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Recent Trends and Fluctuations of Annual Rainfall in the Sudano-Sahelian Ecological Zone of Nigeria: Risks and Opportunities

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This study examines the recent trends and fluctuations in the rainfall regime of the Sudano-Sahelian Ecological Zone of Nigeria in order to discuss the risks and opportunities involve. Rainfall data (1949-2008) for eight meteorological stations were used for this analysis. In order to identify trends, the rainfall series was sub-divided into 30-year overlapping sub-periods (1949-1978, 1959-1988, 1969-1998 and 1979-2008) and the Cramer's (t_k) test was then used to compare the means of the sub-periods with the mean of the whole record period. The results of the test revealed that there was a change towards wetter conditions in the last 30-year period. The student's t-test, t_d, was also used to examine the temporal changes in the rainfall series between the two non-overlapping sub-periods (1949-1978 and 1979-2008) and the result shows that Nguru and Katsina were significantly drier than the long-term mean. The 10-year running mean shows that annual rainfall for all the stations were below the long-term mean from the late 1960s to the early 1990s and above-average afterwards. The results of the linear trend lines revealed an increase in rainfall supply over the period of study. Some of the implications of these findings are that models built on the perceived decreasing rainfall, such as drainages, dams, have to be reviewed. On the other hand, farmers would take the advantage of the long growing seasons by the adoption of multiple cropping systems. It is recommended that government policies related to agriculture and water resources development should take into account the risks and opportunities associated with increasing wet conditions in the Sudano-Sahelian Ecological Zone of Nigeria.

Keywords: climate change, linear trend, long-term mean, running mean, sub-periods, wet and dry years

Introduction

There is now scientific consensus that the global climate is changing (Kandji, Verchot & Mackensen, 2006). Observations show that as climate changes, changes are occurring in the amount, intensity, frequency and type of precipitation. These aspects of precipitation generally exhibit large natural variability, and El Niño and changes in atmospheric circulation patterns such as the North Atlantic Oscillation have a substantial influence. Pronounced long-term trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia (Trenberth et al., 2007). Africa is already a continent under pressure from climate stresses and is highly vulnerable to the impacts of climate change. Many areas in Africa are recognized as having climates that are among the most variable in the world on seasonal and decadal time scales. Floods and droughts canoccur in the same area within months of each other (UNFCCC, 2007).

Climate change is a serious threat to poverty eradication and sustainable development in Nigeria. This is because the country has a large rural population directly depending on climate-sensitive economic and development sectors and natural resources for their subsistence and livelihood (Oladipo, 2008). Studies have indicated that the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria has suffered decrease in rainfall in the range of about 3-4% per decade since the beginning of the 19th century (FRN, 2003).

The total annual evapotranspiration far exceeds total annual precipitation. In Nguru, for example, average annual evapotranspiration is 1,786mm, while the average annual precipitation is 543mm, given a water deficit of 1243mm (Bashir, 2008). As a result of the large inter-annual variability of rainfall in the SSEZ, it is therefore, subject to frequent floods and droughts. Records have shown that severe flooding has become an almost annual occurrence in this zone (Abaje & Giwa, 2010). In 1988 for example, severe flooding in Kano State resulted in the loss of 146 lives, destruction of 180,000 houses, washing away of 14,000 farms, displacement of 200,000 people and damage to residences and infrastructure worth 560 million naira (NEST, 1991). Similarly, the September

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6, 2010 flood in Sokoto State as a result of inundation of Rima River and breakage of Goronyo dam resulted in the submerged of houses in over 50 communities, washing away of thousands of farmlands, loss of over 40 lives and hundreds of livestock, the submerged of nineteen bridges and the collapse of the only bridge linking Usmanu Danfodiyo University with the metropolis on the 9th September, 2010 (Abdulsalami, 2010). Historical records also indicate that droughts have occurred in this zone frequently in the past. Starting from the beginning of the 20th century, droughts were reported in 1903-1905, 1913-1914, 1923-1924, 1931-1932, 1942-1944, 1956, 1972-1973, and 1982-1983, and 1986-1987 (Oladipo, 1993; Odekunle, Andrew, & Aremu, 2008; Bashir, 2008). This tends to point to the fact that the degree of recent rainfall variability may be more severe than in the previous decades. The fact that rainfall in the SSEZ of Nigeria is characterized by large inter-annual variability, the objectives of this study, therefore, is to: (i) Analyze the recent rainfall trends and fluctuations in the zone using precipitation data for the period 1949-2008; and (ii) Discuss the risks and opportunities resulting from the recent trends in the rainfall regime.

The Study Area

The SSEZ (Figure. 1) is located in northern Nigeria between latitude 10^0N and 14^0N and longitude 4^0E and 14^0E. This zone occupies almost one-third of the total land area of the country. It stretches from the Sokoto plains through the northern section of the high plains of Hausaland to the Chad Basins (Odekunle et al, 2008). The average annual rainfall in this zone varies from less than 500mm in the extreme northeastern part to 1000mm in the southern sub-region (Abaje, Ati & Iguisi, 2011) in only about five months in the year, especially between May and September (Ati, Iguisi & Afolayan, 2007). The rainfall intensity is very high between the months of July and August. The pattern of rainfall in the zone is highly variable in spatial and temporal dimensions with inter-annual variability of between 15 and 20% (Oladipo, 1993).

The climate is dominated by the influence of three major meteorological features, namely: the tropical maritime (mT) air mass; the tropical continental (cT) air mass, and the equatorial easterlies. The first two air masses (mT & cT) meet along a slanting surface called the Inter-tropical Discontinuity (ITD). The equatorial easterlies are rather erratic and relatively cool air masses from the east in the upper troposphere along the ITD (Odekunle, 2006; Odekunle et al, 2008). The position of the ITD is a function of the season with considerable short-period fluctuations. Generally, however, it is situated well to the north of SSEZ in July and August, thereby allowing the area to be totally under the influence of mT air mass. It is located south of the zone from October to May, with the effect that the whole of SSEZ is covered by the cT air mass during this period (Odekunle et al, 2008). The whole zone is covered by Savanna vegetation consisting of Sudan and Sahel vegetation with the density of trees and other plants decreasing as one move northwards. These two zones are together referred to as the SSEZ.

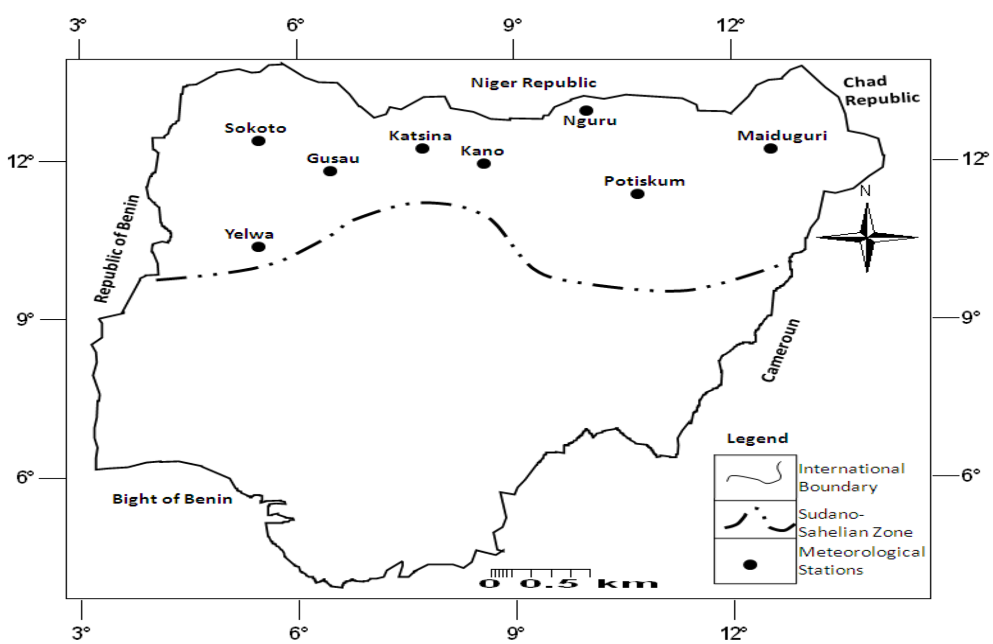

Figure. 1. The Sudano-Sahelian Ecological Zone of Nigeria.

Materials and Methods

The data required for this study are annual rainfall totals spanning a period of 60 years (1949-2008). The data were sourced from the archive of Nigerian Meteorological Agency (NIMET), Oshodi-Lagos. The data were collected at eight synoptic meteorological stations in the SSEZ of Nigeria- Yelwa, Potiskum, Maiduguri, Kano, Gusau, Sokoto, Nguru, and Katsina.

These stations were selected based on the following criteria: 1) they are evenly distributed, 2) all the stations have long period of recorded rainfall data that cover the period of study, 3) they have not been affected by site relocation since their establishment, and 4) the data were tested and found to be normally distributed.

In order to identify trends, the rainfall series was sub-divided into 30-year overlapping sub-periods (1949-1978, 1959-1988, 1969-1998 &1979-2008) corresponding to climatic normals as recommended by the World Meteorological Organisation. The Cramer's test was then used to compare the means of the sub-periods with the mean of the whole record period (see Lawson, Balling, Peters & Rundquist, 1981 for details). The *t*-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n(1+\tau_k^2)} \right)^{1/2} \tau_k$$

where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{S}$$

where $\bar{x}k$ is the mean of the sub-period of n-years. $\bar{x}$ and *S* are the mean and standard deviation of the entire series respectively and t_k is the value of the student *t*-distribution with *N-2* degrees of freedom. It is then tested against the "students" *t*-distribution table, at 0.95 confidence level appropriate to a two-tailed form of test, it is accepted that the different between the overall mean and the mean certain parts of the record are significant.

The period of study was also sub-divided into 2 non-over lapping sub-periods (1949-1978 & 1979-2008). The student's t-test, t_d, was then used to determine if the sub-period means have shown significant changes in the occurrence of wet and dry years through time. The statistics, t_d, is determined as:

$$t_d = \frac{(\bar{X}_2 - \bar{X}_1) - (\mu_2 - \mu_1)}{\left[\frac{N_2 S_2^2 + N_1 S_1^2}{N_2 + N_1 - 2} \cdot \frac{1}{N_2} + \frac{1}{N_1} \right]^{1/2}}$$

where ($\bar{X}_1$ - $\bar{X}_2$) represents the difference in group means, (μ_2-μ_1) is the expected differences (set equal to 0), N_2 and N_1 are the number of cases within each sub-sample, and S_2 and S_1 are their respective standard deviations. When t_d is outside the bounds of the two-tailed probability of the Gaussian distribution, equal to 1.96 at 95% confidence level, a significant shift from the mean is assumed.

To further examine the nature of the trends and fluctuations in the annual rainfall series, 10-year running mean was calculated and plotted. Linear trend line was also plotted using Microsoft Excel Statistical Tool (2007), and then estimation of changes in the annual rainfall was determined. Comparisons were made with the long-term mean totals.

Results and Discussion

The results of the standardized coefficients of skewness (Z_1) and kurtosis (Z_2) for the eight stations show that all the stations were accepted as normal at 95% confidence level. Therefore, the data were not transformed.

The results of the 30-year overlapping sub-period analysis (Cramer's test) of the occurrence of wet and dry years are presented in Table 1. The calculated t_k values for the sub-period 1949-1978 revealed that Nguru and Katsina were significantly wetter than the long-term conditions while Yelwa, Potiskum, Maiduguri, Kano, Gusau and Sokoto had a normal moisture condition. The calculated t_k values for the sub-period 1959-1988 are all negative in which Yelwa, Kano and Sokoto were found to be significantly drier than the long-term mean whereas Potiskum, Maiduguri, Gusau, Nguru and Katsina had a normal condition.

The sub-period 1969-1998 was significantly drier than the long-term mean for all the stations except Yelwa and Gusau that had a normal condition (see Table 1). All stations in the sub-period 1979-2008 were found to be normal at 95% confidence level except Nguru and Katsina that were significantly drier than the long-term mean.

Table 1. Results of 30-year overlapping sub-period analysis (Cramer's Test).

Stations	1949-1978	1959-1988	1969-1998	1979-2008
Yelwa	-0.61	-2.39*	-1.49	0.61
Potiskum	1.49	-0.98	-2.32*	-1.49
Maiduguri	1.49	-1.57	-3.07*	-1.49
Kano	-1.78	-3.18*	-2.45*	1.78
Gusau	0.84	-1.59	-0.99	-0.84
Sokoto	1.42	-2.71*	-2.95*	-1.35
Nguru	3.70*	-0.61	-3.32*	-3.80*
Katsina	2.75*	-0.62	-3.99*	-2.94*

*Significant at 95% confidence level.

It is also observed from the result of the 30-year overlapping sub-period analysis that there appears to be a coherent pattern in the spatial and temporal distribution of the significant cases. About 61.5% of the significant t_k values for all the sub-periods came from the extreme northern stations (Sokoto, Nguru & Katsina). These are some of the most threatened land areas of the country. In these areas, population pressure - including pressure put on pasture resources by livestock from neighboring countries notably Chad and Niger Republic, resulted in over grazing and over exploitation of marginal lands has aggravated desertification and drought in this zone.

A thorough examination of all the significant drier conditions also reveals that about 81.8% of these significant cases occurred in two sub-periods (1959-1988 and 1969-1998). The sub-period 1969-1998 corresponds with the period of the intense drought that ravages Nigeria in the 1970s and 1980s of which much of the impacts were felt in the northern part of the country.

The sub-period 1979-2008 has only two significant cases. This implies that the SSEZ of Nigeria has been experiencing decreasing number of dry conditions over the recent years. This result is not in agreement with earlier conclusions drawn on the rainfall trends in the zone (e.g., Oladipo, 1993; Sawa, 2002). However, these previous studies were based on data covering up to the early 1990s and 2000 respectively. Studies using recent data covering up to 2008 will arrive at the same result with the present study.

The results of the student's t-test, t_d, for the temporal changes in the occurrence of wet and dry years in the rainfall series between the two non-overlapping sub-periods are presented in Table 2. The results indicate that only two stations (Nguru & Katsina) show statistically significant negative t_d values at 95% confidence level, meaning that they were drier than the long-term period. These two stations come from the most extreme northern parts of the study area. Other stations were not significant meaning a normal condition. This implies that the sub-period 1949-1978 was wetter than the sub-period 1979-2008 for Nguru and Katsina. These two stations (Nguru & Katsina) in which the sub-period 1979-2008 was statistically drier than the long-term mean seems to agree with the fact that the extreme northern part of the zone has been experiencing a general tendency towards a decreasing number of wet years and an apparent increasing desertification. Increasing rate of desertification has been estimated to be progressing at the rate of about 0.6 km per year in the area.

Table 2. Results of student's t-test (t_d).

Stations	Sub-periods	Mean	*SD*	t_d
Yelwa	1949-1978	971.98	174.93	0.59
	1979-2008	1001.30	200.04	
Potiskum	1949-1978	727.05	211.08	-1.50
	1979-2008	657.92	129.43	
Maiduguri	1949-1978	634.00	118.16	-1.53
	1979-2008	572.94	179.26	
Kano	1949-1978	829.32	221.32	1.88
	1979-2008	977.45	362.69	
Gusau	1949-1978	941.99	177.69	-0.85
	1979-2007	892.44	256.56	
Sokoto	1949-1978	677.08	155.00	-1.37
	1979-2008	626.80	121.99	
Nguru	1949-1978	518.52	111.97	-5.10*
	1979-2008	382.65	87.03	
Katsina	1949-1978	664.28	139.40	-3.18*
	1979-2008	534.90	164.57	

*Significant at 95% confidence level.

Figure 2 shows the graphical presentation of the annual trends and fluctuations of the rainfall series for the eight stations under investigation smoothened out with the 10-year running mean. The 10-year running mean for Yelwa (Figure 2a) shows annual rainfall above the long-term mean rainfall lasted from the beginning of the data up to the late 1960s. From the late 1960s to the early 1990s, the rainfall was below the long-term mean and with the above-average rainfall afterwards.

From the beginning of the data studied to the late 1960s, the 10-year running mean for Potiskum shows annual rainfall was above the long-term mean. From the late 1960s up to the late 1990s, the running mean shows annual rainfall below the long-term mean; from there afterwards, the annual rainfall was along the long-term mean (see Figure 2b). The running means for Maiduguri and Sokoto show annual rainfall above the long-term mean from the beginning of the data studied up to the late 1960s. From the late 1960s to the late 1990s the rainfall was below the long-term mean. The rainfall started increasing from that point to the end of the data (2008).

At Kano and Gusau, the running mean shows some fluctuations than the previously discussed stations. The running mean for Kano shows annual rainfall along the long-term mean up to 1960 and started increasing from that point to the late 1960s. From the late 1960s up to the late 1990s rainfall was below the long-term mean; after that there was a sharp increase to the end of the data.

On the other hand, the running mean for Gusau was above the long-term mean from the beginning of the data to the late 1960s; from that point rainfall was below-average up to the early 1990s. The rainfall was again above-average from the early 1990s up to the early 2000s and then below-average afterwards. The above-average rainfall for Nguru and Katsina lasted from the beginning of data studied to the early 1970s. From that point, the annual rainfall was below the long-term average for Nguru up to the end of the data, while it was below-average up to 2005 for Katsina and with above-average afterwards.

A general examination of the 10-year running mean (Figure. 2a-h) shows that annual rainfall was below the long-term mean from the late 1960s to the early 1990s. This also coincides with the period of the great droughts of the 1970s and the 1980s in the region. The rainfall started increasing from the early 1990s to the end of the study period. This implies that the zone is experiencing increasing wetness in recent years. This is in good agreement with the observation made by Ati, Stigter, Iguisi, & Afolayan (2009).

From the linear trend lines (Figure. 2a-h), estimation of changes of the annual rainfall expressed in mm for the period of study indicates a decrease of approximately 171.0mm at the rate of 2.85mm $year^{-1}$ at Potiskum. Compared with the long-term average total, it means that the annual rainfall was decreasing at a rate of 0.41% per year.

At Maiduguri, there is a decrease between 1949-2008 of approximately 25.20mm at the rate of 0.42 mm $year^{-1}$; a decrease of approximately 138.0 mm at the rate of 2.30mm $year^{-1}$ at Gusau, a decrease of approximately 73.80 mm at the rate of 1.23mm $year^{-1}$ at Sokoto, a decrease of approximately 228.60mm at the rate of 3.81mm $year^{-1}$ at Nguru, and a decrease of approximately 220.20mm at the rate of 3.67mm $year^{-1}$ at Katsina. When compared with the long-term average totals, it is also clear that the annual rainfall was decreasing at a rate of 0.07% per year at Maiduguri, 0.25% per year at Gusau, 0.19% per year at Sokoto, 0.84% per year at Nguru, and 0.61% per year at Katsina.

On the other hand, there is an increase in the annual rainfall during the study period of approximately 57.60mm at the rate of 0.96mm $year^{-1}$ at Yelwa and an increase of approximately 400.20mm at the rate of 6.67mm $year^{-1}$ at Kano. Compared with the long-term average totals, it means that the annual rainfall was increasing at a rate of 0.10% per year at Yelwa and 0.73% per year at Kano.

The findings when compared with earlier study (e.g. Iliya, 1994) on the rainfall trends of this zone using data for the period 1931-1990, it means that the SSEZ of Nigeria has been experiencing increasing wetness over the recent years. This findng is also in agreement with the observation made by Ati et al. (2007 & 2009), Ati, Muhammed, and Ati (2008) and Odekunle et al. (2008) that this zone is now experiencing wetter conditions in recent years.

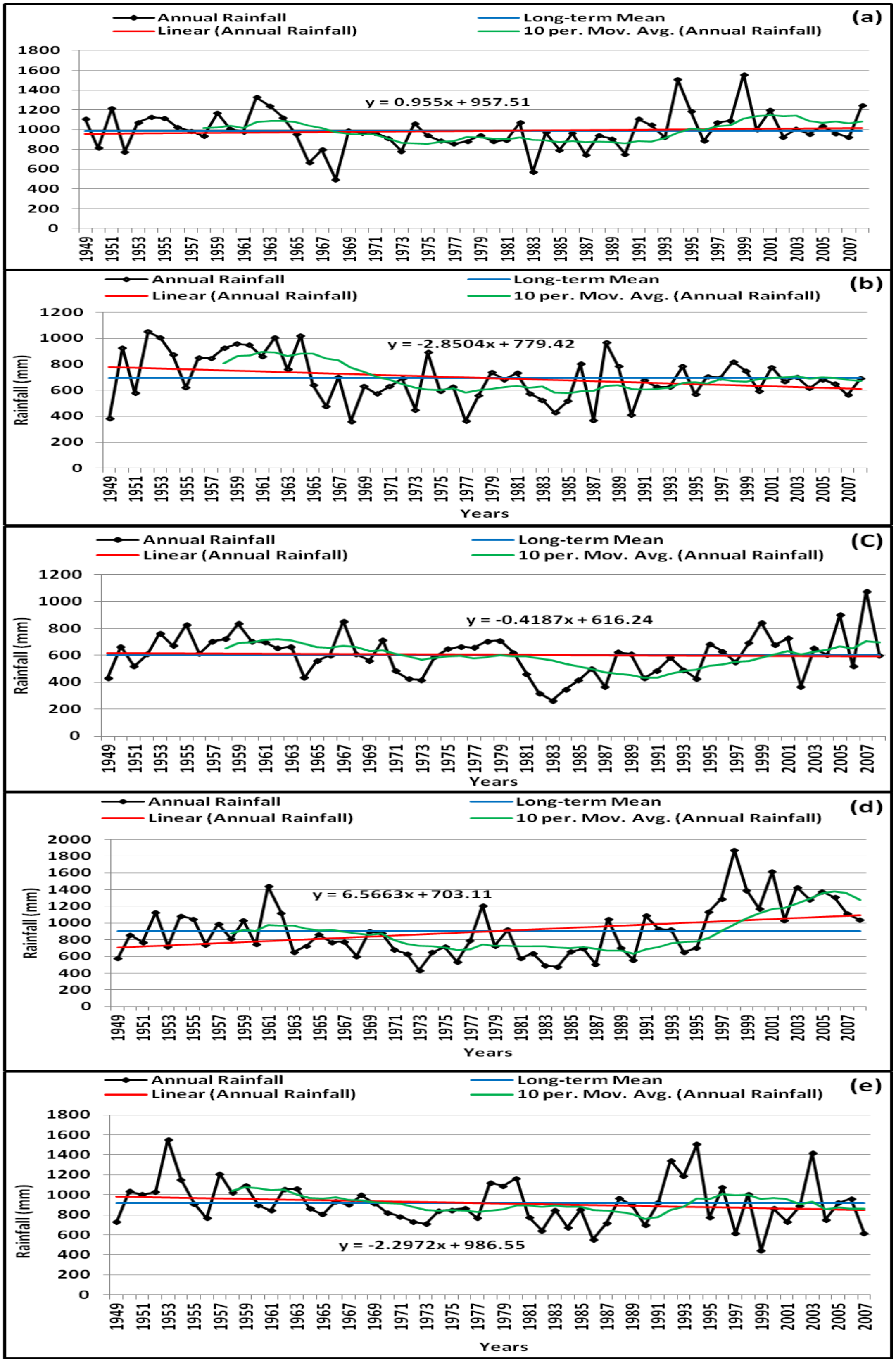

Figure 2. Annual rainfall trends and fluctuations for (a) Yelwa, (b) Potiskum, (c) Maiduguri, (d) Kano, (e) Gusau, (f) Sokoto, (g) Nguru, and (h) Katsina

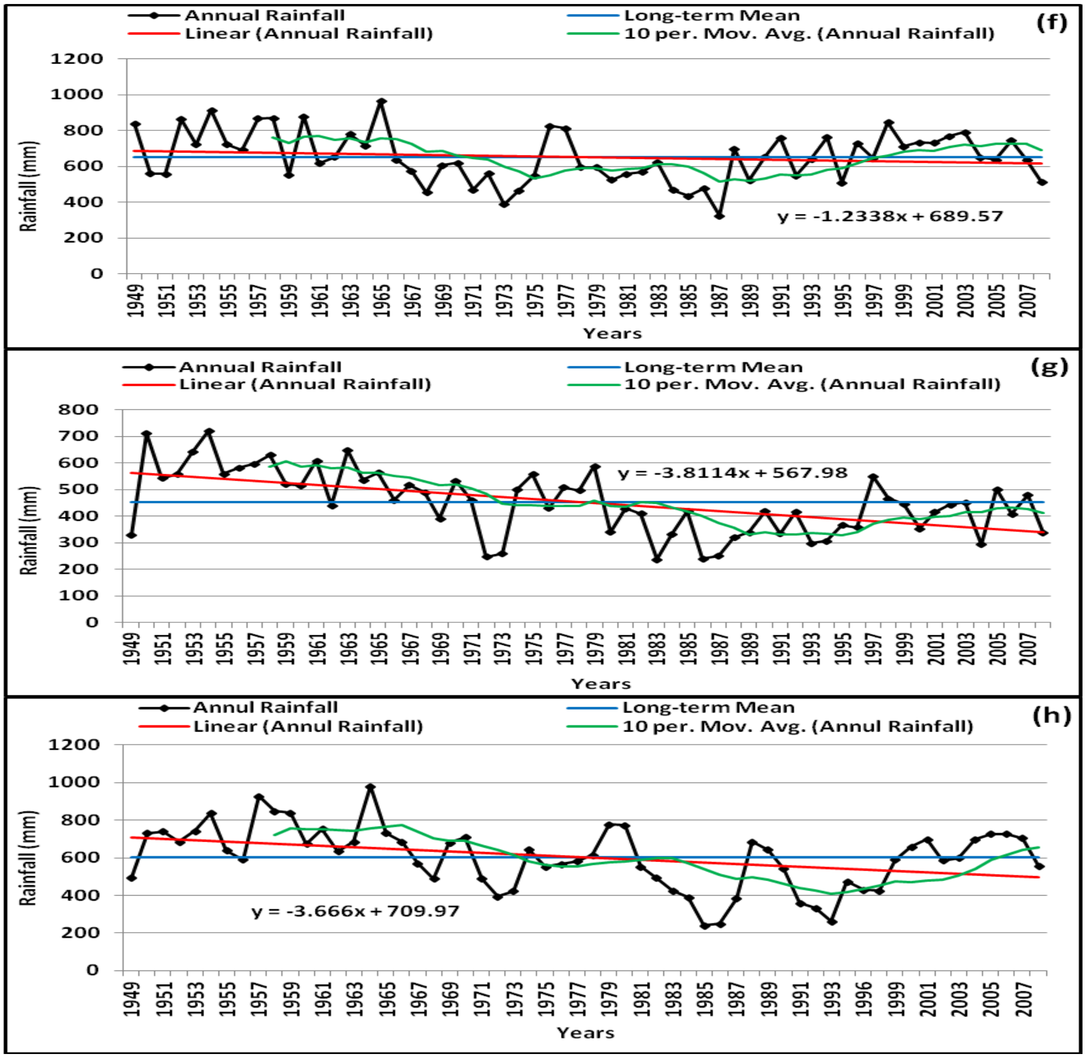

Figure 2. continued.

Risks and opportunities of the trends and fluctuations

Risk is possible loss, and opportunity is possible gain. The risks and opportunities of an increasing in the number of wet conditions rather than increasing in dry conditions in the zone for agriculture, grazing lands, water resources, ecological systems, food security, livelihoods, and human health will certainly be different.

Risks

Increasing trend in rainfall totals may trigger floods and erosion of the top soil. Flooding will results to washing away of top soils/farm lands, disruption of socio-economic activities, overflowing/damage to reservoirs and other infrastructure, and the loss of life and property. The implications on infrastructure are that models built on the perceived decreasing rainfall, such as drainages, dams, e.t.c., have to be reviewed. This will lead to increase burden of the recurrent cost of repair/replacement and increased cost of community services.

At extreme cases of flood, people do abandon their houses and completely relocate to other areas that are not affected by flood. But in situations where the affected persons can not relocate, they are forced to live with the flood. This makes them vulnerable to various water-borne diseases such as malaria, diarrhea, cholera and typhoid fever. Trauma resulting from the circumstance can also cause non-pathogenic diseases such as high blood pressure and diabetes.

Agriculture in the SSEZ is rain fed. But due to increasing trends in rainfall totals, fast-maturing varieties of crops that have been produced, and also those that could withstand water stress may be endangered. The risk is that in the future, new hybrid species may completely displaced those ones and hence the extinction of the former species. The ideal rainfall in the SSEZ of Nigeria is one in which rainfall builds up gradually to a peak in August, and then declines more rapidly, but steadily and gives way to the dry season at the end of September. But when heavy rains are interspersed with many consecutive days of very low or no rainfall, crop failures may occur. These may be due either to the proliferation of pests or limited water at times when plants are most in need.

Opportunities

Agriculture is the backbone of the Sudano-Sahelian economy as it employs over 60% of its labor force. Therefore increasing rainfall is important for the zone as farmers would take the advantage of the long growing seasons by the adoption of multiple cropping systems and the cultivation of deep loamy soils during wetter conditions instead of *fadama* soils during drought years.

Increasing rainfall means water available for irrigation purposes is on the increase creating a favorable condition for irrigation agriculture (Ati et al., 2009). The water resources of the zone are also largely dependent on rainfall amounts. Increasing rainfall means increasing recharge of surface and underground water resources. This increase can be harnessed to create adequate water storage against periods of shortage. Opportunities may be provided by the government for professionals to study and develop realistic methods for utilization of surplus water.

Nearly 70% of Nigerian cattle are concentrated in this zone (Abaje et al., 2011); therefore, increasing rainfall means availability of grazing lands; it also means that harvesting and preserving more fodder or crop residues for release to livestock during drought years would be increased.

Conclusions

The study has examined recent trends and fluctuations of annual rainfall of the SSEZ of Nigeria between 1949 and 2008. The study concluded that, at present, the climate of the region indicates a tendency towards a wetter condition rather than the increasing dryness that was a feature of the period from the 1960s to the 1980s. The implications of increasing in the number of wet conditions rather than increasing in dry conditions in the zone for agriculture, grazing lands, water resources, ecological systems, food security, livelihoods, and human health will certainly be different. For example, models built on the perceived decreasing rainfall, such as drainages, dams, have to be reviewed. On the other hand, farmers would take the advantage of the long growing seasons by the adoption of multiple cropping systems. It has been established that rain falls mostly when an area is overlain by the mT air mass and ceases when the area is overlain by the cT air mass, thereby making the latitudinal position of the ITD a strong determinant of most rainfall attributes. Thus it has been observed that the ITD moves further north in wet years and significantly further south in dry years.

The movement of the ITD is observed to have been initiated by the enhanced heating of the Sahara, which deepens the Sahara low. The deepening of the Sahara low appears to have strengthened the mT air mass so that the ITD makes further incursion and thus increases moisture transport into the SSEZ. Also, the recent increase in wetness, particularly the last decade (1999-2008), may be due to awareness and the general reduction in human activities that causes drought and desertification as a result of the high level of commitment from International Governmental and Non-Governmental Organization such as Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Program (UNEP), and National Drought Mitigation Center (NDMC) amongst others. The findings of the study suggests that government policies related to agriculture and water resources development should take into account the risks and opportunities associated with increasing wet conditions in the study area.

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