Analysis of Rainfall Trends and Water Balance Characteristics of Southern Borno Northeast Nigeria

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Abstract

This study analyzes the trend of rainfall in Southern Borno and in doing that the cumulative index analysis of Walter (1967) was used to calculate onset, cessation and length of rainy days. The result showed that generally, the onset of rainfall is between the months of May and June while cessation is mainly October and average rainy days of 129 days. Thornthwaite and Mather model was used to calculate water budget of the study area. The result showed average monthly PET of 10.182 mm for the period of study, with total average PET of 122.188, the month with the highest PET is April, with a value of 18.783 and the month with the lowest PET is August with a value of 5.337. The weighted average annual deficit in rain water for the study area is 8.429 mm^3 and the annual surplus is 138.578 mm. The result also showed that the area has on the average, five months of WD from November to March, while the remaining months have zero (0) values of water deficit. WS ranging from April to October, while the remaining months have zero values of WS.

Keywords: Cessation, Cumulative index analysis, Onset, PET, Water balance and Water deficit

Introduction

Precipitation trend analyses on spatial and temporal scales have been of great concern during the past century because of the attention given to global climate change from the scientific community especially when climate change started manifesting; the trends indicate a small positive global trend, even though large areas are instead characterized by negative trends IPCC, (1996). Precipitation, in all its forms, is an important element of the physical environment and as such constitutes one of the most valuable sources of water, a strategic resource for human survival and social development. It is the most important hydrological input parameter and hydro climatic factor affecting man and his productivity (Bardossy, 2001; Chukwudi, Nzoiwu, Ezenwaji, Ifeanyi, Enete and Nwabueze, 2016).

Rainfall is one of the major factors affecting food security especially in countries largely dependent on rain-fed agriculture. Beside evaporation rate and soil characteristics, rainfall also controls the state of soil moisture. The role of moisture in agricultural production is even more important in the tropics, where rainfall is highly seasonal over most parts, and varies from year to year, and the growing season is determined by the availability of rain to meet crop water requirements (Ayoade, 2008). In its synthesis report summary for policy makers, IPCC (2007), projected that by 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Thus, agricultural production including access to food, in many African countries is projected to be severely compromised.

Hydrological aspects of precipitation studies, as outlined in Ayoade (1988), are studies relating to variations in precipitation distribution in both space and time, and analysis of precipitation data for hydrological purposes such as determination of run-off, groundwater recharge, soil moisture, flood forecasting and prediction. Precipitation is both spatially and temporally variable, while such characteristic has its attendant consequences. Bardossy (2001) is of the view that intense local precipitation, prolonged and spatially distinct rainfall events have provoked floods both in small/medium catchments and large rivers. Ezenwaji, Okoye and Awopeju (2013) observed in their study that climatic elements (temperature and rainfall) were the greatest contributors to flooding in Awka, Nigeria, during the period 2000 - 2009.

Thus, recent climatic variability and most particularly rainfall variations are becoming increasingly of concern to researchers, institutions and governments. To predict future developments, past statistical trends can be considered along with physically-based climate model projections (Bardossy, 2001). Some studies such as that of Odjugo, (2010) and climate model projections. Abiodun, Salami and Tadross (2011) based on statistical examinations, have shown that changes in precipitation behaviors are already evident in Nigeria. In addition, other scientific interests in Nigeria, ranging from studies examining rainfall anomalies, by Olaniran, (2002) and the trend of precipitation and annual water balance by Ojo, (1990). It is known that possible changes in precipitation behavior can have huge effect on the entire water balance characteristics of a region.

There are few studies on the recent trends and climatic water budgeting in Nigeria, while none of such studies exist on the Southern Borno region, thereby prompting this study. Thus, the aim of this study is to examine the water balance in relation to current trends of precipitation in the study area. The study also intends to contribute to the growing understanding of rainfall characteristics and variability in Nigeria in general.

Description of Study Area

The study area is situated in the Southern part of Borno State, in Northeast Nigeria, the State worst hit and ravage by insurgency. It is politically delineated as the Southern Borno Senatorial district, comprising of nine Local Government Areas and the largest Senatorial district in the State. The Local Government Areas are; Askira-Uba, Bayo, Biu, Chibok, Damboa, Gwoza, Hawul, Kwaya-Kusar and Shani. It is located between latitudes 10° 04^{1}N and 11° 30^{1} N and longitudes 10° 24^{1} and 14° 72^{1}E. Southern Borno shares border with Adamawa State in the East, Gombe State in the South and Yobe State in the West, while the Northern border is with Borno central. Southern Borno region has a population of (1,252,598) according to National Population Commission (NPC, 2006), projected to (2,555,887) in 2017 using 3.5% growth rate. Agriculture is the predominant economic activities of the people of Southern Borno. This consists mostly of the cultivation of cereal crops and rearing of animals at subsistence level. Thus agriculture constitutes over 90% of their economic activities.

The topography is characterized by rugged relief. Southern Borno is drained by three major rivers; the River Gongola and River Hawul which emptied into the Gongola and River Yedzeram that flows into the Lake Chad. There are so many minor rivers which exist as their tributaries. The climate of Southern Borno is the tropical wet and dry type according to Koppen's climatic classification system. The seasonal distribution of rainfall is controlled by the movement of the

Inter-Tropical Discontinuity (ITD) air masses. Rainfall pattern is controlled by the movement of the ITD, characterized by a dry season, November to May, though in some cases, to early June, with the North-East winds dominating during this period. Short wet season occurs normally from late June to early October and is dominated by the South-West winds. In recent times, the onset and cessation periods of the rain in the study area has been observed to vary over time. The mean minimum annual rainfall in the study area is 630.1 (mm^3) while the maximum is 1062.8 (mm^3) with a mean annual rainfall of about 811.3(mm^3). The study area has a mean minimum temperature of 21.4°C, maximum temperature of 33.3°C and a mean temperature of 28.0°C with a mean range of 11.9°C, (NIMET, 2017).

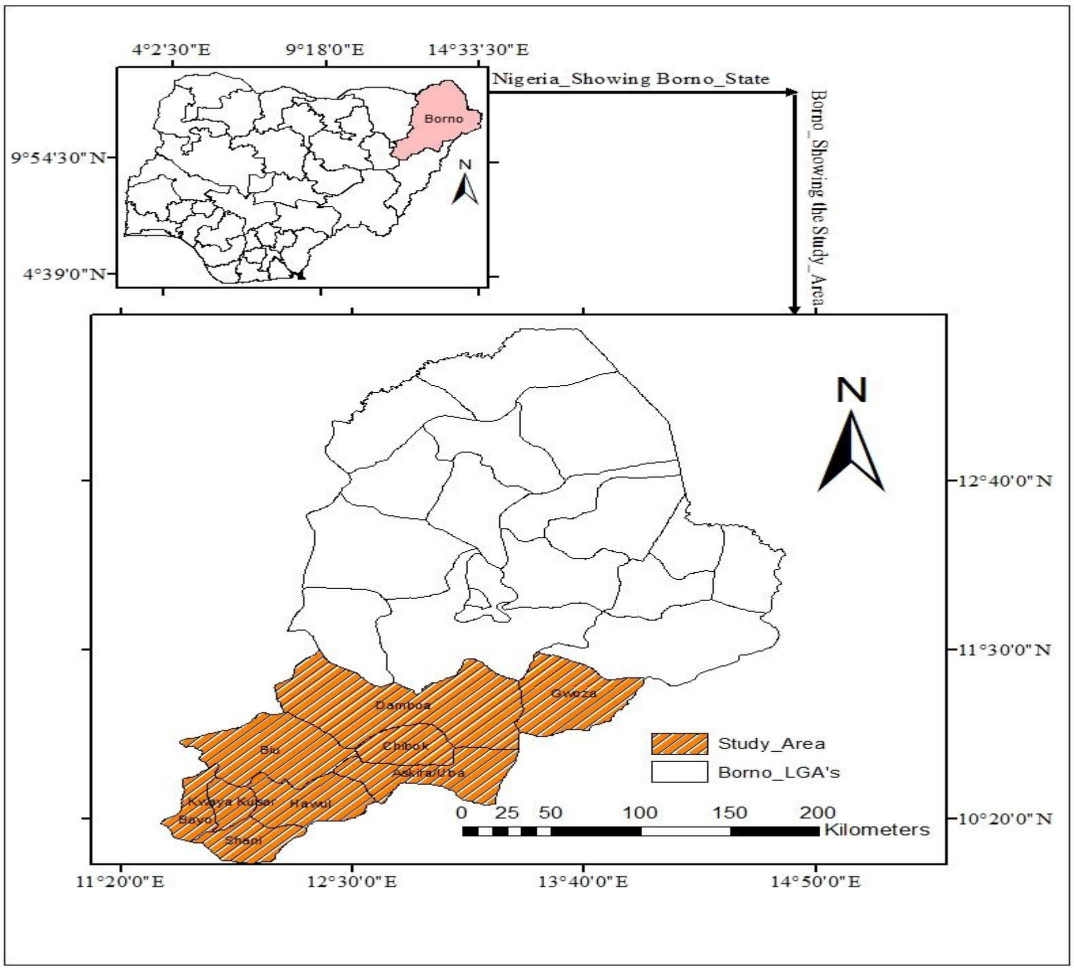

Fig. 1: Map of Study area

Methodology

Data Collection

Daily and monthly precipitation dataset as well as daily sunshine duration used in this study are obtained from the archive of the Nigerian Meteorological Agency (NIMET), Lagos, Nigeria for all the nine Local Government Areas that make up the Southern Borno Senatorial district. It covers a period of 18 years (2000 - 2017). The data were used to evaluate the temporal variations in precipitation characteristics of the study area and to determine other precipitation characteristics.

Method of Data Analysis

Daily precipitation of each LGA that make up the study area for the period of study were summed up to derive the mean monthly rainfall of the LGA's, then mean monthly rainfall were summed and averaged to get mean monthly rainfall of Southern Borno. Monthly values of rainfall for each year were summed up for the 18 year period to generate annual rainfall values for the study area. Temporal variation in the annual rainfall values of the study area was analyzed. Trend in the time series was determined using linear regression. Thus, trend analytical technique and regression analysis were used to analyze the data. For rainfall variability within the study area, descriptive statistics were computed to determine the total, maximum, minimum, mean and standard deviation. In order to further explore changes in precipitation with time, mean annual rainfall was calculated at six year intervals, that is, 2000 to 2005, 2006 to 2011 and lastly, 2012 to 2017. This technique has been proved to be a valuable tool in detecting medium term changes in the mean value of a sequence of regularly spaced observations (Crapper, Fleming and Kalma, 1996). The result is presented in Table 1.

Rainfall onset, cessation and length of rainy days were calculated using cumulative index analysis method of Walter (1967). The method uses the formula as can be seen below for the actual date of onset of rain:

Days in the month × (51 - Accumulated rainfall in previous month) / (Total for the month).

The cessation is the date after which no more than 51 mm^3 of rain is expected. The formula is applied in reverse order by accumulating total rainfall backwards from December to obtain the actual date of cessation. The duration between onset and cessation of rains represent the number of rainy days or length of rainy season, the result is presented in Table 2 below. This method is an effective method for determining effective rainfall by growing season in the tropics. This method has been applied by Adejuwon (2012) to study rainfall seasonality in the Niger Delta belt of Nigeria and Chukwudi *et al* (2016) in Awka to analyze trends in rainfall characteristics and water balance. The rainfall threshold value is defined thus: a day in which the rainfall amount is accumulated to $51mm^3$ is regarded as a rainy day and designated onset, while the cessation of rains is the date after which less than $51mm^3$ of rain is expected. This amount ensures sufficient moisture in the soil to maintain crop growth and gives a reasonable guarantee that planting would be successful if started two weeks later (Adejuwon, 2012). In addition, correlation analysis was performed to determine possible relationship between the number of rain days in a year and annual rainfall for that year.

Water budget computation for the period of study was done for Southern Borno in order to estimate values of Potential Evaporation (PET), Actual Evaporation (ET), Accumulated Potential Water Loss (APWL), Water Deficit (WD), Water Surplus values (WS) and Water Storage (STOR). The model used is based on Thornthwaite and Mather (1957) which has also been used by Ayoade (1973) to compute water balance for Jos and Calabar, Nigeria. The results are presented in Tables 3, 4 and 5.

The Thornthwaite and Mathers (TM) Model is one of the simplest models to determine water balance of a region from individual fields to small watershed. Such model is used to determine a general estimate of water balance regime for individual fields to small watersheds. The monthly potential evapotranspiration was computed using the following equation Singh *and* Hari (2004).

$$PET = 1.6 \times C \times (10\times\frac{T}{I})^{a} \quad (1)$$

Where *PET* is the potential evapotranspiration (mm month-1); *T* is the mean monthly temperature (°C); *I* is the annual heat index for the 12 months in a year ($I = \Sigma i$); *i*- is the monthly heat index (i= [T/5]1.514); a = 6.75 × 10-7 × *I*3. 7.71 × 10-5 × *I*2 + 1.792 × 10-2 × *I* + 0.49239; and *C* is a correction factor for each month (C = [m/30] × [d/12]), where *m* is the number of days in the month and *d* is the monthly mean daily duration (number of hours between sunrise and sunset, expressed as the average for the month). The result is presented in Table 1 and 2

P - PET, is a quantitative estimation of the water excess (+) or deficit (-), P as precipitation. Accumulated Potential Water Loss (APWL) is the potential deficiency of soil moisture associated with low moisture contents of a soil below water holding capacity. Accumulated potential water loss is increased 1) during dry seasons to meet the demands of PET when insufficient supply of water, 2) reduced during wet seasons from soil moisture recharge, and 3) equals zero when soil moisture equal to the available water holding capacity of the soil. The accumulated values APWL for each month, were calculated by running the sum of the daily P-PET values during the periods when (P-PET) is negative value given in Table 2. Those months having positive (P-PET) have APWL zero. The available water which is actual storage of soil moisture (STOR) for each month was calculated as follows:

STOR=AWC x eAWPL/AWC (2)

where AWC is the moisture storage capacity, also known as available water capacity of the soil, which is based upon the land use, soil texture and rooting depth as suggested by Thornthwaite & Mather (1955, 1957). The results were summarized in Table 2.

ΔSM month=STOR month-STOR previous month (3)

A negative value of ΔSM means discharge of water from the storage because of evapotranspiration, whereas a positive value of ΔSM implies infiltration of water into the soil that contributes to the soil moisture storage.

The actual evapotranspiration (AET) was computed for all the months, as given in Equations (4)

AET = PET (STOR/AWC) (4)

Where PET is the potential evapotranspiration, STOR available water and AWC water holding capacity. The results are presented in Table 5 below.

Soil moisture holding capacity of 195.3mm^3 was assumed for the study area. The assumed soil moisture holding capacity was based on results of study by Umara, Dibal and Izuchukwu (2013) who have determined mean water holding capacity in Biu plateau area to be 195.3, as such this was assumed for this study base on Thornthwaite and Mather (1957) in Ayode (2008). The potential evaporation (PET) was then estimated while the relative amounts of precipitation were estimated at six year intervals based on the same method.

Results of Findings

The descriptive statistic result of mean annual rainfall distribution in the study area as presented in Table 1, revealed that average mean annual rainfall for the period of study is 811.3mm^3 and the standard deviation from the mean is 132.5mm^3, maximum rainfall was 1062.8mm^3 recorded in 2003 while the minimum was 630.1mm^3 recorded in 2013, ten years later.

Table 1: Descriptive rainfall statistics of the study area, (2000 to 2017)

	Range	Min.	Max.	Sum	Mean	Std. Error	Std. Dev.	Variance
Rainfall	432.7	630.1	1062.8	12980.4	811.3	33.11	132.5	17546.7

The precipitation trend plot in figure 2 shows that at the beginning of the study period (2000), rainfall was below the mean, then it increases and decreases in 2001 and 2002 respectively until it rises to its peak in 2003. However, rainfall was found to be pronounced in 2004, when it rises from below the average, increasing swiftly to maintain its rise until 2009, when it plunged below the average and subsequently, rising and falling again to reach the second highest during the period under study in 2012. Thus, it can be deduced from the trend that annual rainfall distribution pattern in Southern Borno is characterized by increase from below average to above average, and then below average intermittently to an unprecedented height, before maintaining a steady rise for at least five years, before the subsequent repeat of the scenario. The result also indicated that the area is most likely to receive heavy rainfall nine years after a year with heavy rainfall. Thus, flooding is likely to repeat at an interval of nine years if the trend continues.

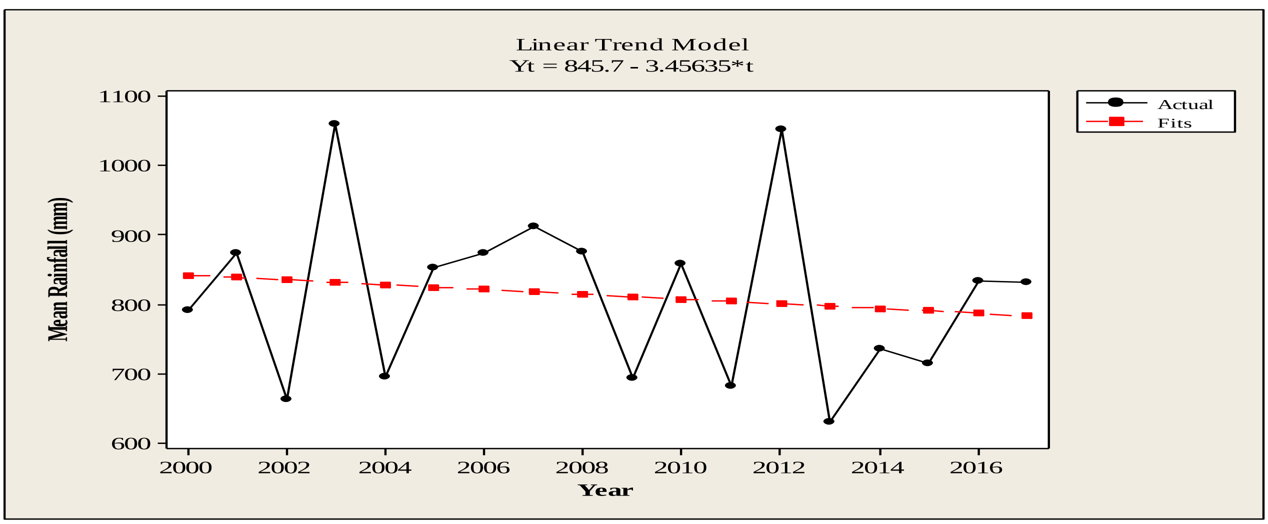

Fig. 2: Trend of mean annual rainfall in Southern Borno between 2000 and 2017

The mean monthly rainfall distribution in Southern Borno in fig.3, shows that the monthly rainfall characteristic is mono-modal, with a single peak usually in August, unlike in Awka

Southeast, Nigeria, where it is bi-modal as revealed by (Chukwudi, *et-al*, 2017). The results also revealed that rainfall in the study area for the period of study is concentrated in five (5) months, beginning from June and ending in October. Higher rainfall is mostly experienced in the months of August and September.

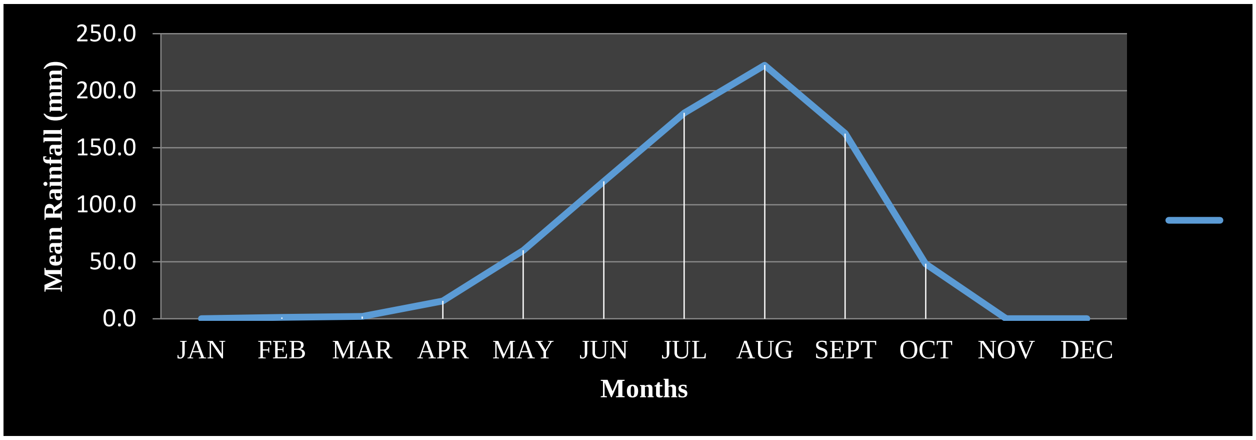

Fig. 3: Average means monthly rainfall of Southern Borno between 2000 and-2017.
Source: NIMET, Lagos

Fig. 4 shows records of average monthly rainfall for the period of study. The result revealed that whenever the mean monthly rainfall of an onset month is below average, maximum monthly rainfall is recorded in the month of September but when the onset monthly mean is above the calculated average, highest rainfall is recorded in the month of August.

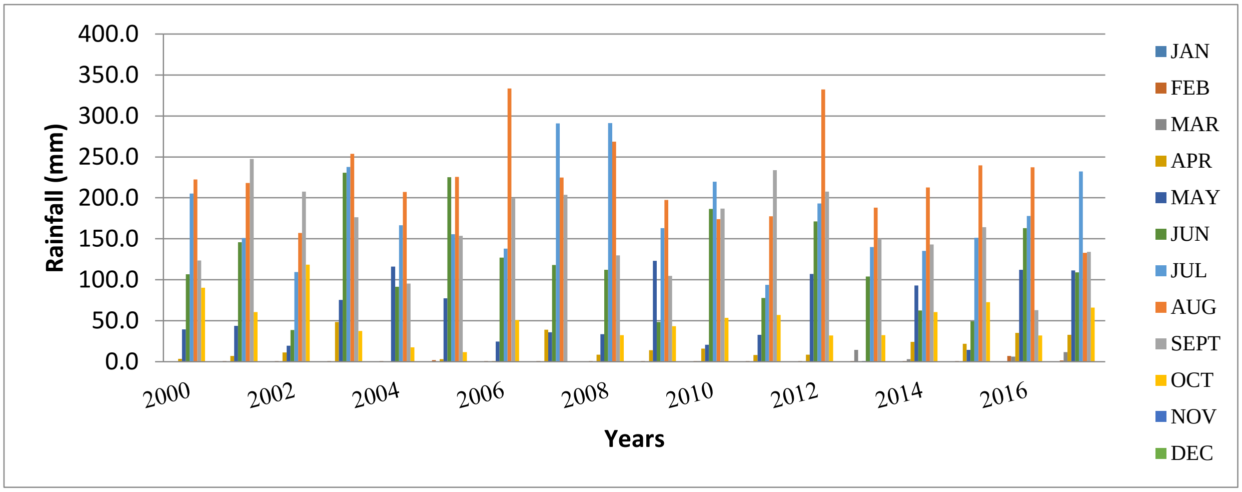

Fig. 4: Monthly rainfall of Southern Borno between 2000 and-2017.
Source: NIMET, Lagos (2017)

Onset, cessation and length of rainy days

Attempt was made to determine the onset, duration and cessation of the rainy season in the study area for the period under investigation using the Cumulative Index Analysis of Walter (1967), where onset of rains in Nigeria is defined in terms of the time of receiving an accumulated amount of rainfall in excess of 51 mm^3. The result is presented in Table 2 below. The result revealed that onset of rains was mainly in the month of May, June and July in the study area for the period of study. It was predominantly in the month of June followed by the month of May, with the number of years for individual months over the period of study being 9 and 6 respectively with an unusual situation in the 2002.

Table 2: Mean annual onset, cessation dates of rains and the number of Rainy days

Year	Onset	Cessation	Rainy Days
2000	3rd June	17th Oct	136
2001	1st June	26th Oct	148
2002	4th July	13th Oct	102
2003	1st May	2nd Sept	125
2004	14th May	11th Sept	131
2005	19th May	8th Sept	113
2006	6th June	31st Oct	148
2007	4th June	8th Oct	127
2008	5th June	4th Sept	92
2009	9th May	2nd Sept	117
2010	5th June	29th Oct	147
2011	7th June	28th Oct	144
2012	12th May	3rd Sept	115
2013	14th June	4th Sept	83
2014	9th May	26th Oct	171
2015	30th June	22nd Oct	117
2016	4th May	9th Sept	134
2017	3rd May	23rd Oct	173

Source: NIMET, Lagos (2017)

Relationship between mean annual rainfall and number of rainy days (Fig.5) was also determined to find out if there is a correlation between the lengths of rainy days and mean annual rainfall in the study area the result is presented in figure 5 below. The relationship between mean total rainfall and rainy days was found to yield a positive correlation $r = 0.116$ ($p = 0.647$) with coefficient of determination of $r^2 = 0.014$. This result is similar to Chukwudi *et-al* (2017) who also found a positive correlation between number of rainy days and annual rainfall in Awka Southeastern Nigeria. The result implies that mean annual rainfall in the study are increase as the number of rainy days also increase meanwhile reduction in the number of rainy days may equally mean reduction in the mean annual rainfall.

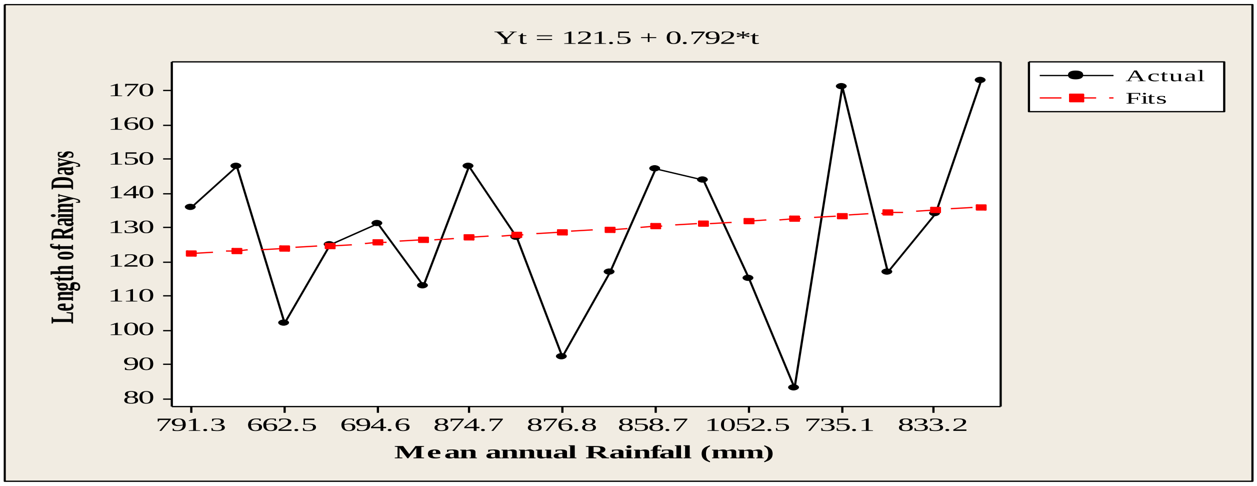

Figure 5: Trend analysis for length of rainy days

A comparison of six years mean of monthly precipitation for the study area was computed and present in table 3 below. The result showed decline in the trend of rainfall after every six years. Thus, it implies that farmers and water users should expect a decline in precipitation after every six years and hence plan accordingly to avoid and or reduce the adverse effects of the decline in precipitation.

Table 3: Six years trend of precipitation of Southern Borno for the period of study

Parameter	2000-2005 (mm)	2006-2011 (mm)	2012-2017 (mm)
Precipitation	822.7	816.5	799.3

Water Balance Computations

Average precipitation as revealed in Table 4 below is 87.507mm^3 which is far below the water holding capacity of the study area. The weighted average annual deficit in the study area is 8.429 mm^3 and the annual surplus is 138.578 mm^3. The result showed that the area has on the average, five months of WD from November to March, while the remaining months, has zero (0) values of water deficit. WS ranging from April to October while the remaining months has zero values of WS. The result showed average monthly PET of 10.182 mm^3 for the period of study with total average PET of 122.188, the month with the highest PET is April with a value of 18.783. Hence, irrigation is required within the periods of water deficit to meet up the soil moisture holding capacity for improved agricultural productions.

Table 4: Average monthly water balance computation for Southern Borno (AWC= 195.3 mm^3).

	P	PET	P-PET	STOR	ΔSM	ET	WD	WS
Jan	0	5.943	-5.943	189.447	-0.126	5.765	-5.943	0
Feb	0	8.862	-8.862	186.636	-2.811	8.469	-8.862	0
Mar	7.541	17.764	-10.223	185.34	-1.296	16.858	-10.223	0
Apr	62.522	18.783	43.739	156.113	-29.227	15.014	0	43.739
May	176.632	16.699	159.933	86.11	-70.003	7.363	0	159.933
Jun	125.36	8.211	117.151	81.304	-4.806	3.183	0	117.151
Jul	228.437	8.209	220.228	63.241	-18.063	2.658	0	220.228
Aug	136.079	5.337	130.742	99.992	36.751	2.737	0	130.742
Sep	168.577	6.935	161.642	85.36	-14.632	3.031	0	161.642
Oct	144.938	8.326	136.612	97.032	11.672	4.137	0	136.612
Nov	0	11.306	-11.306	184.315	87.283	10.67	-11.306	0
Dec	0	5.813	-5.813	189.573	5.258	5.643	-5.813	0
Total	1050.086	122.188	927.9	1604.463	0	85.528	-42.147	970.047

This result means that potential evapotranspiration in the study area is highest in April and lowest in December. The result for available water which is actual storage of soil moisture (STOR) for each month shows that soil moisture storage is high in between months of November to March, which implies that additional water is required to meet up the water deficit in those month. Thus, irrigation is required to meet up plants water demand. While for the months of April to October, storage of soil moisture is low coupled with the surplus water and rainfall within the period, runoff is eminent. As such, rain fed agricultural activities can proof successful within this period.

Water balance status

Summary of the average water balance status of the study area for the period of study was computed and determine, the result is presented in Table 5 below and graphically depicted in fig. 6 below.

Table 5: Summary of P, PET, ET and APWL

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	0	0	7.541	62.522	176.632	125.36	228.437	136.079	168.577	144.938	0	0	1050.086
PET	5.943	8.862	17.764	18.783	16.699	8.211	8.209	5.337	6.935	8.326	11.306	5.813	122.188
ET	5.765	8.469	16.858	15.014	7.363	3.183	2.658	2.737	3.031	4.137	10.67	5.643	85.528
APWL	-5.943	-8.862	-10.223	-43.739	-159.933	-117.149	-220.218	-130.742	-161.642	-136.612	-11.36	-5.813	-1012.236

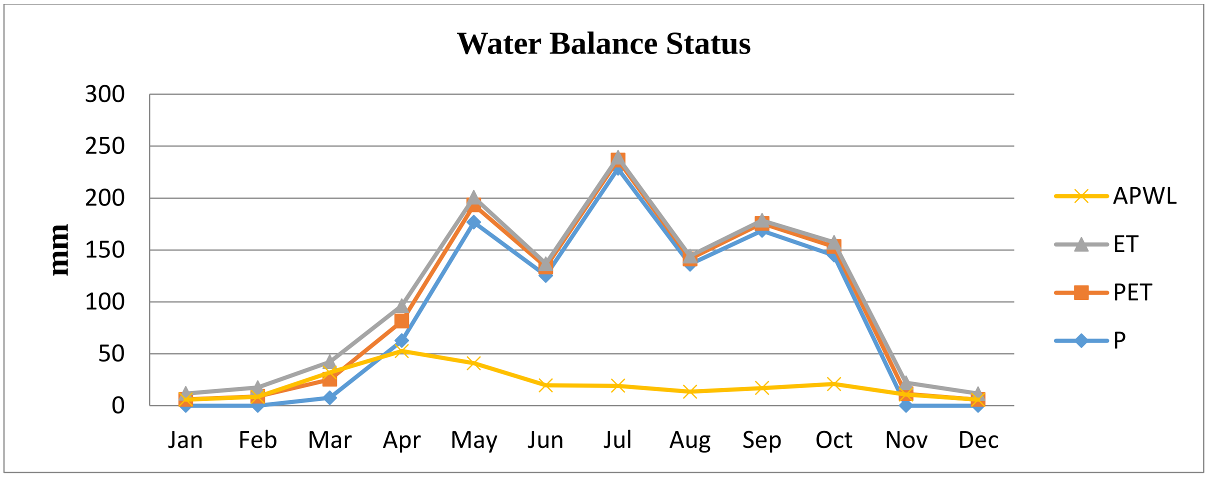

Fig. 6: Status of water balance

Fig. 6 shows the status of water balance, while Table 6presents the summary of water balance. The graph shows that precipitation (P), potential evapotranspiration (PET) and actual evaporation increased from January to reach its peak in July. The accumulated potential water loss does not exceed 50mm^3 throughout the period.

Conclusion

This paper has attempted to determine the characteristics of rainfall in the study area. It analyzes trends in rainfall characteristics and associated water budget components. The results of the study showed that average mean annual rainfall for the period of study is 811.3mm^3 and the standard deviation from the mean is 132.5mm^3, maximum rainfall was 1062.8mm^3 recorded in 2003 while the minimum was 630.1mm^3 in 2013 ten years later. The trend of annual rainfall distribution pattern in Southern Borno is characterize by increase from below average to above average and then below average intermittently to an unprecedented height before maintaining a steady rise for at least five years before the subsequent repeat of the scenario. The water budget components have equally changed. For agricultural purposes, this study establishes that periods of soil moisture utilization and deficit have reduced by a month while periods of soil moisture recharge and amounts of water surplus have increased. Also, the length of rainy season or the growing season has been shown to increase due to changes in onset periods in Southern Borno and a positive correlation is seen to exist between the annual rainfall amounts and the number of rainy days in a year. Therefore, given the nature of rainfall trend, the possibility of harnessing rainwater by relevant agencies as well as households is encouraged as this could help satisfy levels of water demand in the study area. This paper without doubt, underscores the importance and usefulness of determining trends in hydro-climatic parameters of a region and associated water balance components given their potential contribution in planning and development. However, important linkages have been shown to exist between changes in hydro-climatic parameters and how these changes propagate through changes in the frequency of water related problems such as drought due to changes in periods of soil moisture recharge and utilization and as such should be of concern

Recommendations

The study recommends the followings;

- In the period of water deficits, irrigation should be practice to augment crops water need.
- That given the nature of rainfall trend, harnessing rainwater by relevant agencies as well as households is encouraged as this could help satisfy levels of water demand in the study area
- Based on the results of this study, farmers should brace for decline in precipitation after every five years from the preceding year farmers.
- Farmers should always start planting their crops in June every year

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