CLIMATIC VARIABILITY AND RIVER BENUE DISCHARGES IN
YOLA AND GAROUA, WEST AFRICA

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ABSTRACT

Rainfall variability has been a major concern on the alluvial floodplain groundwater in semi-arid regions around the world. There is need to identify changes in the precipitation variability of rainfall on groundwater in river Benue floodplain for improving irrigation activities in North Eastern Nigeria. The climate variation of Yola and Garoua regions were examined, focusing mainly on rainfall and temperature and hydrological data (river discharge) and their response to the river Benue discharge on the alluvial floodplain groundwater sustainability. Method of the time series analysis for rainfall, temperature data, and the Standardised Precipitation Index (SPI) were used to show the variation of rainfall to the River Benue discharge. The study found that the climatic conditions of Yola and Garoua behave differently and they are negatively correlated. It was also observed that the Yola region climate sometimes behaves as the Sahel climate and sometimes do not behave as Sahel climate. The result of Standardised Precipitation Index analysis show that Garoua region did not show any sign of drought events, whilst Yola region showed drought events between 1966 and 1974. This suggests that Yola region is experiencing shortages of water more than Garoua region.

KEYWORDS: Climate Variability, River Benue, Standardised Precipitation Index, Sahel Climate, River Discharge

INTRODUCTION

The causes of rainfall variability in the Sahel region of Africa during the 1970s and 1980s have long been inferred. According to Nicholson (2013), there have been several drought periods followed by wet episodes in African history. The devastating droughts of the early 1970s prompted researchers such as Lamb and Peppler (1992) to look into the possible mechanisms behind such temporal and spatial variability of rainfall. Rainfalls in semi-arid Africa have been noted for inter-annual fluctuations, with greater impacts on the general hydrological cycle, water resources and food security. This is typical of North-Eastern Nigeria where Upper Benue Basin is situated. Le Barbe and Label (2002) carried out a study on rainfall variability in West Africa between 1950 and 1990 and noted a systematic decrease in the number of rainfall events, which appeared to be correlated to the decrease of mean inter-annual rainfall. Nicholson and Palao (1993) made an overview study of Sahel rainfall fluctuations and found the region to have experienced decadal rainfall anomalies since 1960s, depicting decreasing trends. Also a study by Dai et al. (2004) showed rainfall to have positive trends since late 1990s.
Rainfall variability initiates fluctuation in river flows. Coupled spatio-temporal interconnections exist between precipitation, local topography, geology, sediment types and groundwater recharge and river flow (Vincent et al., 2007; Asante et al., 2012; Trung, 2013; Taruvinga et al., 2013). A critical analysis of precipitation patterns over a given drainage basin would serve a great deal of insight into the connection between groundwater recharge and long-term river discharge variability. The influence of climate variables on river flow regimes is complex with intricate interactions between evaporation losses, soil moisture conditions, catchment geology, land use and artificial changes to streams (Biggs, 2009).

Several studies have stressed the necessity of water resources management in Nigeria (Ojo et al., 2003). However, as pointed by MacDonald et al. (2005), limited knowledge of how African groundwater responds to climate change is available. This study analysed the effect of climate variability on river Benue discharge in Yola, northeast of Nigeria and Garoua in northern Cameroon.

STUDY AREA

The Yola region lies between latitudes 9° N and longitude 12° E. The surface elevation of the region varies from 149 to 228 m above mean sea level (MSL) and falls within the Upper Benue Basin, which has a catchment area of about 750 km² (Figure 1). The Yola region is characterised by arid and semi-arid climates, with strongly contrasted dry and rainy seasons. The dry season is from late November to May and is characterised by the pressure of Harmattan wind blowing from the Sahara Desert (Adebayo, 1999). The maximum monthly mean temperatures range from 31 to 40 °C and minimum temperatures range from 15 to 23 °C. Highest temperatures were recorded in April; being the peak period of the dry season in the region. The lowest mean monthly temperatures were recorded in the months of December and January; being the winter period in the region.

Garoua is located at latitude of 9° 18' N and a longitude of 13° 24' E in Northern Cameroon and at an altitude of 242 m (Figure 1) and covers an area of about 4,700 km². The mean annual temperature is about 28 °C. The maximum and minimum temperatures of the region generally follow the seasonal change, being higher during the dry season (October to May). The Maximum value reached up to about 42 °C in March and lower during the rainy season (June to September), with minimum value around 18 °C in January. It is characterised by a tropical climate having a dry season from October to April and rainy season from May to September (Moussa et al., 2011), similar to Yola.

The floodplain is drained by the River Benue, which is the largest and only perennial river in the regions. The river Benue is fed by two major streams in Cameroon, Mayo Kebbi and river Faro (Figure 1) and flows into Nigeria 250 km downstream.
HISTORY OF DROUGHTS AND FLOODS EVENTS IN THE REGION

Drought is caused by deficiency in precipitation for a long period that causes crop failure, water shortages, death of livestock, famine, etc. (Abaje et al., 2013). The West African Sahelian region has been going through a long-term drought since 1960s (Amogu et al., 2010). This trend has been particularly noted in the North Eastern parts of Nigeria.

Regarding the causes of floods in the region, Tukur and Ray (1994) and Ankidawa (2011) found out from observation of the flood events over the years that the release of water from Lagdo Dam (see Figure 1) in Cameroon or prolonged (unprecedented) rainfalls due to climatic changes are largely responsible.

Although flood events are consistently being observed in the past, only few drought events however occurred in Yola such as in 1966 and 1968, which led to the drying of river Benue and its floodplain (Tukur and Ray, 1994; Ankidawa, 2011). Such event will likely re-occur in the region. This will potentially lead to lowering of groundwater level of the floodplain.

It should be noted that the occurrence of drought in Yola region is not the same with the occurrence of droughts in the Sahel. Increase in drought events in the Sahel and decrease in drought events in the Yola region have been shown. This may be due to the differences in the climate been observed between Sahel and Yola region. Sometime Yola climate behaved as Sahel climate for example the droughts that occurred in 1966 and 1968 were both observed in the Sahel and Yola region. However, the Sahelian droughts in 1972 to 1973 and 1997 to 1998, which were observed in the Sahel, were not observed in the Yola region.

The aggregate impacts of droughts on the Nigerian economy are in the order of 4 – 6%, which can be neglected (Benson and Clay, 1998). As pointed out by Izinyon and Ajumuka (2013), general concern existed about the increasing risk from hydrological extremes, from recent changes in frequency and severity of floods as well as droughts leading to increase in hydrological variability. During the 1966 – 1968 droughts, about 250,000 people, along with 12 million animals, were estimated to have died from starvation (Tarhule and Lamb, 2003). Many families and some of their members became engaged in waged employment that involved migration to the urban areas. Nomads living in the traditional grazing lands in the Northern parts of the North East region had to move Southward of Nigeria (Afolayan and Adelekan, 1998). Agricultural yields fell to about 40% of normal yields. It was also reported by Ati et al. (2007), that the droughts of the 1960s were responsible for the social backwardness, left farmers impoverished with poor quality of life, especially among the less privileged ones in the Northern Nigeria.

Some of the measures taken after the 1960s drought were the following: farmers had to change from mono-cropping to multi-cropping and herders had to keep goats and drought-tolerant animals in place of cows (Swinton, 1988). As reported by Afolayan and Adelekan (1998) droughts lead to the migration of families from North to Southern part of Nigeria due to famines.

METHODOLOGY

Data Base

The study was based on the data obtained from the Department of Hydrological Unit of the Upper Benue River Basin Development Authority (UBRBDA), Yola for the analysis. The meteorological data were the rainfall (1960 – 2012), temperature (1960 – 2012) and evaporation (1982 – 2012). The meteorological gauge station was located at UBRBDA, Yola head office South East approximately 5 km from the study site at latitude 9˚ 11’ N and longitude 12˚ 30’ N.
hydrological data were the water stage and discharge of river Benue (1960 – 2012). The discharge gauge station was located on River Benue near the main Yola Bridge approximately 500 m from the study site at latitude 9˚ 15’ 20” N and longitude 12˚ 28’ 04” N. The data set for Garoua included the observed daily temperature and rainfall data for the period 1957 to 2006 obtained from the website of the University Cooperation for Atmospheric Research (UCAR) year.

**Time Series Analysis**

Microsoft excel program was used to compute a Time Series Analysis using data obtained. The Microsoft excel software was used to generate the trend lines automatically for the available data.

**Statistical Analysis**

National Climatic Data Center (NCDC, 2013) defined Standardised Precipitation Index (SPI) as an index based on the probability of recorded amount of precipitation, and the probabilities were standardized. So that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts were below the median, and half were above the median). Among the several proposed indices for analysing the climate variability were methods such as Standardised Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI), etc. SPI is widely used by different researchers for assessing climate variability (Guttman, 1998; Rossi and Cancelliere, 2002; Cancelliere et al., 2007). For the purpose of this study, SPI was used to assess the climate variability of the region and for correlating with river Benue discharge in Yola.

Standardised Precipitation Index (SPI) was used to determine the effects of precipitation shortages to groundwater level, river discharges and soil water content (Ceglar et al., 2008). SPI was designed to assess the precipitation deficit in different time scale such as 3, 6, 9, 12, 24 months. The SPI defined negative values as drought and positive values as wet conditions. As suggested by McKee et al. (1993), to obtain a reliable result, SPI requires a continuous monthly precipitation data for at least 30 years or more. For the case of Yola; fifty two year (52) data were used to estimate the rainfall variability for the region.

**RESULTS AND DISCUSSIONS**

**Time Series Analysis of Yola Region**

Figure 2 shows the average annual temperature for the Yola region for the period 1980 to 2012. It can be seen that fairly consistent patterns was observed between 1980 and 1986. Decrease in temperature by 4.5˚C was however observed between 1995 and 2000. A very weak negative trend was highlighted.

The temperatures in the region were generally high and this had an impact on the groundwater, especially during the dry season period. As reported by Kirtman et al. (2013), between 2016 and 2035 global average temperature was predicted to increase by 1 to 1.5˚C (Kirtman et al., 2013; Abdulkadir et al., 2013). In the North Eastern Nigeria over the period 1961 to 1991, the observed average temperature increase by about 1.5˚C. The floodplain alluvial sediment of the Yola region consisted mainly of sand and sandy silt, therefore any increase in temperature will rapidly increase the rate of water lost from the alluvial floodplain through evapotranspiration, which will lead to the lowering of the groundwater level.
The rainfall regime was characterised by a single peak, the rainy season starting in May/June as the Inter-Tropical Convergence Zone (ITCZ) passes Northwards, with a maximum in August and finishing quite rapidly in October (Adebayo, 1999). The total annual rainfall of the area is on the average 914 mm (taken over the period 1960 to 2012). The higher rainfall rates were observed between June and October each year; while the rest of the months were virtually dry (November to May). This might have resulted in lowering the floodplain groundwater in winter and spring, which influenced irrigation.

High rainfall usually experienced in August and September each year, with changing flood frequency, varies from year to year. For example when the 2012 flood occurred, it submerged the State, causing destruction of lives and properties and displaced over 3000 families (BBC, 2012). Figure 3 shows the variation of the annual rainfall from 1960 to 2012. It can be seen that, after the dip in 1964 to 1968, and then a further dip with a starting point at the beginning of the 1970s. The area had nearly constant rainfall between 1980 to 2000 as recently pointed out by Dai et al. (2004). The present analysis does not show any trend.

Evaporation exceeded rainfall considerably with total annual values between 1676 to 2788 mm. This phenomenon explained the farmers’ strong dependence on groundwater for water supply and irrigation in the region. Evaporation is
generally high due to high insolation but high relative humidity in the region, which is low between January and March and increases from April to reach its peaks in August and September. Figure 4 shows the variation of the annual evaporation for 1983 to 2012. It can be seen that, after the increase shown towards 2004, the area started experiencing a generally lower rates from 2009 onwards. The sharp changes observed in 2008 and the following years could be due to the error in the data measurement. This suggested that the evaporation patterns in the region decreased. It can be seen that the evaporation trend in the region was higher as compared to rainfall trend.

![Figure 4: Variation of Annual Evaporation in Yola for the Period, 1983 – 2012 (For Source of Data see Figure 2)](image)

**Time Series Analysis of Garoua region**

Figure 5 shows the average annual temperature in Garoua over the period 1956 to 2006. The mean annual temperature is about 28 °C. The maximum and minimum temperatures of the region generally follow the seasonal change, being higher during the dry season (October to May). Maximum value reached up to about 42 °C in March and lower during the rainy season (June to September), with minimum value around 18 °C in January. Mean annual temperatures increased from 1957 to 1966 by 1.2 °C. However, from 1967 to 1969 a short decrease in annual mean temperature was observed. This was followed later by a marked decrease in mean annual temperature between 1972 to 1981 by 1.8 °C. Nevertheless, as reported by Ayonghe (2001) and as shown on Figure 5, overall there is hardly any change in the temperature in Northern Cameroon (Cheo et al., 2013).

![Figure 5: Garoua Annual Average Temperature (Produced from Data Obtained from Cheo et al., 2013)](image)
Figure 6 shows the total rainfall distribution over Garoua region. The wet period occurred from May to September with over 1000 mm rainfall. The peak was usually recorded during the July – September period (Mohr and Thorncroft, 2006). The dry period occurred from November to April. The mean annual rainfall amounted to 1018 mm (from 1957 to 2006), hence slightly higher than at Yola. Rainfalls occurred either as low altitude monsoon rains or as occasional high altitude squally showers (Njitchoua et al., 1995). Despite the high value of the annual rainfall, only a small fraction of rainfall contributed to the groundwater recharge because of the high annual evaporation (about 1800 mm) which was nearly double of the mean annual rainfall (Njitchoua et al., 1995).

The rainfall pattern is characterized by noises over the years, with nearly the absence of trend. Drought and flood events have occurred in the region with an increasing frequency over time (Molu and Lambi, 2006).

\[ y = 2.61x - 4.137.91 \]
\[ R^2 = 0.03 \]

**Figure 6: Garoua Total Rainfall per Year (Produced from Data Obtained from Cheo et al., 2013)**

**Comparison between Yola and Garoua Climate Variability**

Figure 7 showed the comparison for the observed annual average temperature in Yola (1983 – 2012) and Garoua (1957 – 2006). Consistency between these two (2) stations was only observed from the period 1990 to 1999. However, for the rest of the years, much difference occurred. An inconsistency was observed especially between 2000 to 2009. This inconsistency could be due to error in the data measurement. No statistical correlation was observed between Yola and Garoua region (Table 1), indicating Yola and Garoua regions behave differently in terms of temperature.

**Figure 7: Annual Average Temperature for Yola and Garoua**
Table 1: Statistical Correlation Values and Significance Range between Yola and Garoua Annual Average Temperature (Significant p-Value range 0 to 0.05, not Significant p-Value Range 0.06 to 1)

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<th>Garoua Correlation</th>
<th>P-value</th>
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<td>Garoua</td>
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<td>1</td>
<td>0</td>
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Figure 8 showed the comparison of the total annual rainfall in Yola and Garoua regions. It can be seen that Garoua region showed slightly higher rainfall values: 100 mm more of mean average rainfall. This was possibly because Garoua (242 m) was 90 m higher than that of Yola (151 m). Garoua is located on the Mandara Mountains (the Adamawa highlands), while Yola is located on the lowland of Adamawa Mountains. The higher catchment area receives more moist air than the lower catchment areas (Dettinger et al., 2004). However, both regions showed noises of total annual rainfall over the years. No correlation was observed between Yola and Garoua regions (Table 2). This suggested that Yola and Garoua regions have different climate patterns.

Table 2: Statistical Correlation Values and Significance Range between Yola and Garoua Total Rainfall (Significant p-Value Ranged from 0 to 0.05, Not Significant p-Value Ranged from 0.06 to 1)

<table>
<thead>
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<th>Garoua Correlation</th>
<th>P-value</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>Garoua</td>
<td>-0.172</td>
<td>1</td>
<td>0</td>
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</tbody>
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River Benue Discharge and Water Stage

Numerous tributaries in Cameroon (see Figure 1) join river Benue. Gauge stations were installed along River Benue at Garoua and Yola, at about 100 km apart in a straight line, for monitoring the flow patterns of the river. Mayo Kebbi and River Faro are the main tributaries to river Benue in Cameroon and the river Benue flows empty into Nigeria East of Yola (see Figure 1). The average discharge of river Benue at Garoua gauge station is about 375 m$^3$/s (Shahin, 2002). As a result of the increased flows from river Mayo Kebbi and river Faro downstream of Lagdo Dam, the monthly discharge of river Benue increased to over 3,500 m$^3$/s (discharges measured at Yola gauge station) (Figure 9).
The Benue river water level is at its highest peak in August and October each year (Figure 10). As rainfall ceases towards the end of October, the river Benue’s water level begins to fall. It can be observed that low mean river stages were recorded in the period January to June. The lowest water level of river Benue at Yola gauge station is observed between April and May each year.

Figure 10 shows the mean river stage hydrograph for river Benue at Yola gauge station, for 1960 to 2012, that showed the impact of Lagdo Dam upstream before and after its construction, i.e. 1984. It can be observed that in the dry season period before the dam construction the floodplain water table is lower. This suggested that Lagdo Dam has positive impact downstream, especially in the study site during the dry season period. This was the time farmers’ exploit the shallow alluvial groundwater for irrigation with low-cost hand-drilling techniques.

The confidence limits showed significance ranges for the water stages except May and July that showed slightly insignificant confidence limits range. This suggested that the mean monthly water stages in river Benue gave significant value range and that the stages were more erratic at the beginning of the wet season.

Figure 11 shows the annual peak river Benue discharge observed at the Yola gauge station for the period 1960 to 2012. Figure 11 suggested an increase in peak discharge. The slope (66.5 m³ s⁻¹ y⁻¹) is statistically significant and may be attributed due to the contributions from tributaries into river Benue upstream of Yola and Garoua. The lowest discharge was observed in 1973. This may be linked to the drought that occurred in the early 1970s. The droughts that occurred between 1966 and 1968 in Yola and West Africa were not well reflected in the discharge plot. The highest discharge was
observed in 2012. This reflected the severe flood that occurred that year. It can be seen, noises over the years, an increased trend that occurred with $R^2$ of 0.26.

![Graph showing total annual discharge of River Benue in Yola](image)

**Figure 11: Total Annual Discharge of River Benue in Yola (For Source of Data see Figure 2)**

In comparison between discharge and rainfall patterns, it was observed that discharge showed significant increase in trend ($R^2=0.26$) while rainfall showed no trend. The increase in the discharge trend could be attributed to the contribution from the tributaries upstream of Yola, we already know that there is a difference between Yola and Garoua. Therefore, it was likely that there was more divergence upstream with some areas in the highlands receiving more rainfall.

**Standardised Precipitation Index (SPI)**

Figure 12 showed the comparison between Garoua and Yola SPI. Between 1970 and 2003, the trend showed some similarity for the two regions. However, major inconsistencies were observed between 1960 and 1969. A sharp decrease was shown for the Yola average SPI value between 1966 to 1970 indicating drought that occurred between 1966 and 1968, but was not seen in Garoua. Showing a clear difference in the rainfall pattern, but the 1966 and 1968 droughts was seen in the Sahel. Table 3 shows the statistical correlation of Standardised Precipitation Index between Yola and Garoua regions. No correlation was observed between Yola and Garoua regions. This suggested that Yola and Garoua regions behaved different in climate. It was also observed that Garoua region did not show any sign of drought events, whilst Yola region showed drought events between 1966 and 1974. This suggests that Yola region is experienced shortages of water than Garoua region. The 1960s droughts of Yola were part of the wide Sahelian pattern that did not reach Garoua.

![Graph showing average standardised precipitation index value for different years in Yola and Garoua](image)

**Figure 12: Average Standardised Precipitation Index Value for the different Years in Yola and Garoua. (Arrows Showing the Drought of 1966 and 1968 in Yola region)**
Climatic Variability and River Benue Discharges in Yola and Garoua, West Africa

Table 3: Statistical Correlation Values and Significance Range between Yola and Garoua Standardised Precipitation Index (Significant p-Value Range 0 to 0.05, not Significant p-Value Range 0.06 to 1)

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<th>Yola P-value</th>
<th>Garoua Correlation</th>
<th>Garoua P-value</th>
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<td>Garoua</td>
<td>-0.052</td>
<td>1</td>
<td>0.73</td>
<td>0</td>
</tr>
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CONCLUSIONS

It was shown that over the period of the last 50 years that: 1. The temperature showed no definite trend (see Figures 2 and 5), 2. The rainfall showed no definite trend (see Figures 3 and 6), 3. The evaporation showed an unrealistic drop in 2008 to 2010 (see Figure 4), 4. The river Benue discharge was on the increase (see Figure 11). However, it showed large variability. It was also observed that the climate of Garoua, only 250 km upstream of Yola was different in terms both of temperature and rainfall.

The outcome of our critical analysis showed that the Yola region climate sometimes behaved as a Sahelian climate. For example, the droughts that occurred in 1966 and 1968 were observed in both Yola region and in the Sahel region. Sometimes the Yola region climates do not behave as Sahel climate. For example, the major droughts in West Africa in the last century that occurred in 1913 – 1914, 1972 – 1973, 1982 – 1983 and 1997 – 1998 did not occur in the Yola region. The weak increase in temperature and rainfall trends observed in this study was in line with what was reported by Kirtman et al. (2013). Therefore, it was necessary to understand the variation of climate in the Yola region; this will enable the understanding of the groundwater levels in the region for abstraction with hand-drilling techniques. It is important to understand the suitability of water abstraction technique in the context of the climate of Yola region.

ACKNOWLEDGEMENTS

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