DETECTION OF DROUGHT ONSET IN SOME STATES OF NORTHERN NIGERIA

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CHAPTER ONE

1.0 INTRODUCTION

The environment as was known, has being evolving or experiencing climatic change in diverse forms, resulting in several natural and artificial/man-made hazards and disasters (Koudahe *et al.*, 2017). The climate change varies from continent to continent or region to region, with no exemption. The effects of climate change is ever increasing with third world countries being the worst hit (https://en.m.wikipedia.org/wiki/climate_change). Diverse environmental hazards is glaring, among which are flooding, erosion, desertifications, droughts, and so on.

1.1 Background to the Study

Drought is one of the devastating recurrent natural and man-made disasters of global concerns (known as a global phenomenon) and seems to be spreading with increasing climatic change (Wilhite, 1994) and due to its widespread and impact, other than flooding, hurricane, earthquakes, lightening, whose effect is non-structural (Seyed *et al.*, 2009), irrespective of the duration of intense drought, its consequences is significant (Avoiding Dangerous Climate Change (ADCC), 2007). All hydro-climatological regions of the world are susceptible to drought and at any time of the year (Wilhite *et al.*, 2000). The phenomenon called drought has a long history with humanity (Seyed *et al.*, 2009) and has been viewed as an event which is normal and recurring climatic feature in all regimes (Wilhite *et al.*, 2000). Drought severity is a derivative of duration, intensity, specific episode of drought spatial extent and demands for human activities, vegetation and regional based water supply (Seyed *et al.*, 2009). Drought occurrence has been reported to be more frequent and extreme the late 1990s (Yu *et al.*, 2014) largely owing to global warming, spread and stretch of drought impacted areas (Huang *et al.*, 2016; Li *et al*., 2019b). Vulnerability and impacts of drought is more in some African countries than others (Olusegun, 2011). The duration, frequency, severity and effects of drought in northern Nigeria is of higher magnitude than those occurring in other parts of Nigeria (Adaega, 2011; Olusegun, 2011).

1.2 Statement of the Research Problem

Walter (2004) reported that since 1994 drought and famine are distinguished as the most fatal disasters that the decade has experienced, resulting in about 275,000 deaths, with hotter and drier climatic changes predicted to occur in developing countries (Mahmoud and Maarteen, 2014). Drought has devasted lots of countries with northern region of Nigeria being the worst hit (FRN, 1999), and nearness of the north to the Sahara Desert, declares high vulnerability. High temperature in the north, is high causative agent, therefore the north is known to be experiencing the "twin hazards, drought and desertification" (Wilhite, 2000; Oladipo, 1995; Olagunju, 2015). Losses arising from drought is enormous and spreading.

The nature and propagation of drought is known for its creeping occurrence or as a creeping phenomenon, which is consistent with climatic conditions all over the world (Seyed *et al.,* 2009; Tannehill, 1947; Ake *et al*., 2001, Wilhite *et al*., 2000), meaning that the occurrence of drought is gradual/slow and many times, it creeps in unawares, people get to know when the effect is already being felt , its0 effect accumulates slowly over time and may linger for years after its demise (Wilhite *et al*., 2000)

There is inadequate studies in drought onset and recovery (Kingtse, 2011). Most studies on drought in northern Nigeria focuses on vulnerability and assessment. Not much studies on drought onset in northern Nigeria has been carried out, as at the time of this study.

1.3 Aim and Objectives of the Study

This research is aimed at the detection of drought onset in some states of northern Nigeria.

The objectives of this research work are to:

i. categorize meteorological drought using Standardized Precipitation evapotranspi ration Index (SPEI) at a 3-months time scale.
ii. identify drought onset in the study area.
iii. establish the pattern of drought onset in the three stations.

1.4 Justification of the Study

Drought has been severally reported and ranked high in global and national environmental hazards or disastrous phenomenon (ADCC, 2007; Walter, 2004; World Bank, 2011; Obasi, 1994) with widespread impacts. Union of Concerned Scientists (UCS, 2015) reported that drought accounts for about $ 9 billion per year in the U.S. Drought, whose occurrence, though not desirable, has devasted lots of countries with northern region of Nigeria being the worst hit in the country (FRN, 1999). The impacts of drought in northern Nigeria are glaring, propagating and adversely progressing to the detriment of northern dwellers and in extension, the whole nation, because drought has multiplier direct and indirect effects. Adequate preparation or preparedness against drought hinges on detecting and responding to drought onset, in order to be proactive with mitigative plans and minimize the propagation and impact of drought.

Therefore, this research findings can be incorporated into necessary drought monitoring, policy guidelines, programme strategies and planning and management of water resources, with the hope of minimizing vulnerability, all related forms of losses and maximize available resources, once the onset are detected. Also, this research work will add to available body of knowledge in relation to drought occurrence in northern Nigeria.

1.5 Scope of the Study

The scope of this research work is limited to the detection of drought onset in three states of Northern Nigeria, namely Sokoto, Kaduna and Borno, by obtaining and analysing appropriate data, examine drought type, in order to detect drought onset, necessary for early mitigative action.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Drought Definition

The complex nature and variability of drought has made if difficult to have a unique globally acceptable definition (Shah and Mishra, 2020; Changnon, 1987; Wilhite, 2005; Van Loon, 2015), among the several reasons are drought gradual accumulation, unspecific onset and demise (Shah and Mishra, 2020a; Changnon, 1987; Kingtse, 2011). Most definitions of drought agrees to the fact that its major driver or trigger is or is initiated by precipitation deficit over time (McKee *et al.,* 1993). For the sake of this study, drought is a period of unusally dry weather that persists long enough to cause serious problems such as crop damage and water shortages due to reduction in precipitation, insufficient soil moisture, high temperature, land-overuse and overpopulation (McKee *et al.,* 1993; Wilhite and Glantz, 1985; www.thebalance.com, www.livescience.com). Drought is a multi-dimensional or multifaceted hazard that is associated with principal season of precipitation occurrence, delays in the commencement of the rainy season, rain occurrence in linkage to the stage of crop growth, rain intensity, amount of rainfall event (Wilhites *et al.,* 2000), soil moisture, streamflow, plants wilting, wildfire, famine and desertification. Common characteristics of drought are intensity, duration, frequency, spatial extent, onset and demise (Wilhite *et al*., 2000; Changnon, 1987; Andreadis *et al*., 2005). Drought has both direct impacts, such as crop yield reduction for farmers and indirect or derivative impacts, such as loss of jobs and businesses for farmers communities (www.thebalance.com). Generally, there is no one single fit-all definition of drought (Wilhite *et al.,* 2000).

2.2 Drought Characteristics

Historical accounts of drought reveals certain key features which distinguish one drought event from another. The characteristics of all drought types are intensity, magnitude, duration, frequency, spatial and temporal-extent, slow onset and recovery (Robinet, 2011; Kingtse, 2011; Svoboda *et al.*, 2002)

2.3 Impact of Drought in Northern Nigeria

The consequences or negative impacts of drought can either be short or long term and affects both living and nonliving things, directly or indirectly. The magnitude or severity of drought impacts varies from region to region, country to country.

The obvious impacts of drought in northern Nigeria, includes high starvation, widespread and compounding poverty, dwindling economic activities, inconsistent rainfall-based agriculture, socio-economic instability, (Olusegun, 2011; Nwokocha, 2016a), poor crop yield, death of livestock, water shortage, loss of arable farmland and vegetation covers, frequent farmers-herders conflicts, rural depopulation, urban economic and resource pressure/stress, increased dependency on government, increased desertification effects (Abdullahi, 2018), lower electricity generation, poor trees growth rate, increased indebtedness, GDP decline, reservoir depletion, lower groundwater level, land degradation (Nwokocha, 2016b). Generally, the impacts of drought (all of the above) are classified under three categories; economy, environment and society/community.

2.4 Overview of Drought in Northern Nigeria

All continents of the world have experienced drought with diverse intensity and duration, at one time or the other. It has been noted that the African continent is characterized by drought event (Abaje *et al.*, 2013) with one-third of Africans are vulnerable to droughts negative effect (Lisa *et al*., 2008). Africa falls within the Sudano-Sahelian region prone to drought (Nwokocha, 2016). The Sudano-Sahelian region, which had suffered drought around the 1970s and 1980s, lost over 200, 000 people, millions of animals, farmers impoverishment and desertification, reduced cloud cover, humanly stimulated high-evaporation rates, social backwardness, poor quality of life, natural support stress, decreasing inflow to water bodies (Olusegun, 2011; FRN, 2003; Ati *et al.,* 2007; Alatise and Ikumawoyi, 2007; FRN, 2005)

Nigeria, particularly the northern part, being part of the affected Sudano-Sahelian drought region of the world (Abaje *et al.,* 2013) is known as the “grain basket” of Nigeria, producing large quantities of most grains in Nigeria, is known for the prevalence of environmental hazards or disasters of various forms and magnitude.

Northern Nigeria is well known for her enormous expanse of arable land and rich in diverse agricultural activities/production, which are transported to other parts of Nigeria and exported to other nations of the world (Obasi, 1994; Bruce, 1994). The occurrence and recurrence of drought in northern Nigeria, among many negative impacts, affects agriculture, which is a major source of livelihood or employment for rural dwellers, and as such agricultural production and farmers morale/involvement is declining (WMO, 2014; Austin *et al*., 1998; Leilah and Al-khateeb, 2005), this also leads to large rural to urban migration, rural depopulation and urban population boost). World Bank (2011) reported that desertification and drought accounts for a yearly loss of about $5 billion to Nigeria.

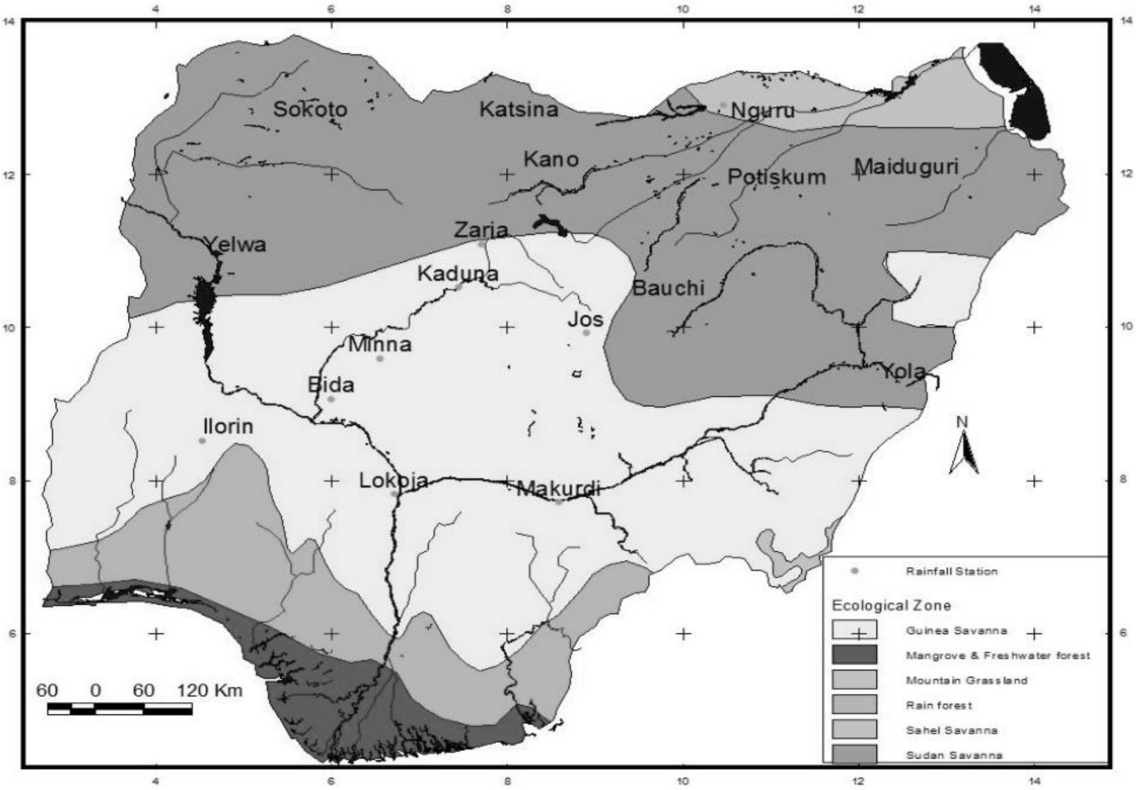

Figure 1.1: Northern Nigeria (Source: Adeaga, 2011)

One-third of the total land area of Nigeria is covered by the north (Abaje *et al.,* 2013), out of which Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe and Zamfara, are the most frequently adversely affected by drought.

2.4.1 Causes of drought in northern Nigeria

With focus on northern Nigeria and the foregoing, concise causes of drought can be summarized into two groups;

i. Natural causes: extreme drought event is highly influenced by global climatic changes (Hao *et al*., 2018; Nwokocha, 2016). This situation results in but not limited to increased variability in rainfall, increased both land and sea temperatures (Sheffield *et al.*, 2012; Kusangaya *et al*., 2014; Clark *et al*., 1999, Savo *et al*., 2016), environmental changes, which is linked to the ecosystem services (Galaz *et al*., 2008). Though this natural causes, hazards or disasters, can be traced to long term activities of humans.

ii. Human causes: in the past, drought was thought to be basically due to natural hazards or disaster, but as researches progressed, it is now known that certain human day to day, month to month and year to year activities contributes significantly to the occurrence of drought in different parts of the world. Simply put, humans are major drought-causative agent. Human activities that are key contributors to drought in northern Nigeria are overgrazing, deforestation, bush burning, migration, continuous land exploitation, extensive cultivation (FRN, 1999; www.earth-policy.org), increased women stress. Since drought affects available grazing land (natural vegetation growth) in the north, large movement of Fulani herdsmen and their herds, from the north to the middle belt, down to the south, has resulted in lots of conflicts over the years, destruction of lives, farm produce and properties (Fidelis, 2013; Burke *et al*., 2007). Also, extended or prolong drought events leads to distress sale of animals (cattle's, camels, rams etc.)

2.4.2 Rainfall Pattern in Northern Nigeria

The rainfall pattern in the northern Nigeria is mostly variable, spatial and erratic. Average annual rainfall ranges from 250mm to 1000mm, days of rain is between 40 and 100 per year (Adefolalu, 1986; Ojo & Oyebande, 1987; FRN, 1999). The zone is susceptible to dry spells which is linked to drought event (Oladipo, 1995) Ferruginous tropical soils covers large portion of the region (Oladipo, 1995).

Generally, there is no uniform distribution of rainfall in Nigeria and reduces towards the northern region, that is, the occurrence of rainfall in the northern region varies from year to year. This variable annual rainfall poses challenges to viable agricultural activities (particularly, vegetative growth). Change in climatic condition is one of the cause for this variable rainfall being experienced in this region.

Rainfall transition is the time-space movement from rainy season to the winter season and this occurs between October and November, hot rainy to dry winter condition (www.toppr.com).

2.5 Types of Drought

Drought event, though may take weeks, months and at times years for its occurrence to be known, has the following well known or major types - Meteorological, Hydrological, Agricultural and Socioeconomical drought (Wilhite and Glantz, 1985).

2.5.1 Meteorological drought: Meteorological drought is the result of prolong insufficient precipitation over an area (Otkin *et al.,* 2018; Wilhite and Glantz, 1985) or a long period without substantial precipitation compared to long-term average of a region (Robinet, 2011), linked to water deficiencies in the hydrologic cycle. Balasubramanian, (2020) slideshare, explained the meteorological drought is defined on the bases of the degree of dryness, in comparison to a normal or average amount and the duration of the dry period (the issues). Comparison is made between current precipitation or dryness and the average or predetermined normal precipitation or dryness. Since climatic conditions that results in drought vary greatly from region to region, definition of meteorological drought has to be based on individual regional conditions.

In summary, this drought type is said to occur when the seasonal rainfall received overran area is less than 25% of its long-term average value, while moderate drought occurs if the rainfall deficit is 26-50% and severe drought when the deficit exceeds 50% of the normal (Manual for drought management, 2009). Data sets required to assess meteorological drought are daily rainfall information, temperature, humility, wind velocity, pressure and evapotranspiration (Drought facts, 2020). Meteorological drought is predecessor to all other drought types (Nhamo *et al.,* 2019; Qianfeng, 2015), in other words, all other drought types originates from precipitation deficit over time and/or space, the early stage is known as meteorological drought, while persistence of this deficiency leads to other drought types (Yohannes *et al*., 2019).

2.5.2 Hydrological drought: Hydrological drought refers to a persistently low discharge and/or volume of water in streams, reservoirs storage depletion, and surface runoff, due to precipitation deficit over a long time (lasting months or years) and it is related to meteorological drought (Drought facts, 2020). In other words, it is a drought arising as a result of deficiency of precicpitation in contribution to surface and surface supplies of water for regular and definite use, such as lower than normal streamflow, ground water level and reservoir level. Below average surface and/or subsurface water (Wilhite, 2000). Such conditions arise, even in times of average (or above average) precipitation when increased usage of water diminishes the reserves (Manual for drought management, 2009). Data sets required to assess hydrological drought are surface-water area and volume, source runoff, streamflow measurements, infiltration, water-table fluctuations and aquifer parameters (Drought facts, 2020).

2.5.3 Agricultural drought: The drought events that impacts on soil moisture, crop production and/or the ecology of an area or region is termed as agricultural drought, that is when shortage or below average precipitation reduces the moisture in the soil, causing extreme crop stress, wilting, poor crop production and and result in substantial loss of yield and ecological change (Qianfeng, 2015; Wilhite, 2000; Manual for drought management, 2009). This type of drought usually arises as a result of meteorological and hydrological drought. Data sets required to assess agricultural drought are soil texture, fertility and soil moisture, crop type and area, crop water requirements, pests and climate (Drought facts, 2020).

2.5.4 Socio-economic drought: Socioeconomic drought associates the supply and demand of some economic good with elements of meteorological, hydrological and agricultural drought (Drought facts, 2020), that is, when the reduction in average precipitation over a period, leads to shortage or decrease in economic goods and services within a society or nation (Wilhite, 2000). Data sets required to assess socioeconomic drought are human and animal population and growth rate, water and fodder requirements, severity of the crop failure, industry type and water requirements (Drought facts, 2020).

2.6 Drought Measurements

The measurement of drought or drought assessment, is the process in which indicators are introduced into an index or multiple indices to determine the drought type and/or its characteristics. Two key factors in drought measurements are indicators and indices

A. Indicator

An indicator can be defined as a quantified parameter or a statistically estimated parameter, that serves to find the disparity of the state of some complex entity and it can be directly measured. Examples of an indicator precipitation, minimum temperature, maximum temperature, relative humidity, (George, 2013), streamflow, runoff, evapotranspiration, ground water levels, water supply, water level, water needs, vegetation health/stress, reservoir and lake levels, weather conditions, soil moisture and water quality (Changnon, 1987). Also, Drought indicators are variables or parameters/input data, to describe the magnitude, duration, severity and spatial extent of drought (Anne *et. al*., 2005). These indicators can help to discover analyze and mitigate impacts of drought. Drought levels signifies the stage or level of severity of drought; levels such as “mild, moderate, severe, extreme drought "or "stage 1, stage 2, stage 3 drought" are used (Anne *et. al*., 2005).

B. Index

Index is a numerical quantification, variation, accumulation or combination of indicators (George, 2013). Indicators can exist without an index, but an index can't exist without an indicator; meaning that an index is a derivative of an indicator or indicators (George, 2013). In essence, drought indices are a derivative of drought indicators, that is, they involve the combination and manipulation of various drought indicators to express/assess and detect drought severity in numerical scales (Anne and Sam, 2015; George, 2013). Indices are employed for the characterization and assessment of drought, and the choice of any index is dependent on the drought type and available data (Anne and Sam, 2015).

2.7 Common Drought Indices

A. Palmer Drought Severity Index (PDSI): This was developed in the year **1965** by meteorologist **Wayne Palmer** (Palmer, 1965)**.** This index is among the most popular and accepted indices for drought assessment and monitoring. PDSI is a soil moisture-based index, first used in the United States of America (Alatise and Ikumawoyi, 2007). For large areas of uniform topography, PDSI is efficient for meteorological and agricultural drought measurement, allowing for drought spatial-temporal scale (Altman, 2013).

Among the advantages of this index are its ability to measure recent-based weather abnormality, to estimate relative dryness or wetness. It is a complex measurement system and an effective way to forecast long-term drought (Drought facts, 2020).

Its limitations are that it does not provide early warnings for drought and is not accurate for use in mountainous areas or areas of frequent climatic extremes, because it does not account for snow (only rain) as precipitation (Drought facts, 2020).

Table 2.1: PDSI classification

RANGE	INDICATION
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

(Drought facts, 2020, http://ponce.sdsu.edu/three_issues_droughtfacts03.html)

B. Palmer Hydrologic Drought Index (PHDI):

This Index is founded on the principles of PDSI with some modification in order for long-term moisture anomalies or dryness or daily inflow, water storage, streamflow and groundwater (Karl and Knight, 1985). The major distinction between PDSI and PHDI is the use of ratio of moisture received to moisture required to determine drought termination. It serves as a useful supplement to PDSI values, in analyzing further hydrological information considered vital to water management decisions in the west (Michael *et al*., 2007).

C. Standardized Precipitation Index (SPI):

SPI was developed or designed by McKee *et al*. (1993), to quantify or measure the precicpitation deficit for multiple timescales (one to 24 months), which indicate the impact of drought on available water resources. The standard precipitation index rely only on precipitation. The record is fitted to a probability distribution which is then transformed into a normal distribution so that the mean SPI for a location and period is zero. SPI is less complex compared to PDSI and it identify drought many months earlier than PDSI, alhough, SPI is also used to supplement the PDSI data. Drought magnitude is the positive sum of the SPI for the months within a drought event. Continuously negative SPI indicates a drought event.

SPI has obtained wide acceptance for drought monitoring and early warning system, as recommend by World Meteorological Organization (Hayes *et al.*, 2011) It is a long time-based index, needing at last 30 years precipitation data.

Table 2.2: SPI VALUES/CLASSIFICATION

RANGE	INDICATION
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severly dry
-2.0 and less	Extremely dry

(Drought facts, http://ponce.sdsu.edu/three_issues_droughtfacts03.html)

D. Standardized Precipitation Evapotranspiration Index (SPEI):

This index was developed by Vicente-Serrano *et al.*, (2010), incorporating temperature component to the SPI method. The parameters required as input are the monthly precicpitation and temperature data, in order to account for drought condition. SPEI requirement for sequencially complete set of data for precipitation and temperature and it being a monthly index, limits its use or applicability (Handbook of Drought Indicators and Indices, 2016).

E. Effective Drought Index (EDI):

In this Index, effective precipitation(EP), deviation (DEP), standardized value of DEP and daily mean (EP) are calculated using daily precipitation data, which establishes of identies the onset water deficit periods. It is adoptable for meteorological and agricultural drought monitoring, though limited by not integrated temperature and difficulty of daily input data (Byun and Wilhite, 1996).

F. Decile (Percentile Ranking) or Monthly Drought:

This index was developed by Gibbs and Maher, 1967, to resolve the shortcomings of the Percent of Normal approach. This is when monthly precipitation data is arranged into deciles by dividing the distribution of occurrences over a long-term precipitation record into tenths of distribution known as decile. The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences (Drought facts, 2020).

Table 2.3: Deciles classification

RANGE	INDICATION
Deciles 1 – 2 Lowest 20%	Much below normal
Deciles 3 – 4 Next lowest 20%	Below normal
Deciles 5 – 6 Middle 20%	Near normal
Deciles 7 – 8 Next highest 20%	Above normal
Deciles 9 – 10 Highest 20%	Much above normal

G. Reclamation Drought Index (RDI):

RDI is a tool for determining the severity and duration of drought and for predicting the beginning and end of a drought period. RDI is calculated at a river basin level. It incorporate the supply components of precipitation, snowpack, streamflow and reservoir levels and is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors (Anne *et. al*., 2005).

Table 2.4: RDI classification

RANGE	INDICATION
4.0 or more	Extremely wet
1.5 to 4.0	Moderately wet
0 to 1.5	Normal to mild wetness
-1.5 to -4.0	Moderate drought
-4.0 or less	Extreme drought

H. Surface Water Supply Index (SWSI):

The surface water supply index (SWSI) complements the Palmer Index for moisture condition. It is designed for small topographic variations across a region but doesn't take snow accumulation and subsequent runoff into cognizance. The SWSI was designed to be an indicator of surface water conditions, including mountain snowpack. The objective of SWSI is to incorporate both hydrological and climatological features into a single index resembling Palmer Index (Anne *et al.,* 2005).

I. Percent of Normal Precipitation (PNP):

The percent of normal precipitation is the ratio of actual to normal precipitation for a given location and a given period, expressed as a percentage. Analysis using the percent of normal are effective when used for a single region and a single season. In other applications, the index can vary depending on the choice of period indicating monthly, seasonal or annual precipitation (Drought facts, 2020; Anne *et al.*, 2005). This results from this index can be used for preliminary analysis (Ognjen, 1993).

J. Crop Moisture Index (CMI):

It is derived from PDSI and looks at moisture supply in the short term for crop producing regions. CMI monitors week-to-week crop conditions, evaluating short-term moisture conditions across major crop-producing regions. CMI is not effective for long term drought monitoring tool, but response fast to precipitation event (Yohannes *et al*., 2019).

2.8 Climate Change and Global Warming

It has been reported by the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC), 2007, that several millions of Africans will suffer stresses prompted by climate change. This will certainly lead to other derivative consequences or hazard/disasters, key among them being agriculture (Kusangaya *et al.,* 2014) which is directly and indirectly linked to virtually all other sectors of human existence. Even though climate changes naturally, increased human activities (greenhouse gases) hasten the change rate, and has short- and long-term worldwide effect (Abdullahi, 2018)

Climate is the average state of the weather over a long period of time in a region (Nenibarini, 2007) and the intersecting components are the atmosphere, hydrosphere, cryosphere, land surface and the biosphere (De Chavez and Tauli-Corpus, 2008). On the other hand, according to De Chavez and Tauli-Corpus, (2008), global warming is defined as the average increase of the earths surface temperature and oceans as compared to previous centres. Changes in temperature, rainfall or wind patterns among other events are part of the expression of climate change (Hartmann *et al*., 2013; Iliya, 2019). The climate of the zone is tropically wet and dry zone and its an arid and semi-arid area, becoming drier with fast encroaching Sahara Desert, dominated by the tropical maritime airmass, which brings rain from April to October and by the dry, dusty tropical continental airmass, October to March (Olusegun, 2011; Abaje *et al.*, 2013).

2.8.1 Brief on Tropical Maritime Airmass, Tropical Continental Airmass, Inter Tropical Convergence Zone

A. Tropical Maritime Airmass (South West Trade)

It is a warm and wet wind, which brings about the rainy season and moves from the Atlantic Ocean to the coast of Nigeria. The wettest part of Nigeria is the delta region (Warri and Port Harcourt) with 12 months of rainfall, but reduces towards the northern regions (https://www.austintommy.com.ng). Rainy season in Nigeria, starts around March and terminates around October along with little or no rain period in August.

B. Tropical Continental Airmass (North East Trade Wind)

The tropical continental airmass moves across the Sahara Desert towards Nigeria, and results to cold, dusty and dry weather, spanning from November and terminates around February (www.austintommy.com).

C. Inter Tropical Convergence Zone (Itcz)

According to Hassan *et al*., (2017), ITCZ is a component of atmospheric circulation, which conforms with monthly and seasonal changes of the sun, and moves to the northern and southern latitudes, influencing widespread atmospheric circulation. It is a flexible or changeable zone, in which the two air masses mix or rub (www.austintommy.com)

D. Monsoon Season

Monsoon is basically the seasonal reversal or rotation of wind direction, which occurs roughly six months from the northeast and six months from the southwest. Common monsoons happen in Africa, Australia, South Asia and the pacific coast of Central America (https://www.britannica.com/science/monsoon). The monso on is now utilized in the description of seasonal atmospheric changes and precipi tation, which is linked to yearly latitudinal oscillation of the Inter-Tropical Convergence Zone, between the north and the south of the equator (hppts://em. m.wikipedia.org/wiki/monsoon). The average monsoon start month for West Africa is June 22 and withdraws between September and October (Innovation Report, 2011).

2.9 Definition of Drought Onset

Since the process of drought starts slowly and transits to a noticeable and impactful stage (Wilhite, 2006), it therefore means there exist an onset that can be meticulously taken note off and advice or guide all relevant stakeholders, likely to be affected by the occurrence of drought, as the intensity increases per time. Drought onset is the point at which the indice values first appeared with a negative value beginning of drought event in are the salient indications associated with the onset or beginning of drought (Kingtse, 2011), signifying the presence or occurrence of drought (Changnon, 1987).

2.10 Importance of Detecting Drought Onset.

Since the impacts of drought cuts across the society, economic and environment, that is, it affects all aspects of human existence in one way or the other, directly or indirectly, detecting the early signs of drought has the following importance, (although list not exhaustive) (Aliereza *et al*., 2015):

i. Seasonal prediction of drought can be improved or made more accurate.
ii. Water resources planning and administration can be made more efficiently by water managers.
iii. Early drought information will guide farmers in their seasonal agricultural decision-making, for maximum agricultural production, e.g. drop type to plant, procurement of fertilizer and best planting methods for each crop, etc.
iv. There will be better or ease of adaptability to drought event.
v. Revelant agencies or bodies can take proactive measures against imminent drought event, e.g. insurance cover, survival plans during drought, etc.
vi. Leads to technological improvement for drought monitoring and prediction.
vii. Better water resources and environmental management principles and processes.
viii. Drought early warning system can be enhanced by detecting the ealy signs of drought.
ix. All forms of economic, environmental and societal losses can be minimized.
x. Rechannelization of state, national and international funds to other areas for the betterment or development of the state/nation.
xi. It helps large scale water users to find a way to conserve supplies or seek alternative supply measures.

2.11 Time-Scale for Drought Analysis

The time unit commonly used for drought studies or assessment is the year and the month (Byun and Wilhite, 1999). However, the use of the monthly data is beneficial in limiting the problems caused by yearly time unit and monthly time unit is long enough to scan out irrelevant events, while allowing for efficient monitoring of drought impacts on agriculture, level of groundwater and supply of water (Ognjen, 1993). Frequent re-evaluation of drought intensity or event is vital for drought risk preparedness of the general public (Byun and Wilhite, 1999). The time-scale is also called or viewed as variable accumulated period and the commonly used time scales are 1, 3, 6, 12, 24 and 48 months (EDO, 2020; McKee *et al*., 1995). Time scale for drought analysis can be grouped as follow;

A. **Short time scale:** This ranges between 1 to 3-months, that is the precipitation accumulation is 30days and/or 3-months, which is a short-term conditions. They are used for the examination or are related to to meteorological and agricultural droughts, due to deficit in precipitation, soil moisture state, crop stress, vegetation response respectively. Generally, Short time scale shows high drough frequency, soil moisture and river discharge in headwater areas (EDO, 2020; WMO, 2012).

B. **Medium time scale**: This ranges between 3 to 12-months and are connected to reservoir storages and discharges in medium course of the rivers, for hydrological drought examination (EDO, 2020).

C. **Long time scale**: This time scale ranges between 12 to 48-months accumulation period and are associated to groundwater storage and variability, used for hydrological drought examination. At the longest time scales, drought frequencies are lower but the duration are longer (https://spei.csic.es/home.html; WMO, 2016;

EDO, 2020). Drought impacts on aquifers are determined by 24 months' time scales.

2.12 The Choice of 3-months time scale

Copernicus European Dro Observatory (EDO, 2020) stated that results obtained by other stuies revealed that SPI-3 has the strongest association with the vegetation, therefore it is preferable for establishing agricultural drought. Since this study involves the determination of agricultural drought, a 3-months accumulation period was adopted.

2.13 Review of Past Efforts on Drought Onset

Since the impact of drought is immense and diverse, lots of researchers had undertaken to study drought, its causes, characteristics, impacts, monitoring, mitigation, management and forecasting, and so contribute to the body of drought knowledge.

The following are relevant and related research works reviewed, main findings and gaps;

A) Drought Onset and Recovery over the United States.

In this paper by Kingtse (2011), precipitation (P) and Soil Moisture (SM) data for the period between 1916 to 2007 was used to examine the drought onset and end, in the United States.

Meteorological and agricultural droughts were studied or identified, employing Standardized Precipitation Index (SPI), derived from observations and the Soil Moisture (SM) anomaly percentiles, from the Northern American Land Data Assimilation System (NLDAS).

Research Main Findings

a. The SPI and SM anomaly percentiles are used to classify drought events (Meteorological and agricultural droughts).

b. Within the study area, SPI and SM Indices were used to define certain thresholds for ɽ-duration, as a means of identifying drought onset of demise.

c. 3-months SPI (SPI-3), a 3-month P mean (P_3) time series was obtained.

d. It is possible to identify the beginning of drought event: the threshold for drought onset is less than -0.8 for SPI Index and the SM percentile is below 25% for the one season or longer.

e. While for drought demise or end, -0.2 for SPI and 35% for SM are the threshold (Svoboda, *et al.,* 2002).

f. The onset of drought has higher predictability than the demise of drought, which is quick to occur but difficult to predict, since heavy rainfall can alter it.

g. The beginning of rainy season marks the likely season for the start or end of drought, that is, as a preferred season for the onset or demise of drought.

h. Drought is related to persistent Sea Surface Temperature (SST) anomalies (SSTAs).

i. It is observed that drought in the Study area, is significantly impacted by El Nino Southern Oscillation (ENSO), though it is not known whether ENSO triggers or end drought.

j. The occurrence of drought over the study area is not of regular intervals.

k. Within a period of 2 to 3 months, the demise of drought can occur, with few strong raining episodes.

B) A Vantage from Space can Detect Earlier Drought Onset: An Approach Using Relative Humidity.

Aliereza *et al.* (2015), proposed an alternative or complementary drought onset detection indicator (Standardized Relative Humidity Index, SRHI) and compared it to the well-known Standard Precipitation Index (SPI), which is a precipitation deficit evaluator, Standardized Soil Moisture Index (SSI) and soil moisture percentiles. The standard relative humidity data was obtained from the NASA Atmospheric Infrared Sounder (AIRS) satellite mission (Aliereza *et al.*, 2015). Precipitation data is a ground-based observation data, while near surface air relative humidity is a satellite-based data.

Research Main Findings

a. Due to limitations (uneven distribution, temporal inconsistencies, spatial inhomogeneous records) that are possible in ground-based observation data, it is important to monitor drought in other locations using satellite data.

b. Drought onset can be detected earlier than precipitation and soil moisture-based indices.

c. AIRS's (version 6, level 3 data) monthly surface relative humidity (at a 1^{o} spatial resolution) was employed for the detection of drought onset.

d. As a supplementary measure, the SPI and SSI data from Global Integrated Drought Monitoring and Protection System (GIDMaPS) are used.

e. The threshold used for the drought onset is the ***D_0*-Drought** (abnormally dry) condition, drought with 30% occurrence probability.

f. To examine early detection of drought, three (3) time series of SPI, SSI and SRHI drought events of 2010 Russian drought, 2010 – 2011 Texas-Mexico drought and 2012 United Stated droughts were investigated.

g. From the time series, the SRHI detected drought earliest, followed by SPI and then SSI.

h. Though SRHI was shown to be capable of detecting drought earlier than SPI, some cases still exist are otherwise.

i. In most parts of the world incorporating SRHI to other indicators can enhance onset drought detection.

j. Despite its efficiency, the propounded SRHI is not intended to substitute the indicators currently available, but used concurrently with other drought indicators.

C) Detecting Drought conditions in Illinois.

In this quantitative evaluation of the drought conditions in Illinois carried out by Changnon (1987), it was intended to answer drought questions such as whether drought is developing, the severity of drought per time and the duration of drought, in order to assist key water stakeholders.

Drought and its various types were defined long with their contributing/causative factors.

The study and/or report covers the four major aspect of hydrologic cycle, which are precipitation conditions, soil moisture conditions, shallow ground water levels and streamflow's; monitoring these conditions made room for the identification and assessment of drought presence (or detection of drought onset), drought-severity quantification and drought termination estimation measures. Also, Changnon (1987), reported that the following are common natural factors or indicators to determine the presence of drought; weather conditions, soil moisture, water table conditions, water quality, and streamflow. In this study, 50-well-distributed weather stations was used, and average precipitation pattern for a given period (3-months or longer) was determined.

Research Main Findings

a. Precipitation is the basis for start and end of drought.

b. Drought conditions varies from region to region in Illinois, with their unique pattern, are relevant for explaining the occurrence and intensity of drought.

c. Precipitation-based scale criteria, for monitoring the occurrence of drought, were drawn for periods spanning from 3 to 60 months. With the developed criteria, the presence or onset of drought can be determined.

d. Guidelines or procedures for examining the severity of drought was developed for periods from 3 to 24-months duration and two categories of severity were established (moderate and severe)

e. Relationship between precipitation deficiency and resultant drought impacts, was developed into a chart.

f. For crop drought severity, there is no stand-alone indicator that exist, therefore various soil moisture values were approved or proposed to be used for its assessment.

g. Drought starts and ends on the basis of precipitation.

h. Procedures for the detection of drought onset or initiation and termination were listed.

i. Less than 3-months dry periods does not signifies drought, except in some abnormal conditions of severe hot and dry weather in June, July and/or August, which may affect crop yields.

j. The criteria that precipitation drought are as follows;

i. A 3-month precipitation drought exists if the state average is ≤ 60% of the mean value.

ii. A 6-month precipitation drought exists if the state average is ≤ 70% of the mean value.

iii. A 12-month precipitation drought exists if the state average is ≤ 80% of the mean value.

iv. A 24-month drought exists if the state average is ≤ 90% of the mean value.

v. A 30-month to 60-month drought exists if the state average is ≤ 95% of the mean value.

vi. The detection of the initiation of drought, requires two activities;

vii. A routine, month-to-month continuous monitoring of precipitation conditions in Illinois at up to 40 locations, and

viii. A continuing operation of the models provided in this report for estimating soil moisture, shallow ground water levels and low flow values.

D) Drought Onset and Termination in India by Deep Shah and Vimal Mishra.

In this study, Shah and Mishra (2020) opined that the multi-faceted negative impacts of drought (socioeconomic, agricultural, environmental and financial) are also felt in India. Several researchers have concluded that the definition of drought is influence or dependent on lots of factors such as rainfall, soil moisture, streamflow, groundwater and vegetation and as such there is no universally accepted or acclaimed definition that fits all, due to drought complexity and multiple hydro-climatic variables (Wilhite, 2005; Wilhite and Glantz, 1985; Van Loon, 2015; Lloyd-Hughes, 2014)

Main Research Finding

a. Integrated Drought Index (IDI), that incorporates precipitation, runoff, soil moisture, and groundwater, was used for drought assessment in India.

b. IDI provides better drought monitoring (in the study area) and management information based on several hydrological variables.

c. Meteorological drought is the main lens through which all other forms of droughts are viewed.

d. 0.25^o daily gridded precipitation (6995 rain gauge stations), minimum and maximum temperatures (1951 – 2016) from India Meteorological Department, IMD (2015)

e. The whole of India was divided into eight clusters, based on similarity of drought event.

f. Drought onset and termination in India was detected based on IDI, using 1951 – 2016 data set.

g. Drought onset was defined the first month in which basin average IDI of a cluster is negative and remains negative for 3-months consecutively.

h. The drought termination was defined as the first month averaged IDI of a cluster is positive and is sustained for three consecutive months.

i. The number of months between drought onset and termination was defined as the drought duration.

j. Drought event was ranked based on overall severity score, which is the production of duration, mean intensity and peak fraction area, according to Shah and Mishra (2020a) description.

k. Relative contribution for the top three drought spells for each cluster was estimated using average of 12-months SPI, I-month SSI, 4-month SRI, to estimate overall severity scores.

l. Empirical Orthogonal Function (EOF) and Maximum Covariance Analysis (MCA) was performed and used to determine the linkage between long-term climate variability and i-month IDI for the 1951 – 2016 period.

m. Estimation of monthly SST departure field was done after removing the monthly mean of global SST from each grid for the 1951 – 2016 period (Mishra *et al.*, 2012)

n. VIC-SIMGM performs satisfactorily captured monthly streamflow temporal variations, groundwater storage variability, variations of groundwater table anomalies with 0.6 as correlation coefficient (r) in the majority river basin.

o. Drought onset and termination was found to occur during the monsoon months (June, July, August and September) in most of the drought clusters.

p. Drought onset and termination in parts of India, is highly affected by precipitation seasonal cycle, while SST anomalies and Atlantic Ocean affects other parts.

q. The two worst droughts occurrence in India (1987 and 2002) were primarily driven by precipitation (Meteorological drought)

r. The Arabian Sea, Bay of Bengal and the India Ocean are the major sources of moisture in most of the clusters.

2.13 Research Gap

Since most of the reviewed journals on drought onset and cessation/termination are done outside the African continent, there is need to check the same research possibility in Subsaharan Africa and as such three states in northern Nigeria are chosen for this study, employing a temperature-based index.

2.14 Drought Monitoring

Africa experience more or frequent drought compared to many other continents of the world (Nhamo *et al*., 2019) and the situation, instead of declining, it is increasing. There is no human control for the amount of precipitation, however monitoring drought and drought early warning, when effectively done and sustained, has capacity to reduce drought vulnerability along with its impact rate.

Drought monitoring is a vital part or component of drought early warning system (Nhamo *et al*., 2019; Yohannes, 2019), in which drought early sign detection is tied to. Drought mitigative plan is subject to effective drought incidents information in temporal and spatial scale, which are obtained from drought monitoring (Pangalou *et al.,* 2009). Nhamo *et al.,* (2019) presented a framework which shows the components of drought early warning system (Figure 2.1).

Figure 2.1: The position of monitoring in drought early warning system (Source: Nhamo *et al*., 2019).

In drought monitoring processes, current knowledge of weather events is contrasted with archives (Yohannes *et al*., 2019). Some of the common indicators/parameters incorporated in drought monitoring are precipitation, rivers and streams, snowpack, water storage, ecological health of the area, soil moisture, evaporation, crop production and so on. Every completed monitoring process, contributes to records current conditions, more knowledge of regional climatic conditions is obtained and aid other vital phase/decisions (Yohannes *et al*., 2019). The United States Drought Monitor is one of the most renown effort at monitoring drought worldwide, established to track and showcase drought magnitude and spatial extent across the United States, achieved by the cooperation of National Drought Mitigation Center (NDMC), US Department of Agriculture (USDA), Joint Agriculture Weather Facility (JAWF), and National Oceanic and Atmospheric Administrations Climate Prediction Center (NOAA/CPC). The cooperation and collaboration of these bodies lead to the development of drought monitoring maps (figure below) and website, providing current weather and drought conditions (NDMC, 2016)

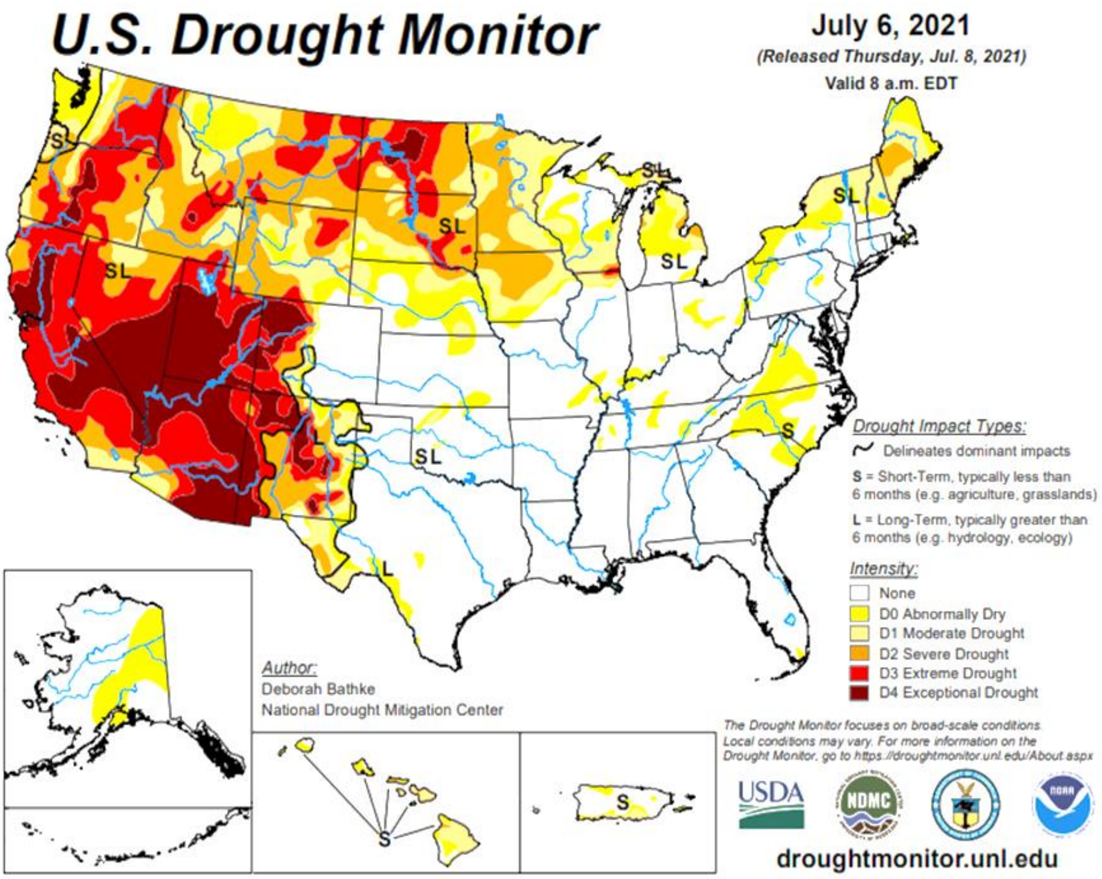

Figure 2.2: US Drought Monitor Map for July 6, 2021 (Source: droughtmonitor.unl.edu)

Due to the sluggish onset feature of drought, monitoring and early warming constitute a crucial component of any detailed drought management plan (Wilhite *et al*., 2000).

The percentile approach is employed in defining the thresholds for drought severity level (Wilhite, 2000a).

Table 2.5: The categories of drought magnitude used in the Drought Monitor (Wilhite, 2002)

Category	Drought condition	Percentile chance (of occurrence)
D0	Abnormally dry	20 to ≤ 30
D1	Drought – moderate	10 to ≤ 20
D2	Drought – severe	5 to ≤ 10
D3	Drought – extreme	2 to ≤ 5
D4	Drought – exceptional	≤ 2

Andries (2017), in a drought study presented a rearrangement (Figure 2.3) of the drought categories developed by Wilhite (2000)

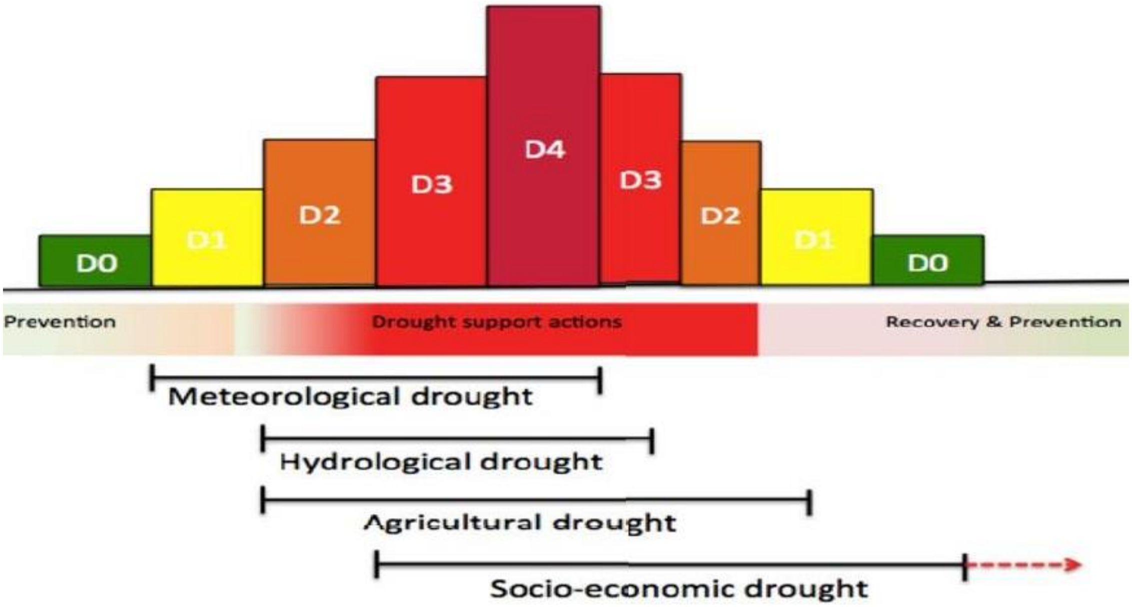

Figure 2.3: Drought types and stages (Source: Andries, 2017)

CHAPTER THREE

3.0 MATERIALS AND METHODS

Studies on drought requires the collection and examination of relevant historical records or data concerning the study area, to establish predefined objectives. This chapter contains information's about the relevant data applied to the analysis methods.

3.1 Brief Description of Study Area

The northern region of Nigeria is found within the main ecological zones, which are Guinea, Savannah (6-9°N), the middle Sudan Savannah (9-11.5°N) and the Sahel Savannah (north of 11.5°N) between latitude 6°27'N and 14'N and longitude 2°44'E and 14°42'E (Oladipo, 1995). The states includes Adamawa, Borno, Bauchi, Gombe, Jigawa, Kdauna, Kano, Katsina, Kebbi, Sokoto, Yobe and Zamfara, covering about 38% of the total land area of Nigeria and it is the grain belt of the country, populated by small scale subsistence farmers and nomadic livestock herders (Loukas, 2004). The occurrence of rainfall in this region varies from year to year.

This variable, annual rainfall poses challenges to viable agricultural activities (particularly, vegetative growth) change in climatic condition is one of the cause for this variable rainfall being experienced in this region (Oladipo, 1995). A study carried out by Adefolalu, (1986), Ojo and Oyebande, (1987), revealed that the northern region is a tropical climate area, dominated by maritime air mass (wet season), with rainfall occurring between April to October, with the month of August being the peak of the rainy season, while the dry, dusty air mass (dry season) occurs between October to March; indicating that this region has basically two seasons (dry and wet).

The northern region is within or part of the Sudano-Sahelian Ecological zone, which had been known to suffer drought and famine between 1970 and 1980, with 200, 000 people and millions of animals left dead (Olusegun, 2011) Ever since, it has being known that this region is vulnerable to drought. The northern region of Nigeria is prone to drought, desertification and famine. In fact, it is estimated that the country is currenty losing about 351, 000 hectares of its landmass to desert conditions annually and such conditions are estimated to be advancing southwards at the rate of about 0.6 km per year (FRN, 1999)

The northern states under consideration for this study are Sokoto, Kaduna and Maiduguri.

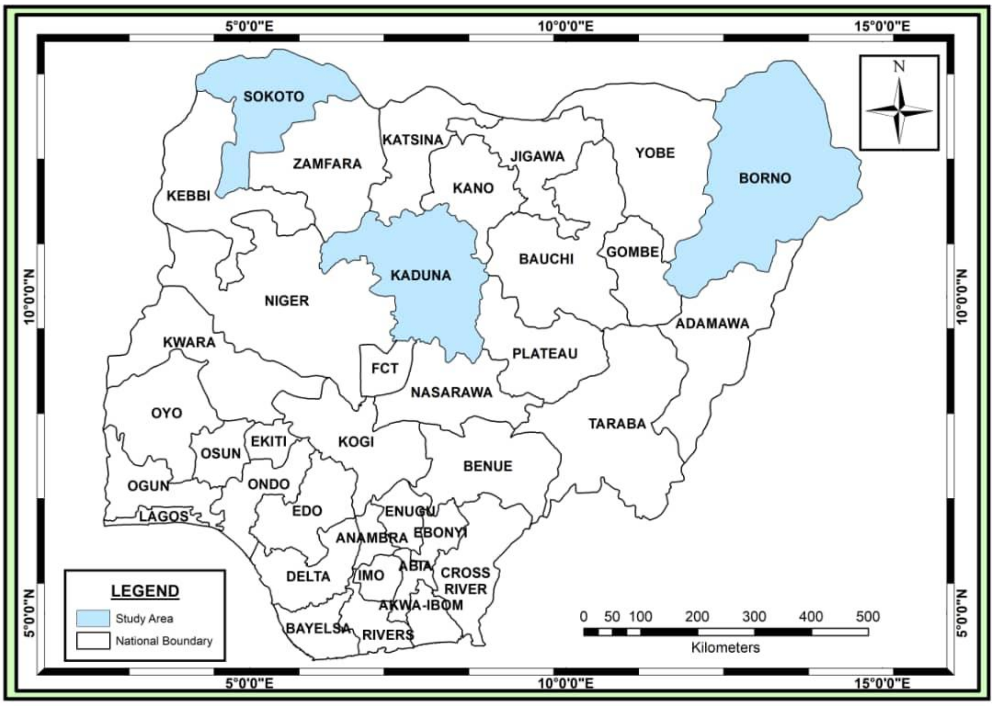

Figure 3.1: Study area map. (Source: GIS Achievers (2021). Nigeria administrative boundary. https://www.schoolandcollegelistings.com/NG/Abuja/109213373746751/GIS-Achievers#

Table 3.1: Location of meteorological stations under consideration

Station	Elevation (m)	Latitude	Longitude
Sokoto	327	13º05’ N	05º15’ E
Kaduna	250	10º31’23”	7º26’25” E
Maiduguri	320	11º50’ N	13º09’ E

(Source: Google scholars, 2021)

3.2 Data Types and Sources

This study involves the use of secondary data. The secondary data are monthly precipitation (rainfall) from the Nigeria Meteorological Agency (NiMet) for the period 2006-2020 and potential evapotranspiration (PET) fom Climatic Research Unit (CRU) dataset.

3.3 Method of Data Analysis

Preliminary analysis was done using Microsoft Package (2019), for the arrangement and computation involving the precipitation (P) and potential evapotranspiration (PET) along with other necessary computations (like parameter estimation, mean, plots and others). The drought index adopted for this study is the Standardized Precipitation Evapotranspiration Index, SPEI.

3.3.1 Standardized Precipitation-Evapotranspiration Index (SPEI)

Most precipitation-based indices compare precipitation and evapotranspiration by ratio of both, which tampers with the effect of potential evapotranspiration, PET, through increased responsiveness to small values and dampening of variability for large values.

Vicente-Serrano *et al.*, (2010), proposed an index called Standardized Precipitation-Evapotranspiration Index (SPEI). The SPEI tends to capture the best features of SPI, RDI and PDSI. It is a simple index that utilizes temperature and precipitation in its computation, that is, it incorporates both rainfall, potential evapotranspiration along with temperature fluctuations and imbibe the multi temporal behavior of SPI (Narenda *et al.*, 2019) making it most useful for climatic change studies, because drought is a multiscalar in nature. According to European Drought Observatory (EDO, 2020) because SPEI incorporates temperature component, it's suited for evaluating the influence of global warming on drought events.

The computation of SPEI incorporation of the difference between precipitation and evapotranspiration, known as "climatic water balance, functioning as an improvement of SPI by assessing the effect of global warming (effect of temperature) on the occurrence of drought (Cheikh *et al.*, 2019).

The choice for SPEI for this study is based on its advantage of capturing the regional temperature or effect of global warming as it influences drought occurrence along with the regular of commonly used precipitation.

The climatic water balance was calculated thus:

$$D_i = P_i - PET_i \quad (3.1)$$

Where D_i – Monthly water surplus or deficit

P_i – Monthly precipitation

PET_i – Monthly potential evapotranspiration

The log-logistic probability density function of a variable D is given by:

$$F(D) = [1 + (\frac{\alpha}{D-\gamma})^{\beta}]^{-1} \quad (3.2)$$

Where α, β and γ are the scale, shape and location parameters, calculated from the sample D, in the range ($\gamma > D < \infty$). These parameters are obtained the formulars proposed by Vicente-Serrano *et al*., (2010);

$$\beta = \frac{2W_1 - 2W_2}{6W_1 - W_0 - 6W_2} \qquad (3.3)$$

$$\alpha = \frac{(W_0 - 2W_1)\beta}{6W_1 - W_0 - 6W_2} \qquad (3.4)$$

$$\gamma = W_0 - \alpha \Gamma(1 + \frac{1}{\beta})\Gamma(1 - \frac{1}{\beta}) \qquad (3.5)$$

where $\Gamma(1 + \frac{1}{\beta})$ is related to the gamma function of $(1 + \frac{1}{\beta})$, the Probability Weighted Moment (PWM) is given as:

$$w_s = \frac{1}{N}(\sum_{i=1}^{N}(1 - F_i)^s D_i \qquad (3.6)$$

w_s is the PWM of order s, N is the number of data points, F_i is a frequency estimator and D_i is the difference between Precipitation and Reference Evapotranspiration for month *i*.

The value of SPEI can be determined as a standardized value of F(D) and mathematically expressed, according to Vicente-Serrano *et al*., (2010), as

$$SPEI = W - \frac{(C_0 + C_1W + C_2W^2)}{1 + d_1W + d_2W^2 + d_3W^3} \qquad (3.7)$$

Where $W = \sqrt{-2lnP}$ for $P \leq 0.5$ and P is the probability of exceeding a determined D value, P = 1 -F(D), if P > 0.5, then P is replaced by I – P and the sign of the obtained SPEI is reversed. The constants are $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$ (Narenda *et al.*, 2019). When the SPEI values are positive it signifies above-average moisture conditions, whereas a negative value signifies a drought condition (table 3.1).

Table 3.2: SPEI classifications of categories

SPEI values	Category (Drought condition)
2.00 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.00 to 0.99	Mild wet
-0.99 to 0.00	Mild drought
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.00 or less	Extreme drought

3.3.2 Potential evapotranspiration (PET)

Drought severity is highly influence by global warming, which causes increased temperature and subsequent rise in evapotranspiration (Vicente-Serrano *et al.,* 2010). Potential evapotranspiration (PET) is incorporated in the calculation of SPEI. For the purpose of the study, the PET values adopted were obtained from Climatic Research Unit (CRU) TS3.10.01 dataset (Begueria *et al.,*2013). The Climatic Research Unit (CRU) is vastly known world's institution that deals with the study of natural and climate change and provides widely usedly used climate dataset (global temperature) for climate system monitoring (https:www.uea.ac.uk/grous-and-centres/climatic-research-unit).

3.4 Adoption of SPEI

Ognjen (1993) stated that the choice of any technique for the estimation and study of drought needs to be practical and reasonable, capturing physical and easily understandable conditions. Research work by Vicente-Serrano *et al.,* (2010) was based on the fact that rise in temperature due to global warming greatly inluences drought conditions. For example, the drought severity that racked central Europe in 2003 was due to the strong role played by temperature, which resulted in evapotranspiration and drought stress (Rebetez *et al.,* 2006). Since global warming is on the increase and higher temperature means higher drought stress (Adams *et al.*, 2009), it is more suitable to adopt drought indices that incorporates temperature data (evapotranspiration) for drought estimation (https://spei.csic.es/home.html).

Standardized Precipitation Evapotranspiration Index (based on precipitation and potential evapotranspiration, PET), was adopted for this study over other temperature based drought indices because it combines the strength/robustness of PDSI and SPI, that is its multi-scalar nature (different timescales of interest) and simplicity of estimation (Dutra *et al.,* 2013). The SPEI at short timescale or period of accumulation is for the detection of meteorological and agricultural drought, while longer perion of accumulation is for water supply and resources management (Dongwoo, 2017). According to EDO, (2020), SPEI is particularly befitting for drought monitoring under global warming conditions.

3.5 How to Detect Drought Onset in the Study Area

With the above basic meaning of drought onset, for a given location/area, the drought onset is when the SPEI is **-0.99** for the season (Vicente-Serrano *et al.*, 2010) or the SPEI is at a **D_0 threshold (abnormally dry condition)** (Aliereza *et al.,* 2015, Kingtse, 2011).

A. How to Evaluate Drought Onset

For the study area,

1. Obtain and prepare the precipitation data (monthly mean, mean according to chosen timescale, etc.)
2. Compute the SPEI the timescale (3-month) Values below -2 or less are extremely dry, while +2 and above, is an extremely wet state.
3. Classify the drought event for the area.
4. Check the value in the established threshold by Svoboda *et al*., (2002).
5. Identify the drought onset from drought categorization.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

All data collected for this study along with all derivative analysis are presented here in order to achieve the objective of the study.

The 3-month time-scale or accumulation SPEI was computed for the period 2006 – 2020 (SPEI-3) for the stations (Sokoto, Kaduna and Maiduguri), which are parts of northern Nigeria. The monthly and yearly SPEI-3 values were obtained to characterize the drought events, particularly the early sign of drought (onset).

4.1 Rainfall Pattern/Distribution in the Study Area

Precipitation, in one form or the other, is a major precursor for drought (Wilhite, 2005; Nhamo *et al.,* 2019; Qianfeng, 2015; Yohannes *et al*., 2019), directly or indirectly, it becomes necessary to assess the pattern of rainfall in the study area, utilizing the rainfall (precipitation) data obtained from NiMet for 2006 – 2020 period. The rainy season in northern Nigeria is known for its spatial distribution or variability (Shiru *et al*., 2018).

The yearly rainfall distribution in each station is here presented in tables The highest total rainfall that occurred in Sokoto, Kaduna and Maiduguri were recorded in the year 2011, 2016 and 2018 respectively while these same years had the highest seasonal total rainfall values, which gives idea of the rainfall distribution in northern Nigeria (Table 4.1). In Sokoto, the largest or highest rainfall amount occurred in 2011 (1146.7mm), then in 2016 (1017.2mm), in Kaduna, the largest rainfall amount was recorded in 2016 (1780.8mm), followed by 2014 (1658.9mm) and then in Maiduguri, the largest rainfall amount occurred in 2020 (1439mm) and 2018 (1004.3mm).

Table 4.1: Summaries of yearly and seasonal rainfall data per station in the study period

	Yearly total rainfall per station			seasonal (april-october) total rainfall per station		
Year	**Sokoto**	**Kaduna**	**Maiduguri**	**Sokoto**	**Kaduna**	**Maiduguri**
2006	634.6	898.7	519.5	634.6	898.7	519.5
2007	716.9	873.2	1073.9	716.9	873.2	1073.9
2008	643.4	793.4	576.9	636.4	793.4	573.0
2009	514.6	1226.9	582.6	514.6	1226.9	582.6
2010	568.1	1262.5	687.5	568.1	1262.5	687.5
2011	**1146.7**	1151.8	543.3	**1146.7**	1150.5	543.3
2012	569.9	1448.2	868.8	569.9	1448.2	868.8
2013	613.4	1655.2	624.1	613.4	1607.2	624.1
2014	699.2	1658.9	543.5	699.2	1655.3	543.5
2015	824.2	1490.7	610.2	699.9	1458.0	610.2
2016	1017.2	**1780.8**	815.9	977.9	**1685.7**	815.9
2017	658.4	1653.8	749.4	656.9	1653.8	749.4
2018	683.8	795.8	1004.3	683.8	795.8	1004.3
2019	772.5	762.2	989.3	772.5	762.2	989.3
2020	859.6	993.1	**1439.0**	859.6	993.1	**1439.0**

The lowest recorded rainfall for Sokoto, Kaduna and Maiduguri occurred in the year 2009, 2019 and 2006 respectively. In Sokoto, the rainfall mostly started in April (33.3%) or May (40%); in Kaduna, the rainfall started in mostly in April (46.7%) or earlier months (33.3%); in Maiduguri, April (33.3%) or May (60%) of each year.

The spatio-temporal rainfall pattern in each of the stations revealed a positive trend, which signifies increment in the amount of rainfall with respect to time, which is in agreement with previous studies (Adakayi *et al.,* 2016*)*. Maiduguri had the most positive slope trend, followed by Sokoto and then Kaduna. Figures 4.1 to 4.3 gives the representation of monthly and yearly rainfall for the study area along with the trend lines and equations. A close look of the monthly rainfall in each of the stations, revealed that the maximum rainfall usually occurs in the month of August, followed by July and September (Table 4.2 to 4.4).

The pattern of rainfall in the stations demonstrated homogeneity of distribution, though varied in actual rainfall amount.

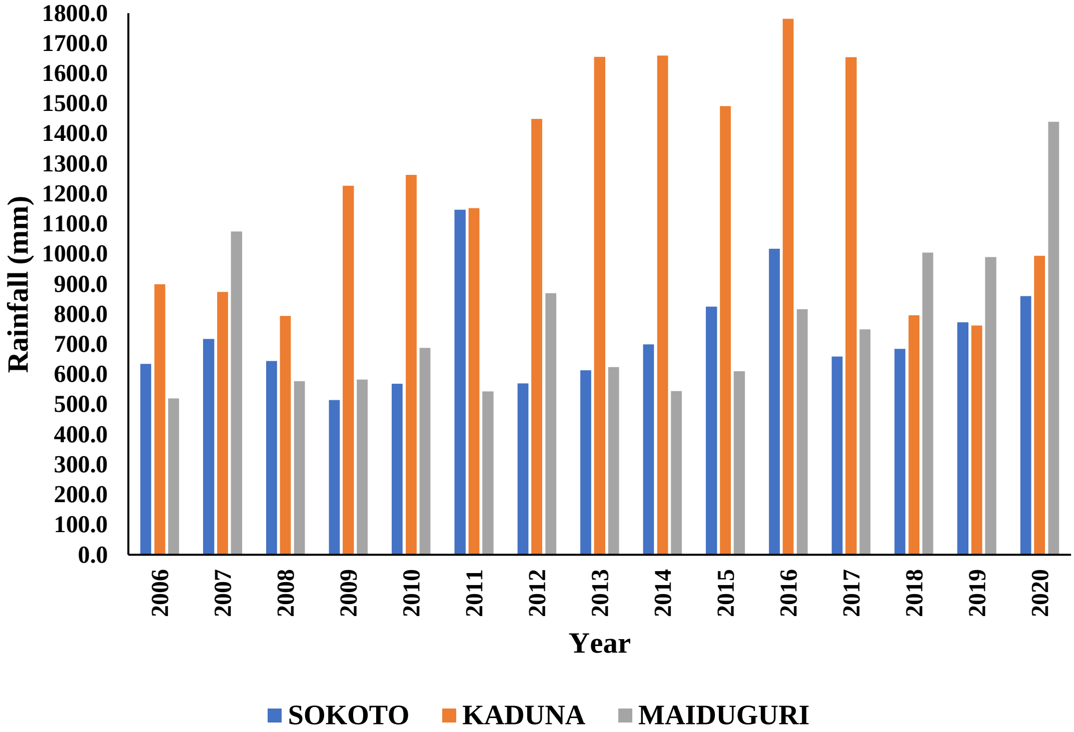

Figure 4.1: Comparison of yearly rainfall total for the three stations

Table 4.2: Monthly precipitation (rainfall) data for Sokoto in mm per year

Month	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0	0	0	0	0	0	0	0	0	4.3	4.1	0	0	0	0
Feb	0	0	0	0	0	0	0	0	0	0	8.9	0	0	0	0
Mar	0	0	7	0	0	0	0	0	0	0	26.3	1.5	0	0	0
Apr	0	0	6.8	0.7	0	0.4	0	0	67.4	11.8	60.3	19.3	22.6	0	2.2
May	104.5	19.2	45.6	41.3	24.8	128.7	92.9	54.5	16.2	72.1	182.8	30.6	3.2	88.4	65.3
Jun	82.5	40.6	65.9	94.7	64.1	126.1	161.2	83.2	61.6	98.3	51	33.4	118.4	54.6	112.4
Jul	146.7	135.5	183.4	152.2	114.6	322.8	29.3	178.2	167.8	193.3	193.3	152.7	152.9	195	174
Aug	171.1	304.5	235.6	130.2	146.7	357.6	174.2	140.7	322.7	129.4	322.7	286.1	191.6	249.4	238.9
Sep	124.3	187.3	99.1	93.9	98	88.2	93.2	92.4	41.8	167.8	167.8	134.8	156.3	101.8	226.14
Oct	5.5	29.8	0	1.6	119.9	122.9	19.1	64.4	21.7	27.2	0	0	38.8	83.3	40.7
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	120	0	0	0	0	0
Total	634.6	716.9	643.4	514.6	568.1	1146.7	569.9	613.4	699.2	824.2	1017.2	658.4	683.8	772.5	859.64

Table 4.3: Monthly precipitation (rainfall) data for Kaduna in mm per year

Month	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	1.3	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	48	3.6	32.7	95.1	0	0	0	0
Apr	10	60.4	8	26.4	29.8	57.1	61.6	74.3	90.8	0	20.1	13.2	0	0	0
May	99.2	99	157.9	65.7	62.5	137.4	212.8	117.6	183.3	89.3	239.8	351.3	109.6	35.1	15.5
Jun	107	182.5	102.3	158	202.8	80.9	140.3	287.1	230.1	112.6	216.5	294	189.2	67.5	132.1
Jul	170.9	222.9	90.2	186.5	190.1	233.4	225.6	344.9	183.5	263.1	324.2	386.9	137.6	309.3	321.5
Aug	223.5	214.5	223.6	462.8	327.8	208	269.4	317.7	546.8	544	498.1	316	219.4	304.7	305.2
Sep	199.6	60	183.7	133.7	300.8	298.7	403.4	428.2	354.3	359.4	351.8	273.6	127.9	20.9	171.2
Oct	88.5	33.9	27.7	193.8	148.7	135	135.1	37.4	66.5	89.6	35.2	18.8	12.1	24.7	47.6
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	898.7	873.2	793.4	1226.9	1262.5	1151.8	1448.2	1655.2	1658.9	1490.7	1780.8	1653.8	795.8	762.2	993.1

Table 4.4: Monthly precipitation (rainfall) data for Maiduguri in mm per year

Month	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	0	0	0.0	7.6	4.8	7.6	0	0	0	0	2.4	0	1.7	0	0
May	38.7	32	27.4	30.8	1.6	34.3	33.8	36.1	0	14.2	94.4	52.4	18.8	71.7	38.4
Jun	78.9	371.6	78.7	3.3	133.6	42.4	76.9	107.7	0.9	61.4	69.6	173.1	118.6	49.5	142.1
Jul	180.8	252.3	155.6	63.3	257.7	92	328	139.8	166.7	257.7	233.1	227.8	264.1	209.1	345.8
Aug	156.9	185	255.6	185	118.1	218.6	228.6	274.2	311.4	118.1	318.9	236.9	346.2	415.3	448.2
Sep	64.2	233	55.7	210.9	136.4	115.8	198.1	33.7	63.3	136.4	97.5	59.2	183.1	113.7	461.5
Oct	0	0	0.0	81.7	35.3	32.6	3.4	32.6	1.2	22.4	0	0	71.8	130	3
Nov	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Dec	0	0	3.9	0	0	0	0	0	0	0	0	0	0	0	0
Total	519.5	1073.9	576.9	582.6	687.5	543.3	868.8	624.1	543.5	610.2	815.9	749.4	1004.3	989.3	1439

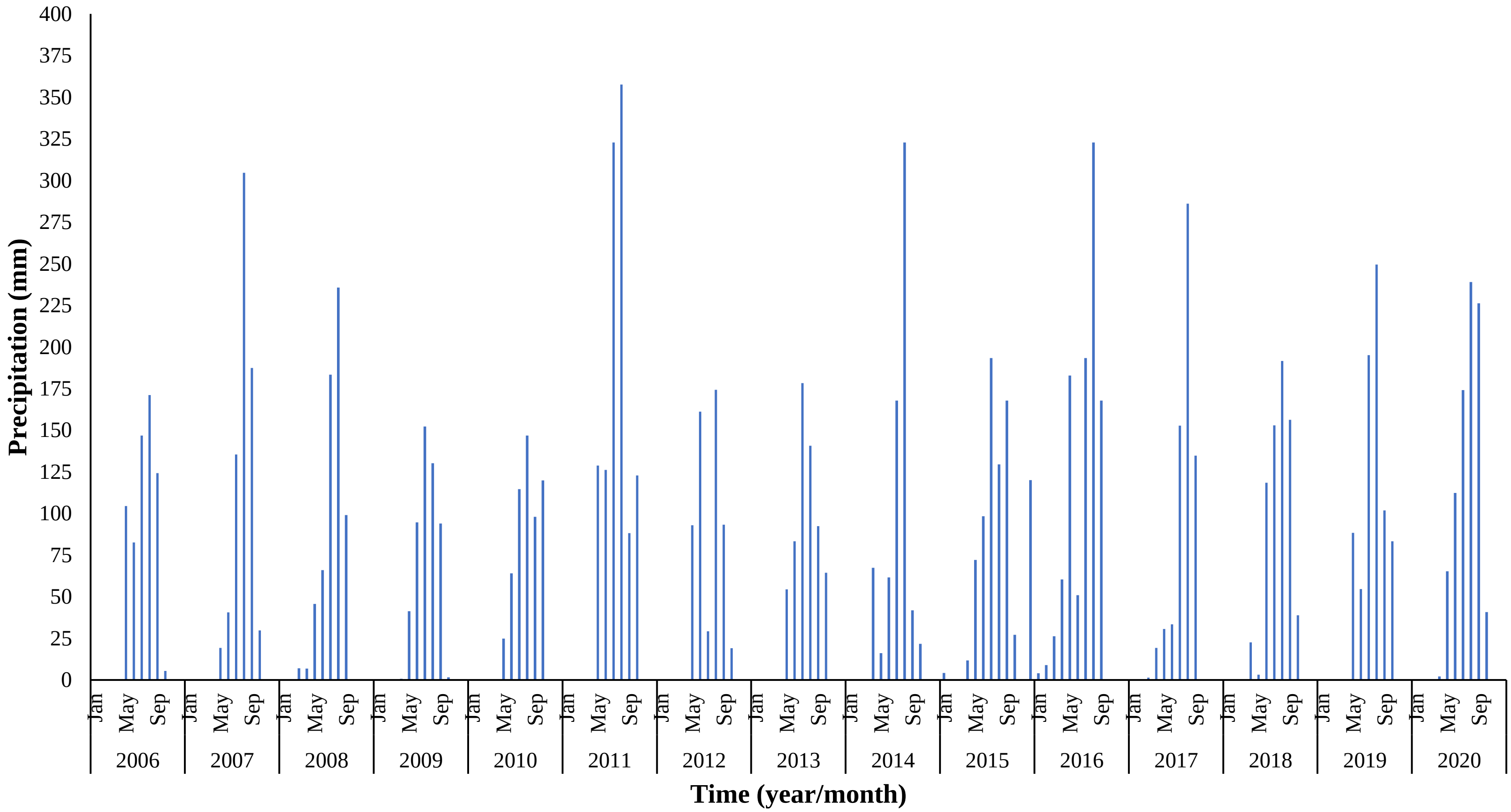

Figure 4.2: Precipitation distribution in Sokoto for the period 2006 – 2020

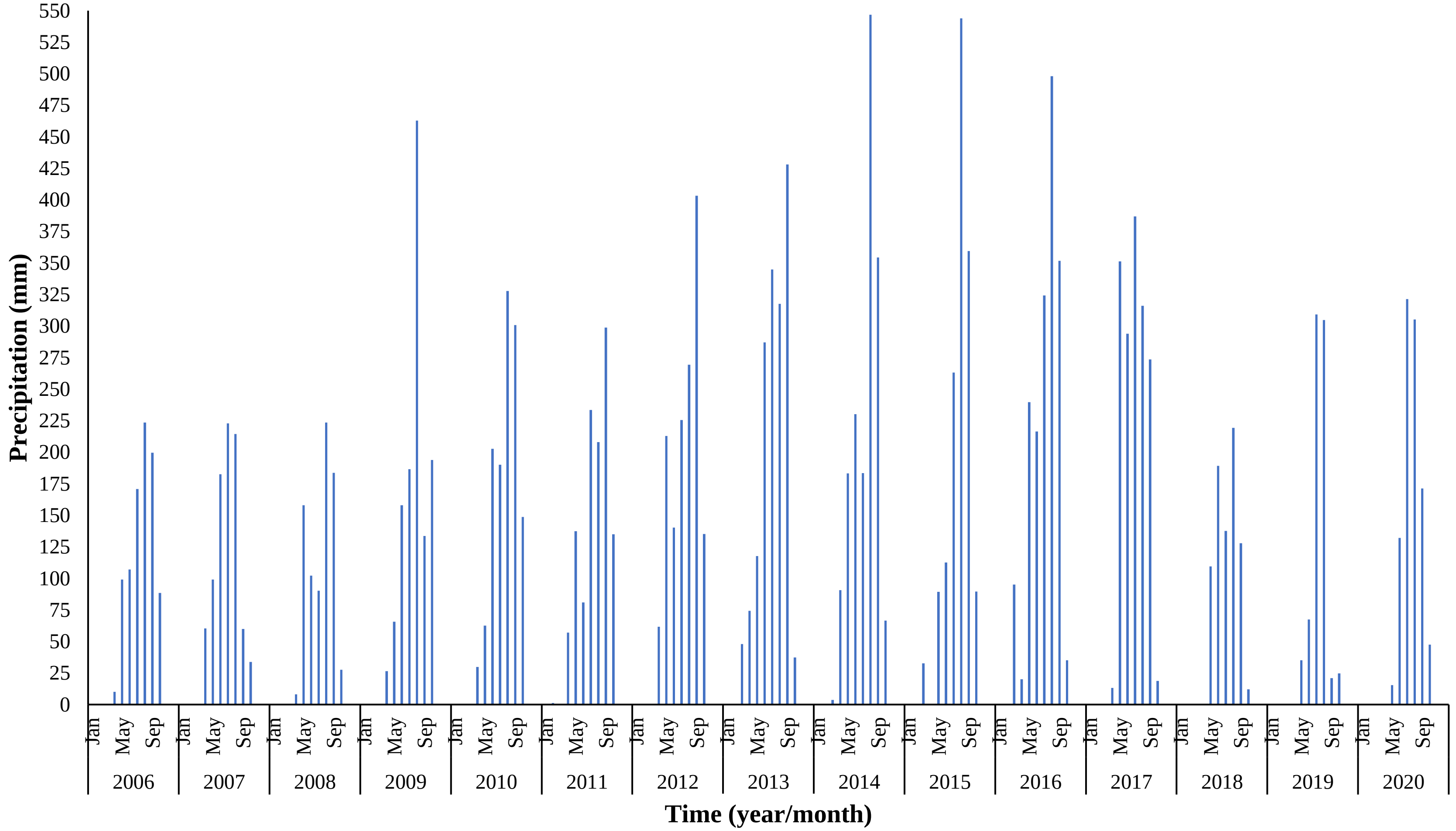

Figure 4.3: Precipitation distribution in Kaduna for the period 2006 – 2020

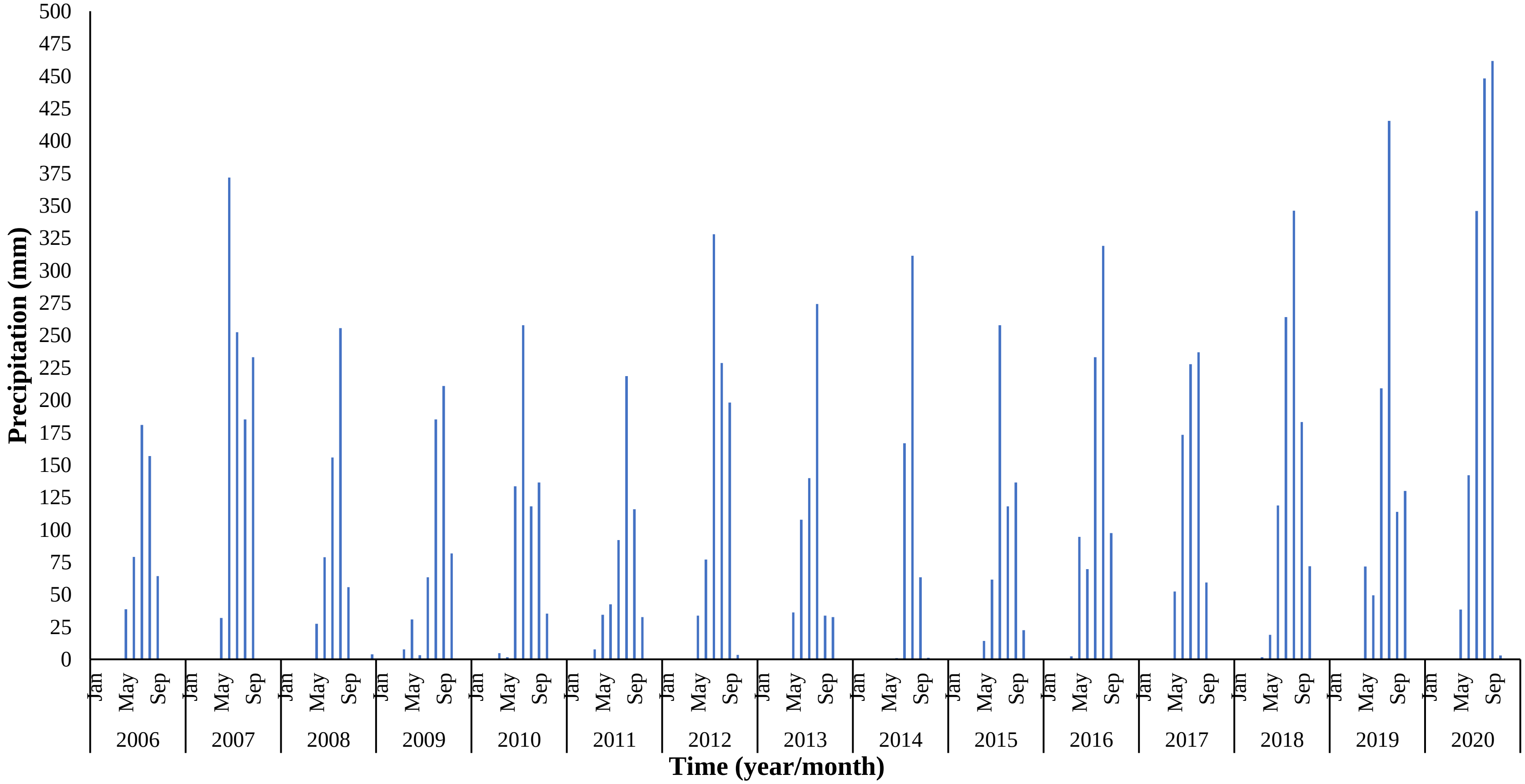

Figure 4.4: Precipitation distribution in Maiduguri for the period 2006 – 2020

4.2 Drought Determination by SPEI-3

The rainfall (P) and potential evapotranspiration (PET) data was used for the establishment of drought event in the study area, using SPEI on a 3-month time scale over the 2006 – 2020 period (which is for short-term and seasonal drought). The SPEI-3 reveals the condition of moisture in the soil or soil moisture, that is the agricultural drought.

The values obtained from the computation of the SPEI-3 and the corresponding drought categories for each of the station are presented in Table 4.5 – 4.12.

Table 4.5 is the adopted but modified drought categorization used for the classification of drought events in the study area.

Table 4.5: Drought category

Extreme Wet	**+ 2.0 and more**
Very Wet	1.5 to 1.99
Moderately Wet	1.0 to 1.49
Near Normal	0 to 0.99
Onset (Mild Drought)	0 to -0.99
Moderate Drought	-1.00 to -1.49
Severe Drought	-1.5 to -1.99
Extreme Drought	-2.0 and less

(Source: Vicente-Serrano *et al.*, 2010)

In each station, the most prevalent drought event obtained is the near normal condition (Table 4.6 – 4.12), followed by the early sign (onset), then moderate (or mild) drought and lastly the severe drought condition.

Table 4.6: SPEI-3 values for Sokoto

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			1.0485	0.8831	0.8686	0.8537	0.8280	0.8026	0.7814	0.7385	0.7196	0.7375	0.8262
2007	0.7959	0.8537	0.8726	0.8786	0.8656	0.8478	0.8222	0.7968	0.7814	0.7862	0.8065	0.8222	0.8275
2008	0.8359	0.7641	0.7833	0.7901	0.8696	0.8507	0.8231	0.7959	0.7112	0.7150	0.7356	0.8212	0.7913
2009	0.8418	0.8577	0.8716	0.8786	0.6206	0.5929	0.5682	0.7843	0.7843	0.7833	0.8007	0.7527	0.7614
2010	0.7699	0.7920	0.8666	0.8756	0.8627	0.2665	0.1577	-0.0184	0.0386	-0.0327	0.4255	0.5885	0.4660
2011	-0.0191	0.0984	-0.1394	0.0085	-0.0314	-0.2753	-0.5132	-0.6385	-0.1552	-0.0438	-0.6180	-0.6643	-0.2493
2012	-0.3821	-0.1081	-0.0716	-0.4518	-0.2403	-0.2526	-0.3249	-0.4412	-0.6792	-0.8900	-0.9375	-0.7350	-0.4595
2013	-0.4953	-0.3492	-0.2054	-0.3024	-0.3235	-0.6540	-0.7585	-1.0049	-1.1789	-1.1907	-1.1378	-1.4106	-0.7509
2014	-1.1667	-1.2960	-0.9308	-1.3091	-1.3399	-1.3150	-1.2399	-1.2492	-1.2950	-1.3296	-1.5111	-1.5984	-1.2984
2015	-1.5367	-1.2603	-1.4770	-1.5439	-1.5358	-1.4837	-1.4140	-1.6856	-1.6409	-1.7196	-1.6228	-1.5546	-1.5396
2016	-1.4466	-1.3348	-1.0256	-0.9431	-0.6650	-0.6327	-0.6410	-0.6323	-0.4564	-0.7350	-0.9560	-1.1791	-0.8873
2017	-1.1492	-0.9841	-1.1977	-0.8042	-0.5556	0.5205	0.5299	0.0856	-0.5252	-0.5915	-0.3533	-0.0243	-0.4208
2018	-0.0648	0.4141	0.6161	0.5222	-0.0944	-0.1107	0.0935	0.4321	0.7785	0.7756	0.7978	0.8143	0.4145
2019	0.8398	0.8547	0.8726	0.8786	0.8706	0.8527	0.8241	0.7930	0.7795	0.7766	0.7988	0.8153	0.8297
2020	0.8379	0.8547	0.8716	0.8817	0.8746	0.8557	-0.1142	0.0947	0.0820	0.7746	0.8007	0.8241	0.6365

Table 4.7: Drought categorization based on SPEI-3 values for Sokoto

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			Mod W	Mod W	NN	NN	MildD	MildD	Mod D	Mod D	MildD	NN	
2007	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2008	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	MildD	MildD	MildD	NN	NN
2009	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	MildD	MildD	MildD	NN	NN
2010	NN	NN	Mod W	Mod W	NN	MildD	MildD	Mod D	Mod D	Mod D	MildD	NN	NN
2011	NN	NN	NN	Mod W	NN	MildD	MildD	MildD	MildD	MildD	MildD	NN	NN
2012	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	MildD	MildD	MildD	NN	NN
2013	NN	NN	Mod W	NN	NN	NN	MildD	Mod D	Mod D	MildD	NN	NN	NN
2014	NN	NN	MildD	MildD	Mod D	SD	SD	ED	ED	ED	SD	SD	NN
2015	MildD	NN	NN	Mod W	NN	NN	MildD	MildD	MildD	MildD	MildD	NN	MildD
2016	NN	NN	Mod W	Mod W	NN	NN	MildD	Mod D	Mod D	MildD	MildD	NN	NN
2017	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2018	NN	NN	Mod W	Mod W	NN	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2019	NN	NN	Mod W	Mod W	NN	NN	MildD	Mod D	Mod D	MildD	MildD	MildD	NN
2020	NN	NN	Mod W	Mod W	NN	NN	MildD	Mod D	Mod D	Mod D	MildD	NN	NN

NN-Near Normal, MildD-Mild Drought, Mod D-Moderate Drought, SD-Severe Drought, ED-Extreme Drought, Mod W-Moderare Wet.

Table 4.8: Identification of Drought Onset in Sokoto

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006			ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2007	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2008	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2009	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2010	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2011	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2012	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2013	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2014	ND	ND	ONSET	drought	drought	drought	**drought**	drought	drought	drought	drought	**Drought**
2015	drought	RECOV	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2016	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2017	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2018	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2019	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**Drought**
2020	RECOV	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**

ND-No Drought, RECOV-Recovery.

Table 4.9: SPEI-3 values for Kaduna

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			0.94	1.22	1.21	0.95	-0.13	-0.94	-1.16	-0.77	-0.01	0.09	0.14
2007	0.00	0.18	0.57	1.19	0.88	0.39	-0.38	-1.05	-1.12	-0.73	0.04	0.31	0.02
2008	0.09	0.11	0.49	1.03	1.17	0.76	-0.16	-0.84	-0.98	-0.56	-0.04	0.23	0.11
2009	0.28	0.40	0.73	1.22	1.22	0.98	-0.13	-0.69	-1.00	-0.60	-0.13	0.12	0.20
2010	0.26	0.51	0.83	1.27	1.24	0.44	-0.23	-0.97	-1.13	-0.89	-0.20	0.20	0.11
2011	0.21	0.31	0.71	1.21	1.09	0.42	-0.16	-0.90	-0.94	-0.71	-0.10	0.13	0.11
2012	0.16	0.28	0.63	1.17	1.07	0.16	-0.48	-1.36	-1.45	-1.22	-0.24	0.24	-0.09
2013	0.18	0.28	0.73	1.19	1.39	0.74	0.07	-1.08	-1.31	-1.14	-0.21	0.20	0.09
2014	0.24	0.29	0.67	1.15	1.17	0.43	-0.33	-1.18	-1.36	-1.11	-0.25	0.20	-0.01
2015	0.16	0.24	0.51	0.94	1.17	1.00	-0.11	-1.11	-1.29	-1.02	0.07	0.08	0.05
2016	-0.02	0.11	0.59	1.19	1.13	-0.12	-0.97	-1.61	-1.52	-1.20	-0.16	0.23	-0.20
2017	0.16	0.19	0.57	0.59	0.72	0.06	-0.83	-1.63	-1.74	-1.39	-0.40	0.19	-0.29
2018	0.09	0.23	0.67	1.29	0.92	-0.03	-0.96	-1.80	-1.82	-1.65	-0.52	0.06	-0.29
2019	0.11	0.19	0.59	1.01	1.19	-0.02	-1.02	-1.68	-1.55	-1.15	-0.07	0.08	-0.19
2020	0.09	0.16	0.51	1.01	1.22	0.81	-0.71	-1.45	-1.70	-1.28	-0.49	0.07	-0.15

Table 4.10: Drought categorization based on SPEI-3 values for Kaduna

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			NN	Mod W	Mod W	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2007	MildD	NN	NN	Mod W	NN	NN	MildD	Mod D	Mod D	MildD	NN	NN	NN
2008	NN	NN	NN	Mod W	Mod W	NN	MildD	MildD	MildD	MildD	MildD	NN	NN
2009	NN	NN	NN	Mod W	Mod W	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2010	NN	NN	NN	Mod W	Mod W	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2011	NN	NN	NN	Mod W	Mod W	NN	MildD	MildD	MildD	MildD	MildD	NN	NN
2012	NN	NN	NN	Mod W	Mod W	NN	MildD	Mod D	Mod D	Mod D	MildD	NN	MD
2013	NN	NN	NN	Mod W	Mod W	NN	NN	Mod D	Mod D	Mod D	MildD	NN	NN
2014	NN	NN	NN	Mod W	Mod W	NN	MildD	Mod D	Mod D	Mod D	MildD	NN	MD
2015	NN	NN	NN	NN	Mod W	NN	MildD	Mod D	Mod D	Mod D	NN	NN	NN
2016	MildD	NN	NN	Mod W	Mod W	MildD	MildD	SD	SD	Mod D	MildD	NN	MD
2017	NN	NN	NN	NN	NN	NN	MildD	SD	SD	Mod D	MildD	NN	MD
2018	NN	NN	NN	Mod W	NN	MildD	MildD	SD	SD	SD	MildD	NN	MD
2019	NN	NN	NN	Mod W	Mod W	MildD	Mod D	SD	SD	Mod D	MildD	NN	MD
2020	NN	NN	NN	Mod W	Mod W	NN	MildD	Mod D	SD	Mod D	MildD	NN	MD

NN-Near Normal, MildD-Mild Drought, Mod D-Moderate Drought, SD-Severe Drought, ED-Extreme Drought, Mod W-Moderare Wet.

Table 4.11: Identification of Drought Onset in Kaduna

YEAR	**JAN**	**FEB**	MAR	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
2006			ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2007	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2008	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2009	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2010	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2011	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2012	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2013	ND	ND	ND	ND	ND	ND	**ND**	ONSET	drought	drought	RECOV	**ND**
2014	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2015	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2016	ONSET	RECOV	ND	ND	ND	ONSET	**drought**	drought	drought	drought	drought	**RECOV**
2017	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2018	ND	ND	ND	ND	ND	ONSET	**drought**	drought	drought	drought	drought	**RECOV**
2019	ND	ND	ND	ND	ND	ONSET	**drought**	drought	drought	drought	drought	**drought**
2020	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**

ND-No Drought, RECOV-Recovery.

Table 4.12: SPEI-3 values for Maiduguri

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			1.08	1.22	0.89	0.26	-0.46	-0.92	-1.01	-0.57	0.09	0.29	0.09
2007	0.26	0.45	0.81	1.22	0.93	-0.60	-1.27	-1.56	-1.44	-0.98	-0.39	0.44	-0.18
2008	0.32	0.38	0.73	1.10	0.99	0.27	-0.39	-1.11	-1.13	-0.77	0.01	0.37	0.07
2009	0.45	0.58	0.90	1.19	1.00	0.70	0.00	-0.57	-1.10	-1.10	-0.59	-0.01	0.12
2010	0.44	0.66	0.96	1.23	1.10	0.14	-0.77	-1.17	-1.24	-0.77	-0.23	0.22	0.05
2011	0.42	0.55	0.90	1.19	0.96	0.39	-0.06	-0.84	-1.06	-0.91	-0.13	0.19	0.13
2012	0.36	0.50	0.83	1.20	0.90	0.21	-0.89	-1.36	-1.56	-1.05	-0.35	0.35	-0.07
2013	0.36	0.49	0.87	1.20	0.99	0.10	-0.45	-1.17	-1.13	-0.88	-0.10	0.22	0.04
2014	0.44	0.53	0.85	1.12	1.10	0.84	-0.07	-1.08	-1.26	-0.93	-0.06	0.36	0.15
2015	0.33	0.44	0.70	0.99	0.98	0.45	-0.55	-1.00	-1.21	-0.68	-0.17	0.20	0.04
2016	0.23	0.38	0.76	1.20	0.59	0.01	-0.80	-1.33	-1.42	-1.00	0.05	0.38	-0.08
2017	0.33	0.38	0.70	1.01	0.74	-0.11	-0.94	-1.38	-1.26	-0.76	-0.03	0.36	-0.08
2018	0.32	0.45	0.76	1.15	0.98	0.10	-0.79	-2.50	-1.60	-1.33	-0.55	-0.08	-0.17
2019	0.28	0.36	0.71	1.01	0.65	0.15	-0.61	-1.41	-1.53	-1.41	-0.52	-0.05	-0.20
2020	0.29	0.41	0.71	1.03	0.87	-0.07	-1.03	-1.70	-2.01	-1.71	-1.01	0.33	-0.32

Table 4.13: Drought categorization based on SPEI-3 values for Maiduguri

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2006			Mod W	Mod W	NN	NN	MildD	MildD	Mod D	MildD	NN	NN	NN
2007	NN	NN	NN	Mod W	NN	MildD	Mod D	SD	Mod D	MildD	MildD	NN	MildD
2008	NN	NN	NN	Mod W	NN	NN	MildD	Mod D	Mod D	MildD	NN	NN	NN
2009	NN	NN	NN	Mod W	NN	NN	MildD	MildD	Mod D	Mod D	MildD	MildD	NN
2010	NN	NN	NN	Mod W	Mod W	NN	MildD	Mod D	Mod D	MildD	MildD	NN	NN
2011	NN	NN	NN	Mod W	NN	NN	MildD	MildD	Mod D	MildD	MildD	NN	NN
2012	NN	NN	NN	Mod W	NN	NN	MildD	Mod D	SD	Mod D	MildD	NN	MildD
2013	NN	NN	NN	Mod W	NN	NN	MildD	Mod D	Mod D	MildD	MildD	NN	NN
2014	NN	NN	NN	Mod W	Mod W	NN	MildD	Mod D	Mod D	MildD	MildD	NN	NN
2015	NN	NN	NN	NN	NN	NN	MildD	Mod D	Mod D	MildD	MildD	NN	NN
2016	NN	NN	NN	Mod W	NN	NN	MildD	Mod D	Mod D	Mod D	NN	NN	MildD
2017	NN	NN	NN	Mod W	NN	MildD	MildD	Mod D	Mod D	MildD	MildD	NN	MildD
2018	NN	NN	NN	Mod W	NN	NN	MildD	ED	SD	Mod D	MildD	MildD	MildD
2019	NN	NN	NN	Mod W	NN	NN	MildD	Mod D	SD	Mod D	MildD	MildD	MildD
2020	NN	NN	NN	Mod W	NN	MildD	Mod D	SD	ED	SD	Mod D	NN	MildD

NN-Near Normal, MildD-Mild Drought, Mod D-Moderate Drought, SD-Severe Drought, ED-Extreme Drought, Mod W-Moderare Wet.

Table 4.14: Identification of Drought Onset in Maiduguri

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006			ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2007	ND	ND	ND	ND	ND	**ONSET**	**drought**	drought	drought	drought	drought	**RECOV**
2008	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2009	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**Drought**
2010	RECOV	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2011	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2012	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2013	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2014	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2015	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**RECOV**
2016	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	RECOV	**ND**
2017	ND	ND	ND	ND	ND	**ONSET**	**drought**	drought	drought	drought	drought	**RECOV**
2018	ND	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**Drought**
2019	RECOV	ND	ND	ND	ND	ND	**ONSET**	drought	drought	drought	drought	**Drought**
2020	RECOV	ND	ND	ND	ND	**ONSET**	**drought**	drought	drought	drought	drought	**RECOV**

Table 4.15: Frequency of occurrence of each drought categories for SPEI-3 in each station

Mod W-Moderate Wet, NN-Near Normal, MildD-Mild Drought, SD-Severe Drought, ED-

Station	Mod W	NN	MildD	SD	ED	Mod D
SOKOTO	25	92	58	4	3	18
KADUNA	39	95	35	6	2	28
MAIDUGURI	23	107	39	10	0	23

Extreme Drought, Mod D-Moderate Drought.

The stations suffered severe drought condition based on the 3-months timescale. The severe drought conditions in Sokoto, Kaduna and Maiduguri according to year of occurrence are;

i. Sokoto – 4 months in 2014, 3 months in 2014 of extreme drought
ii. Kaduna – 2 months in 2016, 2017, & 2019, 3 months in 2018 and 1 month in 2020
iii. Maiduguri – 1 month in 2007, 2012, 2018, 2019 and extreme drought for 1 months in 2018 and 2020.

Sokoto state suffered the longest consecutive months of severe to extreme drought episode in the same year (2014), followed by Kaduna with 2 consecutive months in 2016 and 2017 and 3 months in 2018, and in Maiduguri, only 3 consecutive months of severe to etreme drought was recorded (table 4.13). However, the range of SPEI-3 values are close for all three stations.

Table 4.16: Most critical SPEI-3, drought category and year of occurrence

Station	Duration (consecutive months) Months & year (s)	SPEI-3 value	Drought category
Sokoto	4 (August-December, 2015)	-1.55 to -1.91	SD
	3 (August-October, 2014)	-2.11 to -2.14	ED
Kaduna	2 (August-September, 2016, 2017)	-1.54 to -1.74	SD
	3 (August-October, 2018)	-1.65 to -1.82	SD
Maiduguri	2 (August & October, 2020)	-1.70 to -1.71	SD
	1 (September, 2020)	-2.01	ED

There was no occurrence of extreme wet condition in all three stations within the study period, while moderate or mild wet condition was recorded once in Kaduna state in March, 2006.

Comparison of the yearly SPEI-3 values for the three stations, revealed a similar drought category plot pattern, starting from positive values, followed by negative values, and finally positive values (Figure 4.5).

Table 4.17: Yearly SPEI-3 values for the three stations

YEAR	SOKOTO	KADUNA	MAIDUGURI
2006	0.8262	0.8649	0.7489
2007	0.8275	0.8479	0.7302
2008	0.7913	0.8497	0.7298
2009	0.7614	0.5495	0.7346
2010	0.4660	0.3798	0.6699
2011	-0.2493	-0.3801	0.1125
2012	-0.4595	-0.5145	-0.5016
2013	-0.7509	-0.7474	-0.8378
2014	-1.2984	-1.1713	-1.4109
2015	-1.5396	-1.4555	-1.4871
2016	-0.8873	-1.1708	-0.9760
2017	-0.4208	-0.3212	-0.3577
2018	0.4145	0.4952	0.3422
2019	0.8297	0.8494	0.7214
2020	0.6365	0.8494	0.7196

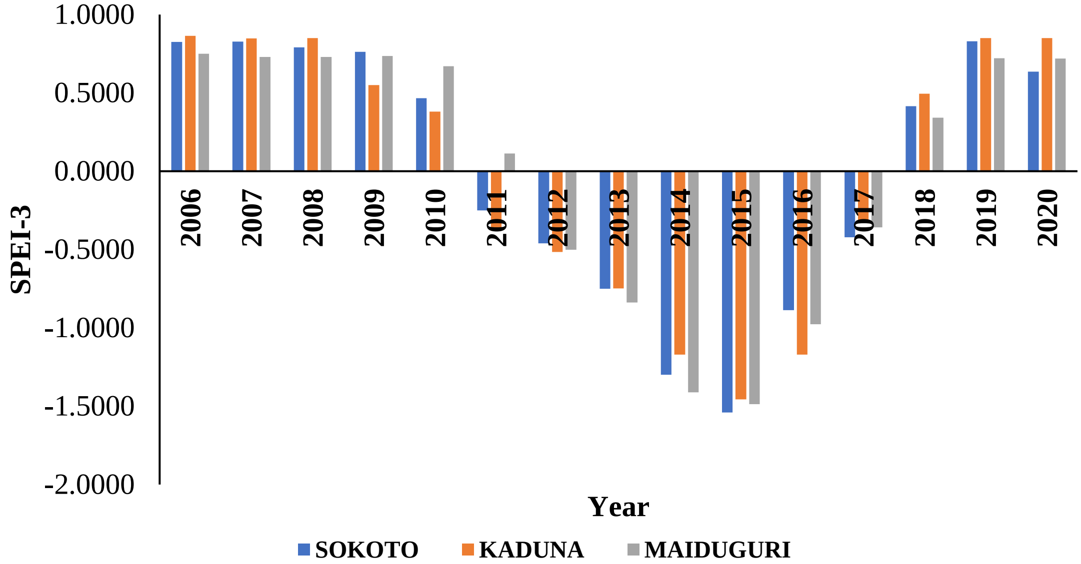

Figure 4.5: Comparison of yearly SPEI-3 values for the three stations

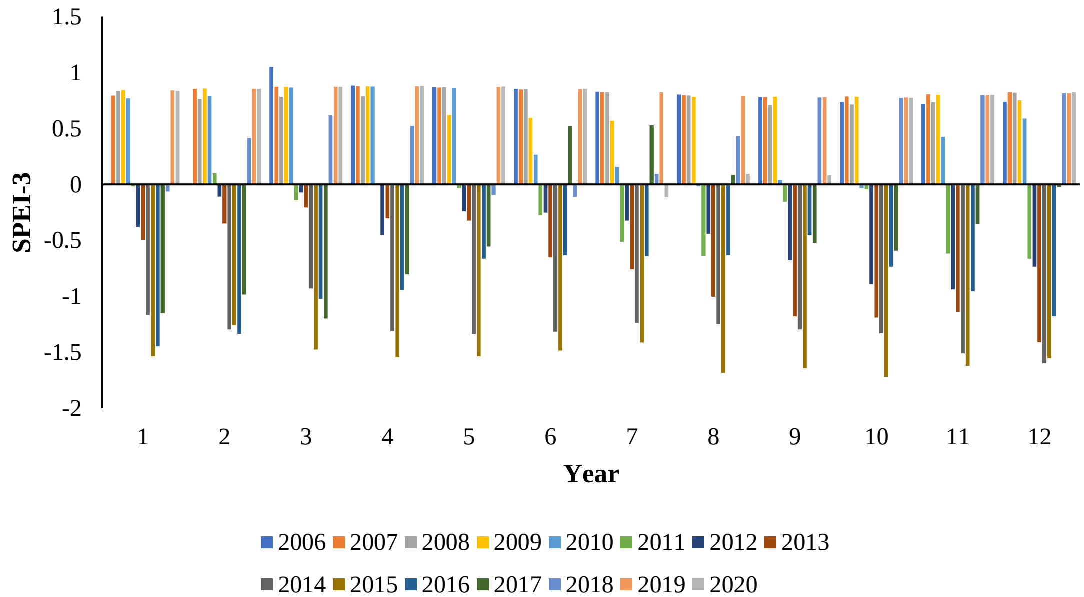

Figure 4.6: Combined monthly SPEI-3 values for Sokoto, 2006 – 2020

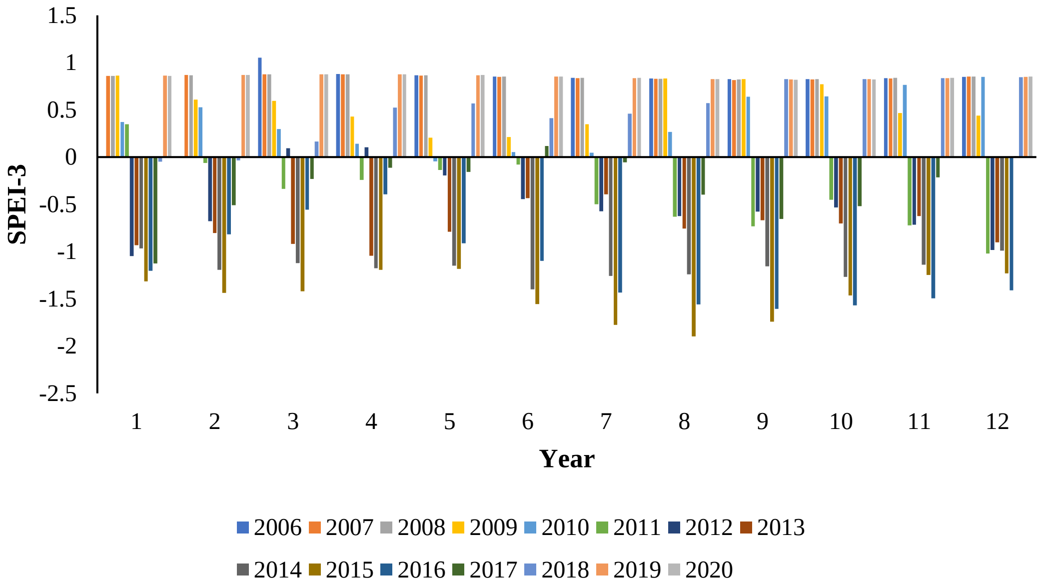

Figure 4.7: Combined monthly SPEI-3 values for Kaduna, 2006 – 2020

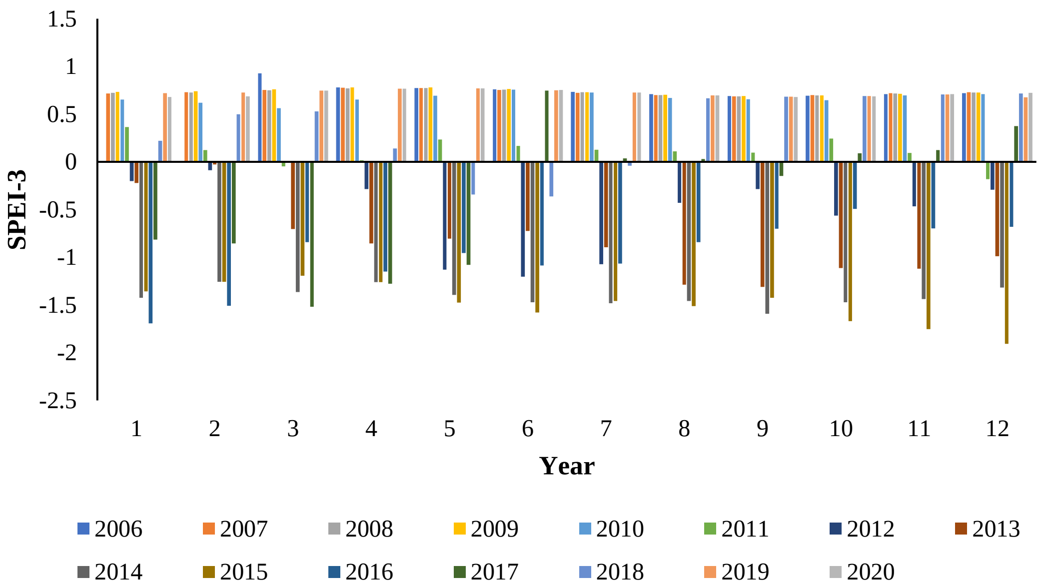

Figure 4.8: Combined monthly SPEI-3 values for Maiduguri, 2006 – 2020

4.3 Interannual Variability of SPEI-3 Values

Figure 4.6 – 4.8 shows the interannual variability of SPEI-3 values for each station over the study period. in Sokoto state, from 2006 – 2009 and 2019, the SPEI-3 values are positive (above 0), in Kaduna state, from 2006 – 2009, 2019 – 2020, the SPEI-3 values are positive, and in Maiduguri state, from 2006 – 2010, 2019 – 2020, the values are also positive, while the rest of the years are vacillating between 0 and -2.0.

The yearly average values for each station demonstrates that in Sokoto, there is a gradual transition from near normal conditions, early signs (onset), moderate drought, severe drought, then reversal process of moderate, early sign and finally to near normal condition. in Kaduna, the transition is from near normal, early sign, peaks at moderate drought, early sign again and then finally at near normal condition.

The SPEI-3 for all the three stations (Sokoto, Kaduna and Maiduguri) varies from +1.0485 to -1.7196, +1.05141 to -1.8964 and +0.9265 to -1.9056 respectively. The drought conditions in the major parts of the last three years (2018 – 2020) is near normal, meaning that drought stresses, losses and other drought related economic, environmental and societal impacts are declining.

4.4 Interraction between Drought Event and Rainfall

Considering occurrence of drought and the rainfall values at same months reveals that at a highly monthly rainfall amount of 544mm in Kaduna, the severe drought condition could not be averted, that is it was not sufficient enough maintain a prolonged high soil moisture content, which is key for agricultural activities. The other two stations had low monthly rainfall within the months or duration of the severe drought event. This situations may be due to a prolonged or sustained period of dryness or other factors. From the foregoing analysis, it is obvious that a high one month rainfall amount may be inadequate to interfere with drought propagation or bring about the termination of a severe drought condition in a particular location.

4.5 Detection of Drought Onset and Pattern in the Study Area

With the drought categorization presented in table 4.7, the monthly and yearly drought categorization for all the stations was done.

The onset of drought and its frequency was detected when the SPEI-3 values are between 0.0 to -o.99 (Kingtse, 2011). The drought onset were detected prior to moderate drought condition, which then propagates to extreme drought or back to near normal conditions.

The pattern of drought onset occurrence per station is as depicted in table 4.18. In Sokoto, the onset was found to occur either March of July, with most of it being in July. In Kaduna, drought onset was noted in January, June, July and August, with those occurring in July being the most frequent. In Maiduguri, drought commenced either in June or July with most being in July.

Table 4.18: Most frequent of Drought Onset per month per Station

	Onset months in Sokoto			Onset months in Kaduna			Onset months in Maiduguri	
YEAR	**MAR**	**JUL**	**JAN**	**JUN**	**JUL**	**AUG**	**JUN**	**JUL**

2006		ONSET			ONSET			ONSET
2007		ONSET			ONSET		ONSET	
2008		ONSET			ONSET			ONSET
2009		ONSET			ONSET			ONSET
2010		ONSET			ONSET			ONSET
2011		ONSET			ONSET			ONSET
2012		ONSET			ONSET			ONSET
2013		ONSET				ONSET		ONSET
2014	ONSET				ONSET			ONSET
2015		ONSET			ONSET			ONSET
2016		ONSET	ONSET	ONSET				ONSET
2017		ONSET			ONSET		ONSET	
2018		ONSET		ONSET				ONSET
2019		ONSET		ONSET				ONSET
2020		ONSET			ONSET		ONSET	

In terms of total detection of drought onset in July and percentage;

i. Sokoto – 14 cases, which represent 93.3%

ii. Kaduna – 11 cases, which represents 68.8%

iii. Maiduguri – 12 cases, which represents 80.0%

This implies that the month of July is a month to watch out for in regards to drought occurrence, in the study area and agricultural activities.

Drought recovery was also noticed to occur mostly in December than other months of the year.

4.6 Drought Onset and Drought Monitoring

From the tabulated drought categorization and monthly rainfall amount data, it can be deduced that even with varying and at times low monthly rainfall amount (2006 – 2010 and 2018 – 2020), drought conditions are mostly near normal, implying that other factors may be influencing the prevailing conditions being experienced or recorded. For instance, in Kaduna, where the largest rainfall amount occurred (1780.8mm), a four months (August – November, 2016) long severe drought event was recorded.

Consequently, drought monitoring should incorporate other drought causative agents or factors than precipitation. So, it is vital to sustain drought early signs detection, employing indices that integrates other parameters, for effective drought condition determination and monitoring, and in general, for the gains of all relevant stakeholders or vulnerable society. When this early signs of drought are detected, other interconnected and applicable drought monitoring, management and mitigative plans/actions can kick into play for minimal drought negative impact or maximum resource utilization and deployment per location within a given geographical space and time.

4.7 Agreement of Result with Previous Studies

The findings in previous studies are in agreement in some aspect due to study period variation. Adeniyi and Uzoma, (2016), in a study over 1960 – 2012 period, revealed that extreme and severe drought conditions have highest occurrence in the 80s then 70s, however it became minimized from the 90s to the 2000s. Also, Adaega, 2011, supported this findings in a study carried out for a period between 1945 – 1995, which discovered that earlier years (1945 – 1972) had moderate to extreme drought conditions, while moderate droughts are common in the 1990s. The above studies are in agreement with this current study, which recorded no extreme wet or extreme drought conditions, but few severe drought events and high prevalence of near normal conditions. Samuel *et al.,* (2019), in a study done for 1980 – 2010, also disclosed that the near normal condition is most common in northern Nigeria.

However, as at the time of this study, in the area of drought onset, no literature was located or found except those mentioned in chapter two, which are conducted in other continents of the world, in which one of the method or procedures was adopted here (Kingtse, 2011)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study evaluated the drought condition and rainfall patterns as it relates to the detection of drought onset in some states of northern Nigeria, particularly Sokoto, Kaduna and Maiduguri stations.

The drought events for each station were determined using SPEI-3 for the 2006 – 2020 period (that is SPEI at a 3-months' time-scale or accumulation) from the monthly precipitation and evapotranspiration (PET) data obtained from NiMet in order to achieve the aim and objectives of the study. The following conclusions can be made based on the main findings of this research work;

Meteorological drought was categorized and tabulated for each station using Standardized Precipitation Evapotranspiration Index (SPEI) at a 3-months' time scale over the study period. Even though near normal drought event was the most prevalent event, there was the occurrence of severe to extreme drought episode in the study area. This is in agreement with studies done by Samuel *et al.,* 2019. Also, some moderate wet conditions were noticed in the study area. Mild drought mostly precedes other negative drought events. The most critical SPEI-3 values (signifying severe and extreme drought) obtained ranges between -1.52 to -2.50 over the study area and period.

Drought onset in the study area was identified over the study period, 2006 to 2020. The SPEI-3 values at which drought commenced are in the range of -0.07 to -0.83.

Based on the identified drought onset and the frequency of occurrence, the pattern was established. In all three stations, the month of July was found to be the most preferred month for the commencement of drought and the month of December, as the recovery or termination month, that is drought is likely to start at the rainy season and end after the rainy season in the northern areas studied over the period. This is in agreement to the research by Kingtse, 2011, though is in a different continent.

5.2 Recommendations

The following are recommendations from this study;

1. Though SPEI performed excellently well, other methods should also be tested and the results compared to establish the effectiveness or suitability of SPEI by considering the coherence of possible results at different temporal accumulations.
2. Based on the findings, though annual timescale may be long, it should be employed to obtain information on temporal evolution of drought, especially regional drought behaviour.
3. Routine drought studies predicated on the analysis of drought characteristics especially drought onset and cessation should be incorporated into national, state and local policy action plans for disaster mitigation and adaptation.

5.3 Contribution to Knowledge

In this research, drought onset was detected for three (3) northern stations of Nigeria using Standardized Precipitation Evapotranspiration Index (SPEI) at 3-months accumulation timescale period, from the monthly precipitation and evapotranspiration (PET) data. Althouhg, near normal drought events was the most prevalent, there was occurrence of severe to extreme drought episode in the study area. The most critical SPEI-3 values range between -1.52 to -2.50 over the study period in the area. Drought onset in the study area over the period 2006 to 2020: The SPEI-3 values at which drought commenced are in the range of -0.07 to -0.83. Based on the Identified drought onset and the frequency of occurrence, the month of July (14/15, 11/15 and 12/15) frequencies for Sokoto, Kaduna and Maiduguri stations respectively, as onset of drought.

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