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Advances In Multidisciplinary & Scientific Research
AIMS Research Journal
A Multidisciplinary & Interdisciplinary Journal

Vol. 2, No. 2, June, 2016

Rainfall Variability: Implications for Flood Frequency in Sokoto, North-Western Nigeria.

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ABSTRACT

Rainfall in the Northern part of Nigeria in general and that of Sokoto in particular varies in space and time. The variability is so marked that it has a devastating effect on the socio-economy of the place. This present studies assessed the variability of rainfall by considering its magnitude, frequency seasonality of occurrence and its implication for flood frequency in the area. The specific objectives of the study include (i) to analyze the variability in rainfall over a period of 62 years (1949-2010), (ii) to examine the relationship between rainfall variability and flood frequency in the study area (iii) to determine the period of flooding in the area and (iv) to examine the adaptation and mitigation options for management of flood in the area. To achieve these, rainfall data for 62 years (1949-2010) and evapotranspiration for the same period for Sokoto station was used, the Spearman rank correlation coefficient was used to ascertain the trend in rainfall, the Standardized rainfall anomaly index was used to examine the variability in rainfall, The Gumbel extreme value distribution was used to determine the magnitude and frequency of extreme rainfall and hence, the recurrence interval for flood occurrence. The results of the study revealed that rainfall in the area is on the increase with a positive correlation of 0.08 which was found to be significant at 95% confidence level

Keywords: Adaptation, Climate change, Flood frequency, Mitigation, Rainfall variability

Aims Research Journal Reference Format:
Ojoye, S., Yahaya, T.I., Odekunle, M.O. & Sulyman A.O. (2016) Rainfall Variability: Implications For Flood Frequency In Sokoto, North-Western Nigeria. Advances in Multidisciplinary Research Journal. Vol 2, No.2 Pp 201-210

1. INTRODUCTION

The potential consequences of climate change are profound, particularly on people in the less developed countries. The question is therefore not whether climate change is happening, but what to do about it. Over the last 20 years climate change has become an increasingly high profile issue both from a social and economic viewpoint. It's not only the scientists and environmentalists who are concerned about climate change. Governments, politicians and the general public are also taking an interest in climate change. As a result of global warming, the type, frequency and intensity of extreme events, such as tropical cyclones (including hurricanes and typhoons), floods, droughts and heavy precipitation events, are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (Kolawole, et. al. 2011).

Increasing flood risk is now being recognized as the most important sectoral threat from climate change in most parts of the world. This has prompted public debate on the apparent increased frequency of extreme, and in particular, on perceived increases in rainfall intensities (Odekunle, 2001). Several studies have adduced extreme rainfall to be the major cause of flood worldwide. Such studies includes Gobo (1988), McEwen (1989), Oriola (1994) Babatolu (1998); FEPA (1998), Fowler and Kilsby (2003) Odekunle (2001), Ologunorisa (2004), and Dami (2008).Other studies have identified the characteristics of extreme rainfall that are associated with flood frequency to include duration, intensity, frequency, seasonality, variability, trend and fluctuation (Olaniran, 1983; Ologunorisa, 2001; Ologunorisa and Diagi, 2005; Odekunle et. al., 2007 and Ojoye, 2012).

Flooding affects more people on an annual basis than any other form of natural disaster. A variety of climatic and non-climatic processes influence flood processes, resulting in river floods,
flash floods, urban floods, and coastal floods. These flood-producing processes include intense and /or long-lasting rainfall. Floods depend on rainfall intensity, volume, timing, phase, and antecedent conditions of rivers and their drainage basins.

In Nigeria, studies on rainfall variability and their implication for flood frequency have been restricted to the southern parts of Nigeria, little or no attempt has been made in the literature to study the implication of recent changes in rainfall pattern on flood frequency in northern Nigeria despite increase frequency of floods in this region, and this is where this study derives its relevance. The present study attempts to examine recent changes in rainfall pattern, its implication on flood frequency and the management practices put in place to mitigate this menace in a seasonally flooding zone in Northern Nigeria.

2. THE STUDY AREA

The study area is Sokoto, north-western Nigeria. The area is found between latitudes 10^0 N and 13^0 58' N; and longitudes 4^0 8'E and 6^0 54' E. The area so defined covers a land area of approximately 62,000km2. It lies to the north-west of Nigeria and shares its borders with Niger Republic to the north, Zamfara State to the South- East, Kebbi State to the South-West, and Benin Republic to the west. The southern boundary is arbitrarily defined by the Sudan savanna.Like the rest of West Africa, the climate of the region is controlled largely by the two dominant air masses affecting the sub- region. These are the dry, dusty, tropical- continental (cT) air mass (which originates from the Sahara desert), and the warm, tropical- maritime (mT) air mass (which originates from the Atlantic Ocean). The influence of both air masses on the region is determined largely by the movement of the Inter-Tropical Convergence Zone (ITCZ), a zone representing the surface demarcation between the two air masses. The interplay of these two air masses gives rise to two distinct seasons within the sub-region. The wet season is associated with the tropical maritime air mass, while the dry season is a product of the tropical continental airmass. The influence and intensity of the wet season decreases from the West African coast northwards. Therefore, precipitation in the whole sub-region of West Africa depends on thunderstorm activity which occurs along disturbance lines called "line squalls" and, about 80 percent of the total annual rainfall for most places is associated with line squall activities which are prevalent between June and September (Adefolalu, 1986).

Sokoto experiences a short rainy period and a long dry season. The rainy season starts about mid-May in the southern fringes of the study area and about mid-June in the northern districts. The season ends about middle to late September in the northern districts, and early October in the southern districts. The dry season, on average, lasts between seven and eight months, usually from October to May. During the dry season the climate is dominated by the dry-dusty wind (harmattan), which blows Sahara dust over the land. When the dust hangs in the air, it causes serious air pollution which results in dirt virtually everywhere, and also reduces visibility. With an annual average temperature of 38.3 ^{0}C, Sokoto is one of the hottest cities in Nigeria, with maximum daytime temperatures hovering between 35^0C and 40^0C which makes this dry environment quite unbearable. The warmest months are February, March and April when daytime temperatures can exceed 45^0C.

3. MATERIALS AND METHODS.

3.1 Data Collection and Analytical Techniques

The data used for this work are from secondary sources. These include data on rainfall, evapotranspiration, and flood occurrence in Sokoto town. The rainfall data used are of two types – annual rainfall and extreme daily rainfall. The annual rainfall data covered the period from 1949-2010, while the extreme daily rainfall data spanned 1990 to 2010. The evapotranspiration records are for the period 1990 – 2010. Information on flood occurrence was collected from local newspaper reports, and past history of flood occurrence in the study area were also sourced from the monographs of the Federal Ministry of Environment. Records of annual rainfall in the study area were collected from the Nigeria Meteorological Agency, Oshodi Lagos. The extreme daily rainfall and evapotranspiration data were obtained from the archives of Nigerian Meteorological Agency. In terms of analysis, basic statistical techniques like computation of totals, means and standard deviations were used for preliminary treatment of the data. The annual rainfall trend was determined using spearman rank correlations. In order to determine the significance of the correlation coefficient, it was tested using the Student's T test statistic at 95%confidence level.

The Standardized Rainfall Anomaly Index (SAI) was used in the analysis of annual rainfall variability. The SAI is given as:

$$\text{SAI} = \frac{X - Xb}{SD} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1.0$$

Where:
X is annual rainfall total,
Xb is the mean of the entire series, and
S.D is the standard deviation from the mean of the series.

The extreme daily rainfall characteristics that were analyzed in this study are magnitude – frequency, seasonality and duration. The Gumbel extreme value distribution was used to determine the magnitude and frequency of extreme rainfall and hence, the recurrence interval. The method of recurrence interval used in this study is usually employed in the description of probability of recurrence or incidence of extreme events (Dury, 1964; Lang, 1997; Versace and Ferrari, 1997 and Ologunorisa, 2004). It is primarily concerned with prediction, such as the estimation of the magnitude of the daily, monthly and annual rainfall total likely to be exceeded on average, say, once during fifty years. Generally, there are two ways by which recurrence interval of rainfall data is carried out, namely: partial series and (b) annual series analyses. The partial series involves the extraction of all values above a given magnitude from the record of daily rainfall over the years of study. The annual series on the other hand involves the selection of the maximum values occurring in each year. The more commonly employed method is the annual series and it was employed in this study to determine various return periods. To determine the period of flooding in the study area, recurrence interval is used.

The procedures involve arranging the annual series in descending order of magnitude. The recurrence interval (RI) is determined thus:

$$\text{RI} = \frac{N + 1}{R} \dots\dots\dots\dots\dots\dots\dots\dots\dots 2.0$$

Where:
N = number of events in the series;
R = rank of individual event;
and RI is return period expressed in years.
The rainfall values were then plotted against their recurrence intervals and a line of "best fit" on the scatter diagram was drawn as described by Dury (1964). The water budget graph was determined by superimposing monthly averages of evapotranspiration on monthly rainfall totals for 1960-2010. From this, the duration of flooding in the study area was determined, and this is the period when rainfall is in excess of evapotranspiration.

4. RESULTS AND DISCUSSION

4.1 Annual Rainfall Trend in North-Western Nigeria.

A trend analysis of the annual rainfall of Sokoto, for the 62 years period (1949-2010) was carried out using the Spearman Rank Correlation statistics. The annual rainfall trend over the study period was shown to have a positive correlation coefficient of 0.08. The significance of the trend was tested by the student's T-test, and was found to be significant at 95 per cent confidence level. This is an indication that there is an upward trend in annual rainfall in Sokoto signifying an increase in rainfall.

The rainfall series for the period 1949 – 2010 was further broken into 20-years intervals (i.e 1949-1968, 1969-1988) and for a 22-years period (1989- 2010) in order to depict short-time trends within the same series (see Babatolu, 1998 and Odekunle et. al , 2007). The results of the analyses are presented in Table 1.0

Table 1.0: Summary of Correlation Coefficient of annual rainfall trends in Sokoto

Time	Correlation	Student T-value	Critical value	Result
1949-2010	0.08	1.68	1.66	Significant
1949-1968	0.64	2.40	1.26	Significant
1969-1988	-0.75	1.60	1.26	Significant
1989-2010	0.53	2.10	1.26	Significant

Source: Author's analysis, 2015

The results in Table 1.0 indicate that there is a little variation between the short-term annual rainfall trends and that of the entire time series (1949-2010). The period 1969-1988 indicated an appreciable rainfall decline (-0.75) when compared to other period and the long term period. This decline was widely reported in literatures and was found to be responsible for the 1972/73 and the 1980s drought that affected the entire northern Nigeria (Dami, 2008; Odekunle et. al., 2007; Ojoye, 2013).

4.2 Annual Rainfall Variability in Sokoto

The figure below showed the rainfall variation for Sokoto over a 62-years period (1949-2010) using the standardized rainfall anomaly index.

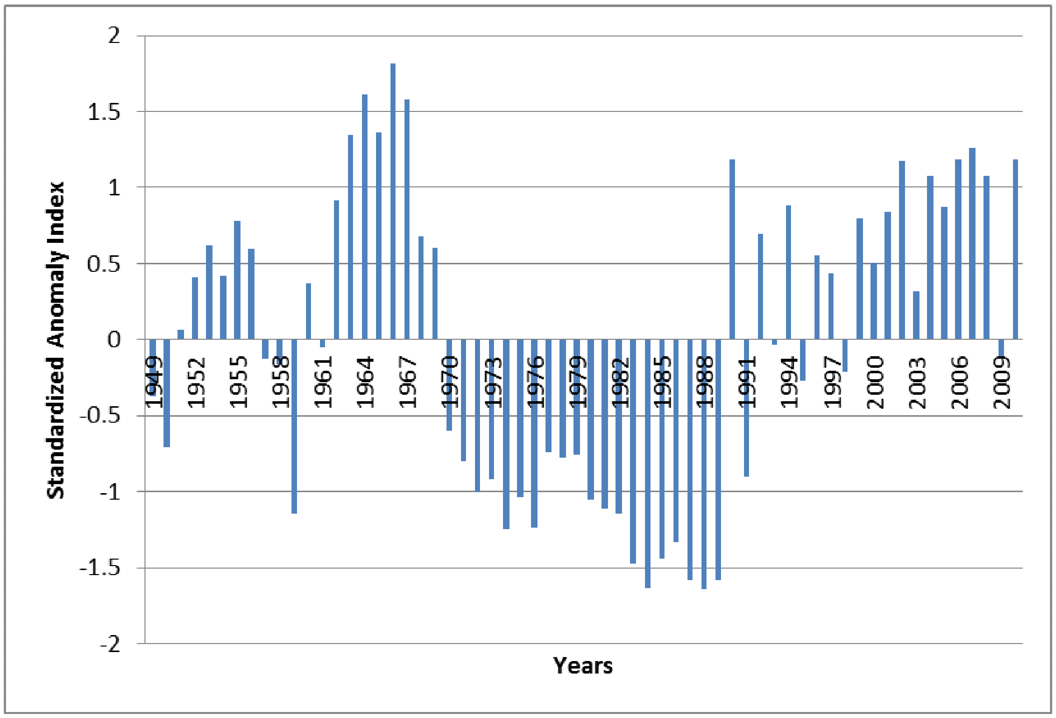


Figure 2.0 : Rainfall fluctuations over Sokoto from 1949-2010.

Figure 2.0 showed that Sokoto has passed through two different sequences over the period; wet and dry season. The station exhibit persistence in the pattern of wet and dry conditions. The remarkably below long-term means were recorded in the periods 1949 and 1950, 1957-1959 and 1970-1989 with 1984 as the year of highest negative deviation. It is apparent from figure 2.0 that the occurrence of wet years was more than the dry years; 28 years was recorded as dry years while the remaining 34 years were wet years. These recent findings contradict the earlier study of Gobo (1988), who argued that for a long-term climatic trend prediction, it is difficult to conclude whether the climate is becoming progressively drier or wetter and corroborate the findings of Odekunle, et. al., (2007) that the northern Nigeria is getting wetter.

4.3 Magnitude- Frequency of Extreme Daily Rainfall in Sokoto

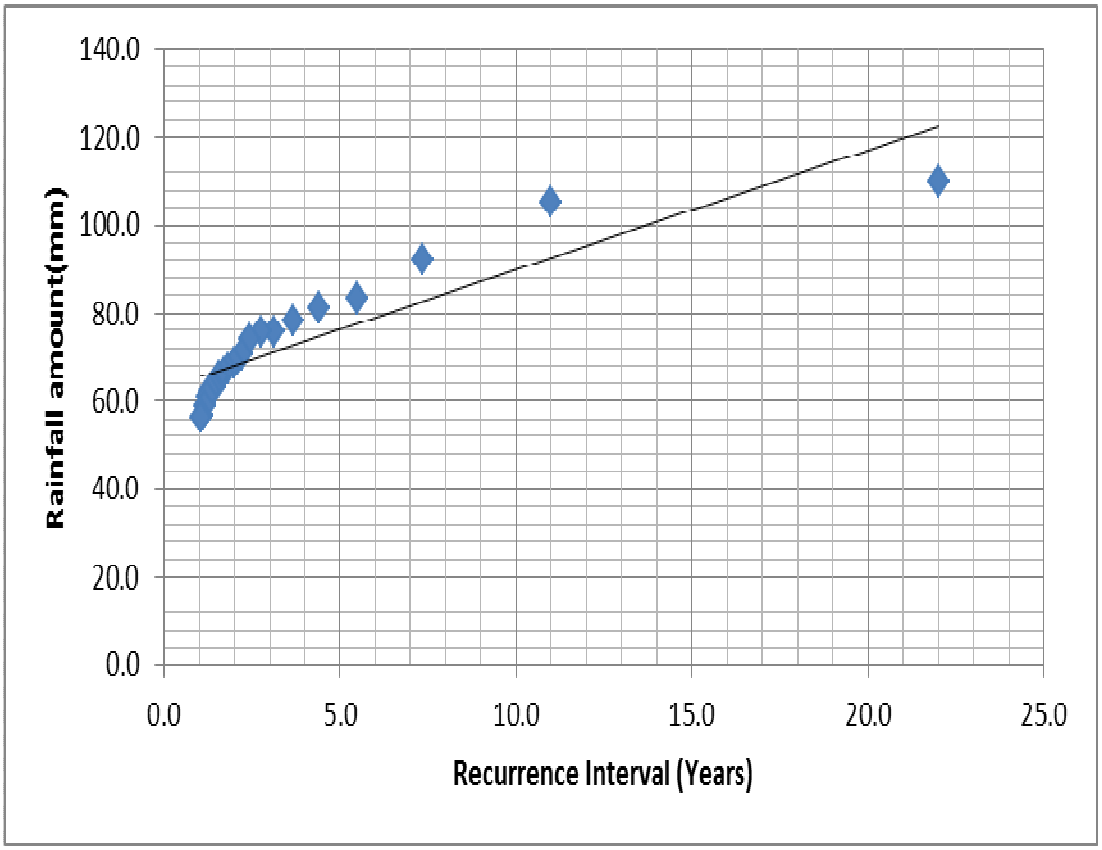
Table 2 shows the values of extreme daily rainfall and their recurrence interval in Sokoto between 1990-2010. The characteristics of the increases, the magnitude of rainfall events increase at a lesser rate until a point is reached where lengthening of recurrence interval will involve no increase in magnitude.

Table 2.0 : Magnitude-Frequency of Extreme Daily Rainfall Events in Sokoto (1990-2010)

Years	Rainfall amount (mm)	Rank	Recurrence Interval (Years)
1990	109.8	1	22.0
1997	105.1	2	11.0
1994	92.4	3	7.3
2001	83.2	4	5.5
2003	81.3	5	4.4
1996	78.2	6	3.7
2002	75.8	7	3.1
1999	75.7	8	2.8
2004	74.3	9	2.4
1998	70.5	10	2.2
1992	68.6	11	2.0
1993	67.5	12	1.8
2005	66.4	13	1.7
2000	65.7	14	1.6
1995	63.3	15	1.5
2007	63.2	16	1.4
2006	62.3	17	1.3
2008	61.0	18	1.2
2010	58.9	19	1.2
1991	56.8	20	1.1
2009	56.4	21	1.0

Source: Author's analysis, 2015

From Table 2.0 it can be inferred that daily rainfall event of 109.8mm which is the highest in the series, can be expected occur once in every 22 years. Whereas, daily rainfall amount of 105.1mm, the second magnitude, can be expected to occur in every 11 years . However, for extreme daily rainfall amounts of lesser magnitudes such as 67.5mm and 61.00mm, their recurrence interval are 1.8 and 1.2 years respectively. The expected recurrence intervals of the extreme daily rainfall magnitudes are depicted in Figure 3



Source: Author's analysis, 2015

Figure 3: Expected Recurrence Interval of Extreme Rainfall Magnitudes

Since a high intensity rainfall is that event which exceeds 48mm/hr (Lang, 1997 and Odekunle, 2001). A proper look at Table 2 reveals that all the 22 years under study have high intensity rainfall events. Figure 2.0 also depict that the year 1984 was the driest year in the 1949-2010 rainfall record of Sokoto.

4.4 Seasonality of Extreme Daily Rainfall in Sokoto

Analysis of the seasonality of extreme daily rainfall event shows that the months of August and September had the highest frequency of 10 and 7 events respectively and a percentage of 47.6 and 33.3 respectively in the series (Table 3 and 4).

Table 3: I Extremes Rainfall Series in Sokoto (1990-2010)

Days	Extreme rainfall amount(mm)	Days	Extreme rainfall amount(mm)	Days	Extreme rainfall amount(mm)
20th August, 1990	109.8	16th September, 1994	92.4	4th August, 1998	70.5
11th September, 1991	56.8	16th August, 1995	63.3	2nd August, 1999	75.7
12th August, 1992	68.6	4th June, 1996	78.2	15th September,2000	65.7
6th September, 1993	67.5	15th September, 1997	105.1	7th August, 2001	83.2

Days	Extreme rainfall amount(mm)	Days	Extreme rainfall amount(mm)
16th July, 2002	75.8	2nd October, 2006	62.3
29th August, 2003	81.3	12th August, 2007	63.2
8th August, 2004	74.3	14th September, 2008	61.0
10th September, 2005	66.4	4th June, 2009	56.4
15th August, 2010	58.9		

Table 4: Seasonality of Extreme Rainfall in Sokoto

Months	Frequency (days)	Percentage of Total
June	2	9.5
July	1	4.8
August	10	47.6
September	7	33.3
October	1	4.8

Source: Author's analysis, 2015

Table 4 also reveals that, the highest days of rainfall extreme of ten events was received in the month of August with a percentage total of 47.6% of the entire rainfall extreme events over the entire twenty-one years of extreme rainfall events. The month of September come next to August with seven extreme rainfall events with a 33.3 % of the total rainfall events. The least of extreme events was recorded in the months of July and October with extreme rainfall of 78.5 mm and 62.3mm respectively.

4.5 Rainfall of different intensities in Sokoto

For this study, the daily rainfall series were splited into three categories based on rainfall accumulated amount; light (< 10.4mm) moderate (10.4 to <25.4mm) and heavy (> 25.4mm) following Ilesanmi, (1972). Using the 21 years of rainfall record, each rainfall category was calculated and expressed as a percentage of the long-term (1949-2010) rainfall. The intensity series were also compared for different sub-periods; 1949-1968, 1969-1988 and 1989- 2010 .The results are presented in Table 5

Table 5: Percentage of Annual Rainfall of different intensities

Years	Light	Moderate	Heavy
1949-1968	28.5	30.7	40.8
1969-1988	29.4	32.0	38.6
1989-2010	22.9	24.8	52.3

Table 5 shows that a greater percentage of the annual rainfall in the three sub-periods falls as heavy rainfall. In the first sub-period (1949-1968) 28.5% of the rainfall falls as light, 30.7% falls as moderate while 40.8% falls as heavy rainfall. In the 1969-1988 sub- period, 29.4% falls as light rainfall, 32.0% falls as moderate while 38.6% falls as heavy rainfall. In the 1989-2010 sub-period 22.9% falls as light, 24.8% as moderate while 52.3% falls as heavy rainfall. This indicates that the sub-period 1989-2010 experienced the greatest amount of rainfall that falls as heavy rainfall. The implication of this is that an increase in heavy shower can drastically increase the annual rainfall which may in turn increase runoff over the study area. This is the case in Sokoto where most parts of the station in the past experienced high runoff which amounts to severe floods of various intensities. This high intensity contributes more to surface runoff than to groundwater recharge.

Olaniran (1983) showed that heavy rains induce flooding when they occur about three or more times in a month during the period of moisture surplus. Based on this factor, the water budget graph of Sokoto was plotted using monthly totals of rainfall (mm) and evapotranspiration for the period 1990-2010 (Fig. 4). The water budget graph depicts the seasonal trend in soil moisture status. The month of August has been shown to have the highest moisture surplus. Excess soil moisture is however received from August to October, the period during which flooding is more likely to occur.

4.6 Implication of Extreme Rainfall for Flood Frequency in Sokoto.

Having examined some characteristics of extreme rainfall it becomes pertinent to assess the implications of such characteristics on flood frequency in the study area. Although McEwen (1989) employed a historic flood chronology data for a similar study, dearth of reliable flood chorology in the study area has necessitated the use of qualitative flood data as carried out by Babatolu (1998). The flood records used for this study were not defined in precise terms as peak over a constant threshold. Therefore, year-to-year correlation of rainfall and flood events was not possible.
From the analysis of rainfall magnitudes and estimated recurrence interval, it was found that available records of flood events corresponded to rainfall events of high recurrence intervals. For instance, the flood events of August, 1999; September, 2000 and July, 2002 corresponded to rainfalls with 2.8, 1.6 and 3.1 years recurrence intervals respectively. Major floods were mostly associated with high recurrence interval storms.

Annual rainfall fluctuation in Sokoto was found to be in progressive Increase (Fig.2), the period 1990 to 2010 was marked by positive deviation from the mean. This period of positive deviation from the mean corresponded to periods of increased frequency of heavy rainfalls and flooding in the series (Table 5). This is in confirmation of the findings of Babatolu (1998), that heavy rainfall events are more likely to reflect annual changes than light or moderate falls. It therefore implies that it is these heavy rainfall events that result in overland flow and hence over bank flooding in Sokoto. The seasonal trend in soil moisture status in Sokoto indicate that, the surplus water will first be utilized in recharging the underground moisture reserve from June and should be available for rapid run-off from August to October . The month of August has been shown to be the month with the highest soil water surplus as well as having the most frequent events of extreme daily rainfall (Table 4) in the series. Thus, seasonality of extreme rainfall evidently had important implications for flood response. The recent flood records 2009 and 2010 are further indicators that floods are to be expected to occur mostly from August.

4.7 Mitigation and Adaptation options to flooding in Sokoto
There is high confidence that adaptation can reduce vulnerability, especially in the short term. However, adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. There is always a distinction between the two types of adaptation measures namely: autonomous adaptation and planned adaptations. Autonomous adaptation action are defined as responses that will be implemented by individual farmers, rural communities and/or farmers' organization which does not constitute a conscious response to climate stimuli, but only depend on perceived or real climate change in the coming decades without any intervention or coordination by regional and national governments and international agreements. Options for autonomous adaptation are largely extensions or intensifications of existing risk management and production enhancement activities, and are therefore already available to farmers and communities.

Planned adaptations are the result of deliberate policy decisions and specifically take climate change and variability into account, and have so far been implemented infrequently. Planned adaptations, therefore, including changes in policies, institutions and dedicated infrastructure will be needed to facilitate and maximize long-term benefits of adaptation response to climate change.

With the situation at hand of river flooding in Sokoto, planned adaptation solutions and policy co-ordination across multiple institutions may be necessary to facilitate adaptation to flood damage. Autonomous adaptation measure would not be effective to achieve adaptation of projected flood impacts in coming decades, since it has been asserted that there would be continual increase in global temperature consequent to extremes in precipitation.

The following planned adaptation options would be effective for such a disaster in Sokoto

i. Environment policy reforms, changes in urban and housing design, removal of laws that can inadvertently increase flood vulnerability.
ii. Appropriate infrastructure investments: build-up of unblocked drainage patterns, flood defenses, increasing investment; improved health care through flood shelters and assist anceshelters as part of community emergency preparedness programmes.
iii. Changes in water and land-use management policies:
iv. Developing state backed flood insurance schemes.
v. Expansion and provision of alternative water passages

However, any of these responses will entail cost, not only in monetary terms but also in term of societal impacts including the need to manage potential conflicts between different interest groups. The lack of funding available in various forms as well as difficulties in accessing the funds which are available represents a major barrier for adaptation, particularly for local community action.

5. CONCLUSION AND RECOMMENDATIONS

The results from this study reveal that there was a remarkable continuous upward trend in annual rainfall amounts in Sokoto from 1990 to 2010. The period of recent upward trend (1990 – 2010) however recorded the highest frequencies of extreme rainfall events, with corresponding flood frequencies. It is also apparent from the analysis that Sokoto is getting wetter, and receiving unprecedented heavy rainfalls. It is therefore, not the annual rainfall total that is an important cause of increased flood frequency in Sokoto but the percentage of it that falls as heavy falls. The study thereby recommends the construction of unblocked drainage patterns, flood defenses, improved health care through flood shelters and assistance shelters as part of community emergency preparedness programmes.

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