

HYDROLOGICAL ASPECTS OF DROUGHT IN LOKOJA, KOGI STATE, NIGERIA.

BY

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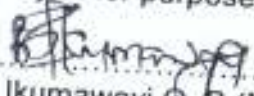


AUGUST 2005

CERTIFICATION

(a) (By the Student)

This work has not been presented elsewhere for the award of a degree, or any other purpose.


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(b) (By the Supervisor(s))

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It is my prayer that it shall be well with all of you in Jesus name. Amen.



DEDICATION

This project is dedicated to Almighty God who will never share His glory with any man and in whom there is no variableness or shadow of turning, the unchangeable God who has been my help since the beginning of my study in FUTA.

ABSTRACT

Drought existence is not new in Lokoja (Kogi State) of Nigeria, considering the fact that the entire sahel region is susceptible to climatic anomalies. The climatic phenomenon cannot be prevented nor eradicated; rather the effects on humanity can be mitigated. This study was conducted to assess the drought potential of Lokoja using long term rainfall data and then determine the most appropriate technique for the evaluation of drought in the area. The rainfall data was collected from the meteorological department of Lokoja in Kogi State. The study which covered 73- year period (1931-2003) was conducted on Lokoja in Kogi State of Nigeria using the rainfall data. Four major techniques were used for the evaluation; these are Stochastic Component Time Series, Rainfall Anomaly Index, Cumulative Rainfall Information, and the Drought Severity Index based on the quartile range.

The results obtained from technique showed that 8 distinct years namely 1931,1935,1940,1943,1951,1981,1990,1999 experienced severe drought while 1942, 1987, 1983 and 1982 experienced more severe drought. Drought threatened the region for many years within the period of the study but that of 1942 was most severe.

Rainfall Anomaly Index is the most appropriate technique for the evaluation of drought in Lokoja because it gives the rainfall indices as well as yearly anomalies. It offers more explanations than the other techniques about the severity and impact of drought in the study area.



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CHAPTER ONE

1.0 INTRODUCTION

Drought is a natural component of the climatic system. With reference to global climatic anomalies, drought is not a strange phenomenon to African continent especially in the sahel region in which the Northern part of Nigeria and the middle belt lie. (Okorie 2003). Drought is one of the most serious problems in history and the ecosystems that arise from climatic variability. Although, its impact does not come through sudden events such as flood and thunderstorms, drought is one of the most damaging phenomena of natural disasters over long periods. Le Houerous, (1996) stated that droughts occur in almost all agricultural lands in the world, but arid lands are the most susceptible. Drought in general, occurs from less precipitation over an extended period of time. Drought is a weather related natural disaster; it affects vast regions for months or years. Drought is also one of the world's costliest natural disasters, causing an average of \$6-\$8 billion in global damages annually and collectively affecting more people than any other form of natural disaster (Wilhite 2000).

Numerous specialized indices have been proposed to qualify drought. Extensive listings of available indices are to be found in WMO (1975) and Heim (2000) publication. Drought is difficult to define precisely, but operational definitions such as agricultural, socio-economic, meteorological and hydrological droughts often help to define the onset severity and end -of-droughts. It is a climatic phenomenon and as climate can either be normal or abnormal, the probability of drought occurrence on the global environment is positively skewed (Okorie 2003). Meteorological drought is defined usually on the basis of the degree of dryness (in comparison) to some normal or average amount and the duration of dry period while agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between

actual and potential evapotranspiration, soil water deficits and reduced groundwater of reservoir levels.

The hydrological drought is associated with a deficiency in the bulk water supply, which may include water levels in streams, lakes, reservoirs, and aquifers. Many nations have experienced considerable distress arising from drought occurrences (famines), cessation of economy particularly within the developing world where economies are tied strictly to agriculture (Okorie, 2003).

Human beings often increase the impact of a high use of water that cannot be supported when the natural supply decreases. It has impact on food production and it reduces life expectancy and the economic performance of large region or entire countries. The impact of drought results from the relation between a natural event and demands on the water supply, and it is often exacerbated by human activities. The experience from droughts has underscored the vulnerability of man because if total rainfall is inadequate, or if rainy season terminates early, the crops may not mature and yields will be very low. Thus, it is often the distribution rather than the total amount of precipitation during the rainy season that is more significant factor for agricultural productivity.

The agricultural and the hydroelectric power sectors of Lokoja are affected during drought, therefore, man, animals and the economy will be affected. The hydrological drought impacts affect the agricultural sector while droughts result in significantly reduced hydroelectric power generation production because power plants are dependent on stream-flow.

Objectives of the study

The objectives of this study are to:

- i. assess the drought potential of Lokoja, using long term rainfall data.

- ii determine the most appropriate technique for the evaluation of drought in Lokoja.
- iii evaluate the severity and impact of drought in Lokoja area.

2 Justification for the study

The study aims at finding out the occurrence of drought at Lokoja as well as its impact on the area. It is to analyse the rainfall data, using different techniques for drought evaluation.

The most appropriate technique for the evaluation of the severity and impact be determined to modify the undesirable effects of drought for effective water resources development within the study area.

3 Scope and Limitation of the study

This study was limited to the hydrological aspects of drought due to the difficulty in obtaining the necessary information, so as to examine the other types of drought. Therefore, the study was only limited to the Lokoja rainfall record of 73 years between 1931 and 2003.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Drought, a Climatic Phenomenon

Drought is a natural component of the climatic system. Because of the varied nature of water use, drought assumes a variety of definitions each of which is dependent on the water scarcity or deficit. However, drought can be regarded as "lack of sufficient water to meet essential needs".(Ambenje, 2000). Droughts in the tropics produce perhaps more disastrous situation than flood. The effect and statistical analysis are far less known than for floods and prevention of their effects is much more difficult than the effect of floods. The most significant difference probably lies in the duration of the extremes.

One of the worst droughts in Africa was experienced during the period between 1968 and 1974 in the Sahel region, namely Chad, Mali, Mauritania, Niger, Senegal, Upper Volta and Gambia, where the latter suffered most. Then, the drought extended to Southern Sudan and Ethiopia (Gibbs and Maher, 1967). During the dry period, the rivers Senegal and Niger fell to the lowest water levels measured where Lake Chad was reduced from its normal size. Drought can be monitored through the application of various statistical techniques and this requires the availability of long-term series of historical data. The statistical techniques for monitoring drought range from highly sophisticated models like the Palmer drought index to simple procedures such as the use of percentiles, deciles and quartiles (Gibbs and Maher, 1967).



2.2 Drought Definitions and Occurrences

Drought means different things to different people. No single parameter be it precipitation, runoff, evapotranspiration, temperature, soil moisture or crop yield can serve as an adequate or comprehensive drought index. The droughts in the tropics do produce perhaps

more disastrous situation than flood. Many definitions of droughts are based on the adaptability of husbandry to the average conditions. Drought can also be described as short period of rainfall or dry spell. Hydrological drought may be defined as period during which stream-flows are inadequate to supply established uses under a given water management system. Commonly, hydrology is involved in two kinds of drought studies; they may be concerned with low flows, which will be limiting for a water supply served by diversion without storage and are also critical in water pollution problems. They may also be concerned with extended periods of low flow as they may affect the yield of a storage reservoir (Linsley, et al. 1988). Drought is really a matter of definition. The glossary of meteorology defines it as a period of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious or hydrological off-balance (crop damage, water supply shortage e.t.c.) in the affected areas. Drought also means water deficiency and it can be regarded as "lack of sufficient water to meet essential needs" (Ambenje, 2000).

Droughts are natural hazards with varying patterns in space, time and intensity (Brown, *et al.* 2002). Therefore, they may affect people and agriculture at local scale for short period or cover broad regions or have impacts that are felt for years, for example, the dust bowl (Brown et al, 2002). Thus, the economic effects of drought are significant, it has been estimated that drought results in annual economic losses in the US of between \$6-\$8 billion (FEMA, 1995). Drought, a climatic anomaly measured by the departure of actual rainfall from the amount required for normal operation of the established economy of an area, is stronger to Northern Nigeria and occurs as one of the most devastating natural disasters that affect the region (Oladipo, 1985). However, records show that drought is recurrent in Northern-Nigeria (Van Apeldoorn, 1981).

2.3 Causes of Drought.

Drought originates from a deficiency of precipitation over a long period of time, usually a season or more and this deficiency results in a water shortage for some activity, group, or environmental sector. Drought arises from climatic irregularities and creates more drought impact, it does not occur through sudden events such as flood and storms. The ultimate cause of drought is climate fluctuations and variations. In arid and semi-arid environments, precipitation is very low but evapo-transpiration is very high. Also, in a tropical wet and dry zone it was observed that: rainfall is seasonal, there is rainfall variability, wasteful use of water, under-utilization of available water demand occasioned by population growth, urbanization and increase in socio-economic activities and poor standard of living of people. This shows that water shortages may arise from natural and man-made induced causes.

2.4 Drought Types

There are three major forms of drought namely meteorological, hydrological and agricultural.

(i) Hydrological drought: This is associated with a deficiency in bulk water supply. It includes water levels in streams, lakes, reservoirs, and aquifers. Of the major drought forms, hydrological drought may be the slowest to develop (Soule, 1992). For example, a shortage of snowfall may not manifest as runoff until half a year later. This inertial also means that hydrological drought can persist longer than other forms of drought (Kenyantash and Dracup, 2002). Hydrological drought may be defined as a period during which stream-flows are inadequate to supply established quantities or amount under a given water management system (Linsley, et al. 1988).

(ii) Agricultural drought: Since most crops are planted, agricultural drought is specifically concerned with cultivated plants, as opposed to natural vegetation (Kenyantash and Dracup,

2002). Due to the continuous need of adequate water by plants, agricultural drought may set in rapidly, and can similarly terminate suddenly. It is characterized by important short-term changes to the volumetric soil moisture (the fraction of pore space that soil water occupies) in the root zone (WMO 1975, Rawls, 1993). Thus, it is often the distribution during the rainy season that is the most relevant factor in food production (Wilhite and Glantz 1985, Adedoyin 1989). Le Houerous, (1996) stated that drought is experienced in almost all types of agricultural lands in the world, but that arid lands are most susceptible. Agnew and Warren (1996) described agricultural droughts as a spatial phenomenon that causes significant reductions in agricultural productivity, mainly due to an inadequate supply of soil moisture.

(iii) Meteorological drought: Meteorologists usually explain drought in a given region in terms of abnormal atmospheric circulation patterns which favour subsistence over the region. The meteorological drought can be said to be the shortage of rainfall in close to or above normal conditions. Meteorological drought can be defined as the deviation of precipitation from normal over an extended period of time (Agnew, 1990).

2.5 Effects of Drought

2.5.1 Effects of Drought on Man.

Adedokun (1978) reported that the problem of drought and desertification has plagued the Sahelian region of West Africa in varying degrees of severity since the early 70's. This has subjected more than six million people to the danger of starvation, poverty and death (Swift, 1973). The need for water by man cannot be over emphasized; therefore lack of water or shortage of water will affect man in much area like drinking, domestic and industrial uses etc that can lead to death. In Northeast Thailand, drought has the most profound effect on the way of living and regional economy and it is also a major menace to regional food supplies (Mongkolsawat, et al. 2000). Droughts sometimes affect the government in allocation of water

for rural consumption more accurately and at the right place. Prathumchai, et al. 2001 observed that the drought could cause immigration.

2.5.2 Effects of Drought on Agriculture.

Drought may affect people and agriculture at local scales for short periods or cover broad region or have impacts that are felt for years e.g. the dust bowl (Brown, et al. 2002). Due to the continuous need of adequate water by plants, agricultural drought may set in rapidly, and can similarly terminate suddenly. Drought causes a lot of hazards to agriculture and it has caused a lot of harm to the crops. It can also cause dryness, starvation and death to both plants and animals. The drought injuries experienced by different livestock are those arising from scarcity or lack of food and water so, losses through animal deaths on a large scale are events well known in some countries (Yeates, 1964).

When moisture is a limiting factor, local variation in topography, soil and other factors have more effect on plant communities than when moisture is not limiting. Effects of some parasite are very high in drought periods for example; ticks may build up where cattle are forced to congregate for feeds and water. An interesting effect of drought is to increase the amount of abrasive dust blown about in the air in many areas. This can cause damage to plants, and whereas some pests such as scale insects, are more or less plugged into the plant and are unaffected, many of their predators or parasites may be injured or killed, or suffer from reduced food supply. Drought potentially plays a part in reducing the incidence of diseases (WMO, 1975).

2.6 Severity of Drought as a Function of Rainfall

Drought is a climatic phenomenon and as climate can either be normal or abnormal, the probability of drought occurrence on the global environment is positively skewed (Okorie, 2003). One undisputable cause of 'famine' in Northern Nigeria is the failure of crops resulting

from insufficient or untimely rainfall. This region was severely hit by droughts and famines during the sahelian drought episode of late 1960s to 1980s. They experienced severe land degradation problems. extremely varying climate, topography, ecology and soil use were chosen as one of the most difficult cases among African dry lands (Okorie, 2003). The persistent and severe drought has indeed, a number of time resulted in famine in the Northern Nigeria. For instance during the drought of 1972-1973, about 3000 animals died and farm yield dropped by up to 60% (Zhenmin and Zhiliang, 2003). It has been noted also that the sub-saharan region of Nigeria is vulnerable to drought incidence. Frequent occurrences of drought in the zone have been largely responsible for social backwardness and general poor quality of life especially among less privileged ones (Zhenmin and Zhiliang, 2003).

In general, drought is measured in terms of deficiency in the rainfall or stream flow below a pre-defined reference level. The cumulative deficit during a drought spell is known as the severity. The severity is the product of the duration D , and the magnitude M , where D is the duration during which flows are consistently below some truncation level (e.g., the hydro climatic mean), and the magnitude M is the average departure of flow (Dracup, et al. 1980).

2.6.1 Drought and Economic Losses

Food and fiber production is the vital end point of agricultural activities. Even from a superficial survey, it can be shown that losses from an extended continental drought can amount to many hundreds of millions of dollar. Direct losses result from reduced crop yield; pasture deterioration and livestock deaths. A complete list would include the returns of most agricultural products. other direct financial losses result from transport of emergency of food supplies for humans and animals, establishment of emergency water supplies either by additional bores for immediate use or surface water storage for future use, and wind erosion (WMO, 1975).

It is unlikely that an accurate integrated figure of world losses due to drought will ever be possible because of the great difficulty in isolating the direct cause of many losses, but it would certainly amount to an enormous sum of money. Some of the complexities in preparing estimate were outlined by Heathcote, (1969). The drought problems always exist somewhere in the world so that economy of some nation or nations is always being adversely influenced by this factor.

2.6.2. Space and Time Characteristics of Drought

It is virtually impossible for a continent to be affected simultaneously although drought affecting about half of Australia might be expected once in 50 years (WMO, 1975). Yevjevich, (1967), reports of a study by Caffey of inter-station correlation of annual rainfall in the United States and some of the areal properties of continental drought. The average areal coverage of severe large continental drought is of the order of 5-15 millions square kilometers. The more severe a large drought, the larger is its areal coverage. Also, the shape of the area covered by drought is expected to be closer to an ellipse than to a circle.

2.7 Differences between Drought and Aridity

It can be assumed that the basic cause of drought is inadequate precipitation. The most frequently applied method for rapid assessment of drought is to examine the incidence of rainfall at a point, or better, over an area. The incidence of drought depends very much on the definition used. For example, by definition based on available water, the arid zone of the world would be almost permanently drought stricken, but by reference to normal rainfall, they could be classified as less subject to drought than some heavy rainfall of available water while ignoring the possibility of climatic change as a permanent climate feature of a region (Wallen, 1967). Drought on the other hand, is a temporary feature in the sense that considers in the context of variability, it is experienced only when rainfall deviates appreciably below normal.

Aridity is by definition, restricted to regions of low rainfall, and usually high temperature, whereas drought is possible in virtually any rainfall of temperature regime.

(i) **Soil Water**

The prime factor controlling the water balance of the plants - soil environment is the water supply available to the plant. Every increment of water falling on the surface is partitioned according to the water balance equation given by

$$P = Q + U + E \pm \Delta W \text{ ----- } 2.1$$

where P is the precipitation or irrigation water added (mm)

Q is runoff (mm)

U is deep drainage passing beyond the root zone (mm)

E is actual evapotranspiration (mm)

ΔW is change in soil water storage (mm)

In extended rainless period and in the absence of irrigation, P, Q, and U are zero. Therefore

$$E = - \Delta W \text{ ----- } 2.2$$

The actual evapotranspiration depends on changes in the soil water and is usually much less than potential evapotranspiration, which may be high. Drought in agricultural sense does not begin with cessation of rain but rather when available stored water will support actual evapotranspiration at only a small fraction of the potential evapotranspiration rate. This phase of the plant-soil-water relationship is quite complex and has been subject of considerable investigation in recent years.

Available soil water is the amount of water retained in the root zone of a soil between field capacity and the permanent wilting point. The rate of transpiration by a crop depends largely on the availability of soil water as determined by the root system of plant. As water within the main root zone becomes depleted, new root growth expands downwards and

horizontally, tapping new sources of water. This helps to maintain transpiration but usually at an ever-decreasing rate. The presence of water table within reach of the root is advantageous for maintaining transpiration and growth during dry periods.

(ii) Precipitation

Over the greater part of the earth's surface, soil water is supplied by precipitation in the form of rainfall. Fog and dew, almost without exception, are minor moisture sources. Hail is important because of severe damage it often causes to plants. In terms of drought, however, the areal benefit of the accompanying rain may more than offset the hail damage (WMO, 1975). In some season, there may be sufficient flow while in some there may be reduction of flow. The role of snowfall in drought relief depends on several factors. The main contribution of snow-flow in drought relief depends on several factors. The main contribution of snowfall might be to replenish the reserve of soil water accumulated prior to the beginning of the growing season. In areas of high precipitation, soil water is usually replenished by autumn and spring rains so that snow may be super flows and contributes mainly to runoff and stream flow. Advantage may be taken of the well-known barrier effect of windbreaks and shelter barriers at the expense of the area farther downward (WMO, 1968).

(iii) Dew and Fog

Another contribution to soil water may come in the form of dew although; some strong claims have been made regarding the amount of moisture available from this source. Most studies have indicated that dew cannot be regarded as making significant contribution to drought relief except perhaps in the arid zone. WMO (1975) concluded that dew formation is limited to a "no-rain" synoptic situation as it depends on surface cooling by radiation with a clear sky and a low wind speed to reduce heat exchange with higher levels. Other factors aiding dew formation are relatively high humidity and open shaped vegetation to maximized

radiation losses. Dew may originate as condensation from the overlying air, as condensation of vapor moving upwards from the soil or as guttation, which is water exuded from leaves under conditions of high root pressure and near zero-transpiration.

(iv) **Surface Runoff**

Surface runoff is also referred to as stream flow. It occurs after a period of time, highly dependent on initial catchments, wetness and catchments characteristics. Surface runoff does not reach a high value until infiltration and recharge are significantly reduced. It can be extreme high under high intensity rain. The effectiveness of rainfall depends considerably on the proportion, which is lost by surface runoff. Runoff enters a well-defined channel where it eventually contributes to groundwater recharge or reaches the sea and can also be redistributed within a small area by flowing from slight elevations to depressions.

The latter type of runoff results in an accumulation of water at a point in the field, which may thereby receive an amount, which is two or more times the depth of the rainfall. The most favoured vegetation in the drought-prone arid zone is that which grows in and along the watercourses where soil moisture is replenished spasmodically, usually within a year and water stored from deep drainage is available for extended period to deep-rooted plants such as trees.

2.8 Techniques to Drought Occurrences.

2.8.1 Statistical Techniques.

There many statistical techniques relevant to droughts but few are attached to the rainfall data while others are relevant to the stream flow, river basins, flood, Dams etc. using statistical techniques, a multiplicity of data can be reduced to manageable form and so enable the relevant data to be distinguished from the irrelevant. Statistical methods are particularly

useful in checking the validity of a hypothesis involving complex natural phenomena (Bruce et al, 1980). Some of the statistical parameters include:

(i). **Mean:** This is given by

$$\bar{x} = \frac{1}{n} \sum (x_i) \quad \text{-----} \quad 2.3$$

where,

\bar{x} = mean of samples

$\sum x_i$ = sum of samples

n = number of years.

(ii). **Median:** This is the quartile, which divide the distribution into two equal parts. It is the middle value of a distribution. It is expressed as:

$$Q_2 = \frac{Q_3 - Q_1}{2} \quad \text{-----} \quad 2.4$$

where Q_1 , Q_2 and Q_3 are the first, second and third quartiles respectively.

ii). **Standard deviation:** It is denoted by σ and its is for a normally distributed variable, it is the positive square root of the variance given by:

$$\sigma = \sqrt{\frac{1}{n} \sum (x_i - \bar{x})^2} \quad \text{-----} \quad 2.5$$

where n is number of years.

x_i = samples sum

\bar{x} = mean of samples

(iv). Coefficient of skew ness, γ_1 : the normal distribution $\gamma_1 = 0$

If γ_1 is positive the distribution is said to show positive skewness and the longer tail of the curve is to the right. Under those circumstances

$$\gamma_1 = \frac{\sum (x_i - \bar{x}_i)^3}{n \sigma^3} \quad \dots\dots\dots 2.6$$

where x = samples sum

\bar{x} = Mean of samples

n = number of years

σ = Standard deviation in (mm).

A station would experience a lower level of rainfall more frequently than indicated by the normal distribution.

(v). Coefficient of variation given by V

$$V = \frac{\sigma}{\bar{x}} \quad \dots\dots\dots 2.7$$

σ = Standard deviation (mm)

\bar{x} = mean of samples

2.8.2 Other Techniques for Drought Evaluation

There are many techniques for the evaluation of drought and some of them are:

- (i) Palmer Drought Severity Index (PDSI): The most prominent index of meteorological drought in the United States is the Palmer Drought Severity Index. The PDSI was created with the intent of measuring the cumulative departure of moisture supply (Palmer, 1965). It is a dimensionless number typically ranging between 4 and -4, with negative quantities indicating a shortage of water. Computation of PDSI is complicated. Gibbs and Maher, (1967) considered its application for Australia but instead recommended rainfall deciles.

(ii) Percentiles, Deciles and Quartiles: A large degree of statistical dispersion for precipitation measurements can render the mean a poor reference for typical condition. The climatological observations above or below the median may be divided into 10 quartiles or deciles, deciles-based system for monitoring meteorological drought was suggested by Gibbs and Maher, (1967). The rainfall decile begins by ranking the precipitation totals for the preceding three months against records. If the sum falls within the lowest decile (ninth percentile) of the historical distribution of 3-month totals, then the region is considered to be drought affected (Kinninmonth, et al. 2000).

(iii) Gumbel recurrence interval: This is given by

$$T = \frac{n+1}{M} \quad \text{2.8}$$

T = the recurrence interval in years

n = the number of observations in the series

M = the rank of a particular observation.

(iv) Drought Area Index (DAI): This is given by

$$I_k = 0.5I_{k-1} + \frac{1}{48.55P_k} \left(\frac{\bar{P}_k}{\sigma_k} \right) \quad \text{2.9}$$

I = Intensity of drought (dimensionless)

k = month number

P = monthly precipitation (mm)

\bar{P} = Average precipitation (mm)

σ = Precipitation standard deviation (mm)

(v) Rainfall Anomaly Index (RAI): This is given by:

(v) Rainfall Anomaly Index (RAI): This is given by:

$$RAI = \pm 3 \frac{P - \bar{P}}{\bar{E} - P} \quad \text{2.10}$$

P = measured precipitation (mm)

\bar{P} = Average precipitation (mm)

\bar{E} = Average of 10 extrema (mm)

For positive anomalies, the prefix is positive and E is the average of the ten highest precipitation values on record. For negative anomalies, the prefix is negative and the ten lowest measurements were used.

- (vi) Drought severity Index (DSI) based on the quartile range: The description of the quartile ranges are useful in classifying drought index. The Q_1 is the first quartile, Q_3 is the third quartile and the minimum is the minimum cumulative rainfall for the years of records and the maximum is the maximum cumulative rainfall for the years. The values of the quartiles give the rainfall distribution of the quartile range into which the cumulative rainfall gives the information on drought severity, as showing in table 2.1.

Table 2.1 Drought Severity Index based on quartile range. Ambenje (2000)

RANGE	COMMENTS
< Min	Driest on record
Q_1 - Min	Dry
Q_1 - Q_3	Near normal
Q_3 - Max	Wet
> Max	Wettest on record

Q_1 is 1st quartile range

Q_3 is 3rd quartile range

Min is minimum Cumulative rainfall

Max is maximum Cumulative rainfall

(vii) Stochastic Component Time Series: This is given by

$$Z_t = \frac{E_t - \bar{E}}{S_t} \quad \text{2.11}$$

\bar{E} = Mean of rainfall (mm)

S_t = Standard deviation of the series (mm)

E_t = Rainfall series (mm)

(viii) Cumulative Rainfall Index which is gotten from the graph of the rainfall cumulative distribution curve. This is to assess cumulative anomalies for some months and to minimize drought impacts.

(ix) Monte Carlo simulations, which are given as:

$$\text{(a) Skewness} = \frac{\sum (x - \bar{x})^3}{n\sigma^3} \quad \text{2.12}$$

and

$$\text{(b) kurtosis} = \frac{\sum (x - \bar{x})^4}{n\sigma^4} \quad \text{2.13}$$

x = Total rainfall (mm).

\bar{x} = Mean of rainfall (mm)

n = Number of years

σ = Standard deviation (mm)

The statistical techniques for monitoring drought range from highly sophisticated models like the Palmer drought index to simple procedures such as the use of percentiles, deciles and quartiles. Gibbs and Maher (1967) considered the application of palmer drought severity index for Australia but instead recommended rainfall deciles.



CHAPTER THREE

3.0 Research Methodology

3.1 Location

The study area partially covers the major area of Kogi State. Kogi State is one of the newly created states, and it was carved out from part of Benue, Kwara and Niger States. It is located on Latitude 11°N and Longitude 6°E and on the Latitude 8°N and Longitude 7°E , as shown in fig. 3.1. 73 years rainfall data (1931-2003) was obtained from the Meteorological department of Lokoja in Kogi State.

3.2 Geology

Kogi State (Lokoja) lies on the basement complex formation, which comprises mainly of quartz- feldspatic granite, gneisses and schists. These rocks in their unaltered state are largely impermeable and have no groundwater storage capacity. Aquifers are limited to structural features produced by weathering and tectonic processes (Abel and Ron, 1990).

3.3 Topography

Lokoja is of low to moderate relief with a few scattered laterites capped hills where elevations rarely exceed 400m above sea level. The water supply in Lokoja is not only for irrigation and hydroelectricity; the flood plains are intensively cultivated. Vegetation is of the Guinea savannah type and annual rainfall ranges between 1000 and 1500mm

3.4 Climate

The annual average temperature is about 27°C . Mean or annual average sunshine hour is 6.7 sunshine hour/day. In this region, the months of January, February, November and December always experience a high temperature of between 33 and 36°C . Rainfall in Lokoja is seasonal and varies from year to year. The two seasons are the dry and wet seasons. The dry

season lasts for about 7 to 8 months (October to April) and wet season about 4 to 5 months (May to September). The mean annual humidity of Lokoja is 70%.

3.5 Drought Analysis Techniques: The following techniques were used for this study.

3.5.1 Stochastic Component Time Series

This technique is explained by the equation 2.11 that is,

$$Z_t = \frac{E_t - \bar{E}}{S_E}$$

where Z_t is the Stochastic Component Series for each year.

E_t is the total annual rainfall (mm) for each year

\bar{E} is the mean annual rainfall (mm) for each year and

S_E is the standard deviation (mm) for each year

The total annual rainfall (E_t) for each year was calculated (details in Appendix 2).

The annual mean rainfall \bar{E} and the standard deviation of each year (S_E) were also calculated.

Then the Stochastic component time series (Z_t) for each year was then obtained.

3.5.2 Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI) was developed by Van Rooy (1965), and the technique is explained by the equation 2.10 that is,

$$RAI = \pm 3 \frac{P - \bar{P}}{E - \bar{P}}$$

where RAI is the Rainfall Anomaly Index for each year

P is the total annual rainfall (mm) for each year

\bar{P} is the average precipitation (mm) for the 73-years period.

\bar{P} is the average precipitation of 10-extrema (mm) for both positive and negative anomalies.

\bar{E} The total annual rainfall (P) for each year was calculated and ranked in the order of their magnitudes from the highest to the lowest in a descending order as shown in (Appendix 3).

The average precipitation \bar{E} for the 73-years of record was calculated, and also the average precipitation of 10 - extrema. The extrema average were obtained for the positive and negative anomalies respectively. Then, the Rainfall Anomaly Index (RAI) for the year was obtained for both positive and negative anomalies are as shown in Appendix 3. The Rainfall Anomaly Index was obtained using the 10 - highest extrema average while the negative Rainfall Anomaly Index was obtained using the 10 - lowest extrema average.

3.5.3 Cumulative Rainfall Information

The cumulative rainfall information technique was used to assess cumulative impacts of rainfall anomalies, and clearly depicts the aggregate amount and duration of water surplus or deficit. The data was presented in a frequency array showing the frequencies of occurrence as shown in Appendix 4. The annual rainfall for each year was arranged serially, one after the other. The rainfall information technique was also used in plotting the cumulative rainfall against the years of record and the percentiles were calculated using the equation

$$q = P \frac{(n + 1)}{100} \quad \text{----- 3.1}$$

where P is the percentiles, in the number of years of record and

q is the percentiles

The 25th (1st quartile), 50th (2nd quartile) and the 75th percentile (3rd quartile) were obtained from the rainfall information.

3.5.4 Drought Severity Index based on the quartile range

This is a particular example of the application of cumulated frequency distributions. The limits of each quartile range of the distribution are calculated from a cumulated frequency curve or an array of the data. The first and the third quartile members were calculated using the equations:

$$Q_1 = \frac{n + 1}{4} \text{ member} \quad \text{-----} \quad 3.2$$

$$Q_3 = 3 \frac{n + 1}{4} \text{ member} \quad \text{-----} \quad 3.3$$

where Q_1 is the first quartile range for the 73 - years period

Q_3 is the third quartile range for the 73 - years period and

n is the total cumulative of the data.

The Quartile ranges were calculated to be the ranges of the values between quartiles. Thus, the first quartile range and the third quartile range were needed for the rainfall information of the drought severity index.

The values of the quartiles give a reasonably complete picture of a particular rainfall distribution and knowledge of the quartile range into which a particular total falls gives useful information on departure from normal. The descriptions below of quartile ranges are useful in classifying the drought severity index.

Drought severity index based on quartile range according to Ambenje, (2000) can be given as:

$<$ Min for the period of driest record

Q_1 - Min for dry record

$Q_1 - Q_3$ for near normal

Q_1 - Max for wet and

$>$ Max for wettest period on record

It should be noted that,

Q_1 is the first quartile range.

Q_3 is the third quartile range

While Min is the minimum cumulative rainfall and

Max is the maximum cumulative rainfall.

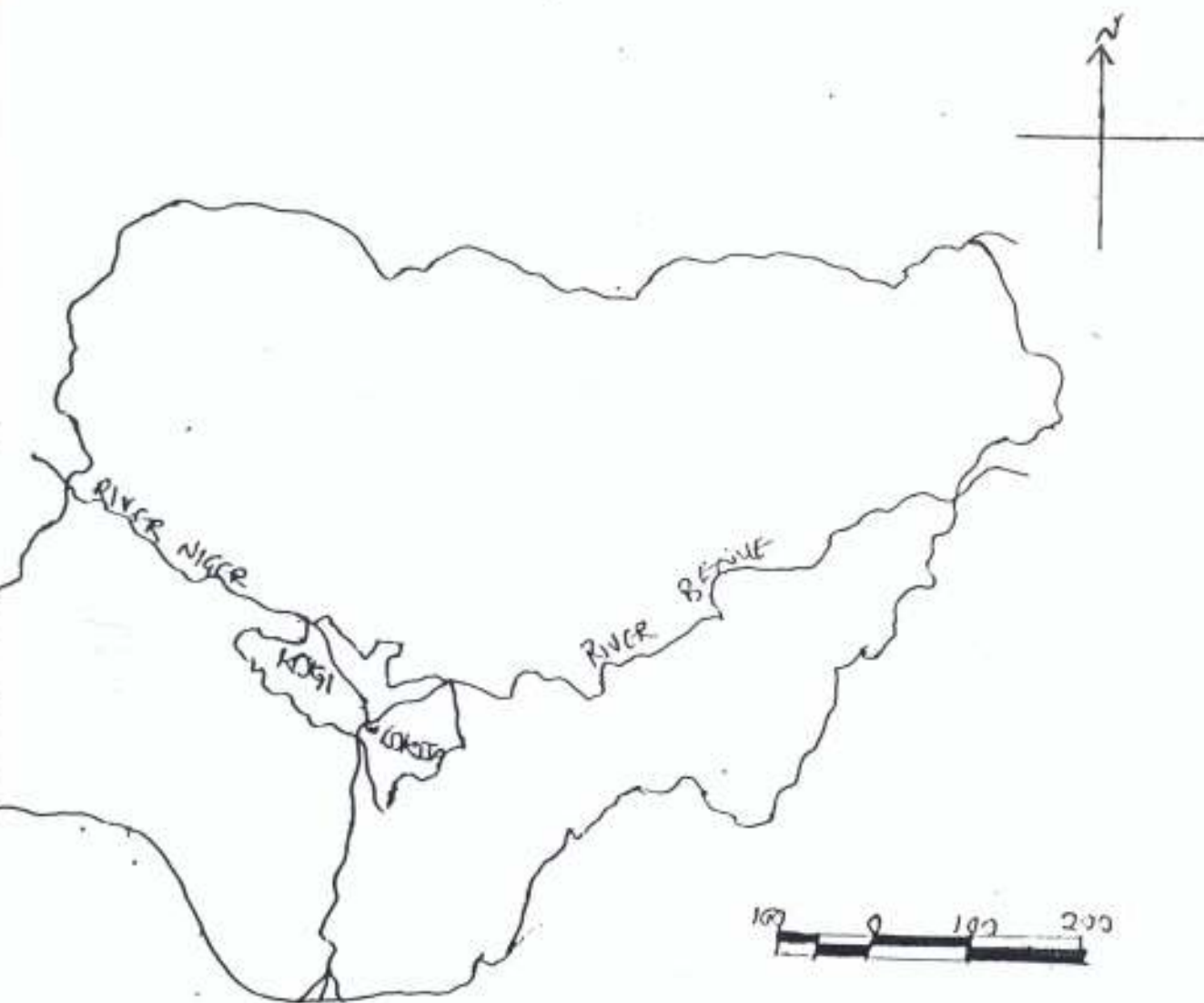


FIG. 3-1 MAP OF NIGERIA, SHOWING LOKUJA IN KOGI STATE.

CHAPTER FOUR

4.0 Results and Discussion

4.1 Rainfall Distribution Pattern of Lokoja

Fig. 4.1 shows the graph of total annual rainfall (mm) against the years of record in the study area. The lowest annual rainfall of 579mm was experienced in 1969 while the highest annual rainfall of 1601mm was experienced in 1934. 59 out of the 73 year records had low rainfall values while the remainder had heavy rainfall. The years that experienced heavy rainfall were all within the range of the mean rainfall of 1500mm. Lokoja rainfall records for the 73 - years is shown in Appendix 1. The trend of the rainfall pattern is Stochastic in nature. From Fig. 4.1, it can be seen that the rainfall of Lokoja is one of much low than heavy rainfall, which implies that drought is experienced in the area very often.

From Fig 4.1 shows that only 1 year that is, 1934 had rainfall value above 1500mm; 2 years, that is 1978 ad 1985 had rainfall value of approximately 1500mm. 21 years had the rainfall values between 1200 and 1500mm, that is 1939, 1948, 1949 1953, 1954, 191955, 191957, 191960, 191962, 1963, 1966, 1968, 1970, 1971, 1972, 1975, 191991, 191998, 2000 and 2003.

The rainfall values between 900 and 1200mm were obtained within 38 years while the rainfall values between 700 and 900mm were obtained for 10 years, that is 1931, 1936, 1940, 1942, 1943, 1946, 1956, 1982, 1983 and 1987, while 1969 had a rainfall value below 600mm.

4.2 Assessment of Drought Potential using Long - Term Rainfall data

Fig 4.2 shows that the Stochastic Component Time Series for the year 1931 was very low. 1980 had the greatest Stochastic Component Time Series of 583.41. 4 years had the Stochastic Component Time Series between 300 and 500, that is, 1964, 1965, 1979 and 1984. This implies that, the time of occurrence of drought was low. The years that had the Stochastic Component Time Series between 100 and 300 include 1932, 1933, 1974, 1975, 1995, 1996

and 1998. Drought occurrence between 1966 and 1973 was low, so drought years were minimized. Between 1999 and 2003 low occurrence of drought also occurred, Fig. 4.2 show the different occurrences and the long term rainfall data. 61 years had the Stochastic Component Time Series of between 10 and 100 which shows that the time of drought occurrence in the study area was so high. The years were drought years because none had the component time series to be above 1000. Therefore, the accumulation of low drought time of occurrence along the years confirmed the drought existence since it does not come through sudden event.

1942 had the least Stochastic Component Time Series of 15.37 which shows that the time of occurrence of drought was extremely high. Therefore, the year 1942, was a period of dry spell. Between the years 1934 and 1963, the Stochastic Component Time Series was very low which means there is drought accumulation during these years. Table 4.1 shows the years of drought occurrence in Lokoja between 1931 and 2003.

Table 4.1 Years of Drought Occurrence

Extreme low drought	Low drought	Fairly high drought
1931	1932-1933	1964
1934-1963	1974-1975	1965
1966-1973	1995-1996	1979
1976-1978	1998	1980
1981-1983		1984
1985-1994		
1997		
1999-2003		

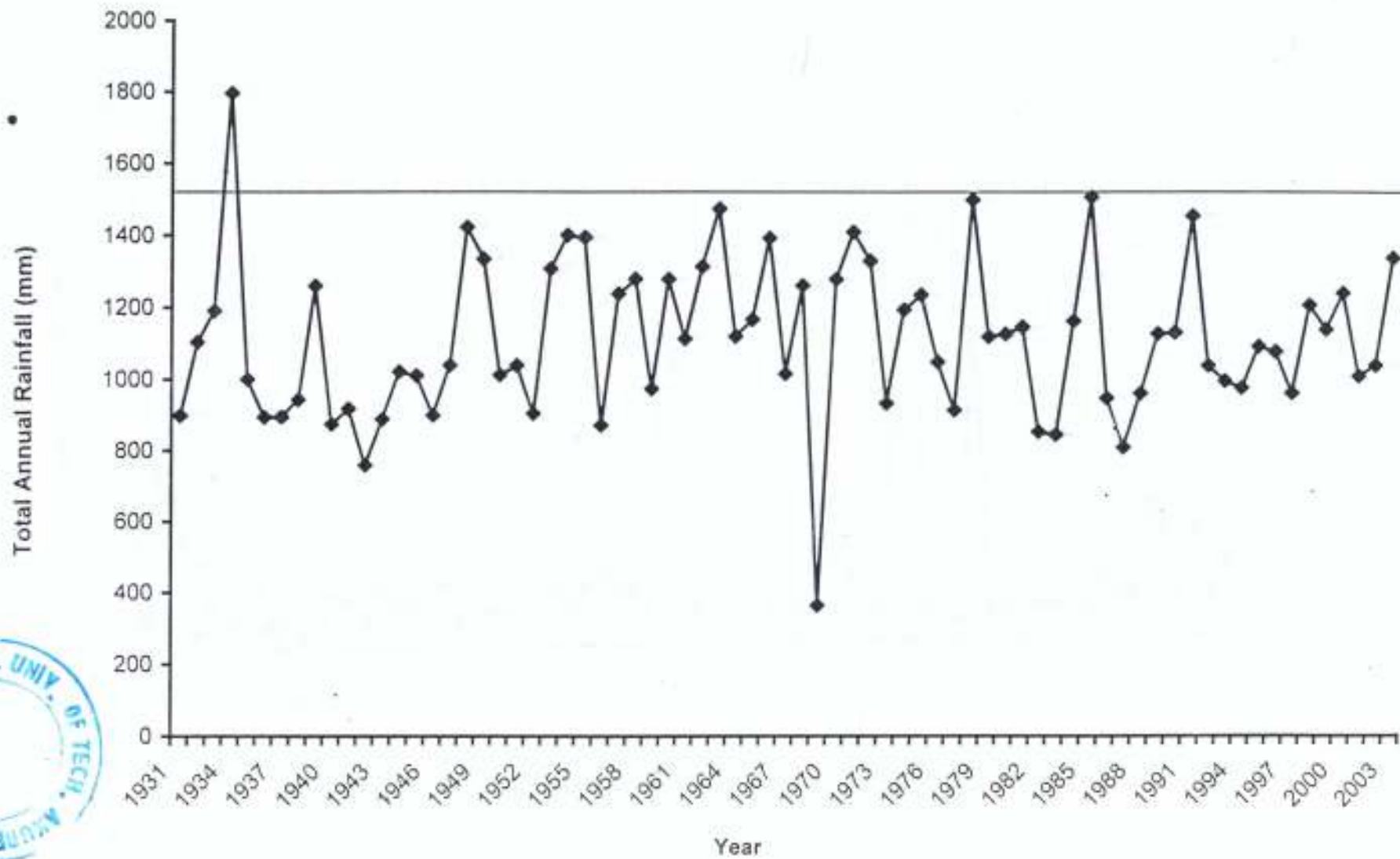


Figure 4.1: Total Annual Rainfall (mm) of Lokoja (1931 - 2003)



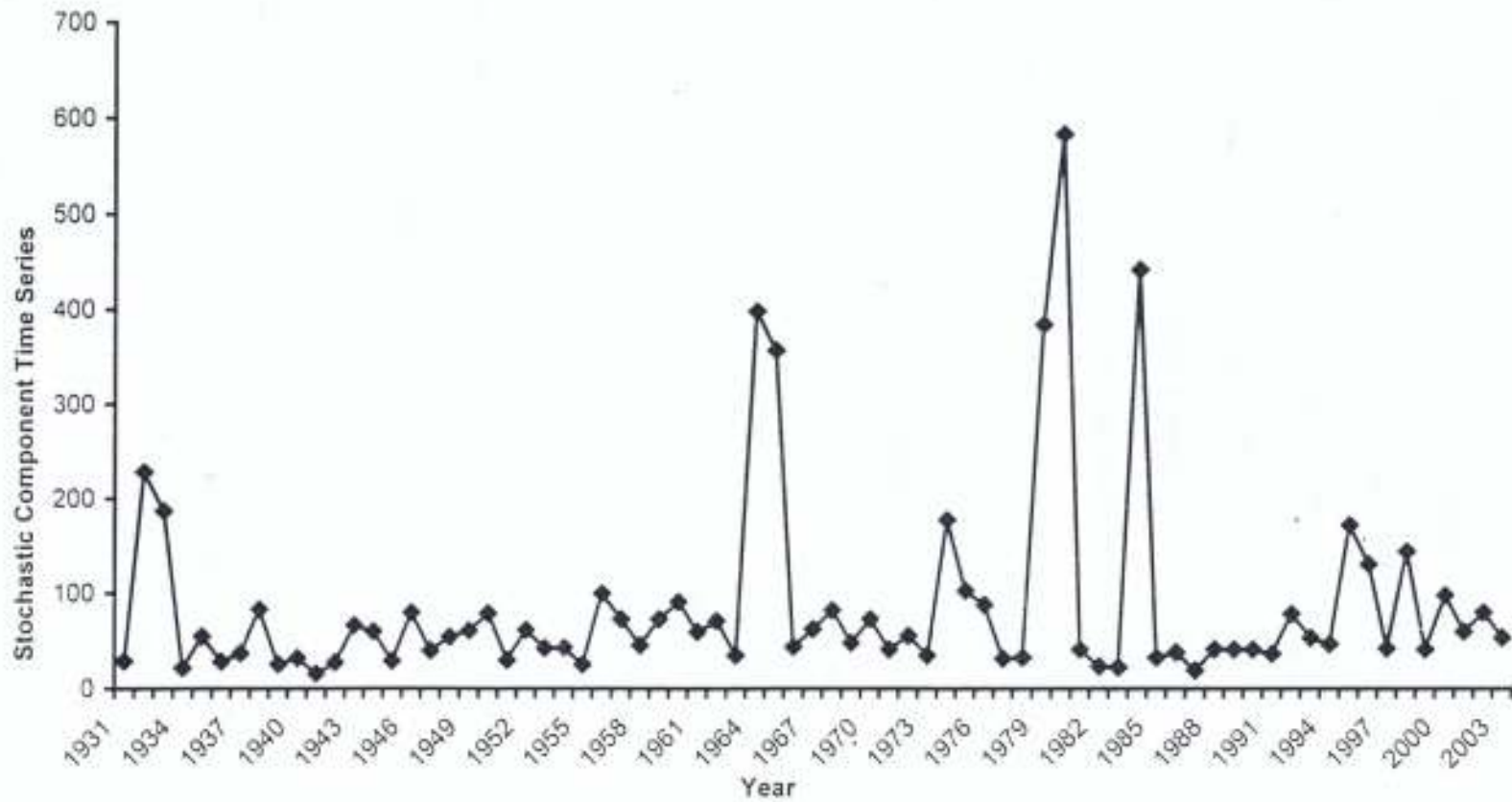


Figure 4.2 : Graph of Stochastic Component Time Series against Years for Lokoja (1931-2003)

Fig 4.3 shows the occurrence of drought for the 73 years of record. The year 1934 had the highest Rainfall Anomaly Index as given in appendix 3 while 1942 had the least Rainfall Anomaly Index. In the year 1999, the anomaly Index for both the positive and negative magnitude was -0.02 which confirms the rainfall anomalies in the study area. The 73 years record as shown in fig 4.3, shows clearly the years in which the drought occurred and their index values. 30 years had positive Rainfall Anomaly Index values while 43 years had negative Anomaly Index values. Since the anomalies decreases down the graph as given by Fig 4.3, the years with negative anomaly index experienced drought more than the years with positive anomaly index.

Rainfall Anomaly Index exhibits linear trend, the linearity tapers off at lower index values, indicating slightly different responses to more severe drought. The range of the positive extrema was 1472mm while the range of the negative extrema was 858mm and the average precipitation for the 73-years record was 1142mm. The positive anomaly index ranges from 5.94 to -3.48 while negative and may index ranges from 6.92 to -4.06. The significance of the two curves shows that, the anomaly index either positive or negative has almost the same drought period. Also, the rainfall values decrease down the graph, thereby showing that there is reduction of rainfall in the region. Both negative and positive anomalies show that drought occurred in the area.

Fig 4.4 gives the Cumulative Rainfall Information based on the 73-years of record. A cumulative departure of rainfall from mean conditions can show long-term tendencies in water availability. The Cumulative Rainfall for the 73-years period is 82,189mm. The cumulative frequency curve is particularly useful for the evaluation of drought as well as the drought periods so as to prevent water shortage during the drought years. s When comparing rainfall frequencies at different stations or different months or years at the same station, for example,

the Cumulative Rainfall Information can be used to monitor the station. The average rainfall was 1126mm while the mean annual rainfall of the Lokoja station was 1500mm, this shows that there was drought occurrence because of the low-level of total rainfall.

The first, second and third quartile ranges were also obtained from Fig 4.4 are 20140, 42691 and 62648mm respectively. These quartile ranges are useful when assessing the drought periods and help in monitoring the drought years, thereby providing excess water to overcome or minimize subsequent drought years. The 25th, 50th and the 75th percentiles are equivalent to the quartile ranges respectively and are for the same purpose. Fig 4.4 gives the range and years in which the drought occurrences can be assessed and monitored for planning purposes.

The Drought Severity Index based on quartile ranges was used for monitoring the drought especially, meteorological drought which was obtained by the classification of the drought severity. The minimum amount of cumulative rainfall for the 73-years of record was 898mm while the maximum cumulative rainfall was 82,189mm. The first and third quartile ranges are 20140mm and 62648mm respectively. The classification of the rainfall amount and the rainfall cumulative gives clear and useful information on how the drought can be assessed in the area. The ranges, show the range of rainfall at which drought occurred.

Below is the result obtained from the classification of the Drought Severity Index information for Lokoja area. Drought severity Index based on quartile range for Lokoja between 1931 and 2003 is given as:

< 898mm for the period of the driest on record.

20140 – 898mm for dry record.

20140 – 62468mm for near normal.

62648 -82189mm for wet and

< 82189mm for wettest period on record.

Min cumulative is 898mm.

Max cumulative is 82189mm.

Q_1 (first quartile range) is 20140mm

and Q_3 (third quartile range) is 62648mm

4.3 Evaluation of the Severity and Impact of Drought in Lokoja

Fig 4.2 shows the graph of the Stochastic Component Time Series against the years based on the 73 years of record and equation 2.11 shows how the Stochastic Component Time Series was obtained. From the Fig. 4.2, 1931 had a very low time series of drought occurrence, which shows that drought was not severe and the impact was not much. (1932 - 1933) had a fairly high time series. Also, (1934 - 1963), (1966 - 1973) were all drought years with low Stochastic Component Time Series.

Appendix 2 shows the Stochastic Component Time Series for the 73 years on the study area and some years experienced low period of drought occurrence. Between 1934 and 1963, there was low Stochastic Component Time Series for 30 years. The severity of drought and the impact was felt so much during the 30 years. Drought does not occur through a sudden event like flood or storm, therefore the occurrence of drought for several period of time brought about the severity.

1932 and 1933 had a Stochastic Component Time Series of 227.90 and 186.35 respectively, which means that the years also experienced some drought with moderate severity. The severity and impact of drought was also found to be less between 1964 and 1965 as given in Fig. 4.2. Between 1966 and 1978, the agricultural and socio economic sectors were affected by severe drought. There was much severity because the stochastic component time series was low compared with 1979 and 1980 which had the time series to be between 400 and 700. 3 years, which is 1981, 1982 and 1983 had low Stochastic Time Series but the severity and impact was not as much as those years with intense drought.

Rainfall Anomaly Index (RAI)

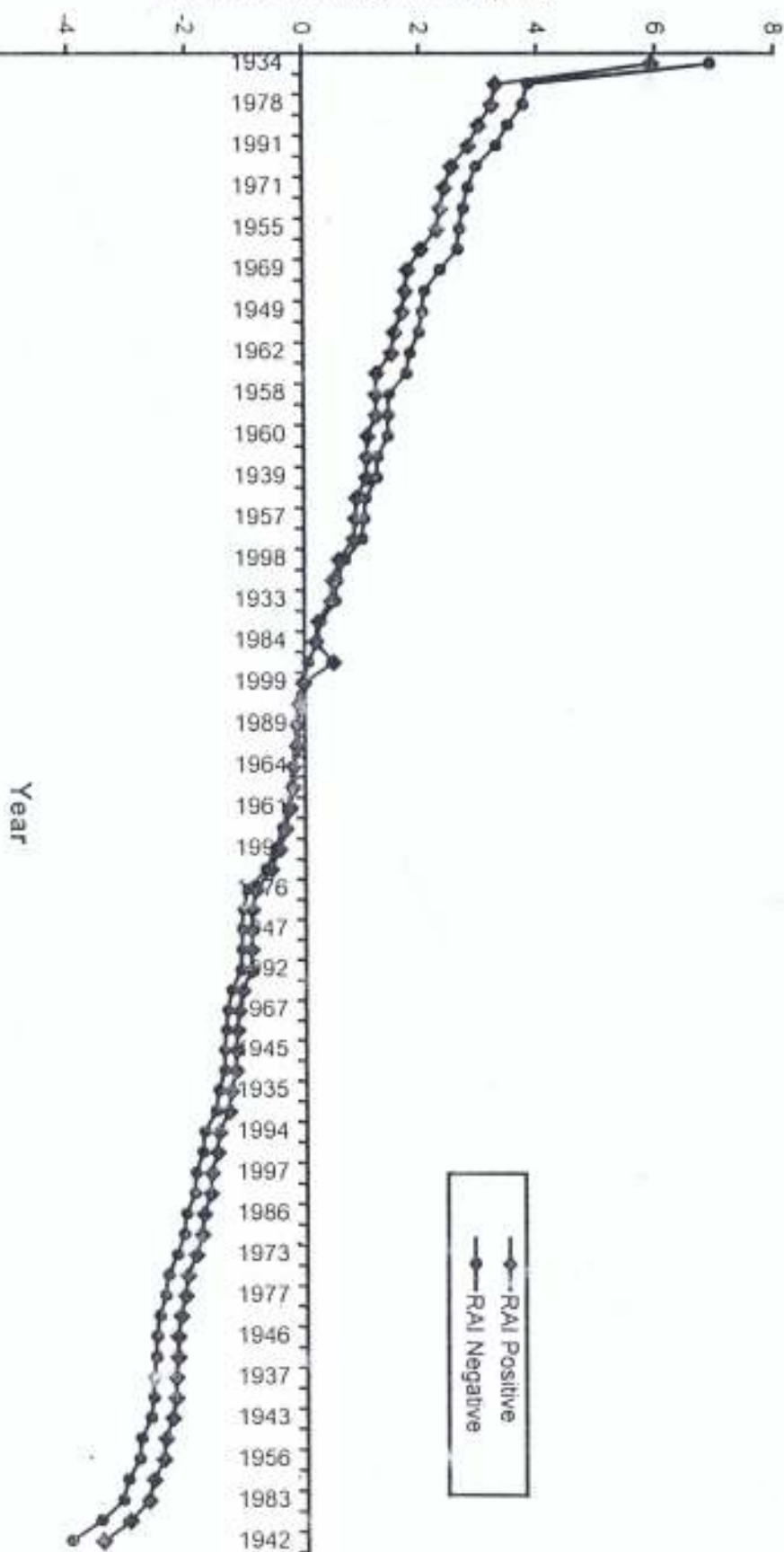


Figure 4.3: Graph of Rainfall Anomaly Index (RAI) against Years (1931 - 2003)

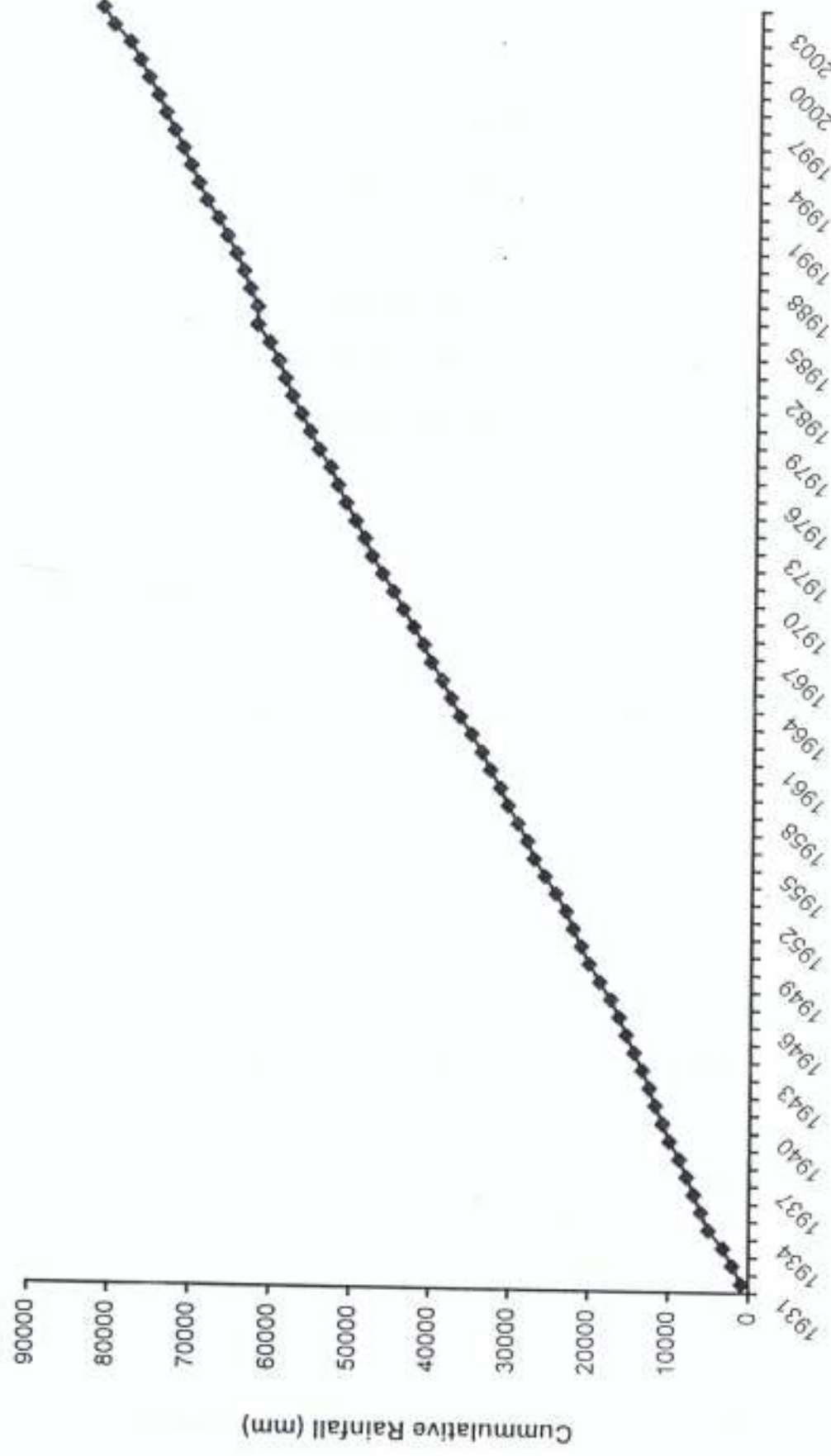


Figure 4.4: Graph of Cumulative Rainfall Information against Years

The year 1984 had a fairly high Stochastic Component Time Series, so there was not so much severity and the impact was not felt during the year. The years that are between 1985 and 2003 had very low Stochastic Component Time Series. Therefore, high drought severity was experienced and greater drought impact was felt in the area. From Fig 4.2, 66 years had high drought severities which led to a greater impact of drought in the agricultural and hydroelectric power generation of the area of study, 7 years, that is, 1933, 1964, 1965, 1979, 1980 and 1984 had fairly high Stochastic Component Time Series; therefore, much drought impact was not the felt during these years.

From Fig 4.3, the index values decrease down the curve and therefore the lesser the anomaly index the greater the severity of drought and impact. The part of the curve that had positive index value is of moderate drought severity while the part with negative index value is of extreme severe drought. Appendix 3 gives the details of the Rainfall Anomaly Index showing the indices. From appendix 3, it can be seen that the lower the total annual rainfall, the greater the drought severity and impact.

The range of the Rainfall Anomaly Indices for positive index was (5.94 to -3.48) and negative index was (6.92 to -4.06). Comparing these indices, it was very clear that they both have the same or almost the same index. The curves also show that the anomalies decrease down the curves showing the deficiency of rainfall, which amounts to drought. From Fig 4.3, 1981, 1990 and 1999 had close indices when the positive and negative anomalies were considered. 1934 had the highest annual rainfall and the highest Rainfall Anomaly Index while 1942 had the least annual rainfall and the least Rainfall Anomaly Index. The highest Rainfall Anomaly Index may not have the highest drought severity. 1999 had great drought severity because the curves confirmed this by having the same positive and negative anomaly indices of -0.02. Since the Rainfall Anomaly Index incorporates a ranking procedure to assign magnitudes

to positive and negative precipitation anomalies, the annual rainfall amount for each year were arranged in descending order because of the rainfall deficiencies. Also the linearity shows the reduction of the index values, indicating that drought severity increases down the curve.

The Rainfall Anomaly Indices, which are of negative value, exhibit the severity of drought in the area, which had a very great impact on the agricultural and hydroelectric power sectors which in turn affect the crop yield and hydro- power generation. The intensity of drought, which occurred in some years greatly, led to the drought severity. The last 9 years with the least total annual rainfall, that is, 1936, 1940, 1942, 1943, 1947, 1956, 1982, 1983 and 1987 had the highest drought severity. The severity led to total dryness creating huge impact of drought. About fifty years out of the 73 years of record were with high drought severity and with great impact.

Therefore, Lokoja in Kogi State experienced great drought. The drought years, which were of very low index values, had extreme drought severity, which led to dryness and adverse effect on the agricultural and socio-economic sectors.

The Drought Severity Index based on the Quartile Ranges is one example of cumulative frequency distribution. In this method, the limit of the distribution was calculated from a cumulative frequency curve as shown in Fig 4.4. When the annual rainfall is less than the minimum cumulative rainfall (898mm) it was then classified under the driest on record. However, they experienced an exceptional severe drought, which made the impact of drought to be so high during the years. Therefore, 1936, 1937, 1940, 1942, 1943, 1956, 1982, 1983, 1987 experienced exceptional severity of drought and this made a lot of drought impacts to be felt to the level of death and contemplation of immigration. The annual rainfall between the minimum cumulative rainfall (898mm) and the first quartile range (20140mm) was classified under the dry condition, which signify extreme drought severity. All the years except the years with

exceptional drought severity experienced either severe or extreme severe drought. From the drought classification, Lokoja is classified between the dry condition and the driest condition.

4.4 Determination of the Most Appropriate Technique for the Evaluation of Drought in Lokoja

Since many economic activities heavily depend on agriculture and hydropower generation in the area of study, rainfall fluctuations therefore, plays a significant role in determining the economy of the area. All the techniques used for this evaluation made it possible for drought to be monitored. The Stochastic Component Time Series monitors the drought by giving the time of occurrences of the drought. The rainfall pattern shows the irregularities in the timing and magnitude. Fig. 4.2 shows the time of occurrences of drought in Lokoja and the Stochastic Component Time Series were used in predicting the drought periods or years. The years with low Stochastic Component Time Series were noted for severe drought due to the accumulation of drought as seen in Fig. 4.2. Only the time of occurrence of drought were shown using this method.

The Rainfall Anomaly Index also gives the yearly anomaly indices and explains the severity and impact of drought in the area of study. Fig. 4.3 shows the Rainfall Anomaly Index, the drought years were analysed yearly in a decreasing order of rainfall. As the total rainfall decreases, the drought severity increases. The indices explain better the drought severity and impact in Fig. 4.3. The Rainfall Anomaly Index was used to monitor the drought in the area, predict the drought years and shows the years with the highest and least severity. Through this, the impact of drought and severity were known. The years of moderate, extreme and exceptional drought was also shown using Rainfall Anomaly Index and Fig. 4.3 shows the details.

Cumulative Rainfall Information was used to monitor and assess the drought as shown in Fig. 4.4. It was assessed by using the cumulative rainfall but cannot give the details about the years with drought severity and impact. The Drought Severity Index based on quartile range was to monitor and assess drought by classification into driest, dry, near normal, wet and wettest. Out of the four techniques used to evaluate the drought in Lokoja, Rainfall Anomaly Index is the most appropriate technique.

5.0 Conclusion and Recommendations

5.1 Conclusion

Four techniques namely the Stochastic Component Time Series, the Rainfall Anomaly Index (RAI), the Cumulative Rainfall Information and the Drought Severity Index based on quartile range were used to evaluate the occurrence of drought in the study area.

The Stochastic Component Time Series shows the time of occurrence of drought; the Rainfall Anomaly Index gives the yearly anomaly indices and also explains more about the severity and impact of drought in the study area. The Cumulative Rainfall Information was used to monitor and assess the drought in the study area, and the Drought Severity Index based on the quartile range is to monitor and assess the drought by classification into driest, dry, near normal, wet and wettest using the quartile ranges.

The most suitable technique is the Rainfall Anomaly Index. The occurrence of drought affected the crop yields as well as the hydroelectric power generation.

5.2 Recommendations

Since drought is one of the hydrological hazards and this study only covered the aspect of rainfall for drought occurrence, the following recommendations are suggested;

- (1) Rainfall records should continue to be taken with automatic rainfall gauges and recorders.
- (2) Other techniques should be examined to further the study of drought occurrence in the study area.
- (3) Relevant Data collection should be intensified on the impact of drought, on agriculture, and hydro- electric power generation in the study area.

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YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
1931	00.00	00.00	16.76	108.71	169.67	76.71	141.48	117.09	184.15	83.53	00.00	00.00	898.14
1932	00.00	00.00	48.26	44.80	134.11	110.49	176.78	142.74	132.08	197.35	50.00	00.00	1103.88
1933	22.09	06.85	132.08	121.66	127.00	193.55	102.62	237.74	172.72	50.29	18.28	06.35	1191.26
1934	00.00	00.00	34.52	248.41	242.06	155.54	102.62	364.03	235.03	218.69	00.00	00.00	1600.92
1935	00.00	01.27	19.71	39.52	56.13	269.75	129.03	191.00	149.09	104.64	10.92	00.00	999.49
1936	00.00	01.77	26.64	69.59	187.71	95.75	59.44	42.16	209.80	160.02	01.01	39.37	893.31
1937	00.00	64.15	90.17	34.79	98.81	89.66	94.49	105.66	186.69	129.28	00.00	00.00	943.31
1938	00.00	00.00	42.92	46.99	83.82	144.27	47.75	109.75	274.82	98.29	13.46	00.00	943.10
1939	00.00	55.05	79.50	260.78	198.73	120.65	166.12	129.79	172.27	184.65	00.00	10.92	1259.80
1940	00.00	02.54	29.46	50.80	102.89	169.67	156.97	73.91	123.12	91.94	20.32	00.00	873.50
1941	00.00	01.27	42.67	128.27	88.90	131.32	194.82	122.93	148.87	42.41	23.36	00.00	917.19
1942	06.35	17.27	55.37	43.94	131.83	72.14	122.17	44.95	186.02	84.32	00.00	00.00	757.93
1943	00.00	00.00	26.16	16.51	147.83	84.58	133.10	166.37	173.23	131.06	09.14	00.00	887.73
1944	00.00	10.16	28.44	67.56	71.12	73.41	199.90	269.66	209.80	178.74	03.81	00.00	1021.80
1945	00.00	00.00	03.81	18.03	127.76	176.28	199.90	89.66	187.07	80.26	00.00	07.11	1009.42
1946	00.00	53.08	00.49	35.30	93.73	101.60	164.34	67.05	207.86	178.56	00.76	00.00	898.65
1947	00.00	00.00	00.00	49.02	100.84	292.87	151.89	205.48	148.82	94.74	31.14	00.00	1039.36
1948	00.00	25.52	25.40	108.45	147.93	343.92	205.99	247.02	207.46	68.97	07.87	00.00	1422.04
1949	00.00	25.14	101.85	95.25	212.60	144.27	181.36	192.27	236.33	131.06	00.00	00.00	1334.26
1950	14.22	00.00	63.50	59.43	178.05	149.35	173.09	27.43	174.49	127.00	17.52	00.00	1011.68
1951	00.25	02.54	33.52	34.79	87.88	85.09	150.88	113.03	172.86	244.34	30.98	00.00	1038.86
1952	00.00	00.00	22.09	88.90	284.73	143.26	173.48	89.40	171.82	94.73	00.25	00.00	903.73
1953	00.00	42.02	70.86	13.20	211.33	85.60	310.64	119.63	244.60	126.49	24.38	00.00	1308.10
1954	00.00	10.92	148.33	109.72	154.94	224.99	63.50	103.12	322.32	185.92	30.22	00.00	1401.06
1955	10.16	00.00	41.65	86.10	156.97	194.06	355.35	133.35	289.30	138.68	00.00	00.00	1394.44
1956	00.00	30.22	96.92	34.54	201.17	199.64	18.27	65.27	105.15	136.65	00.25	24.89	870.45
1957	00.00	00.00	35.56	48.76	132.33	129.79	255.81	239.77	214.37	133.09	10.16	00.00	1238.50
1958	00.00	02.03	96.52	76.70	113.54	58.17	30.48	245.87	294.13	135.35	07.62	00.00	1279.24
1959	44.70	00.25	12.95	81.53	160.50	175.77	188.98	93.98	172.46	75.69	13.46	00.00	973.07
1960	00.00	00.00	21.10	134.40	92.20	281.90	131.80	211.30	176.60	144.50	13.00	00.00	1278.10
1961	00.30	00.00	29.50	179.60	175.30	113.30	300.00	55.60	236.70	105.90	00.00	00.00	1113.10
1962	00.00	00.00	47.50	104.10	92.20	143.00	141.50	272.00	214.90	152.10	63.10	00.30	1313.70
1963	00.00	15.70	05.30	170.70	151.60	202.40	186.90	432.30	194.10	51.60	00.00	00.00	1473.60
1964	00.00	00.00	04.60	99.10	187.50	262.10	144.00	62.20	185.70	132.80	00.00	00.00	1119.60
1965	01.80	55.60	16.00	93.00	43.20	179.30	255.00	230.90	213.10	78.70	00.00	00.00	1166.60

1966	00.00	00.00	00.00	122.40	205.50	134.60	199.10	251.70	291.30	124.20	00.00	00.00	1614.50
1967	00.00	00.00	69.60	94.70	79.60	87.90	110.50	127.00	321.10	124.20	00.00	00.00	1261.10
1968	00.00	06.40	12.20	83.80	122.40	117.10	200.00	320.80	281.40	101.60	14.50	00.00	579.20
1969	00.00	00.00	10.80	47.80	83.10	109.60	89.90	104.00	60.80	51.30	52.80	00.00	1278.20
1970	20.40	00.00	85.10	110.20	168.40	209.00	72.60	370.30	200.20	43.00	00.00	00.00	1409.20
1971	01.00	00.00	10.90	28.70	151.40	154.70	264.90	448.60	241.80	107.20	00.00	00.00	1329.10
1972	00.00	42.90	86.40	126.20	384.30	175.00	79.20	138.70	156.50	54.60	00.00	00.00	932.10
1973	00.00	00.00	03.80	65.80	161.00	74.90	72.40	205.70	211.30	137.20	00.00	00.00	1194.00
1974	00.00	00.00	01.50	122.90	111.30	226.40	294.40	55.10	176.50	206.20	00.00	00.00	1235.40
1975	00.00	03.30	40.90	58.20	137.70	93.70	240.80	100.80	293.10	130.80	01.80	00.00	1048.40
1976	00.00	04.30	40.60	06.60	212.90	164.60	128.00	71.90	121.20	160.70	77.00	00.00	913.10
1977	00.00	04.30	06.40	256.30	132.20	141.40	153.70	129.30	231.60	107.90	00.00	00.00	1498.10
1978	00.00	00.00	42.20	114.10	226.80	129.80	165.40	174.40	281.80	207.80	13.40	00.00	1118.90
1979	00.00	00.00	109.10	83.90	149.10	161.10	95.20	152.10	197.50	125.70	32.50	00.00	1126.50
1980	00.00	06.40	02.90	80.30	212.20	43.30	194.30	195.50	276.40	111.60	00.00	00.00	1146.90
1981	00.00	00.00	20.50	194.50	94.70	226.10	285.90	237.30	121.50	80.50	00.00	00.00	852.10
1982	00.00	03.60	25.70	61.80	97.70	75.30	122.30	91.70	157.90	83.40	00.00	00.00	843.60
1983	00.00	00.00	47.70	64.10	99.60	193.20	120.30	172.00	125.40	15.00	00.00	00.00	1162.00
1984	00.00	00.00	43.60	27.00	123.50	297.20	120.00	201.60	290.90	44.20	00.00	00.00	1506.00
1985	00.00	00.00	26.30	54.40	266.30	164.30	96.90	339.50	288.70	27.10	00.00	00.00	946.50
1986	00.00	00.00	07.10	05.50	72.00	255.80	106.30	181.20	202.00	61.10	00.00	00.00	808.50
1987	00.00	02.80	33.71	55.80	87.80	73.00	165.20	205.40	172.10	63.00	00.00	00.00	959.90
1988	01.40	04.70	02.40	127.10	123.70	189.80	197.40	99.90	228.60	56.20	00.00	00.00	1127.00
1989	00.00	00.00	23.40	157.90	130.00	214.60	164.40	164.40	163.50	139.60	00.00	00.00	1131.00
1990	00.00	00.00	00.00	119.30	135.80	121.80	217.70	153.10	260.80	83.77	00.00	00.00	1454.00
1991	00.00	24.00	33.10	114.40	189.10	362.50	243.30	350.90	117.20	14.40	00.00	00.00	1038.00
1992	00.00	00.00	00.00	20.30	215.50	118.80	122.60	36.70	335.00	95.50	00.00	00.00	995.10
1993	00.00	00.00	49.40	69.10	248.70	164.10	114.80	131.30	227.70	38.80	00.00	00.00	976.30
1994	00.00	00.00	00.00	25.50	137.90	124.50	227.60	113.90	214.60	88.80	00.00	00.00	1092.00
1995	00.00	00.00	06.40	14.39	158.10	268.30	91.56	232.00	222.00	84.40	03.50	00.00	1077.00
1996	00.00	00.00	00.00	124.80	120.60	218.70	227.50	216.90	159.80	118.90	00.00	00.00	961.80
1997	00.00	00.00	13.20	76.80	173.20	269.00	102.80	89.10	119.10	70.60	00.00	00.00	1207.00
1998	00.00	00.00	00.00	14.39	244.70	366.40	81.80	148.50	169.40	119.00	00.00	00.00	1139.40
1999	00.00	00.00	25.24	27.10	80.20	207.06	158.30	256.80	283.50	95.70	00.00	00.00	1240.51
2000	00.00	00.00	00.00	28.80	145.60	251.90	241.80	279.50	224.22	68.69	00.00	00.00	1008.86
2001	00.00	00.00	02.40	123.20	113.90	156.07	132.30	138.80	325.59	16.60	00.00	00.00	1039.90
2002	00.00	00.00	26.40	69.90	31.30	138.00	222.00	208.90	184.30	160.60	00.50	00.00	1338.44
2003	00.00	00.00	00.00	76.80	164.65	280.00	197.69	228.10	242.90	164.80	03.50	00.00	

APPENDIX 2

Analysis of Drought using Stochastic Component Time Series in Lokoja (1931 – 2003)

YEARS	ANNUAL RAINFALL (E_t) (mm)	MEAN ANNUAL RAINFALL \bar{E} (mm)	STANDARD DEVIATION S_E (mm)	$Z_t = \frac{E_t - \bar{E}}{S_E}$
1931	898.14	74.85	28.68	28.71
1932	1103.88	91.99	4.44	227.90
1933	1191.26	99.27	5.86	186.35
1934	1795.27	149.61	77.01	21.37
1935	999.49	83.29	16.74	54.73
1936	893.31	74.44	29.25	28.00
1937	894.08	74.51	29.16	28.11
1938	943.10	78.59	23.38	36.98
1939	1259.58	104.97	13.91	83.01
1940	873.50	72.79	31.59	25.35
1941	917.19	76.43	26.44	31.80
1942	757.93	63.16	45.21	15.37
1943	887.73	73.98	29.91	27.21
1944	1021.08	85.09	14.19	65.96
1945	1009.42	84.12	15.57	59.43
1946	898.65	74.89	28.62	28.78
1947	1039.36	86.61	12.04	79.13
1948	1422.40	118.53	33.10	39.39

1949	1334.26	111.19	22.71	53.86
1950	1011.68	84.31	15.30	60.61
1951	1038.86	86.57	12.10	78.70
1952	903.73	75.31	28.02	29.57
1953	1308.10	109.00	19.63	61.09
1954	1401.06	116.76	30.59	41.98
1955	1394.44	116.20	29.81	42.88
1956	870.45	72.54	31.95	24.97
1957	1238.50	103.21	11.43	99.33
1958	1279.24	106.60	16.23	72.25
1959	973.07	81.09	19.85	44.94
1960	1278.10	106.51	16.10	72.77
1961	1113.10	92.76	11.22	90.94
1962	1313.70	109.48	20.29	59.35
1963	1473.60	122.80	39.14	34.51
1964	1119.60	93.30	2.58	397.79
1965	1166.60	97.22	3.00	356.46
1966	1392.10	110.01	29.53	43.42
1967	1014.50	84.54	14.97	62.12
1968	1261.10	105.09	14.09	82.04
1969	1363.50	113.63	26.16	47.78
1970	1278.20	106.52	16.11	72.73
1971	1409.20	117.43	31.55	40.94
1972	1329.10	110.76	22.11	55.10

1973	932.10	77.68	24.68	34.62
1974	1194.00	99.50	6.18	177.10
1975	1235.40	102.95	11.06	102.39
1976	1048.40	87.37	10.97	87.61
1977	913.10	76.09	26.92	31.09
1978	1498.10	124.84	42.02	32.68
1979	111.90	93.24	2.67	384.14
1980	1126.50	93.86	1.77	583.41
1981	1146.90	95.58	25.80	40.75
1982	852.10	71.07	34.11	22.90
1983	843.60	70.30	35.11	22.03
1984	1162	96.80	2.41	441.99
1985	1506	125.50	42.95	32.14
1986	946.50	78.90	22.98	37.75
1987	808.50	67.40	39.25	18.88
1988	959.90	79.99	21.40	41.12
1989	1127	93.90	25.31	40.82
1990	1131	94.25	25.42	40.78
1991	1454	121.20	36.83	36.19
1992	1038	86.50	12.20	77.99
1993	995.10	82.90	17.26	52.85
1994	976.30	81.00	19.47	45.98
1995	1092	91.00	5.84	171.40
1996	1077	89.80	7.60	129.89

1997	961.80	80.20	21.18	41.62
1998	1207	100.60	7.72	143.32
1999	1139.40	94.90	25.60	40.80
2000	1240.51	103	11.67	97.44
2001	1008.86	84.10	15.63	59.16
2002	1039.90	86.70	11.98	79.57
2003	1338.44	111.54	23.21	52.86

Source: Roesner and Yevjevich, (1966)

APPENDIX 3

Analysis of Rainfall data (mm) at Lokoja using Rainfall Anomaly Index (RAI)

YEAR	ANNUAL RAINFALL (mm)	RANKING (M)	$RAI = \frac{+3P - \bar{P}}{E - \bar{P}}$	$RAI = \frac{-3P - \bar{P}}{E - \bar{P}}$
1934	1795.27	1	5.94	6.92
1985	1506.00	2	3.31	3.86
1978	1498.10	3	3.24	3.77
1963	1473.60	4	3.02	3.51
1991	1454.00	5	2.84	3.31
1948	1422.40	6	2.55	2.97
1971	1409.20	7	2.43	2.83
1954	1401.06	8	2.36	2.75
1955	1394.44	9	2.30	2.68
1966	1392.50	10	2.28	2.65
1969	1363.50	11	2.02	2.35
2003	1338.44	12	1.79	2.08
1949	1334.26	13	1.75	2.04
1972	1329.10	14	1.70	1.98
1962	1313.70	15	1.56	1.82
1953	1308.10	16	1.51	1.76
1958	1279.24	17	1.25	1.46

1970	1278.20	18	1.24	1.45
1960	1278.10	19	1.24	1.44
1968	1261.10	20	1.09	1.26
1939	1259.58	21	1.07	1.25
2000	1240.51	22	0.90	1.05
1957	1238.50	23	0.88	1.03
1975	1235.40	24	0.85	0.99
1998	1207.00	25	0.59	0.69
1974	1194.00	26	0.48	0.56
1933	1191.26	27	0.45	0.53
1965	1166.60	28	0.23	0.27
1984	1162.00	29	0.19	0.22
1981	1146.90	30	0.05	0.06
1999	1139.40	31	-0.02	-0.02
1990	1131.00	32	-0.10	-0.11
1989	1127.00	33	-0.13	-0.15
1980	1126.50	34	-0.14	-0.16
1964	1119.60	35	-0.20	-0.23
1979	1118.90	36	-0.21	-0.24
1961	1113.10	37	-0.26	-0.30
1932	1103.88	38	-0.34	-0.40
1995	1092.00	39	-0.45	-0.52
1996	1077.00	40	-0.59	-0.68
1976	1048.40	41	-0.85	-0.99

2002	1039.90	42	-0.92	-1.08
1947	1039.38	43	-0.93	-1.08
1951	1038.86	44	-0.93	-1.09
1992	1038.00	45	-0.94	-1.10
1944	1021.08	46	-1.09	-1.34
1967	1014.50	47	-1.15	-1.37
1950	1011.68	48	-1.18	-1.40
1945	1009.42	49	-1.20	-1.40
2001	1008.86	50	-1.21	-1.50
1935	999.49	51	-1.29	-1.55
1993	995.10	52	-1.33	-1.75
1994	976.30	53	-1.50	-1.78
1959	973.07	54	-1.53	-1.90
1997	961.80	55	-1.63	-1.92
1988	959.90	56	-1.65	-1.06
1986	946.50	57	-1.77	-1.10
1938	943.10	58	-1.80	-2.22
1973	932.10	59	-1.90	-2.37
1941	917.19	60	-2.04	-2.37
1977	913.10	61	-2.08	-2.42
1952	903.73	62	-2.16	-2.52
1946	898.65	63	-2.21	-2.57
1931	898.14	64	-1.21	-2.58
1937	894.08	65	-2.25	-2.62

1936	893.31	66	-2.25	-2.63
1943	887.73	67	-2.31	-2.68
1940	873.50	68	-2.43	-2.84
1956	870.45	69	-2.46	-2.87
1982	852.10	70	-2.63	-3.06
1983	843.60	71	-2.71	-3.15
1987	808.50	72	-3.03	-3.52
1942	757.93	73	-3.48	-4.06

P=1141.28mm

E = + Extrema = 1471.76mm

- Extrema = 857.93mm

Source: Van Rooy, (1965).

APPENDIX 4

Cumulative Rainfall Information of Lokoja (1931 - 2003).

YEARS	ANNUAL RAINFALL (MM)	CUMULATIVE RAINFALL (MM)
1931	898.14	898.14
1932	1103.88	2002.02
1933	1191.26	3193.28
1934	1795.27	4988.55
1935	999.49	5988.04
1936	893.31	6881.35
1937	894.08	7775.43
1938	943.10	8718.53
1939	1259.58	9978.11
1940	873.50	10851.61
1941	917.19	11768.8
1942	757.93	12526.73
1943	887.73	13414.46
1944	1021.08	14435.54
1945	1009.42	15444.96
1946	898.65	16343.61
1947	1039.36	17382.97
1948	1422.40	18805.37

1949	1334.26	20139.63
1950	1011.68	21151.31
1951	1038.86	22190.17
1952	903.73	23093.9
1953	1368.10	24402.00
1954	1401.06	25803.06
1955	1394.44	27197.50
1956	870.45	28067.95
1957	1238.50	29306.45
1958	1279.24	30585.69
1959	973.07	31558.76
1960	1278.10	32836.86
1961	1113.10	33949.96
1962	1313.70	35263.66
1963	1473.60	36737.26
1964	1119.60	37856.86
1965	1166.60	39023.46
1966	1392.00	40415.46
1967	1014.50	41429.96
1968	1261.10	42691.06
1969	1363.50	44054.56
1970	1278.20	45332.76
1971	1409.20	46741.96
1972	1329.10	48071.06

1973	932.10	49003.16
1974	1194.00	50197.16
1975	1235.40	51432.56
1976	1048.40	52480.96
1977	913.10	53394.06
1978	1498.10	54892.16
1979	1118.90	56011.06
1980	1126.50	57137.56
1981	1146.90	58284.46
1982	852.10	59136.56
1983	843.60	59980.16
1984	1162.00	61142.16
1985	1506.00	62648.16
1986	946.50	63594.66
1987	808.50	64403.16
1988	959.90	65363.06
1989	1127.00	66490.06
1990	1131.00	67621.06
1991	1454.00	6907.06
1992	1038.00	70113.06
1993	995.10	71108.16
1994	976.30	72084.46
1995	1092.00	73176.46
1996	1077.00	74253.46

1997	961.80	75215.26
1998	1207.00	76422.26
1999	1139.40	77561.66
2000	1240.51	78802.17
2001	1008.86	79811.03
2002	1039.90	80850.93
2003	1338.44	82189.37