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STATISTICAL VARIABILITY OF HYDRO-METEOROLOGICAL VARIABLES AS INDICATORS OF CLIMATE CHANGE IN NORTH-EAST SOKOTO-RIMA BASIN, NIGERIA

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ABSTRACT

The aim of this study is to examine the variability patterns of rainfall and actual evapotranspiration during two climatic scenarios as an insight in climatic response to global warming. The comparison between evapotranspiration during the periods (1943-1977) and (1978-2012) at the five studied weather stations revealed a general decrease in rainfall and actual evapotranspiration in the second climatic period. This has a lot of implications for water resources development including water supply project, agriculture and tourism in the study area.

Key word: Climate change, Climatic variability, Actual evapotranspiration, Global warming

INTRODUCTION

Air temperature is probably the most widely used indicator of climatic changes both on global and regional scales. It has been established that global temperature increased by 0.3–0.6^{0}C since the late 19th century and by 0.2–0.3^{0}C over last 40 years (1PCC, 2007; Khalil, 2013). In the last 140 years, the 1990s was the warmest period (Jones and Briffa, 1992, 1PCC, 2001). In Nigerian context, Karmalkar et al., (2010) have shown that mean temperature annual in temperature in Nigeria has increased by around 0.8^{o}C between 1960 and 2006 and average rate of 0.18 ^{o}C per decade. This increase has been accompanied by statistically decreasing trend of 3.5mm in rainfall per month (1.8%) per decade between1960-2006. Similarly, Odjugo (2010) had found that the period of drastic rainfall decline in Nigeria corresponds with the period of sharp temperature rise. The author found that temperature increase in Nigeria has been gradual until the late 1960s and this gave way to a sharp rise in air temperatures from the early 1970s, which continued till date. The mean air temperature in Nigeria between 1901 and 2005 was 26.6^{o}C while the temperature increase for the 105 years was 1.1^{o}C.

As a consequence of climatic change, a significant impact on hydrological parameters, through runoff, evapotranspiration, soil moisture, etc. is expected (Nemec and Schaake, 1982; Gleick, 1986; Bultot et al., 1988). Evapotranspiration (ET) is the major component of hydrological cycle after precipitation and determines the crop water requirement. The principal factors that influence the crop water requirement (or ET) depend on several climatic parameters, such as rainfall, temperature, humidity, sunshine hours etc. Any change in climatic parameters due to global warming will also affect evapotranspiration or crop water requirement. Thus, unabated global warming will increase dry conditions in semi arid regions of the world by decreasing actual evapotranspiration while increase potential evapotranspiration, aggravate the processes of desertification in conjunction with the ever-growing impact of man and domestic animals on fragile and unstable ecosystems (Houerou and Le Houerou, 1993). Unfortunately, measurements of evapotranspiration are rarely available to describe the influence of changing climate on the evapotranspiration regime in most developing countries. In the absence of measurements, an alternative approach is to use hydrological models to estimate the values of evapotranspiration, using meteorological data. The aim of this study is to examine the variability patterns of rainfall and actual evapotranspiration during two climatic scenarios as an insight in climatic response to global warming.

MATERIALS AND METHODS

Study Area

The study area is located in the northwestern Nigeria and lies largely in the far north Sahel of West Africa in 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 Sokoto River joins the Niger about 75 km downstream of the border and extends upstream with a broad floodplain for about 387 km (Hughes and Hughes, 1991). There is an estimated 470,000 ha of seasonal floodplains on the Niger/Sokoto system (Ita, 1993). The Sokoto River's source is near Funtua in the south of Katsina State, some 275 km in straight line from Sokoto. It flows north-west passing Gusau in Zamfara State, where the Gusau Dam forms a reservoir that supplies major towns with water (Fig.1). Further downstream the river enters Sokoto State where it passes by Sokoto and is joined by the Rima River, then turning south and flowing through Birnin Kebbi in Kebbi State. Flood ponds are common within the flood basins of most of the major rivers and are usually cut off from the main river channels during periods of low water.

The Sokoto Basin is underlain by a sequence of inter-bedded semi-consolidated gravels, sands, clays and some limestone and ironstone of Cretaceous to Quartenary age resting on pre-Cambrain 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).

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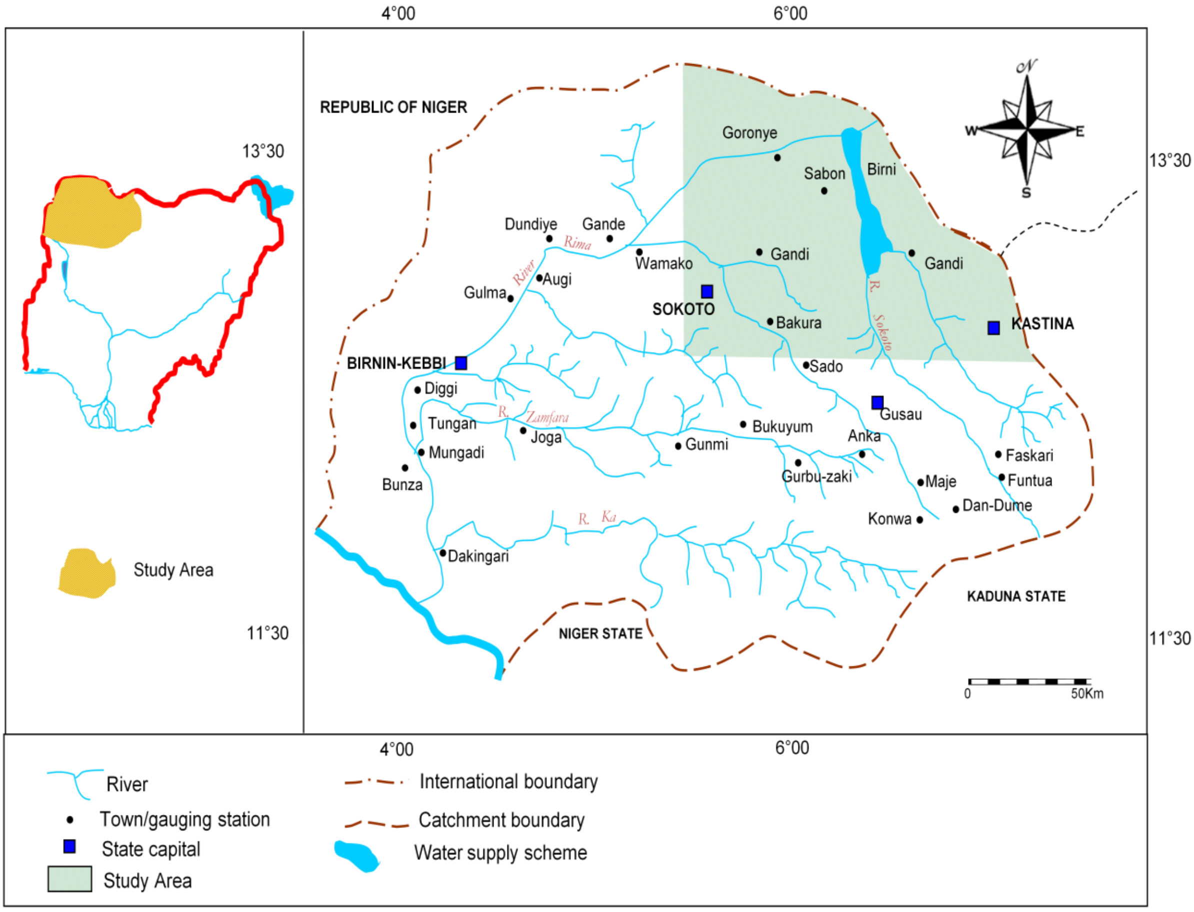

FIG. 1: SOKOTO RIVER BASIN

Source: (Adopted from Ita. 1993)

The sedimentary sequences are sub-divided from bottom to top into the late Jurassic to early Cretaceous Illo and Gundumi formations, the Maestrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formation. Thick sediments of both marine and continental origins constitute the series of aquifers in the basin with the oldest being the Gundumi formation that uncomformably overlies the basement complex. The Sokoto Basin is a semi-arid region marked by distinct weather conditions-the wet and dry seasons. Rainfall is highly seasonal and controlled by the movement of the Inter Tropical continuity (ITD). Rainy season 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^{o}C-40 ^{o}C. During the harmmattan season, daily minimum temperature may fall below 18^{o}C. Between February and April which is the peak of heat, temperature reaches the highest of 44^{o}C. In the extreme north, the shrubby and thorny vegetation of the Sahel zone is dominant vegetation type.

Data collection

High-resolution precipitation datasets in millimeter which is available on high-resolution (0.5x0.5 degree) grids resolution 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) was used in this study. The data covers the entire globe for the period 1901-2012 is available on http://www.cru.uea.ac.uk/ Rainfall and temperature data were assembled on monthly basis for a period of 70 years for Goronye, Gandi, Sabon-Brini, Galadi and Bakura locations. This climatic period was chosen to enable the comparison between two climatic period s (1943-1977 and 1987-2012). This first climatic period as used in the study is represented as 1943-1977 while 1987-2012 represents the second climatic period. More so it has been according to Ziegler *et al*. (2003) data lengths longer than 30 years are needed to detect the acceleration of the hydrological cycle. Quality control of CRU datasets has been discussed in detail by New *et al* (2000) and Mitchel and Jones (2005).

Data Analysis

Data analysis involved comparisons using the standard meteorological procedure of means of the selected parameters. Analysis of data was achieved using the SPSS and excel analysis toolPak. The Thornthwaite water balance computer software version 1.10 which was developed by the United States Geological Survey department was used for computing components of water balance. Water balance components investigated in the study include rainfall and actual evapotranspiration (AET).

Actual evapotranspiration (*AET*) was derived from potential evapotranspiration (*PET*), P_{total}, soil-moisture storage (*ST*), and soil-moisture storage withdrawal (*STW*). Monthly *PET* was estimated from mean monthly temperature (*T*). In this study, *PET* was calculated by using the Hamon equation (Hamon, 1961):

$$PET_{Hamon} = 13.97 \times d \times D2 \times Wt, \qquad (1)$$

where PET_{Hamon} is *PET* in millimeters per month, *d* is the number of days in a month, *D* is the mean monthly hours of daylight in units of 12 hrs, and *Wt* is a saturated water vapor density term, in grams per cubic meter, calculated by:

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

where *T* is the mean monthly temperature in degrees Celsius (Hamon, 1961)

When P_{total} for a month is less then *PET*, *AET* is equal to *Ptotal* plus the amount of soil moisture that can be withdrawn from storage in the soil. Soil-moisture storage withdrawal linearly decreases with decreasing *ST* such that as the soil becomes drier, water becomes more difficult to remove from the soil and less is available for *AET*. *STW* is computed as follows:

$$STW = ST_{i-1} - \left[abs(P_{total} - PET) \times \left(\frac{ST_{i-1}}{STC}\right)\right], \qquad (3)$$

where ST_{i-1} is the soil-moisture storage for the previous month and *STC* is the soil-moisture storage capacity. According to McCabe and Wolock, (1999), if the sum of P_{total} and *STW* is less than *PET*, then a water deficit is calculated as *PET–AET*. If P_{total} exceeds *PET*, then *AET* is equal to *PET* and the water in excess of *PET* replenishes *ST*.

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When *ST* is greater than *STC*, the excess water becomes surplus (*S*) and is eventually available for runoff.

Model input and Model calibration

Input parameters to the water-balance model include, mean monthly temperature (*T*, in degrees Celsius), monthly total precipitation (*P*, in millimeters), runoff factor, direct runoff factor, soil-moisture storage capacity, latitudinal location (in decimal degrees) of the location of interest. The latitude of the location is used for the computation of day length, which is needed for the computation of potential evapotranspiration (*PET*). Others are rain and temperature thresholds, snow temperature threshold, and maximum snow-melt rate of the snow storage) which can be modified/changed through the model graphical user interface. Calibration of the water balance model and development of scripts were carried out at the Mathematical/ICT Laboratory, National centre for Energy and Environment, university of Benin.

RESULTS AND DISCUSSION

From table 1, it was observed that Goronye town recorded an average rainfall amount of 584.1mm during the first climatic period, with standard deviation value of 120.6. Minimum and maximum values were determined as 325.5mm and 788.7mm respectively. In the first climatic period, rainfall range value was calculated as 463.2mm with coefficient of variation value of 20.6. In the second climatic period, there was a decline in the average rainfall amount to 484.9mm. Minimum and maximum rainfall was determined as 294.2mm and 740.4mm respectively. Rainfall range in the second climatic period was recorded as 446.2mm. The coefficient of variation value (22.5) in Goronye in the second climatic period revealed that rainfall was more variable in the second period when compare with C.V value 20.6 in the first climatic period.

Table 1: Descriptive statistics of rainfall variation during the first (1943-1977) and second (1978-2012) climatic periods

Rainfall (mm)								
Climatic Station	Period	Mean	SD	Min	Max	Range	Sum	CV
Goronye	First Climatic Period	584.1	120.6	325.5	788.7	463.2	20442.6	20.6
	Second Climatic Period	484.9	109.3	294.2	740.4	446.2	16969.8	22.5
Gandi	First Climatic Period	671.6	128.4	350.7	861	510.3	23506.7	19.7
	Second Climatic Period	573.6	113.2	326	794.9	468.9	20074.6	19.7
Sabon-Birni	First Climatic Period	601.8	129.0	315.4	824.4	509	21063.7	21.4
	Second Climatic Period	496.3	108.1	296.6	716.9	420.3	17370.9	21.8
Galadi	First Climatic Period	681.9	137.9	351.1	885.3	534.2	23865.7	20.2
	Second Climatic Period	571.4	121.6	326.9	746.8	419.9	19998.6	21.2
Bakura	First Climatic Period	750.7	137.7	423.2	1043.4	620.2	26274.4	18.3
	Second Climatic Period	607.4	143.9	326.9	870.9	544	21259.4	23.7

Sabon-Brini town recorded an average rainfall amount of 601.8mm during the first climatic period, with standard deviation value of 129. Minimum and maximum values were obtained as 315.1mm and 824.4mm respectively. In the first climatic period, rainfall range value was calculated as 509 mm with coefficient of variation value of 21.4. In the second climatic period, there was a decline in the average rainfall amount to 496.3mm. Minimum and maximum rainfall amounts were observed as 296.6mm and 716.9mm. The coefficient of variation value (21.8) calculated for Sabon-Brini in the second climatic period shows that variability nature of rainfall in the both climatic periods are near to similar.

In Galadi town, an average rainfall amount of 681.9 mm was recorded during the first climatic period. This value, declined to 571.4 mm in the second climatic period. Minimum and maximum rainfall values during the first climatic period were computed as 351.1 mm and 885.3 mm respectively with rainfall range value of 534.2 mm and standard deviation value of 137.9. Coefficient of variation in the first climatic period was calculated as 20.2. In the second climate period, Galadi town recorded minimum and maximum rainfall amounts of 326.9 mm and 746.8 mm respectively with range value of 419.9 mm. Coefficient of variation in the second climatic period was determined as 21.2 which suggests that rainfall events were more variable than events in the first climatic period.

Bakura town recorded an average rainfall amount of 750.7 mm during the first climatic period, with standard deviation value of 137.7. Minimum and maximum values were found to be 423.2 mm and 1043.4 mm respectively. In the first climatic period, rainfall range value was calculated as 620.2 mm with coefficient of variation value of 18.3. In the second climatic period, there was a decline in the average rainfall amount to 607.4mm. Minimum and maximum rainfall was determined as 326.9mm and 870.9 mm respectively. Rainfall range during the second climatic period was recorded as 544mm. The coefficient of variation value (23.9) in Bakura during the second climatic period revealed that rainfall was more variable in the second period when compare with C.V value 18.3 in the first climatic period. In the table 2, statistical variability of actual evapotranspiration during the two climatic periods north-east of the Sokoto-Rima Basin is presented in Table 2.

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Table 2: Descriptive statistics of variation in actual evapotrasnpiration during the first (1943-1977) and second (1978-2012) climatic Period s

Actual Evapotranspiration								
Climatic Station	Period	Mean	SD	Min	Max	Range	Sum	CV
Goronye	First Climatic Period	479.7	87.9	276.7	615.9	339.2	16789.7	18.3
	Second Climatic Period	406	82.1	250	586.9	336.9	14210.2	20.2
Gandi	First Climatic Period	534.4	86.6	298	690.9	372.9	18704.5	16.2
	Second Climatic Period	479.2	85.8	277.2	642.8	365.6	16770.5	17.9
Sabon-Birni	First Climatic Period	502.9	99.2	268.1	630.6	362.5	17603.8	19.7
	Second Climatic Period	419.4	86.3	252.1	593.5	341.1	14678.1	20.6
Galadi	First Climatic Period	535.4	90.5	298.4	675.5	377.1	18738.4	16.9
	Second Climatic Period	475.7	93.2	277.8	634.6	356.8	16650.4	19.6
Bakura	First Climatic Period	577.0	83.4	359.7	735	375.3	20196	14.4
	Second Climatic Period	545.8	78.5	367.7	678.2	310.5	19104.4	14.4

In the first climatic Period, in Goronye town, a total AET value of 16789.7mm with an average value of 479.7mm was recorded. Minimum and maximum AET values of 276.7mm and 615.9mm respectively were calculated in Goronye in the first Period. A range value of 339.2 mm was calculated with coefficient variation (CV) value of 18.2. In the second climatic Period, changes were observed in character of AET over Goronye town. A total sum of 14210.2mm with an average AET value of 406.0mm were recorded which represent a downward trend from the AET character in the first Period. Minimum and maximum AET amounts during the second climatic Period were recorded as 250mm and 586.9mm with range value of 336.9mm. The coefficient variation value of 20.2 indicates that AET distribution in the second climatic Period was more variable that events in the first climatic Period. In addition, annual range of AET in the second climatic Period was observed to be lower in the second climatic Period.

In Gandi town, a total sum of 18704.5mm with an average AET amount of 534.4mm were recorded in the first climatic Period. Similar to pattern observed in Goronye town, this value declined to 16770.5mm and 479.2mm as total and average AET in the second climatic Period. Minimum and maximum AET values during the first climatic Period in Gandi town were determined as 298mm and 690.9 mm with range value of 372.9mm. Coefficient of variation in the first climatic Period was calculated as 16.2. In the second climate Period, Gandi town recorded minimum and maximum AET amounts of 277.2mm and 642.8mm respectively with range value of 365.8mm. Coefficient of variation of AET in the second climatic Period was determined as 17.9 which represent an upward deviation from variability character in the first climatic Period.

Sabon-Brini town recorded a total AET of 17603.8mm with an average of 502.9mm during the first climatic Period. Minimum and maximum AET values in the first climatic Period were calculated as 268.1mm and 6306mm respectively. In the first climatic Period, AET range value in Sabon-Brini was calculated as 362.5mm with coefficient of variation value of 19.7. In the second climatic Period, there was a decline in the total and average AET distributions to 14678.1mm and 416.4mm respectively. Minimum (252.1mm) and maximum (593.5mm) AET in the second climatic period suggested that evidence of downward deviation from values observed in the first climatic period. Coefficient of variation value (20.6) in Sabon-Brini town during the second climatic period revealed that AET was more variable in the second period when compare with CV in the first climatic period. Range value of AET in the second climatic period was calculated as 341.1mm which suggest AET range in Sabon-Brini decreased in the second climatic (Table 2).

In Galadi town, total and average AET amounts of 18738.1mm and 416.4mm were recorded during the first climatic period. In the second climatic period, this values, dropped to 16650.4mm and 535.4 mm in the second climatic period. Minimum and maximum AET values during the first climatic period are determined as 298.4.mm and 675.5mm with range value of 377.1mm. Coefficient of variation of AET in the first climatic period was calculated as 16.9. In the second climate period, Galadi town recorded minimum and maximum AET amounts of 277.8mm and 634.6mm respectively with range value of 356.8mm. Coefficient of variation in the second climatic period was determined as 19.6 which revealed that AET in Galadi town was more variable in the second period than in the climatic first period.

In Bakura town, a total sum of 20196 mm with an average AET amount of 577.0mm were recorded in the first climatic period. Similar to patterns observed in previous towns in northeast part of the basin, this value declined to 19104.4mm and 545.8mm as total and average AET in the second climatic period. Minimum and maximum AET values during the first climatic period in Bakura town were determined as 359.7mm and 735 mm with range value of 375.3 mm. Coefficient of variation in the first climatic period was calculated as 14.4. In the second climate period, Bakura town recorded minimum and maximum AET amounts of 367.7mm and 678.2mm respectively with range value of 310.5mm. Coefficient of variation of AET in the second climatic period was determined as 14.4 which represent similar variability coefficient in the first climatic period.

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Character of annual AET during the two (2) climatic periods showed varying degrees of spatial variability in terms of total, maximum, minimum amounts and range for different locations in the basin. Lowest AET values corresponding to declining rainfall were found in the extreme north of the study area including Goronye and Sabon-Brini towns in the second climatic period. Highest values of AET were generally observed to be higher in the first climate period, than character observed in the second period which coincides with decreasing rainfall amounts during the second climatic period. In the Tropics, values of actual evapotranspiration vary much more, especially as they partly dependent on rainfall amount. The comparison between evapotranspiration during the periods (1943-1977) and (1978-2012) at the five studied weather stations revealed a general decrease in rainfall and AET evapotranspiration in the second climatic period. This has lot of implications for water resources development including water supply project, agriculture and tourism etc. Under the changing climate in Sahel region of Nigeria as evident in the study, the study recommends an adaptation model which integrates additional water supply, water demand management and improving water quality in the basin. Scientific determination of supplementary irrigation needs of food crops and selection of suitable irrigation method are most the important factors for maximizing yield production.

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