RAINFALL ANOMALIES IN NIGERIA: THE CONTEMPORARY UNDERSTANDING

By

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Mr. Vice-Chancellor, Sir,
Deputy Vice-Chancellors (Academics and Administration)
Registrar, Dean of Faculty of Business and Social Sciences,
Deans of other faculties,
Deans of Postgraduate School and Student Affairs,
My Colleagues in Academics, Great Unilorin Students,
Our Distinguished Guests, Ladies and Gentlemen

1.0 INTRODUCTION

In order to set the tone for this intellectual discourse, let us start with the poser: *'what is an inaugural lecture?'* An inaugural lecture is an address which is given to mark the inauguration or installation of a university professor at a formal occasion. In due reference to this obligation, the Registrar of this University formalized the Unilorin position in a memorandum to Deans of Faculties dated 3 January, 2002 (Ref UI/REG/SEO/165) when he wrote inter alia

> *An Inaugural Lecture is an academic obligation which all persons appointed/promoted professors in the University of Ilorin would be required to fulfill in the course of their career in the University.*

In the light of the position of this University on the subject as quoted above, giving an inaugural lecture is not time bound, rather, it is an obligation which much be fulfilled in the course of one's career as a professor in this University. When the Unilorin position is examined further, holding an inaugural lecture is imperative in order to confer recognition and respectability on the university professor for the chair he/she occupies in the academic subject which he/she professes. Mr. Vice-Chancellor Sir, our distinguished audience, I therefore feel greatly honoured to be given the opportunity to present the 55th in the series of inaugural lectures of this great University and thereby pay my due!

Inaugural lectures, as instituted at the University of Ilorin, have been used to serve many ends. Among the 54 inaugural lectures already given, five objectives are apparently discernible. Some of the lectures address contemporary issues which are germane to the progress of the society. In many others, the topics selected encapsulate much of the research activities of the lecturer. Yet, some use inaugural lectures as a forum to address the academic community on important issues of mutual concern, while some others use it as a forum for presenting the progress of activities in a discipline and the manner in which these represent contributions to knowledge and society in general.

The first inaugural lecture in geography at the University of Ilorin was given by Professor J. O. Oyebanji in 1986 on the topic *'Coat of Many Colours'* which is about the manifestation of inequality in human well-being at different geographical scales and the use of social geography as a veritable tool of urban and regional planning in Nigeria. Two years later i.e. in 1988, Professor S. O. Onakomaiya, in the second inaugural lecture in the discipline, titled *'Unsafe at Any Speed'*, examined the different dimensions of road accidents in Nigeria, a phenomenon which, in his words, *"is fast degenerating into a destructive force against our stock of skilled, able-bodied and trained manpower."* The third in the series of inaugural lectures in geography was given recently (November, 2001) on the topic *'Better By Far'* by Professor J. F. Olorunfemi. In this lecture, Prof. Olorunfemi documented the long history of the problem of accurate and acceptable population headcount in Nigeria and also the importance of remote sensing as a suitable technique of obtaining reliable population estimates for different spatial units.

Mr. Vice-Chancellor Sir, distinguished colleagues, ladies and gentlemen, all the three previous inaugural lectures in geography serve one common end which, according to Onakomaiya (1988), is the 'desire to expose the contemporary relevance of geography both as an academic discipline and as a tool for solving social, economic, and environmental problems'. They can also be seen as posing great challenges for further research and education as well as be considered as thought-provoking and beneficial to the citizenry. In my search for topic for this inaugural lecture, therefore, I have decided to continue this time-honoured tradition of the Department by addressing you on the topic “Rainfall Anomalies in Nigeria: the Contemporary Understanding”. This will be the fourth inaugural lecture in geography and also the first in the specialized branch of climatology.

Episodes of rainfall anomaly are both of historical and contemporary interest. Some of the episodes are listed in Table 1. The first one dates back to the biblical time of Noah about 4,000 years ago when it rained for 40 days and 40 nights with the resulting flood waters reaching 6 m level and lasting 150 days. According to biblical account only Noah, his household and representatives of animals/birds collected by him, survived the prolonged and widespread flooding (Genesis, Chap. 7, verses 4-20). Oguntoyinbo (1982) also cited the widespread famine of 1887 in southwestern Nigeria which was called **‘Iyan s’odi dogbun’** meaning ‘a famine which turned the moat into an

TABLE 1

Some Episodes of Rainfall Anomaly in History

S/N	Date	Area Affected	Mode of Occurrence	Remarks	Source
1.	About 4000 years ago	Biblical world of that time	40 days and 40 nights of continuous rainfall. The flood waters reached 6m level and lasted 150 days	Only Noah, his household and representatives of animals/birds collected by him survived the widespread flooding	Genesis,Chap.7: 4-20.
2.	About 3,000 years ago	Egypt	7 years of abundant rainfall followed by seven years of severe drought	During the 7 years of abundance the land produced plentifully. In the case of the 7 years of widespread famine there was lack of food over the land	Genesis, Chap. 41:47-56
3.	Between 974 and 852B.C	Samaria	3 years without rainfall	There was widespread shortage of food	1 Kings, Chap 18:1
4.	1887	SW Nigeria	Widespread famine	**Iyan S’odi dogbun’** (a famine which turned the moat into an impassable trench)	Oguntoyinbo (1982) citing historical events reported by Ajayi.
5.	1903-4	SW Nigeria	Widespread famine	**Iyan K’ehin S’ara’** (a famine which caused man to turn his	Oguntoyinbo

				back of his relations)	(1982) citing historical events reported by Ajayi
6.	1910-14	Hausaland	Widespread famine	**Kakalaba** famine	Thambyaphpillay, 1979.
7.	1918	SW Nigeria	Widespread famine	**'Iyan lapelape (Lapelape** drought during which people trekked from Igboho to Ibadan (150 km by shortest route to buy food items).	Oguntoyinbo (1982) citing historical events reported by Ajayi
8.	1972	Hausaland, Nigeria	Widespread famine caused by drought	Called **Yan Buhu**	Thambyahpillay, 1979
9.	1942	Hausaland,	Widespread famine caused by drought	Called **Yar Gusau**	**-**do-
10.	1941-44	Ekitiland, Nigeria	Widespread drought	Called **Iyan f'owo re mi** i.e. famine in which life is saved with cash	Adefolalu (personal communication)
11.	1945-6	SW Nigeria	Widespread famine	**'Iyan Abantila'**	Oguntoyinbo (1982) citing historical events reported by Ajayi
12.	Oct., 19, 1976	Ilorin, Nigeria	One week of heavy rainfall from 14-19 Oct.	24 houses submerged by water and 50 others evacuated	Olaniran (1983)
13.	Aug. 30, 1979	Ilorin, Nigeria	Caused by two prolonged heavy rainfalls on 27th and 29th in the month of August which was characterized by moisture surplus	One house and two cars were submerged while many houses built on banks of river Asa were temporarily abandoned	-do-
14.	Aug. 31, 1980	Ibadan, Nigeria	Floods are called **'omiyale, agabara ya sobu'** in local palance. This particular event was caused by prolonged and high intensity	300 lives were lost while property damaged was estimated at N1.5 million (about 1.5 billion now)	Akintola (1992)

			rainfall 273 mm in magnitude, the highest daily rainfall ever received in a century.		

Impassable trench' as well as a similar famine in the same area from 1903 – 4 which was labeled **'Iyan K'ehin S'ara'** meaning a famine which caused man to turn his back on his relations. Ekitiland experienced **'Iyan f'owo re mi'** which means 'famine in which life is saved by cash or cash survival famine' from 1941-44 (Adefolalu, personal communication). Incidents of famine, caused by drought, have also been reported in the history of events of Hausaland such as the **Kakalaba famine** of 1913-14, the **Yan Buhu** famine of 1927 and **Yar Gusau** famine of 1942 (Thambyahpillay, 1979).

In recent times, we can also cite the Ilorin flood of October 19, 1976 which was preceded by one week of rainfall and which led to the submergence of 24 houses and evacuation of 50 others (Olaniran, 1983). Given the pervasive influence of floods in Ibadan in the 1960s and 1970s they became known, in the local parlance, as '**omi ya'le, agbara ya sobu'** meaning that both residential and commercial areas are invaded by flood waters. Perhaps, the worst flood in the history of the town occurred recently on 31 August, 1980. This devastating flood was caused by prolonged and high intensity rainfall, 273 mm in magnitude and it culminated in the loss of 300 lives. The property damaged was estimated then at N1.5 million (about N1.5 billion now) (Akintola, 1992).

The episodes described when considered together put into focus the relationship between climate and humans. They also underscore the need for studies of rainfall anomaly especially in the tropics, where rainfall is the most variable element of the climate. In particular, climate prediction which is a focal issue or point in the United Nations Framework Convention for Climate Change (UNFCC), will benefit from such documented frequency of inter-annual or decadal rainfall anomalies in Nigeria.

1.2 Meaning of Rainfall Anomaly

Given the pervasive influence of precipitation extremes as depicted in Table 1, what then is rainfall anomaly? The popular concept of climate is that it is some sort of average weather and its fluctuations based on 30-year record. Computations based on this length of data define the "normal" climatic conditions. Thus, the normal or mean annual rainfall of Ilorin based on 1971-2000 rainfall data is 1200mm. Once this normal condition is established, any particular year at Ilorin can be described in terms of its departure from this normal. In effect, the 1530mm annual rainfall received at Ilorin in 1999 can be described as 27.5 per cent above normal while the 990.3 mm annual rainfall received by the town in the year 2000 can be expressed as 17.5% below normal. These departures are referred to as **anomalies.** A persistent departure from the normal e.g. above average rainfall of the same sign constitutes a **Climatic fluctuation**. If the fluctuations persisted for along a time and were, furthermore, statistically significant, then we might say, there had been a climatic change (Farmer and Wigley, 1985, p.5). However, according to Landsberg (1975) climate change should, additionally involve a shift of climatic condition to a new equilibrium position.

In my research work on the rainfall climatology of West Africa spanning more than two decades now, I have examined different characteristics of rainfall for evidence of quasi-periodic oscillation, trend, fluctuations and climate change. The rainfall characteristics analysed are listed in Table 2.

With the subject matter of this address resolved, the rest of this inaugural lecture is divided into six parts. These are the theoretical background, manifestations of rainfall anomalies in Nigeria, and environmental impact assessment of rainfall anomalies. The others are rainfall forecasting and prediction, the conclusions, and finally the recommendations.

2.0 THEORETICAL BACKGROUND: CAUSATIVE MECHANISMS OF RAINFALL ANOMALIES IN NIGERIA

2.1 The ITD Model

Nigeria receives rainfall from the southwesterlies which invade the country from the Gulf of Guinea coast, i.e. the tropical Atlantic. This moist airstream is overlain by the northeast trades which originate from above the Sahara and are thereby dry and dust laden. The zone of contact of the two air masses at the surface is a zone of moisture discontinuity and it is known as the Inter Tropical Discontinuity (ITD) zone. The ITD advances inland as far as 22-25^{0}N in August at the margin of the Sahara i.e. considerably beyond Nigeria's northern border (Adejokun 1964; Adedokun, 1978) while it does not retreat equatorward beyond 4^{0}N latitude during the 'Harmattan' dry season (see Adefolalu, 1983). Five weather zones are associated with the ITD

(Figure 1). Zone A to the north of the ITD is rainless as well as Zone B to the immediate south because they do not contain rain-producing clouds. Rainfall in the ITD occurs in zones C and D where conditions favour the development of clouds of great vertical extent. Thunderstorms and squall lines are associated with zone C weather and monsoon rains with Zone D weather. Consequently, rainfall is spatially discontinuous when Zone C weather prevails. On the other hand the monsoon system gives continuous rains which may last 12 hours or more (see Olaniran, 1995). Overall, rainfall occurs at a distance of about 500km south of the surface location of the ITD, 4-6 weeks behind it in its annual cycle.

When the fifth weather type associated with the ITD i.e. zone E, prevails over an area, light rainfall usually results because Zone E weather is dominated by layered stratiform clouds.

The position of the ITD fluctuates seasonally and the different ITD zones affect different areas of the country at various times (Figure 2). Between January/February and August, the ITD migrates northward and there is a corresponding shift northward of the area of rainfall activity, and from the end of August when the ITD is at its most northerly position, zone E weather migrates a short distance inland causing a period of reduced rainfall in the costal area, a phenomenon known as the ‘little dry season’ or the ‘July/August break’. During this period the southwesterlies become deflected into westerlies which bring little or no rain. This causes rainfall to increase eastward over southern Nigeria during the July – August period (Olaniran, 1988 a, b).

The account of the rainfall-producing systems presented above for Nigeria, depicts rainfall activity over the country as a function of the migration pattern of the ITD (see Ayoade, 1970; Kowal and Knabe, 1972; and Olaniran, 1985; 1988 a; 1988 b). Accordingly, droughts in Nigeria, and indeed over West Africa, are associated with a restricted northward advance of the ITD. On the other hand, wet years result from a considerable northward advance of the ITD. Different from this simplistic picture, the ITD itself is erratic in its south-north advance and north-south retreat. It moves in a series of surges, retreats and stagnations. Data presented by Walker (1958) showed that along longitude 3^0E in that year the ITD advanced up to 11^0N latitude in January but retreated southward to 6^0N latitude in February

TABLE 2: Rainfall Characteristics Analyzed for Evidence of Quasi-Periodic Oscillation, Trends, Fluctuations, and Climate Change Based on Nigerian Data

1. Rainfall amount
2. Rainfall frequency
3. Rainfall intensity
4. Rainfall size i.e. light, moderate and heavy rainfalls
5. Timing of rainfall (start, end and duration of the rains)
6. Seasonal rainfall regime
7. Spatial distribution
8. Rainfall belt

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i.e. the following month, a retreat of 500 km. Oguntoyinbo and Richards (1977) also reported a similar situation for southern Nigeria during 1972/73. Such irregular movements of the ITD have implications for the location of the area of rainfall activity over the country. Often, they cause a false start of the rainy season i.e. early onset of rainfall at a location which is subsequently followed by a prolonged dry spell.

Long-term rainfall variability in Nigeria is accounted for, not by the ITD mechanism alone, rather, other factors such as the tropical easterly jet (TEJ), sea surface temperature anomaly (SSTA), biogeophysical feedback mechanism, and the El Nino Southern Oscillation (ENSO) also enter the picture. Often, the search for explanation may be extended to sunpots cycle. Overall, rainfall anomalies in Nigeria are caused by both tropical and extra tropical factors. These factors are now treated in turn.

2.2 Tropical Easterly Jet (TEJ)

The TEJ is part of the Indian summer monsoon system and it extends from India over Africa in the Northern Hemisphere summer months, generally at a height of around 12-15 km. The west-east axis of the TEJ is located between 4-10^{o}N. On the southern side of the axis, conditions are conducive to the ascent of air and consequently rainfall occurrence whilst the northern side is marked by subsidence. The TEJ, therefore, reinforces aridity over the extreme northern part of the country but causes a belt of above average rainfall in the central part.

2.3 Tropical Atlantic Sea Surface Temperature Anomaly (SSTA)

Different from the large-scale southward displacement of the ITD, drought occurrence can also be attributed to factors which inhibit rainfall activity behind (i.e. to the south of) the ITD. This may take the form of a weakening of the rainy reason “intensity”.

According to Palmer (1986), warming of the tropical Atlantic ocean reduces the meridional gradient of sea surface temperature (SST) south of the ITD and this results in a weakening of the Hadley meridional circulation (i.e. the pattern of circulation of the atmosphere over the tropics). The weakened circulation reduces the intensity of the southwest monsoon flow into West and Central Africa and consequently rainfall over southern Nigeria.

2.4 Biogeophysical Feedback Mechanism (BFM)

Farmer and Wigley (1985) have provided an excellent summary of the studies of Otterman (1974), Charney (1975) and Rasool (1984) on biogeophysical feedback mechanism (BFM). All these researchers agree that reduced rainfall, combined with human and animal activities (such as overgrazing) could reduce the vegetation cover and increase the reflectivity, or albedo, of the land surface. Higher albedo changes the heat balance of the surface-atmosphere system and ultimately this leads to increased divergence in the lower atmosphere and reduced uplift over the higher albedo region. These changes, in turn, lead to less rainfall and maintenance of drought condition.

Undoubtedly BFM, as described above, has served to reinforce drought conditions over the northern part of Nigeria. This is due to large scale depletion of the vegetation for fuel wood and as well as due to overgrazing by animals in this part of the country (Oguntoyinbo, 1982 and Adefolalu, 1990)

2.5 El Nino Southern Oscillations and Other Teleconnections

According to Oguntoyinbo (1986) the atmosphere does much of its work over large geographical scales so that climatic anomalies tend to be extensive in space. Thus, it is common to find the variation of one element in one area correlated with its variation in another area sometimes quite remote or correlations may exist between different elements over such distance. Linkages such as these are called teleconnections.

Teleconnection studies are on-going to establish linkage between Nigerian rainfall and the El Nino Southern Oscillation (ENSO). El Nino is the term used to describe the extensive warming of the upper ocean in the tropical eastern Pacific lasting up to a year or even more (Figure 3). The cooling phase of El Nino is called La Nina. Changes in the El Nino events are related to changes in the Pacific Walker circulation. The zonal atmospheric circulation pattern over the Indo-Pacific region, first described by Gilbert Walker, is known as the Walker circulation.

Collectively, these changes form of a wider tropical fluctuation which is known as the 'southern oscillation' (SO). This oscillation is the fluctuation in the intensity of the inter-tropical general atmospheric and hydrospheric circulation over the Indo-Pacific region

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(Figure 3). The oscillation may be referred to either as southern oscillation (SO) or El Nino South Oscillation (ENSO).

ENSO has been shown to relate strongly to variations in Nigerian rainfall (Adebayo, 1999). Data reported by Owen and Ward (1989) and by Adebayo (1999) also confirm the relationship between extra-tropical SSTA (e.g. SSTAs over the North Atlantic, North Pacific and South Pacific) and rainfall fluctuations in Nigeria (Figure 3). According to Owen and Ward (1989), when the El Nino pattern is strongly positive (i.e. positive SSTA pattern in the eastern tropical Pacific) there is a tendency for the Sahel to be dry, but wet when the pattern is strongly negative. Adedoyin (1989) also reported a significant positive correlation between tropical east Pacific SSTA and rainfall intensity at the beginning of the rainfall season in Nigeria.

2.6 Sunspots Cycle

Sunspots are darkened portions of the solar surface and locally they may affect the output of radiation. Lockwood (1979) gave an excellent explanation of the pattern of occurrence of sunspots. They exhibit cycles of 11 years and the double sunspots cycle of 20-22 years. Cycles of 9 and 14 years have also been reported for sunspots (Lockwood, 1979)

Generally, increases in sunspot cycles have been associated with wetter conditions while decreases in the cycles have been associated with drier conditions. Evidence of sunspots cycles has not been found in Nigerian rainfall data (Ayoade, 1973; Olaniran and Sumner, 1989a, b and c and Olaniran, 1990). This implies that the occurrence of dry and wet conditions in the country cannot be explained by reference to the sunspots-drought theory.

3.0 MANIFESTATION OF RAINFALL ANOMALIES IN NIGERIA

The spatio-temporal patterns of rainfall anomalies in Nigeria are examined in this lecture for three distinct periods: the pre-historical (or palaeo) period up to 1500 AD, the historical period from 1500-1900 AD and the instrumental period which coincides with the 20th century.

3.1 The Pre-Historical (Palaeo) Period (20,000 BP-1500 AD)

Present day knowledge of rainfall variability in Nigeria during the palaeo period has been gleaned mainly from the records of Lake Chad. Among the researchers who attempted a reconstruction of past climates over the lake are Maley (1973, 1981) using the results of pollen analysis, Kutzbach (1980) based on water-and energy-balance equations and Tetzluff and Adams (1983) based on the comparison of evaporation rates over the lake and early-Holocene Lake Chad. Nicholson and Flohn (1980) have also presented circulation patterns over Africa for three distinct periods between 20,000 and 4,500 BP. However, these results must be treated with caution because as noted by Ojo (1985) lake level fluctuations reflect the control of both climatic and non-climatic factors.

From the data summarized on lake level fluctuations by Street and Grove (1976), it can be inferred that the extreme northern part of Nigeria experienced arid conditions 21,000-12,500 BP. Using biogeographical evidence they showed further that equatorial lowland rainforest was scanty in West Africa (including the southern part of Nigeria) during this period.

Farmer and Wigley (1985) who summarized the data reported by several researchers noted that between 12,500 and 5,000 BP the climate became progressively wetter and a belt of expanded lakes in Africa developed. In particular, in the early Holocene (9,000 - 6,000 BP), Lake Chad was reported to have extended over vast area known as Mega-Chad covering some 320,000 km^2 (Schneider, 1969). Ojo (1985) quoting data reported in the literature noted that the shoreline of Mega-Chad could be traced to Bama Ridge, 128.7km in the southwest and to Koro Toro, 644 m in the east. The water level of Mega-Chad has been put at between 50-53 m above the lake level in the late 20th century (see Farmer and Wigley, 1985; Ojo, 1985).

Mega-Chad prevailed until about 700 AD while the levels of the lake showed evidence of desiccation in the period between 700 and 1500 AD. In summary, the condition that prevailed in Nigeria 20,000 BP-1500 AD was characterized by alternating dry and wet conditions which differed in severity and geographical extent.

3.2 Historical Period (1500-1900 AD)

The historical period covered 1500 to 1900 AD. The reconstruction of rainfall climate for this period has been based on records of lake levels and accounts of travelers. The caution in treating data pertaining to the pre-historical period is therefore also applicable here.

Farmer and Wigley (1985) examined the data reported for this period in the literature and from their analysis it can be inferred that in Nigeria north of 10^oN latitude, conditions wetter than the present, apparently prevailed from about the 16th to and including the 18th centuries. This period contained major droughts in the 1680s and around 1735-56. Drought occurred again in the 1830s possibly spanning much of the period 1810-1850.

However, in the late 19th Century, relatively good rains prevailed with average rainfall perhaps 20-40% greater than that of the 1980s. Data presented for Lake Chad by Grove and Pullan (1963), using the account of the explorers, also corroborated this position; they noted the lake probably reached high levels from 1866-1870 (see Ojo, 1985)

In summary, therefore, the rainfall climate of Nigeria from 20,000 BP to 1900 AD was characterized by alternating dry and wet conditions. Expectedly, because of data constraints, the rainfall climate of the pre-historical and historical periods has been presented in qualitative terms. Happily, the long period of rainfall measurements during the 20th Century has now afforded the opportunity to undertake quantitative analysis on Nigerian rainfall data. The discussion below on rainfall anomalies in Nigeria during the instrumental period is, therefore, based on the results of the quantitative analysis to which the rainfall records have been subjected.

3.3 Instrumental Period

The rainfall data of Nigeria have been analysed for evidence of quasi-periodic oscillations, trends, i.e. secular change, occurrence of dry and wet episodes and spatial coherence of rainfall anomalies. Furthermore, the spatial patterns of rainfall anomaly have been mapped while the data have been searched for evidence of change in rainfall belts and in the seasonal rainfall regime. The data have also been investigated for evidence of climate change. The results obtained are now discussed in turn.

3.3.1 Quasi-periodic oscillations in Nigerian rainfall

Evidence of sunspots cycles has not been found in Nigerian rainfall data. Rather, Nigerian rainfall has been found to be characterized by quasi-periodic oscillations. The cycles which are manifested in Nigerian rainfall data are those of 2.0-2.4, 2.7-2.9, 3.2-3.6, 3.9-4.4, and 5.6-6.6 years with those in the range 2.0-2.4 years and of 2.7-2.9 years being the strongest and most common (Ayoade, 1973a,b). These results approximate the spectral peaks reported in the literature for the El Nino Southern Oscillation of 2.2-2.4, 2.8, 3.8 and 5.3-6.6 years. This suggests teleconnection between ENSO and rainfall variability in Nigeria.

3.3.2 Trends in Nigerian rainfall

The rainfall characteristics in Nigeria have been examined for secular change i.e. dominant trend notably by Olaniran (1990, 1992) and by Olaniran and Sumner (1989, 1990a,b). The dominant trends obtained are summarized in Figure 4.

Our results show that there has been a progressive early retreat of rainfall over the whole country spanning up to a half a century now and consistent with this pattern there has also been a significant decline of rainfall frequency i.e. the number of rain days in September and October which, respectively, coincide with the end of the rainy season in the northern and southern parts of the country. Furthermore, the combined effect of these declines was found to lead to a significant decrease in annual rain days over the whole country. In effect, except farmers change to early maturing crop varieties, streamline their farming calendars with the changing rainfall regime or have access to irrigation water, the secular changes in rainfall frequency reported above for the country pose serious threat to the maturity of annual crops and consequently to food security for the nation.

In the light of the totality of the evidence available to us (Figure 4), the progressive decline in rainfall activities may be captured thus: the decline begins with the inhibition of rainfall activity south of the ITD in July / August over the Sahelian Zone and as the ITD retreats, inhibition in rainfall activity is extended to the Sudan Savanna belt, Sahel's immediate neighbour to the south, in September and finally to the rest of the country by October.

Contrary to the long-term decline in rainfall widely reported for the 1970s and 1980s for subtropical West Africa, some areas of Nigeria have experienced a progressive increase in rainfall activities during certain periods. This is the situation over Southern Nigeria (Coastal and Guinea Savanna belts), which experienced progressive increase in August rainfall amount without a corresponding increase in rainfall frequency (Figure 4). This translates to a progressive increase in mean rainfall intensity over southern Nigeria thereby affording meteorological explanation for the widespread floods reported for many parts of Nigeria during the 1999 raining season by Adefolalu et al (2001). These floods are now becoming a feature of Nigerian climate and they show that the country is concurrently experiencing extreme rainfall conditions, one of drought and the other of floods. What a great paradox?

Our data also show evidence that since 1968 the start of the rains has been getting progressively delayed over southern Nigeria, a fact that is further corroborated by the significant

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decline in April rainfall (amount and frequency). By these results southern Nigeria is increasingly vulnerable to crop failure.

3.3.3 Occurrence of dry and wet episodes

Figure 5 shows the occurrence of dry and wet episodes during the last eight decades of the 20th century when a good network of rainfall measuring stations had been established in Nigeria. During the period 1921-2000 there was a countrywide occurrence of droughts during two periods: firstly from the 1930s to 1950 and recently from 1970 to the mid 1990s. During the last three decades each drought event persisted more in northern Nigeria than in southern Nigeria. For instance, the Sahelian Zone experienced drought from 1970-1977 and from 1980 virtually till 1990 while in the Sudan Savanna belt, the most recent drought lasted 10 years, 1981-1990. In contrast, southern Nigeria (Coastal and Guinea Savanna zones) experienced drought of 3-4 years duration at a time.

The period 1921-2000 also witnessed two distinct wet episodes: 1921-35 and 1951-70. Thereafter, i.e. from the mid 1970s to 2000, the occurrence of wet episodes was a localized affair being regionally restricted rather than occurring countrywide. As with the dry episodes, the wet episodes prior to the mid 1970 were also more pronounced, in terms of duration, in northern Nigeria than in southern Nigeria.

While in broad terms, dry and wet episodes have occurred within the periods identified above, they are not necessarily in phase in the four regions of the country. Thus, the wet episode of 1920-1925 in the Sahel did not start until two years later in the Sudan Savanna belt, three years later in the Guinea Savanna zone while its emergence was delayed by six years in the Coastal Area.

The differential pattern of occurrence of dry and wet episodes between southern and northern Nigeria is further consolidated by rainfall variability in the country on the decadal time scale (Figure 6). Over northern Nigeria, rainfall decreased in an irregular pattern which intensified over time from 1921-2000. Thus, the heavy rainfall of 1921-1936 was not matched by the subsequent increase in rainfall, which were experienced. Also, the reduced rainfall of 1936-1950 became more pronounced during 1971-1990. Apparently, therefore, rainfall decline over northern Nigeria has a long history, which is now almost a century long. In contrast, rainfall variation over southern Nigeria was characterized by fluctuations about a long-term average from 1921-2000.

While the droughts of the 1970s had attracted the greatest attention due to the publicity given to the events by the national and international press, they were dwarfed, in terms of severity, by the drought events of the 1980s in all the four regions of the country. Thus, whereas mean rainfall in the Sahel was 93.8% of the normal during 1971-80, the region received only 81.7% of the normal rainfall during 1981-90. The corresponding areal averages for the Sudan Savanna belt are 98.6% during 1971-80 and 89.8% during 1981-90.

The 1961-70 decade ranked as the wettest in southern Nigeria during the 20th century: rainfall was 6.1 per cent above the normal in the Coastal belt and 7.0 per cent above normal in the Guinea Savanna Zone. On the other hand, the wettest decade experienced in northern Nigeria was 1951 – 60: rainfall was 6.3% above average in the Sudan Savanna belt and 18.9% above normal in the Sahel.

3.3.4 Spatial coherence of rainfall variations in Nigeria

If the onset of rainfall is getting persistently delayed over the Coastal belt of the country, will the Guinea Savanna belt that lies immediately north of it, also experience delayed start of the rains? Also, if the rains retreat earlier than usual over the Sahelian Zone, will the other regions to its south similarly experience this? The answers to these questions lie in a study of the spatial coherence of rainfall variations between the four regions of the country. Olaniran (1990) and Olaniran and Sumner (1989, 1990a,b) have studied the degree of spatial coherence of rainfall variation between the four regions of Nigeria. The results of these studies are summarized in Figure 7.

It was found that different pictures of spatial coherence emerge according to the rainfall characteristic analysed. A high degree of association was found in the date of retreat of rainfall and in the annual rainfall frequency i.e. rain days over the whole country. The implication is that the other three regions to the south will similarly experience a later or earlier retreat of rainfall that begins in the Sahel. This is also true for variation in rain days (Figure 7).

Our data also present evidence of high degree of inter-regional association in total annual and growing season rainfalls for the three regions that lie south of 11^{o}N latitude. Thus, if annual rainfall is heavy over coastal Nigeria it will also be so in the two belts northward, the Guinea and

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Sudan Savanna belts. As regards the high degree of association in the dates of onset of rainfall, this was found to be limited to southern Nigeria implying that if the rains are earlier or late over the Coastal Area, this experience will be shared by the Guinea Savanna Zone.

Overall, southern Nigeria and the Sahel emerge as distinct regions with respect to spatial coherence in rainfall variations in the country. On the other hand, the Sudan Savanna belt emerges a transitional zone embracing the feature of ether the Sahel or southern Nigeria but generally more of the former i.e. the Sahel.

3.3.5 Spatial patterns of rainfall anomaly over Nigeria

What are the configurations of rainfall anomalies in Nigeria? The answer to this question was attempted by Olaniran (1991) who mapped rainfall anomalies for the country for a set of dry and wet years. Overall, six spatial rainfall anomaly types were found to emerge (Figure 8)

In spatial type I anomaly, above average rainfall occurs over southern Nigeria but below average rainfall over the northern part of the country. Sometimes, the lines dividing the country into areas of opposite rainfall anomalies may be tilted thereby giving rise to many variants of spatial type I anomaly. In spatial type II anomaly the central area of the country receives above average rainfall while the coastal and extreme northern parts of Nigeria receive below average rainfall. Nonetheless, the width of the central area of above average rainfall may vary in different dry years. Spatial type I and II anomalies were found to occur in 40 per cent of the monthly periods for the set of dry years studied.

The converse of the spatial type I anomaly described above can be observed in some months of dry years. This takes the form of above average rainfall over northern Nigeria but below average rainfall over southern Nigeria. This is referred to as spatial type III anomaly.

The monthly anomaly maps also depict evidence of a countrywide occurrence of below average rainfall. This is spatial type IV anomaly and it can be experienced at the beginning, during, and end of the rainy season. Spatial type IV anomaly was found to occur in 30% of the monthly periods for the dry years studied. Another type of anomaly displayed is what can be described as countrywide occurrence of above average rainfall. This is spatial type V anomaly.

Wet years show the converse of spatial type II anomaly in some months. This takes the form of below average rainfall in the central area but above average rainfall in both the coastal

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and the extreme northern parts of the country. This is spatial type VI anomaly. Variants of this anomaly type occur in terms of the width of the central area of below average rainfall.

The frequency of occurrence of spatial type VI anomaly in wet years is very low. Similarly, types III and V anomalies are not common in dry yeas, rather, they are common in wet years. In fact, spatial type III and V anomalies occur in 53.3% of the monthly periods for the set of wet years studied with respect to rainfall amount but 66.7% with respect to rainfall frequency.

The anomaly maps show further that countrywide occurrence of above average rainfall may contain scattered areas of below average rainfall (type IV anomaly). The converse of this also occurs with spatial type V anomaly. This is what Jackson (1978) describes as "localness" of variability patterns and it is due to the spatially discontinuous nature of tropical rainfall.

Some monthly anomaly patterns are very complex such that they cannot be classified into any of the six anomaly types described above. These complex spatial anomaly types may result from the interaction of the numerous factors which influence rainfall variability over the country as described in the theoretical background.

3.3.6 Shifts of rainfall belts in Nigeria

In order to ascertain whether there are shifts in rainfall belts in Nigeria, rainfall distribution over the country for the 30-year period, 1941 – 70 was compared with that of the recent 30-year period, 1971-2000 (Figure 9).

Compared with the distributional pattern for 1941-70, rainfall pattern changed significantly during the recent three decades, which ended in 2000. The localness apparent in the 1941-70 distribution (Fig. 9a) disappeared over the country during the latter 30-year period (Fig. 9b). In fact, rainfall distribution was more latitudinal during the recent period than in the former period. The study of Adefolalu (1986) also shows a progressive weakening of the localness between 1941 and 1980.

On the map for the earlier 30-year period, the 400 mm and 500 mm isohyets do not appear but they surface on the rainfall map for the recent 30-year period. On the 1941-70 map, annual rainfall is 600 mm in the extreme northeastern corner around Nguru but on the latter map this 600 mm isoline has shifted southward by 60 km. Also on the rainfall map for 1941-70, the 1200 mm isopleth which passes through Mokwa, Kaduna, Jos and Ibi (Figure 9a) shifts

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considerably southward on the rainfall map for the latter three decades passing through Ilorin, Lokoja and Yandev (Fig. 9b). This represents an average southward shift of 230 km.

Fig. 9 further shows that on the Jos Plateau the 1400 mm isohyet is replaced by the 1250 mm isoline while in the Niger Delta it is a case of the 2500 mm isohyet replacing the 2900 isoline between the two climatic normal. Also, the east-west 2000 mm isohyet reaches the coast at Lagos in the southwestern corner of the country on the 1941-70 rainfall map but it reaches the coast through Benin on the 1971-2000 rainfall map. Thus, the point at which this isopleth reaches the coast in the latter 30-year period has contracted eastward by 160 km.

The pronounced southward shifts in rainfall belts reported above during the recent climatic normal, 1971-2000, have expectedly been accompanied by changes in rainfall amounts. In the Sahelian Zone, annual rainfall decreased by 100 –150 mm between the two periods studied while in the coastal belt the decrease was of the order of 100 mm. Over the central part of the country, change in rainfall amount occurred in clusters: over the Jos Plateau annual rainfall decreased by 125 mm, southwest of the Plateau by 50-100 mm around Ilorin, Bida and Mokwa, but by 50-75 mm southeast of the Plateau in the Enugu - Yola axis. On the other hand, in the Ibadan-Lokoja –Osogbo area, rainfall increased by 50-75mm between the two periods.

The shift in rainfall belts and the concomitant reduction in rainfall amount associated with them, no wonder, resulted in the southward expansion of the boundary of the Sahel over the northern part of the country. Also, the large scale southward displacement of the 1200 mm isohyet in the central part of the country was responsible, in broad terms, for the low levels of water in hydro electricity power (HEP) generating dams (Kainji, Shiroro and Jebba) which are all located in this part of the country as often widely reported in recent decades.

3.3.7 Change in the seasonal rainfall regime

Signal of climate change may be obtained from a changed seasonal rainfall regime. Thus, Bello (1998) compared the seasonality of rainfall distribution in Nigeria in two periods, 1930-61 and 1962-1993 (Figure 10). During 1930-61 period, Bello found the rainfall regime in the forest zone to be equable (i.e. rainfall was received all the year round) but this changed into one of a rather seasonal rainfall regime during the 1962-93 period. In the extreme northeastern corner of the country, the seasonal rainfall regime of most rain in 3 months during 1930-61, changed into an extreme seasonal regime of almost all rain in 1-2 months during 1962-93. Also, the markedly

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seasonal rainfall regime with a long drier season experienced by the Sahelian Zone during 1930-61 changed to a seasonal regime of most rain in three months during 1962-93.

Greater "bunching" of the rains during 1962-93 than during 1930-61 meant, in effect, reduction in dry season rainfall during 1962-93. Data reported in an earlier study by Adefolalu (1986) confirmed decline in dry season (November-March) contribution to mean annual rainfall. Thus, according to Adefolalu (1986) locations north of 8°N latitude in the country received over 90% of the total annual rainfall in April-October while for southern stations the proportion of wet season rainfall was 84-88% of the annual total.

Pertaining to the implication of this trend Adefolalu concluded that "the drying trend during the dry season is perhaps the most significant variation form normal which tends to aggravate the water deficit during real drought years". In the light of these results, the comparatively less equable seasonal rainfall distribution during drought years has been compounded by reduction in dry season rainfall during such periods to create water supply problems for agriculture and humans.

3.3.8 Evidence of climate change in Nigeria from rainfall data

In spite of the extensive decline in rainfall activities already discussed in this lecture, can we conclude that rainfall climate has changed over Nigeria in the context of climate change? In search for evidence of climatic change based on Landberg's definition, Olaniran (1991) partitioned the 1921-85 rainfall series for each of the four regions in Nigeria into light ($\leq$ 10.4mm/day), moderate (between 10.4 and 25.4 mm/day) and heavy (>25.4 mm/day) rainfalls. Each series was analysed for fluctuations and trends. Figure 11 gives a summary of the trends depicted by the different intensity series. Additionally, the rainfall statistics for the 10 driest years and 10 wettest years up to 1985 were computed (Table 3).

Only the heavy and the moderate rainfall series in the Sahelian Zone and the heavy rainfall series in the Sudan savanna belt were found to depict evidence of climate change as defined by Landsberg. In these series, values decreased more in dry years than they increased in wet years (Table 3) and additionally each series presented evidence of a significant decline in rainfall condition during the period studied. Furthermore, the heavy rainfall series was found to show the greatest decrease, compared with the two other series, in dry years over northern Nigeria (the Midland and Sahelian Zones). In an earlier study (Olaniran, 1985) it has been

This space is for figure 11

reported that heavy rainfalls contributed 44-52 per cent of the annual rainfall in northern Nigeria. It can therefore be concluded that situations such as these have led to the persistence of drought conditions over northern Nigeria.

In contrast to the situation over northern Nigeria, the moderate and heavy rainfall series over southern Nigeria can be said to depict only evidence of high frequency oscillations. Although they show a tendency to increase more in wet years than they decrease in dry years , the increase in wet years was found not to be statistically significant. They are therefore characterized by as many runs of dry years as of wet years. Over southern Nigeria heavy rainfall contribute 44-60 per cent of the annual rainfall (Olaniran, 1985)

3.3.9 Summary on the manifestations of rainfall anomalies in Nigeria

The analysis carried out in this section has shown that the occurrence of rainfall anomalies in Nigeria has a long history being as old as the origin of our known world. Three regions emerged in the country during the 20th century based on the spatio-temporal patterns of rainfall anomalies. The Sahelian Zone manifested evidence of climate change in rainfall regime; the rainfall belt shifted southward by about 60 km and annual rainfall was reduced by 100-150 mm during the last three decades over this part of the country, a development which was further compounded by the concentration of most rainfall in 1-3 months.

Contrary to the situation that prevailed in the Sahel, southern Nigeria was characterized by alternating wet and dry conditions during the 20th century. Like the Sahel, this region also experienced reduced rainfall during the last three decades of the century but of the order of 100 mm and during the same time, seasonal rainfall distribution became less equable. The rainfall belt contracted eastward at the coast by about 160 km.

The midland area of the country (the Sudan Savanna belt) took the character of a transitional zone between the Sahel and southern Nigeria during the 20th century but it shared more in common with the Sahel than with southern Nigeria. This zone witnessed a southward displacement of the rainfall belt by about 230 km.

While southern Nigeria was subjected to widespread flooding and erosion mainly in August and September of the last three decades, reduced rainfall, aggravated by over exploitation of fragile ecosystems over northern Nigeria, led to equatorward expansion of desert conditions over the region.

TABLE 3

Rainfall Statistics in Dry and Wet Years in Nigeria (amount in mm).

	Dry Years			**Wet Years**		
	Light	**Moderate**	**Heavy**	**Light**	**Moderate**	**Heavy**
(a) Coastal Area						
Mean	320.0	551.3	1199.8	336.7	591.4	1442.3
% of normal	102.1	97.7	91.7	107.7	105.4	110.2
% of Deviation from normal	+2.1	-2.3	-8.3	+.7.7	+5.4	+10.2
(b) Guinea – Savanna Zone						
Mean	217.2	386.5	589.4	233.5	407.3	680.4
% of normal	101.5	98.2	95.9	109.1	103.5	110.7
% of Deviation from normal	+1.5	-1.8	-4.1	+9.1	+3.5	+10.7
(c) Midland Zone Sudan Savanna						
Mean	194.1	401.8	502.7	218.2	423.1	556.8
% of normal	93.5	98.3	92.3	105.0	103.6	102.3
% Deviation from normal	-6.5	-1.7	-7.7	+5.0	+3.6	+2.3
(d) Sahelian Zone						
Mean	102.3	200.9	264.3	131.5	243.1	373.5
% of normal	87.7	88.6	77.9	112.9	107.2	110.1
% Deviation from normal	-12.3	-11.4	-22.1	+12.9	+7.2	+10.1

Source: Olaniran (1991)

4.0 IMPACT ASSESSMENT OF RAINFALL ANOMALIES IN NIGERIA

It has been established in this lecture that during the 20th century, Nigeria experienced alternating wet and dry episodes on the decadal time scale. These are opposite sides of the same coin and they had far reaching impacts such as desertification, flooding, erosion, reduced stream flows and shortages of water supply as well as declines in agricultural production in different parts of the country during the period.

In his review of studies on desertification, Adefolalu (1990) noted that meteorological drought (i.e. reduced rainfall) is a reinforcing, rather than, the initiating factor of desertification. According to the review, when highly fragile ecosystems at the margin of deserts are over exploited for grazing by animals, water supply through wells and some agriculture, the soil water level drops below the depth penetrated by plant roots when the rains fail. In such a situation the danger of expanding desert conditions becomes imminent. And with the prolonged drought over northern Nigeria for up to 85% of the last three decades, fragile ecosystems have been disturbed leading to equatorward expansion of desert conditions in the country. Data presented by Adefolalu show that sahelian vegetation of shrub and dry grassland, which was non-existent in Niger State (situated between 9^o and 11^oN) in 1977 occupied between 15 and 20% of the state in 1987. The situation in states north of Niger State namely Kebbi, Sokoto, Zamfara, Kano, Katsina, Jigawa, Yobe and Borno can then be imagined.

Thank goodness, the country has been giving appropriate response to desert encroachment through afforestation initiatives which now date back to more than 20 years ago. However, we cannot yet say 'uhuru' as regards the fight against desert encroachment. The recent increase in the litre price of kerosene from N17.00 to N24.00 may tempt the urban poor and rural dwellers to over exploit vegetal cover for fuel wood thereby, reversing the gains from afforestation initiatives. Nigeria should therefore screen policies and project for their environmental implications. Otherwise, it will be a case of one step forward another one backward.

Nigeria experienced widespread flooding and erosion in 1999 (Table 4). Based on the data reported, the flood events and erosion occurred mainly in August and September of that year and they had a countrywide pattern of occurrence. Adefolalu et al (2001) summed the impact of the 1999 flooding thus:

> *'There were at least 56 deaths, over N12 billion ha of farmlands washed away resulting in estimated farm produce loss of 100 million tons. Infrastructural facilities (houses, schools, roads, etc.) destroyed will cost over N50 billion to rehabilitate or replace.*

Given the enormity of the damage, the poser is 'what went wrong in 1999?' A progressive increase in August rainfall spanning about half a century now was reported above for southern Nigeria in this lecture. Although 1991-2000 was a decade of normal rainfall condition (Fig. 6), rainfall was about average only in the Sudan Savanna belt in 1999 (just 1.9% below the normal) but well above normal in the other three regions in that year: 9.5% above the 60-year mean in the Sahel, 30.5% above average in the Guinea Savanna belt and 11.5% above the long-tern mean in the Coastal Area. The increasing wetness of the August / September period was therefore triggered towards widespread flooding and erosion by the heavy rainfall of 1999.

Reference has been made above to the fluctuations in the level and extent of Lake Chad during the palaeo and historical periods. The cyclic pattern was shown to reflect alternating wet and dry conditions of the periods.

For the instrumentation period, the data presented in the literature show that the surface area of the lake was 23,500 km^2 in 1963 but this shrank to between 2,300 and 2,500 km^2 in 1984. Such was the high rate of shrinking of the lake's surface area that Adefolalu (1983) had projected that Lake Chad would be extinct by the year 2000 such that the proposal now under consideration by the Lake Chad Commission, is for water to be transferred from the Congo Basin, over a distance of 75 km, to save Lake Chad from extinction.

Babatolu (1998) documented the sensitivity of water resources to fluctuations in rainfall climate using the old Niger River Basin Development Authority Area (NRBDA) as a case study. He reported that wetter climate causes a greater change in runoff than does drier climate. He reported further that the widespread decrease in rainfall of the order of 4.9-14.7% over the basin during the 1980s led to a corresponding decrease of 20.4-35.8% in runoff over the entire basin. Furthermore, according to Babatolu, the decrease in rainfall from 1980-1990 together with the increasing demand for underground water over the basin resulted in the abandonment of about 10% of the wells in use, due to very low yield.

Table 4

Flooding Episodes and Destruction in Nigeria

S/N	DATE	TOWN	OCCURRENCE	REMARKS
1.	July, 1999	Lagos: Lagos State	Widespread flooding	One life lost, Property damaged worth billions of Naira
2.	July, 1999	Agiliti (outskirt of Lagos) in Lagos State	Ogun river overflow	40 lives claimed
3.	August, 1999	Chanchaga, Mariga, Magama, Rijau, Wushishi, Borgu, Gbako, Munya, Lapai, Bida, Agwara (Niger)	Many villages flooded, farmlands washed away	Thousands of families rendered homeless, Damage undetermined. Two lives lost in Minna.
4.	August, 1999	Bar Beach (Lagos), Lagos State.	Coastal Erosion	Several metres of coastline washed away. Multi-billion Naira property threatened.
5.	August, 1999	Goronyo (Sokoto) in Sokoto State.	Flooding of community by River Rima	Loss undetermined
6.	August, 1999	Virtually all 27 LGAs in Imo State	Widespread erosion	Many lives, farmlands, homes lost. Thousands rendered homeless
7.	August, 1999	Parts of Jigawa & Yobe States.	Floods	3,000 farmlands submerged (rice, maize, sorghum destroyed)
8.	August, 1999	7 LGAs in Borno State	Floods	Hundreds rendered homeless. N25m property destroyed in Railway Corporation Quarters (Maiduguri)
9.	August, 1999	Ogidigben (Delta State)	Atlantic Surge	7,000 people threatened
10.	August, 1999	Shira (Bauchi State)	Floods	Seven villages washed away, N20m property lost.
11.	August, 1999	Bauchi Municipality (Bauchi State)	Floods	5 dead, 30 injured, 100 houses collapsed
12.	August, 1999	Chiyaku & Kwari (Jigawa State)	Erosion	90 houses destroyed
13.	August, 1999	Yola (Adamawa)	Floods	Property worth millions destroyed
14.	August, 1999	Fufore LGA (Adamawa)	Floods	13 villages submerged, hundreds of acres of farmlands washed away.

15.	Sept., 1999	Ondo State – Akure North, Owo, Ilaje-Ese Odo	Floods/ Atlantic surge	1000s of hectares of farmland washed away. Hundreds of houses destroyed, fishing villages affected.
16.	Sept., 1999	Ikere, Ado, Aramoko, Efon, Moba, Ilaje-Meje and Emure (LGAs)	Floods/Erosion	Farmlands, schools submergd, all intra-LGA roads washed away. Severe gullying.
17.	Sept., 1999	Birinin Kudu LGA (Jigawa)	Floods (NTA Documentary of 28/9/99)	6,000 homeless, millions of Naira property lost.
18.	Sept., 1999	NIGER (Mokwa, Lavun, Lapai, Agaie LGAs)	Floods from Jebba and Shiroro dams	17 dead, farm products, household losses. Problems of rural-urban migration.
19.	Sept., 1999	Hawal LGA (Borno)	Six villages flooded	Hundreds rendered homeless, Damage undetermined
20.	Sept., 1999	Kwara	Nigeria's premier sugar factory BACITA sugarcane farms flooded	Five-year loss due to flooded farms; N1.417 Billion since 1994
21.	Sept., 1999	Rivers State-entire low-lying areas	Atlantic surge/Flooding	Farmlands submerged
22.	Sept., 1999	Bayelsa (entire State)	Floods	Houses destroyed, fishing communities displaced. Losses in millions of Naira

Source: Adefolalu et al (2001)

Agricultural production is not insulated form the vagaries of weather despite the many years of advances of crop and animal husbandry in the country. For much of the country in 1973, the rains failed causing widespread crop failure. This situation was well captured by Oguntoyinbo (1981) when he said that "early planting encouraged by the false start of the rains was subsequently followed by rainfall cessation. In consequence, crops already planted and beginning to germinate after the early rains were soon killed off by lack of moisture:. The 1973 situation described by Oguntoyinbo was again repeated in 1973.

When the crops do not fail, the vagaries of weather can still cause variation in yield. Olaniran (2001) presented data which show more than 50% variation in millet yield at Kano (Sahelian Zone) between wet and dry years and the same range of variation in cane sugar yield at Bacita (Southern Sudan Savanna belt) between wet and dry years. Similarly, livestock husbandry is vulnerable to adverse weather based on data reported by Oguntoyinbo and Richards (1977) for the Sahelian Zone of Nigeria.

Impact assessment undertaken in this section has shown the vulnerability of Nigeria to geo-environmental degradation caused by rainfall anomalies over the country. Further, it has been established that droughts cause declines in agricultural productivity thereby raising the problem of food security for the nation. Such may also compound the woes of peasant farmers thereby making them to sink deeper into poverty.

Yet, we cannot wish away rainfall anomalies in the country. What then is our hope for the future? We should develop the knowledge and skill for early warning about rainfall trends. With such early warnings we will then be able to embark on forward planning and thereby mitigate the adverse effects of precipitation anomalies. Attention is therefore next focused on the forecasting and predication of rainfall trends in this lecture.

5.0 RAINFALL FORECASTING AND PREDICTION

Good rainfall forecast is desirable on three times scales, namely; a few hours up to 10 days, a few weeks up to a season and for periods greater than a season. Forecast on a scale of 2-10 days would aid the timing of agricultural activities such as sowing, fertilizer application, irrigation, and harvesting. Forecast on the scale of a day and above will allow emergency action to be taken and minimize damage to life and property in the case of an impending flood event.

In the UK and USA rainfall is monitored and estimated using radar and satellite technologies complemented by general circulation modelling (GCM). The information from radar weather station is integrated to distinguish between precipitation of different intensities and users of the system can receive instantaneous precipitation data which will aid short term forward planning (Sumner, 1988). The operational reliable radius for radar is 200 km and consequently a country of the size of Nigeria requires a network of 14 radar stations. Paradoxically, the country operates a network of only two radar stations, one in Lagos and the other in Kano. Sometimes the radar system even breaks down as recently experienced from 2000-2001 by the Lagos station.

Weather satellites are used for sensing clouds from which precipitation rates are estimated and the information obtained therefrom may usefully be interpreted to give insight into precipitation intensity at the ground surface beneath although satellite-deduced precipitation is usually higher than actual rainfall. Satellites have an excellent location for the observation of areas not within the reach of radars, or which are not extensively instrumented at the ground because of inaccessibility (Sumner, 1988). In particular, satellite data provide useful guide for accurate monitoring of the position and tracking of the rain-producing weather systems. This is of immense value for rainfall forecast on the time scale of hours up to the lifespan of the rainfall-producing weather systems. Unfortunately, Nigeria is yet to join the League of Nations with meteorological satellites (METEOSAT)

The General Circulation Model (GCM) used by the UK Meteorological Office for climate research has 11 levels in the vertical and a horizontal grid with a spacing of 2.5^{o} of latitude and 3.75^{o} of longitude (Owen and Ward, 1989). For Nigeria to operate according to this standard its potential upper air network observation stations should be a least 11. Contrary to this, the country makes upper air observations at four levels and at only two locations, Lagos and Kano. Against the backdrop of these fundamental limitations, the Nigerian Meteorological Services is only able to give general, rather than specific daily weather forecast.

Also, in seasonal rainfall forecast or prediction, the objective is to provide advance information. Thus, statistical models are being derived based on time-lag teleconnections. According to the ITD model earlier discussed, the southwesterlies advance inland from Gulf of Guinea coast. This implies that the date of the onset of rainfall at southern stations can be used as a lead, to determine the onset of rainfall for northerly locations. In the case of the end of the rains, the ITD retreats in the north-south direction, implying that the end of the rains at a northern station can be used as the lead, for determining the end of the rains for southern locations. Olaniran (1984) used this concept to derive multiple regression equations for calculating the timing of rainfall activities over the old NRBDA in Nigeria.

In addition to the ITD as a predictor variable , two other predictor variables were considered, namely, the east-west moving disturbance lines and topography. In the study normal, wet and dry years were differentiated by deriving separate equations for each. The equations were found to explain between 64.7 and 76.7% of the variability in the timing of rainfall activities over the basin. There is a reasonable physical basis for these relationships and they show that advance information can be obtained on the timing of rainfall activities. However, the equations need to be tested with more recent data and improved upon with countrywide rainfall data.

Olaniran et at (2001) have also attempted seasonal rainfall forecast for southern Nigeria using the regression model. Rainfalls received during 'wet' dry seasons (November - March) were correlated with the subsequent rainy season (April- October) rainfall with the former as the predictor variable. The correlation coefficient r = 0.88 (77% explanation) was obtained for the Coastal Zone but r = 0.20 (4% explanation) was obtained for the Guinea Savanna belt. These results suggest that a 'wet' dry season over the Coastal Area will be subsequently followed by a rainy season of heavy rainfall. Persistence of meteorological condition from the 'wet' dry season to and throughout the subsequent rainy season is the physical basis of the good forecast. However, 'wet' dry season is experienced only in southern Nigeria and its frequency is low (we found 12 'wet' dry seasons in the 1941/42 – 1989/90 rainfall record).

The meteorological basis of the link between reduced rainfall over the Sahelian Zone of West Africa and SSTA has been explained above. Today, the UK Meteorological Office integrates the tropical Atlantic and extra-tropical SSTAs in the general circulation model (GCM) for experimental annual rainfall forecast for the Sahel. While the results obtained are encouraging it has been established that for improved performance of the integrated SSTA-GCM approach, there is need to develop techniques for predicting the patterns of SSTA ahead of the rainy season.

We have noted above that radar station and upper air observation networks are grossly inadequate in Nigeria. This has limited the Nigeria Meteorological Services to giving general daily weather forecast, rather than, specific daily weather forecast. Additionally, the localized and sporadic nature of tropical rainfall as well as the absence of synoptic systems (such as are experienced in temperate latitudes) makes weather forecast on the scale of 1-10 days difficult (Farmer and Wigley, 1985).

6.0 CONCLUSIONS

We have examined rainfall anomalies in Nigeria through three periods: the palaeo period from about 20,000 years BP to 1500 AD, the historical period from 1500 – 1900 AD, and the instrumental period which so far concedes virtually with the 20^{th} Century. The rainfall anomalies tell one story which is well captured by the biblical saying "As it was in the beginning, so it is now, and ever shall be. ". The rainfall anomalies which have occurred, although we may want to wish them away, are part of our climate and its variations. Mr. Vice-Chancellor, our distinguished audience, I cannot play God, but in the light of the evidence before us, I wish to say that the rainfall anomalies which either occurred in the past or are currently being experienced over the country, will also occur in future. This is our first major conclusion from this lecture.

The second major conclusion is that based on the spatio-temporal patterns of occurrence of the rainfall anomalies in the country during the 20th century, Nigeria can be divided into three regions. The first is the Sahelian Zone comprising Kebbi, Sokoto, Kastina, Kano, Jigawa, Yobe, and Borno States (i.e. area of the country north of 11^{0}N latitude). In this zone the rainfall climate has changed , the rainfall belt shifted southward by about 60km, annual rainfall was reduced by 100-150 mm during the last three decades, while most rains now occur in 1-3 months.

The second region is southern Nigeria where the rainfall climate is characterized by alternating wet and dry conditions on the decadal time scale. This region also experienced reduced annual rainfall during the last three decades but of the order of 100mm. Seasonal rainfall distribution has also become less equable. The rainfall belt has contracted eastward at the coast by about 160km.

The third region is the Sudan Savanna belt from the Niger State in the west to Adamawa State in the east. This belt is a transitional zone between the Sahel and southern Nigeria but it took more of the character of the Sahel than that of southern Nigeria during the 20th century. Over this region the rainfall belt has been displaced southward by about 230km.

Thirdly, rainfall anomaly in Nigeria can be perceived as a phenomenon in which atmospheric circulation, rainfall, sea surface temperature changes (through changes in upwelling) and remote meteorological events are linked in a complex, and as yet incompletely understood manner. This has made rainfall anomalies difficult, if not impossible, to forecast on the seasonal time scale. Also the country lacks adequate radar stations and upper air observation networks and this has hindered effective short-term rainfall forecast on the scale of 2-10 days.

Finally, it should be admitted that more work has been done on climatic variability in Africa under the initiative of the west i.e. the developed countries than by African governments and by extension scientists from Africa. In this regard the efforts of the following organizations are praise worthy – the United Kingdom Meteorological Office, the Climate Research Unit of the University of East Anglia, the UK Overseas Development Administration, and the World Meteorological Organization (WMO) through its various research initiatives. In order to supplement these efforts, we should re-organize climatic based research and indeed environmental – based research in Nigeria.

7.0 RECOMMENDATIONS

Our recommendations in this lecture will be based mainly on the lessons from the story about four people named Everybody, Somebody, Anybody and Nobody. There was an important job to be done and Everybody was sure Somebody would do it .Anybody could have done it, but Nobody did it Somebody got angry about that, because it was Everybody's job. Everybody thought Anybody could do it, but Nobody realized that Everybody wouldn't do it. It ended up that Everybody blamed Somebody when Nobody did what Anybody could have done.

The important job to be done is co-ordination of research on the status of the Nigerian environment for its proper management and protection. The job is beyond the capability of individual researchers working in isolation in different parts of the country. Neither is this the responsibility of environmental scientists from the UK, US, France, etc whose research activities are on subtropical Africa. There is therefore the need for a body that will co-ordinate research efforts and be the vanguard for a well informed monitoring, management and protection of the Nigerian environment as well as minimize the negative impacts of environmental change. I will therefore like to make a case for the establishment of a National Climate Research Centre with a status similar to others in EU, USA, Latin American States and Australia to be funded from a National Science Foundation (NSF), which should also be established.

Among the roles of the Climate Research Centre will be

i. Initiating, conduction and co-coordinating research on the status of the Nigerian environment with particular emphasis on climate – rainfall prediction,
ii. undertaking impact assessment of climate change in Nigeria,
iii. disseminating research results to end users, and
iv. collaborating and co-operating with all stakeholders on the environment both at the national and international levels.

In addition, because the occurrence of rainfall anomalies is countrywide, government should intensify its irrigation projects by focusing more on medium and small scale schemes than hitherto, so that the countervailing effect of irrigation in agricultural production can be more effective. In the same vein appropriate technology is required in order to meet the challenges posed to agriculture by rainfall anomalies in Nigeria.

Furthermore, the Nigerian Meteorological Services should be strengthened to increase its network of radar weather stations from 2 to 14 and its network of upper air observations, from 2 to 11. Additionally, Nigeria should endeavour to join the League of Nations using meteorological satellite (METEOSAT). All these are imperative for good weather forecast on the time on the time scale of hours to 10 days in the country.

8.0 ACKNOWLEDGEMENTS

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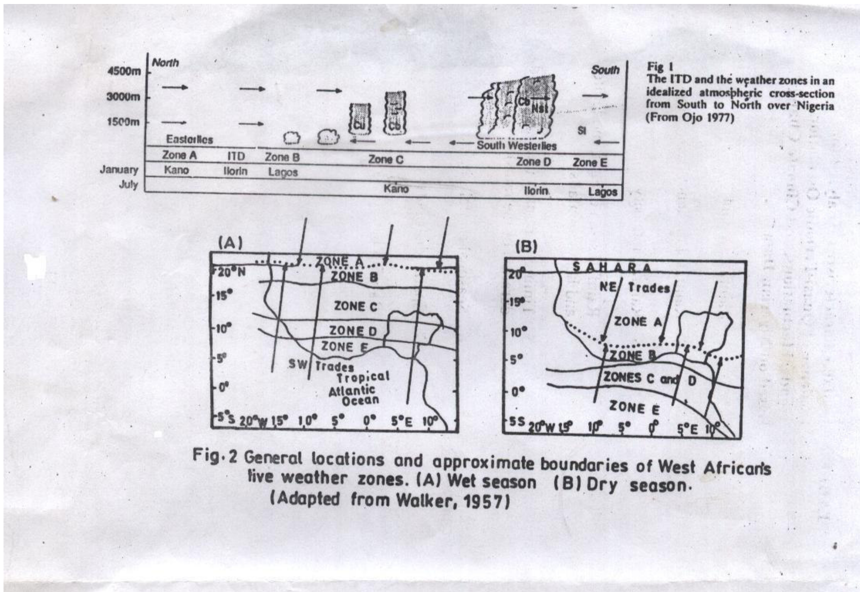


Fig 1
The ITD and the weather zones in an idealized atmospheric cross-section from South to North over Nigeria (From Ojo 1977)
North
South
4500m
3000m
1500m
Easterlies
South Westerlies
Zone A
ITD
Zone B
Zone C
Zone D
Zone E
January
July
Kano
Ilorin
Lagos
(A)
(B)
ZONE A
ZONE B
ZONE C
ZONE D
ZONE E
SW Trades
Tropical Atlantic Ocean
SAHARA
NE Trades
ZONES C and D
Fig. 2 General locations and approximate boundaries of West African's five weather zones. (A) Wet season (B) Dry season.
(Adapted from Walker, 1957)

Fig 1&2

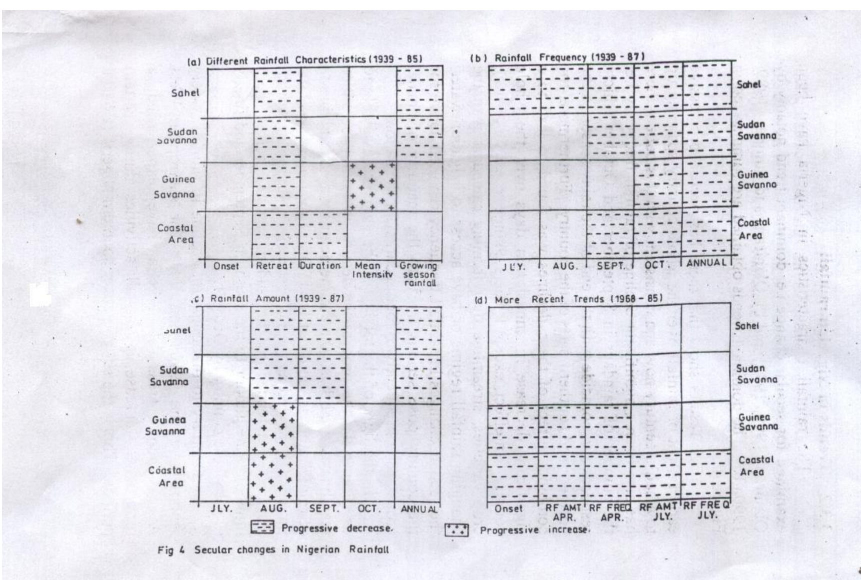
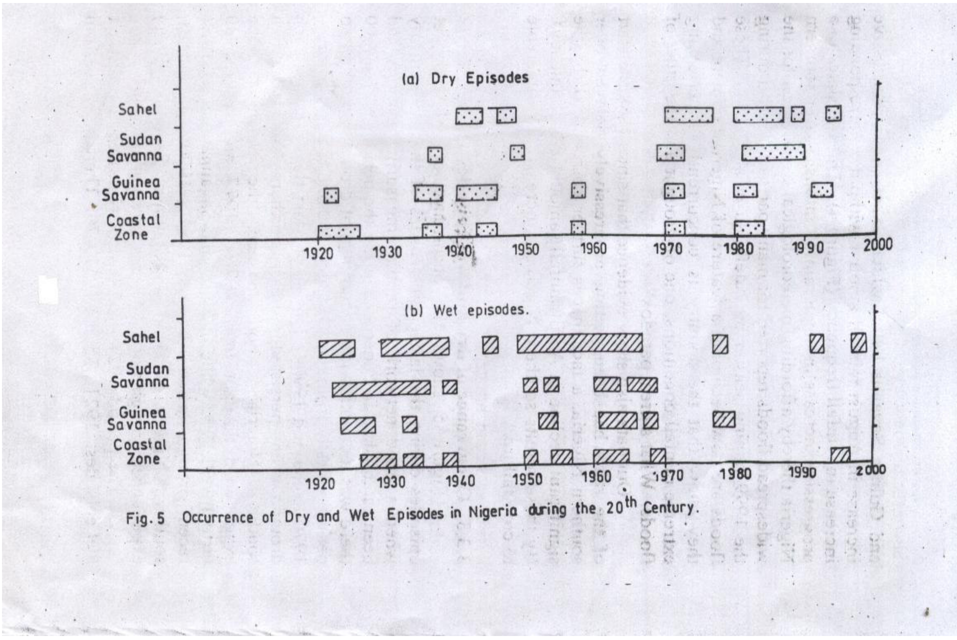
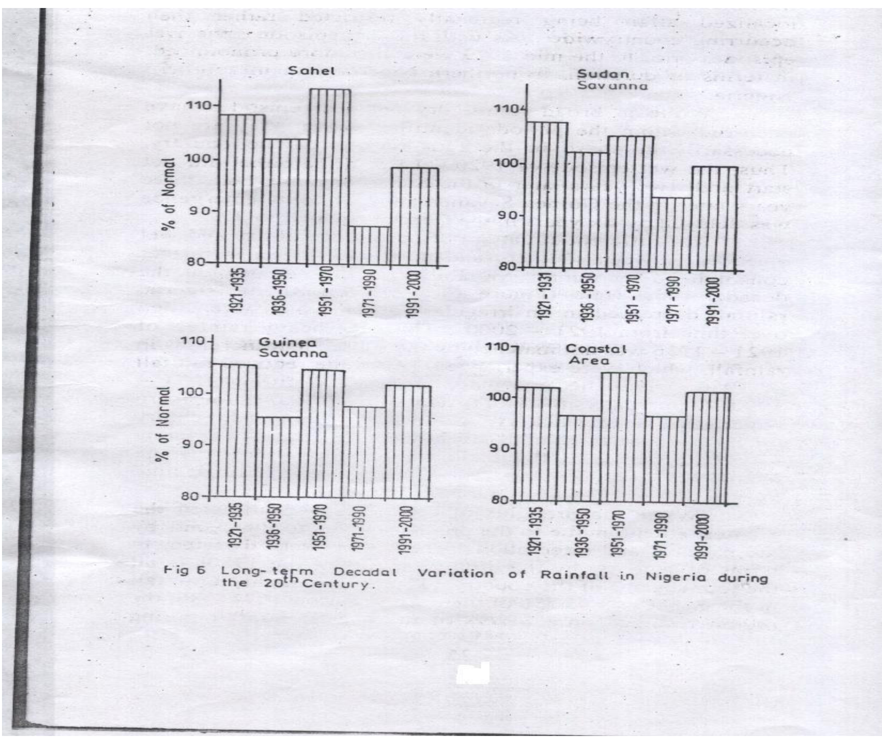

(a) Different Rainfall Characteristics (1939 - 85)
(b) Rainfall Frequency (1939 - 87)
(c) Rainfall Amount (1939 - 87)
(d) More Recent Trends (1968 - 85)
Sahel
Sudan Savanna
Guinea Savanna
Coastal Area
Onset
Retreat
Duration
Mean Intensity
Growing season rainfall
JLY.
AUG.
SEPT.
OCT.
ANNUAL
RF AMT APR.
RF FREQ APR.
RF AMT JLY.
RF FREQ JLY.
Progressive decrease.
Progressive increase.
Fig 4 Secular changes in Nigerian Rainfall

Fig 4



(a) Dry Episodes
Sahel
Sudan Savanna
Guinea Savanna
Coastal Zone
1920
1930
1940
1950
1960
1970
1980
1990
2000
(b) Wet episodes.
Fig. 5 Occurrence of Dry and Wet Episodes in Nigeria during the 20th Century.

Fig 5



Sahel
Sudan Savanna
Guinea Savanna
Coastal Area
% of Normal
110
100
90
80
1921-1935
1936-1950
1951-1970
1971-1990
1991-2000
1921-1931
Fig 6 Long-term Decadal Variation of Rainfall in Nigeria during the 20th Century.

Fig 6