mm in July, -59.8 mm in August and -1.6 mm in September. Values of supplementary irrigation for selected crops were generally lower in this part of the basin than requirement for maize in North West as well as decrease with increasing rainfall amount.

Table 5a: Monthly supplementary irrigation water need for maize (grain) in mm, southwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	94.1	106.8	154.1	177.4	174.5	148.6	135.0	121.4	116.4	125.1	107.0	95.1
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	71.5	81.2	117.1	134.9	132.6	112.9	102.6	92.3	88.4	95.1	81.3	72.3
P _e , mm	0	0	0	2	32	60	111	152	90	8	0	0
IR, mm					100.6	52.9	-8.4	-59.8	-1.6			

Source: Author's computation, (2017)

Table 5b: Monthly supplementary irrigation water need for groundnut in mm, southwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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ET _o , mm	94.1	106.8	154.1	177.4	174.5	148.6	135.0	121.4	116.4	125.1	107.0	95.1
K _c	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
ET _{crop}	69.6	79.1	114.0	131.3	129.1	109.9	99.9	89.8	86.1	92.6	79.2	70.4
P _e , mm	0	0	0	2	32	60	111	152	90	8	0	0
IR, mm					97.1	49.9	-11.1	-62.2	-3.9			

Source: Author's computation, (2017)

Table 5c: Monthly supplementary irrigation water need for tomato/cabbage/carrot in mm, southwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	94.1	106.8	154.1	177.4	174.5	148.6	135.0	121.4	116.4	125.1	107.0	95.1
K _c	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
ET _{crop}	74.3	84.4	121.7	140.2	137.9	117.4	106.7	95.9	91.9	98.8	84.5	75.2
P _e , mm	0	0	0	2	32	60	111	152	90	8	0	0
IR, mm					105.9	57.4	-4.3	-56.1	1.9			

Source: Author's computation, (2017)

Table 5d: Monthly supplementary irrigation water need for onion (dry) in mm, southwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	94.1	106.8	154.1	177.4	174.5	148.6	135.0	121.4	116.4	125.1	107.0	95.1
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	71.5	81.2	117.1	134.9	132.6	112.9	102.6	92.2	88.4	95.1	81.3	72.3
P _e , mm	0	0	0	2	32	60	111	152	90	8	0	0
IR, mm					100.6	52.9	-8.4	-59.8	-1.6	87.1		

Source: Author's computation, (2017)

3.9. Monthly supplementary irrigation needs of selected crops in the Northwestern part of the basin

Tables 6a-6d show the supplementary irrigation needs of selected crops in the Northwestern part of the basin area. Monthly supplementary irrigation needs of maize (grain) was 127.7 mm in May, 74.4 mm in June, 11.7 mm in July, -32.3 mm in August and 32.02 mm in September. Values of supplementary irrigation were observed to decrease with increasing rainfall amount. Highest supplementary irrigation requirement was found in May. This very high value may be attributed to general high temperature value which characterize onset of rainfall in the study area. Supplementary irrigation needs for groundnut cultivation for the months of May, June, July, August and September were 123.9 mm, 71.1 mm, 8.9 mm, -34.8 mm and 29.6 mm respectively. Tomato, cabbage and carrot require supplementary irrigation needs of 133.3 mm, 79.3 mm, 15.9 mm, -28.6 mm and 35.7 mm for the months of May, June, July, August and September respectively. Monthly supplementary irrigation requirement in onion (dry) cultivation were estimated as 127.7 mm in May, 74.4 mm in June, 11.7 mm in July, -32.3 mm in August and 32.0 mm in September.

Table 6a: Monthly supplementary irrigation water need for maize (grain) in mm, northwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	88.2	101.4	148.1	178.7	186.4	159.7	140.4	124.6	121.1	130.1	106.3	90.4
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	66.9	77.04	112.5	135.8	141.7	121.5	106.7	94.6	92.0	98.8	80.8	68.7
P _e , mm	0	0	0	0	14	47	95	127	60	2	0	0
IR, mm					127.7	74.4	11.7	-32.3	32.02			

Source: Author's computation, (2017)

Table 6b: Monthly supplementary irrigation water need for groundnut in mm, northwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	88.2	101.4	148.1	178.7	186.4	159.7	140.4	124.6	121.1	130.1	106.3	90.4
K _c	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
ET _{crop}	65.2	75.0	109.5	132.2	137.9	118.1	103.9	92.2	89.6	96.3	78.7	66.9
P _e , mm	0	0	0	0	14	47	95	127	60	2	0	0
IR, mm					123.9	71.1	8.9	-34.8	29.6			

Source: Author's computation, (2017)

Table 6c: Monthly supplementary irrigation water need for tomato/cabbage/carrot in mm, Northwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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ET _o , mm	88.2	101.4	148.1	178.7	186.4	159.7	140.4	124.6	121.1	130.1	106.3	90.4
K _c	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
ET _{crop}	69.6	80.1	116.9	141.2	147.3	126.1	110.9	98.40	95.65	102.7	84.01	71.4
P _e , mm	0	0	0	0	14	47	95	127	60	2	0	0
IR, mm					133.3	79.1	15.9	-28.6	35.7			

Source: Author's computation, (2017)

Table 6d: Monthly supplementary irrigation water need for onion (dry) in mm, northwest, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	88.2	101.4	148.1	178.7	186.4	159.7	140.4	124.6	121.1	130.1	106.3	90.4
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	66.9	77.04	112.6	135.8	141.7	121.4	106.7	94.6	92.0	98.8	80.8	68.7
P _e , mm	0	0	0	0	14	47	95	127	60	2	0	0
IR, mm					127.7	74.4	11.7	-32.3	32.0			

Source: Author's computation, (2017)

3.10. Supplementary irrigation needs of Selected Crops in Northeastern part of the basin

Supplementary irrigation needs of selected crops in Northeastern part of the basin area are presented in Tables 7a-7d. Monthly supplementary irrigation needs of maize (grain) was 125.2 mm in May, 125.2 mm in June, 7.5 mm in July, -37.9 mm in August and 34.6 mm in September. The negative value of supplementary irrigation need in August shows rainfall is at peak and maize does not require supplementary irrigation. These values are generally higher than water needs of maize in southwestern part of the basin. Supplementary irrigation needs for groundnut cultivation for the months of May, June, July, August and September were 121.7 mm, 72.4 mm, 4.8 mm, -40.4 mm and 32.2 mm respectively. These values are generally higher in this part of the basin compared to the requirement for groundnut in southwest. Tomato, cabbage and carrot require supplementary irrigation needs of 130.6 mm, 80.2 mm, 11.6 mm, -34.3 mm and 38.1 mm for the months of May, June, July, August and September respectively. Monthly supplementary irrigation requirement in onion (dry) cultivation were estimated as 125.2 mm in May, 75.5 mm in June, -7.5 mm in July, -37.9 mm in August and 34.6 mm in September. These values are generally higher when compared to water requirement for onion in southwest and north-western parts of the basin.

Table 7a: Monthly supplementary irrigation water need for maize (grain) in mm, northeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	81.4	92.5	136.9	168.5	177.9	154.7	134.9	121.1	117.9	123.1	99.3	83.2
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	61.9	70.3	104.1	128.0	135.2	117.5	102.5	92.0	89.6	93.5	75.5	63.2
P _e , mm	0	0	0	0	10	42	95	130	55	2	0	0
IR, mm					125.2	75.5	7.5	-37.9	34.6			

Source: Author's computation, (2017)

Table 7b: Monthly supplementary irrigation water need for groundnut in mm, northeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	81.4	92.5	136.9	168.5	177.9	154.7	134.9	121.1	117.9	123.1	99.3	83.2
K _c	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
ET _{crop}	60.2	68.5	101.4	124.7	131.7	114.4	99.8	89.6	87.2	91.1	73.5	61.6
P _e , mm	0	0	0	0	10	42	95	130	55	2	0	0
IR, mm					121.7	72.4	4.8	-40.4	32.2			

Source: Author's computation, (2017)

Table 7c: Monthly supplementary irrigation water need for tomato/cabbage/carrot in mm, northeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	81.4	92.5	136.9	168.5	177.9	154.7	134.9	121.1	117.0	123.1	99.3	83.2
K _c	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
ET _{crop}	64.3	73.1	108.2	133.1	140.6	122.2	106.6	95.7	93.1	97.2	78.5	65.7
P _e , mm	0	0	0	0	10	42	95	130	55	2	0	0
IR, mm					130.6	80.2	11.6	-34.3	38.1			

Source: Author's computation, (2017)

Table 7d: Monthly supplementary irrigation water need for onion (dry) in mm, northeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	81.4	92.5	136.98	168.5	177.9	154.7	134.9	121.1	117.9	123.1	99.3	83.2
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	61.8	70.3	104.1	128.0	135.2	117.5	102.5	92.0	89.6	93.5	75.5	63.2
P _e , mm	0	0	0	0	10	42	95	130	55	2	0	0
IR, mm					125.2	75.5	7.5	-37.9	34.6			

Source: Author's computation, (2017)

3.11. Supplementary irrigation needs of selected crops in Southeastern part of the basin

Supplementary irrigation needs of selected crops in south-eastern part of the basin are presented in Tables 8a-8d. Monthly supplementary irrigation needs of maize (grain) was 81.0 mm in May, 33.7 mm in June, -39.5 mm in July, -99.6 mm in August, -26.0 in September and 72.6 mm in October. These values are generally lower than water needs of maize in other parts of the basin. Supplementary irrigation needs for groundnut cultivation for the months of May, June, July, August, September October were 77.9 mm, 31.1 mm, -41.8 mm, -101.8 mm, -28.1 mm and 32.2 mm respectively. These values are lower in this part of the basin compared with water requirements for groundnut in the northwest, southwest and northeast parts of the basin. Tomato, cabbage and carrot require supplementary irrigation needs of 85.6 mm, 37.6 mm, -35.9 mm, -96.4 mm, -22.9 mm and 75.9 mm for the months of May, June, July, August, September and October respectively. Monthly supplementary irrigation requirement in onion (dry) cultivation were estimated as 81.0 mm in May, 33.7 mm in June, -39.4 mm in July, -99.6 mm in August, -26.0 mm in September and 72.6 mm in October.

Table 8a: Monthly supplementary irrigation water need for maize (grain) in mm, southeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	82.7	92.2	131.6	151.4	151.3	129.9	117.8	108.4	103.9	108.7	92.8	82.5
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	62.8	70.1	100.0	115.1	115.0	98.7	89.6	82.4	78.9	82.6	70.6	62.7
P _e , mm	0	0	0	3	34	65	129	182	105	10	0	0
IR, mm					81.0	33.7	-39.5	-99.6	-26.0	72.6		

Source: Author's computation, (2017)

Table 8b: Monthly supplementary irrigation water need for groundnut in mm, southeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	82.7	92.2	131.6	151.4	151.3	129.9	117.8	108.4	103.9	108.7	92.8	82.5
K _c	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
ET _{crop}	61.2	68.2	97.4	112.1	111.9	96.1	87.2	80.2	76.9	80.4	68.7	61.0
P _e , mm	0	0	0	3	34	65	129	182	105	10	0	0
IR, mm					77.9	31.1	-41.8	-101.8	-28.1	70.4		

Source: Author's computation, (2017)

Table 8c: Monthly supplementary irrigation water need for tomato/cabbage/carrot in mm, southeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	82.7	92.2	131.6	151.4	151.3	129.9	117.8	108.4	103.9	108.7	92.8	82.5
K _c	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
ET _{crop}	65.3	72.9	103.9	119.6	6	102.6	93.1	85.6	82.1	85.9	73.39	65.19
P _e , mm	0	0	0	3	34	65	129	182	105	10	0	0
IR _{mm}					85.6	37.6	-35.9	-96.4	-22.9	75.9		

Source: Author's computation, (2017)

Table 8d: Monthly supplementary irrigation water need for onion (dry) in mm, southeast, Sokoto-Rima river basin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET _o , mm	82.7	92.2	131.6	151.4	151.3	129.9	117.8	108.4	103.9	108.7	92.8	82.5
K _c	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
ET _{crop}	62.8	70.1	100.0	115.1	115.0	98.7	89.6	82.4	78.9	82.6	70.5	62.7
P _e , mm	0	0	0	3	34	65	129	182	105	10	0	0

IR, mm					81.0	33.7	-39.4	-99.6	-26.0	72.6		
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Source: Author's computation, (2017)

4.0 Conclusion

The first three decades 1940, 1950 and 1960 were the wet decades in the Sokoto-Rima River Basin. This rising trend was interrupted by a break in 1970. There was a continuous downward trend in annual rainfall distribution from 1970 with a sign of weak rising trend around 2000. Temperature on the other hand showed evident of rising trends for all the sections of the basin from 1970 into 2010. Between 1940-1960 mean temperatures clustered below mean line. These correspond to periods of drought in the arid and semi-arid Nigeria. For example using the Standard Precipitation Index (SPI), Abubakar and Yamuda (2013) showed that drought occurrence was first noticed in this zone in 1968 with a Standardized Precipitation Index value of (-0.34), indicative of a mild drought. These negative SPI values of drought episodes continued up to 1973, with the exception of 1970. From 1981-1997, the zone again witnessed the longest drought episodes, which lasted for nearly a decade and half. This period was characterized by absolute dryness except. However, there were moments of respite in the later years (1996-2004) during which drought episodes were fast recovering from dryness to wetness. Cause of drought in this zone during the 1970s, 1980s and 1990s has been linked to the prevalence of a stagnated anti-cyclonic circulation of the tropical atmosphere over areas that normally should be exposed to the rising arm of the tropical Hadley Cell circulation by mid-summer (Kalu, 1987; Adefolalu, 1986; Kamara, 1986). These conditions are themselves related to the tropical component of the global general circulation system. This study present evidence of changing climate and variability and since the basin houses big irrigation projects and dams such as the Goronyo Irrigation and the Bakolori Dam and Bakolori Irrigation Project, north of the basin, we must be concerned regarding the impact of this observation on the water availability within the basin for ongoing irrigation and other water resources projects as a result of rapid moisture loss by evaporation and evapotranspiration. Results of supplementary irrigation showed that water of different quantity is required in the months of onset and cessation of rains. This has a lot of implications for early crop plantation. A temporal water deficit is fatal to crop development especially during the vegetative and flowering stages of the crops. Finding from the study also showed that an all-year- round planting can be carried out adopting the supplementary irrigation schedule provided in the study.

References

- Abaje, I. B., Ati, O. F. and Iguisi, E.O. (2011). *Drought in the North-Eastern part of Nigeria and the risks on human health*, in E. O. Iguisi, O. A. Ati, R. O. Yusuf and A. E. Ubogu (eds) NMets Zaria 2011 Proceedings of the International Conference of the Nigerian Meteorological Society, pp. 527-538.
- Abdul-Rahaman, I., Campion, B. B. and Edziye, R. (2016). Rainfall and temperature changes and variability in the Upper East Region of Ghana. *Earth and Space Science*, 3, doi:10.1002/2016EA000161.
- AbdulKadir, A., Usman, M. A. and Shaba, A. H. (2013). Climate change, aridity trend and agricultural sustainability of the Sudano-Sahelian belt of Nigeria. *International Journal of Development and Sustainability*, 2(2), pp. 1436-1456.
- Abubakar, L. U. and Yamuda, M. A. (2013). Recurrence of drought in Nigeria. Cause, Effects and Mitigation. *International Journal of Agriculture and Food Science Technology*, 4(3), pp. 169-180.
- Adefolalu, D. O. (2007). *Climate change and economic sustainability in Nigeria*. Paper presented at the International Conference on Climate Change and Economic Sustainability held at Nnamdi Azikiwe University, Enugu, Nigeria, 12-14 June 2007
- Adefolalu, D. O. (1986). Rainfall trends in Nigeria. *Theoretical and Applied Climatology*, 37, pp. 205-219.
- Adejuwon, J. O. (2006a). Food crop production in Nigeria II: Potential effects of climate change. *Clim Res*, 32, pp. 229-245.

- Adejuwon, J. O. (2006b). Food security, climate change variability and climate change in sub-Saharan West Africa. *Assessment of Impacts and Adaptations to Climate Change (AIACC)*. AIACC Project Office, Washington DC.
- Adelana, S. M. A., Olasehinde, P. I. and Vrbka, P. (2003). Isotope and geochemical characterization of surface and subsurface waters in the semi-arid Sokoto Basin, Nigeria. *African Journal of Science and Technology*, 4(2), pp. 76–89.
- Allen, R. G., Smith, M., Perrier, A., and Pereira, L. S. (1994). An update for the definition of reference evapotranspiration. *ICID Bulletin*, 43(2), pp. 1-34.
- Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). *Crop evapotranspiration – Guidelines for computing crop water requirements*. FAO Irrigation and Drainage, Paper No. 56, FAO, Rome.
- Anyadike, R. N. C. (1987). The Linacre evaporation formula tested and compared to others in various climates over West-Africa. *Agricultural and Forest Meteorology*, 39, pp. 111-119.
- Aondoakaa, S. C. (2012). Effects of Climate Change on Agricultural Productivity in the Federal Capital Territory (FCT), Abuja, Nigeria. *Ethiopian Journal of Environmental Studies and Management EJESM*, 5(4), pp. 559-566.
- Audu, E. B. I., Audu, H. O., Binbol, N. L. and Gana, J. N. (2013). Climate Change and Its Implication on Agriculture in Nigeria. *Abuja Journal of Geography and Development*, 3(2), pp. 8-19.
- Ayoade, J. O. (1983). *Introduction to Climatology for the Tropics*. Spectrum Books Ltd, Ibadan.
- Ayuba, K. H. and Dami, A. (2011). *Environmental Science. An Introductory Text*. Published by Apani publications, pp. 44, 73 & 75.
- Bello, N. J. (2010). *Climate Change: Implications for food production and security in Nigeria*. In: Climate Change Impacts and Adaptation: Developmental Issues. A Special Book on Climate Change. Published by Nigerian Meteorological Society, pp. 3 & 5
- Dingman, S. L. (2002). *Physical Hydrology*, 2nd edition, Prentice-Hall, Upper Saddle River, 646 pp.
- Ekpoh, I. J. (1999). Rainfall and Peasant Agriculture in Northern Nigeria. *Global Journal of Pure and Applied Sciences*, 5(1), pp. 123-128.
- FAO (2002). *Crop Water Requirements and Irrigation Scheduling*. In: A. P. Savva and K. Frenken (eds.) FAO Irrigation Manual Module 4 Rome, Italy.
- FAO (2018). *Northeastern Nigeria Adamawa, Borno and Yobe States Results of the 2017 rainy season programme*. Food and Agriculture Organization of the United Nations Rome, 2018.
- Food and Agriculture Organization of the United Nations FAO (1986). *Irrigation Management, Training Manual*, No 3. Via delle Terme di Caracalla, 00100 Rome, Italy.
- Hamon, W. R. (1961). Estimating potential evapotranspiration. *Journal of the Hydraulics*, 87, pp. 107–120.
- Hanafi, A. and Jauffret, S. A. (2008). Long-term vegetation dynamics useful in monitoring and assessing desertification processes in the arid steppe, southern Tunisia. *Journal of Arid Environments*, 72(4), pp. 557–572.
- Huang, S. and Siegert, F. (2006). Land cover classification optimized to detect areas at risk of desertification in North China based on Spot Vegetation imager. *Journal of Arid Environments*, 67(2), pp. 308 – 327.

IPCC (2007). *Climate Change 2007: Synthesis Report*. Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Ita, E. O. (1993). *Inland Fishery Resources of Nigeria CIFA Occasional Paper No 20*. Rome, FAO. 1993. 120 pp.

Jagtap, S. (2007). *Managing vulnerability to extreme weather and climate events: Implications for agriculture and food security in Africa*. In: Proceedings of the International Conference on Climate Change and Economic Sustainability held at Nnamdi Azikiwe University, Enugu, Nigeria, 12-14 June 2007.

Junliang, J., Guoqing, W., Jianyun, Z., Qinli, Y., Cuishan, L., Yanli, L., *et al.* (2016). Impacts of climate change on hydrology in the Yellow River source region, China. *Journal of Water and Climate Change*, jwc2018085 <https://doi.org/10.2166/wcc.2018.085>

Kalu, A. E. (1987). *The recurrence of severe droughts in northern Nigeria*. In: Proceedings of the 1985 Commonwealth Meteorologists Conference, Meteorological Office College, Reading.

Kamara, S. I. (1986). The origin and types of rainfall in West Africa. *Weather*, 41, pp. 48-56.

Kim Chang-gil. (2009). *Strategies for Implementing Green Growth in Agricultural Sector*. In: Proceedings in Green Korea 2009 - Green Growth and Cooperation. National Research Council for Economics, Humanities and Social Science.

Ma, Z., Kang, S., Zhang, L., Tong, L. and Su, X. (2008). Analysis of impacts of climate variability and human activity on streamflow for a river basin in arid region of northwest China. *Journal of Hydrology*, 352, pp. 239-249.

McCabe, G. J., and Markstrom, S. L. (2007). *A monthly water-balance model driven by a graphical user interface*. U.S. Geological Survey Open-File report 2007-1088, 6 pp.

Mitchell, T. D. and Jones, P. D. (2005). An Improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.* 25, pp. 693–712.

Mortimore, M. J. and Adams, W. M. (2001). Farmer adaptation, change and crises in the Sahel. *Global Environmental Change-Human and Policy Dimensions*, 11, pp. 49–57.

Mu, X., Zhang, L., McVicar, T. R., Chille, B. and Gau, P. (2007). Analysis of the impact of conservation measures on stream flow regime in catchments of the Loess Plateau, China. *Hydrological Processes*, 21, pp. 2124-2134.

National Emergency Management Agency (NEMA) (2010). Post Disaster Assessment for Nigeria.

New, M., Hulme, M. and Jones, P. D. (2000). Representing twentieth century space–time climate variability. Part 2: Development of 1901–96 monthly grids of terrestrial surface climate. *J. Climate*, 13, pp. 2217–2238.

NPC (2006). *2006 Population and Housing Census*. Priority Table Volume III Population Distribution by Sex, State, LGA & Senatorial District National Population Commission Abuja, Nigeria April, 2010.

Nwafor, J. C. (2007). *Global climate change: The driver of multiple causes of flood intensity in Sub-Saharan Africa*. Paper presented at the International Conference on Climate Change and Economic Sustainability held at Nnamdi Azikiwe University, Enugu, Nigeria, 12-14 June 2007.

Obi, C. O. (2010). Climate Change and Management of Degraded Soils for Sustainable Crop of Production. *Tropical Built Environment Journal*. 1(1), pp. 33, 36 & 37.

- Odjugo, P. A. O. (2001). Global warming and food production: A global and regional analysis. *Afr J Environ Stud.* 2(2), pp. 85-91.
- Oguntunde, P. G., Abiodun, B. J. and Lischeid, G. (2011). Rainfall trends in Nigeria, 1901–2000. *J. Hydrol.*, 411, pp. 207–218.
- Penman, H. L. (1948). Natural evaporation from open water, bare soil, and grass. *Proceedings of the Royal Society of London*, A193 (1032), pp. 120-146.
- Qin, D.Y., Lü, J.Y., Liu, J. H. and Wang, M. N. (2009). Theories and calculation methods for regional objective ET. *Chinese Science Bulletin*, 54(1), pp. 150-157.
- Singh, S. K, Singh, K. M., Singh R. K. P., Kumar, A. and Kumar, U. (2014). Impact of Rainfall on Agricultural Production in Bihar: A Zone-Wise Analysis. *Environment and Ecology*, 32 (4A), pp. 1571-1576.
- Sivakumar, M. V. K. (2007). Interactions between climate and desertification. *Agricultural and Forest Meteorology*, 142. 2-4, pp. 143–155.
- Sombroek, W. G. and Zonneveld, I. S. (1971). *Ancient Dunes Fields and Fluvial Deposits in the Rima Sokoto River Basin, Soil Survey*. Paper No. 5, Netherland Soil Survey Institute, Wageningen, 109 pp.
- Sonia, K., Max, R., Minus, V. B. and Michel, L. (2007). Local facilitation, bistability and transitions in arid ecosystems. *Theoretical Population Biology*, 71(3), pp. 367–379.
- Susana, B. A. and Kelley, A. C. (2006). Aridity and desertification: Exploring environmental hazards in Jáchal, Argentina. *Applied Geography*, 26(1), pp. 61 – 85.
- Thompson, O. A. and Amos, T. T. (2010). Climate Change and Food Security in Nigeria. *Journal of Meteorology and Climate Science*. 8(2). pp. 92-95.
- Zhang, S. and Lu, X. X. (2009). Hydrological responses to precipitation variation and diverse human activities in a mountainous tributary of the lower Xijiang, China. *CATENA*, 77, pp. 130-142.
- Zhao, H. L., Zhao, X. Y., Zhou, R. L., Zhang, T. H. and Drake, S. (2005). Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of Arid Environments*, 62(2), pp. 309–319.