ASSESSMENT OF THE EFFECT OF VARIABILITY IN RAINFALL PARAMETERS ON SELECTED CROPS YIELD IN BENUE STATE, NIGERIA

BY

Hungur AGASHUA

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT,

FACULTY OF PHYSICAL SCIENCE,

AHMADU BELLO UNUIVERSITY,

ZARIA, NIGERIA

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Hungur AGASHUA
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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN GEOGRAPHY

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT,
FACULTY OF PHYSICAL SCIENCES,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

JULY, 2023

DECLARATION

I declare that the work in this dissertation entitled ASSESSMENT OF THE EFFECT OF VARIABILITY OF RAINFALL PARAMETERS ON SELECTED CROPS YIELD IN BENUE STATE, has been carried out by me in the Department of Geography and Environmental Management, Faculty of Physical Sciences, Ahmadu Bello University, Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Hungur, AGASHUA	_____	_____
Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled ASSESSMENT OF THE EFFECT OF VARIABILITY IN RAINFALL PARAMETERS ON SELECTED CROPS YIELD IN BENUE STATE by Hungur, AGASHUA meets the regulations governing the award of the degree of Master of Science Degree in Geography and Environmental Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. B. A. Sawa Chairman Supervisory Committee	_____ Signature	_____ Date
Dr. H. Mohammed Member Supervisory Committee	_____ Signature	_____ Date
Dr. S. Abbas Head of Department	_____ Signature	_____ Date
Prof. M.N.Shuaibu Dean School ofPostgraduate Studies	_____ Signature	_____ Date

DEDICATION

This research work is dedicated to GOD through JESUS CHRIST, in whom are hidden all the treasures of wisdom and knowledge according to Colossians 2:3.

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ABSTRACT

Rainfall plays a key role in crop production and agriculture as a whole. There are many parameters of rainfall all of which are of great importance to agriculture but most researchers studied onset date (OD), cessation date (CD) of rains and Length of growing season (LGS). Also, most researchers used Walter's 1960 method to estimate onset and cessation dates of rain. This research assessed the effect of rainfall variability on selected crops yield in Benue State. Rainfall and crops yield data were used for the study. Rainfall data were obtainedfrom Akperan Orshi Polytchnic, Gboko and Nigerian Meteorological Agency (NiMet) Makurdi stations whereas crops yield data were obtained from Benue State Agricultural and Rural DevelopmentAgency(BNARDA),Makurdi.Itexaminedthetrendsofrainfallparametersand selectedcropsyield,assessedtherelationshipbetweenthemandforecastedtheyieldfor2050. The research employed Man Kendall test to estimate the trends of the derived rainfall parameters and selected crops yield, Pearson Product Momentum Correlation to estimate the relationship between rainfall parameters and crops yield, stepwise multiple regression to develop forecast models and forecast error percentage formula (FE %) was used to test the validity of the developed forecast models. This research used the developed forecast models to forecast crops yield for 2050. This research found out that no rainfall parameter indicated significant trend at both Gboko and Makurdi stations. Maize, sorghum and soya beans yield showed increasing significant trends at 0.01 significant level. Among the rainfall parameters, ODhadsignificantrelationshipwithsoyabeansat0.05significantlevel,numberofrainydays (NRD) had significant relationship with rice at 0.05 significant level and amount of rain in the months of the growing season (ARMGS) showed significant relationship with rice and soyabeansyieldsinGbokoat0.01and0.05significantlevelsrespectivelywhileonlyCDhad significant relationship with rice yield at Makurdi station at 0.01 significant level. Resultsfor stepwise multiple regression analysis gave three (3) yield forecast models: $Y = 2.214 – 0.637\text{Log}X_1$ for rice and $Y = 0.005 + 0.418\text{Log}X_2$ for soya beans at Gboko and Y = 4.130–

3.805LogX_3 for rice at Makurdi. The forecast models that passed the validity test using FE% andwerebestfitfortheforecastoftheselectedcropsyieldinBenuestateweretwo;Y=2.214 –0.637LogX_1forriceatGbokoonthebasisofARMGSandY=4.130–3.805LogX_3forrice inMakurdionthebasisofcessationdate(CD).Researchesofthissuchareofgreatimportance as it will foster adequate planning by the BNARDA and other agencies, since the selected crops constitute the main staple food crops among the populace. The research recommends a comparative study on the use of Walter's (1967), Adefolalu's (1993) and Hybrid methods to estimate onset, cessation dates and length of growing season and that farmers should apply the two developed forecast models for rice yield forecast in the state.

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CHAPTER ONE

INTRODUCTION

1.1 Background to theStudy

Climate is the mean state of the atmosphere of a location over a defined period of 25 to 30 years or more (Chinago, 2020). Murdock, Fraser and Pearce, (2007); Bothe, (2018) and Adenodi, (2018) defined climate as the average weather condition or the statistical description in terms of the mean and variability of relevant elements of weather of a place over a period of time extending from months to thousands or millions of years. According to Bothe, (2018) the classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). Werndl (2015) and Frigg, Thompson and Werndl (2015) agreed at a definition of climate as the distribution of climate variables "over time for regimes of varying external conditions". Climate therefore is the weather condition of a place, usually taken at an average of 30 years and above. Climate imposes cost on man but also bestows benefits. For instance, storms and floods causes damage and sometimes loss of life, but the day to day variations contributes to the rich variety of flora and fauna, which add so much to the quality of lives (Ayoade, 2003 and Alexander,2015).

Weather on the other hand is the instantaneous, specific or currrent state of the atmosphere of a place at a time (Moore, Spittlehouse, Whitfield and Stahl, 2008). Both climate and weather are not and never static. They change with time depending on the prevailing condition. The variation of climate in recent times mainly as a result of human interference has led to climate change (IPCC, 2001b; Stern, 2006; IPCC, 2007). The state of climate is usually explained using variables known as climatic variables. These variables include: temperature, precipitation, wind, sunshine, cloud, atmospheric pressure and humidity. Climateisaprimarydeterminantofagriculturalproductivity,especiallyinthedeveloping countries like Nigeria, where agriculture is basically dependent on natural circumstances

against the controlled environmental condition in developed countries (Akinseye, Ajayi and Oladitan, 2013).

Idumah, Mangodo, Ighodaro and Owombo (2016) defined climate change as the gradual change in the mean climatic state of a place. Sawa (2019) defined climate change as the statistically significant deviation in the mean of climatic elements overtime. Despite the growing knowledge of climate change and its impacts on agriculture, yet many uncertainties remain (Odejimi and Ozor, 2016). Climate Change is one of the greatest challenges of the 21st century (Ayinde, 2010, IPCC, 2013).

Climate change has impacted man and agriculture both positively and negatively however, more of the negative (Ntag, 2018). Abnormal temperatures have led to global warming and rainfall which is of great importance to agriculture has been affected by this global warming. Excessive rainfall has often led to flooding and erosion which in turn degrades the soil. High winds have often led to degradation of biodiversity through uprooting of trees. In recent years, yields of staple crops such as grain crops (maize, wheat, sorghum, rice) and fruit crops, such as mangoes, have decreased across Africa, widening food insecurity gaps (Ketiem, Makeni, Maranga and Omondi, 2017). In Nigeria, there have been reports of climate change having impacts on the livelihoods of farmers generally (Abiona, Fakoya and Esun, 2016; Ifeanyi-obi, Togun and Lamboll, 2016; Onyeneke, Igberi, Uwadoka and Aligbe, 2018). It is projected that crops yield in Africa may fall by 10 – 20% by the year 2050 or even up to 50% due to climate change (Jones, 2003; IPCC, 2007; Nwaobiala and Nottidge, 2012). The fundamental effect of climate change on agriculture is its direct impact on food production. Almost all sectors in agriculture depend on drives of weather and climate whose variability subject rural farmers to production and financial risk (Ozor, Madukwe, Ene and Amaechina, 2012, Ajiboye, Adedeji, Bamiro and Otunnaiya,2015).

Precipitation is the general name that stands for all forms of moisture that fall from the atmosphere on to the ground. These include rainfall, frost, mist, snow, fog, sleet, haze, hail and dew (Aphu, Danso, David and Dzameh, 2015). Rainfall is the most widely experienced form of precipitation in the tropics. This is as a result of the high temperature which in turn is a result of high insolation received within the region. According to Sala and Laurenroth (1982), Carberry (2007) and Chinago (2020), rain is precipitation in the form of droplets that have condensed from atmospheric water vapour and then become heavy enough to fall undergravity and ranges in diameter between 1-5 mm. Rain is a major component of the watercycle and is responsible for depositing most of the fresh water on the Earth. Three types of rainfall exist and include: convectional, orographic or relief and frontal or cyclonic rainfall. However, convectional rainfall is the type that is usually experienced in the tropics which is as a result of high temperatures. Convectional rainfall is formed when water bodies on the surface of the earth are heated by the sun. The water molecules become lighter (water vapor) (Aphu *et al*., 2015). The lighter air rises, cools down adiabatically, and then condenses on the condensation nuclei in the atmosphere. When water vapor rises further, it converges and moves gradually upwards. As the air converges, it condenses to form thick cumulous clouds. The rising clouds become heavier and unstable. This unstable cloud then drops to the ground as raindrops or rainfall (Aphu *et al.,* 2015). Even within the tropics, rainfall varies. Rainfall is one of the major climatic resources of Nigeria and can be used as an index of climatic change. Crops, animals and humans derive their water resources mainly from it (Adenodi, 2018). Rainfall effectiveness indices are the major control of crops yield in the West African savanna region where the study area (Benue State) is located. It is not only the total amount of rainfall in the study area that matters; but how effective the rain is in terms of its time of occurrence, spread, intensity, frequency, and availability as soil moisture (Adefolalu, 1993). The term ‘precipitation effectiveness’ which is also referred to as ‘rainfall effectiveness’has

beeninterpreteddifferentlynotonlybyspecialistsindifferentfields,butalsobydifferent

workers in the same field (Sawa and Adebayo, 2011). Rainfall effectiveness is that portion of total precipitation used to satisfy vegetation need; that is the actual available precipitation used in plant development (American Meteorological Society, 2009). Rainfall effectiveness is defined as water requirement of a crop, that is, the amount of water needed to raise it and this includes water to meet both consumptive and special needs such as land preparation (Forbes and Watson, 1992). Cooper (1990) defined rainfall effectiveness as that portion of total annual or seasonal rainfall which is useful directly or indirectly for crop production to the site where it falls. Agriculturalists may consider rainfall effectiveness as that portion of the total rainfall which directly satisfies crop water needs (Bello,2012).

Rainfall effectiveness indices are of great importance such that knowledge of them would greatly positively impact agriculture. It could improve the yield of crops. These parameters include: onset and cessation dates of the rains, monthly rainfall, length of growing season, rainfall intensity, seasonality index, annual rainfall, amount of rain during the months of the growing season, index of replicability, seasonality index, specific water consumption and pentad dry spell (Sawa, 2016 and 2019). The amount of moisture (soil water) available to crops depends on rainfall onset, cessation, length of the growing season and the antecedent soil moisture which influence the success or failure of a cropping season (Ntat, Ojoy and Suleiman, 2018). Each of the rainfall effectiveness indices has its specific role and impact on crops. Farmers' awareness of these indices could help determine the type of crop to plant, the time to plant, time to harvest and so forth. Rainfall is an indispensable natural occurrence in food production especially in the developing countries of the world (Kyei-Mensah, Kyerematen and Adu-Acheampong,2019).

According to Ntat *et al*., (2018), rainfall is a climatic parameter that touches the manner and mode man lives. Obot and Onyenkwu (2010) added that, it affects every facet of the ecological system both flora and fauna. It plays a very important role in the production of

crops as it provides moisture to the soil for plant photosynthesis. Generally, rainfall regime is the most important climatic factor influencing agricultural activities particularly in the tropical region. Although, there have been several debates that rainfall and temperature are the most important climatic determinants of crop survival and production in the tropics especially in Nigeria, however, it has been observed on a general note that; temperature has remained uniform especially during the growing season, on the other hand, the amount, distribution and reliability of rainfall appear to be the definite constraint to agriculture in Nigeria (Audu, 2012). Rainfall can vary considerably even within a few kilometers distance and on different time scales. This implies that crops yield is exceedingly variable over space and time. Rainfall therefore, has the greatest effect in determining the crops that can be grown, the farming system, the sequence and timing of farming operations (Adejuwon, 2005). Rainfall determines not only where and when to plant a crop but also whether the crop will yield effectively or not (Alexander, Bakpo and Woke, 2015, Adenodi, 2018). Rain has some characteristics which are of practical implications, such as its amount, intensity, duration, seasonality and diurnal distribution, frequency of rainy days and variability (Ntat *et al.*, 2018).

Kalu and Egbe (2011) defines agriculture as all the productive occupation of man that organizes various forms of resources (natural human and material) to create or provide food fiber and other forms of raw materials and their transformation into various utilizable or consumable forms. Agriculture refers to all the productive activities in which man works with nature to produce plants and rear animals for harvest. In many countries, and virtually every developing country, agriculture is the biggest industry. Agriculture plays a very important role in every country as it contributes to two fundamental aspects of development: national food security and national, social and economic stability (Abu and Adakole, 2017). It provides not only food but also raw materials for manufacturing industries like textiles,

sugar, vegetable oil and so forth (Ganiyu, Akinniran and Adeyemo, 2013). Agriculture is strategic to the Nigerian economy and plays a key role of supplying food for the population, raw materials for industries, earning high foreign exchange which is next only to that from crude oil, providing market for the industrial sector and a key contributor to wealth creation and poverty alleviation. All the countries of the world import or export large quantities of agricultural products which brings about economic development of the world (Alabi, 2009). Agriculture is the first occupation of man and has remained a primary and important one ever since. Without food, man will not survive on earth; and without agricultural resources, many industries will close down. Agriculture as an economic activity generated between 1% and 60% of national GDP in many countries, with a world average of about 4% in 2017 (World Bank 2019). There is still need to produce about 50% more food by 2050 in order to feed the increasing world population (FAO2018a).

According to Ismaila, Gana, Tswanya and Dogara (2010), agriculture remains the main stay of the Nigerian economy. More than 70% of the working adult population in Nigeria are employed in the agricultural sector directly or indirectly and over 90% of Nigeria's agricultural output comes from peasant farmers who dwell in the rural areas where 60% of the population live. Despite the focus of the Nigerian government on the oil sector and its strategic importance, agriculture has played the most significant role in the lives of citizens of Nigeria (Ismaila *et al*., 2010). It provides a source of employment to a significant number ofNigerians.

Crop production is an integral part of agriculture dealing with the cultivation, protection, harvesting and storage of cultivated plants for man's use. It is the sum total of all activities involved in producing, preparing and processing of agricultural crops **(**Akanbi, Olabode, Olaniyi and Ojo, 2004). Crop production plays immense role in enhancing food security at household level(Abuand Adakole, 2017).Themain climatic elementsthat affect crop

production are the same as those influencing natural vegetation. These include: rainfall, solar radiation, temperature, moisture, wind, among others. They all largely determine the global distribution of crops and livestock as well as crop yield and livestock productivity within a given climatic zone (Abu and Adakole, 2017. All crops have their optimal climatic requirements for their optimal growth and a range of climatic requirements outside which they cannot be successfully grown. In other words, they have their climatic limits for economic production. As such, it will therefore not be economically viable to grow a crop outside its climatic limits. It is not within man's ability to influence the occurrence (timing), distribution and amount of rainfall (Stroosnyder, 2008), however Nunez, Verbist, Wallis, Schaefer, Morales and Cornelis (2011) stated that the knowledge of their frequency for a variety of durations is necessary, if they are to be well managed for efficient crop production.

The role of food crops to the modern society is associated to its importance as food crop throughout the world. In most parts of Asia and Africa, grain products for instance comprises of 80% or more of the average diet, in central and western Europe, as much as 50% and in the United State, between 20 - 25% (Ismaila *et al*., 2010). In Nigeria the major grown crops include; rice, maize, sorghum, soybean, wheat, pearl, millet, yam, beans, cassava and so forth (Ismaila *et al.,* 2010). In Benue State, the major cultivated crops are rice, maize, sorghum and soyabeans which constitutes the major staples among the populace (Odoemenem and Asogwa, 2010). Due to increase in population, there is great need to produce more of these crops in other to prevent food insecurity and climate generally plays a very significant role in the study area (Benue state). Rainfall is the major element of climate which promotes agricultural activities in regions like the study area where agriculture is mostlyrainfed.

1.2 Statement of the ResearchProblem

According to Terseer, Yahaya, Samsudeen and Tsado (2019), rainfall is the leading climatic factor that influences crop growth and productivity. Porter and Semenov (2005) and Mage, Iorlamen and Orvesen (2015) stated that crops exhibit known observed responses to weather and climate that can have a large impact on crops yield. In the tropical environment where the study area lies, temperature is not a limiting factor to plant growth but the variability of rainfall is the problem (Sawa, 2019). Adenodi (2018) and Adams and Bamanga (2020) confirmed that there is evidence of rainfall variability in Nigeria. Enokela and Seini (2013); Aho, Akpen and Ojo (2019) and Terseer *et al.,* (2019) in their separate studies observed a significant variation in rainfall in the study area (Benue State). Sawa (2016) stated that rainfall has many parameters, all of which are of great importance to agriculture.

Some of the researches conducted on the impact of rainfall parameters on crop yields include; Edeh, Eboh and Mbam (2011) researched on rainfall intensity and number of rainy days in Ebonyi State. Using coefficient of variation and stochastic production function, they found out that the increase in both rainfall parameters (intensity and number of rainy days) led to decrease in the yield of rice in the study area. Ocholi, Ocholi and Isah (2016) also observed that rainfall intensity affected crop yields in Anyigba, Kogi state in their research on rainfallintensity.

Adamgbe and Ujoh (2012) investigated the variations of onset and cessation dates, length of growing season, number of rainy days and annual rainfall and the implication of such variations on maize rice, sorghum and soyabeans yields in Benue State. They used Walter's (1967) method to compute onset and cessation dates. They observed that all the rainfall parameters played a significant role in the yield of all the crops studied using multiple correlationanalysis.

Mage, Iorlamen and Orvesen, (2015) examined the variations in rainfall characteristics and their impact on Soya beans yield in Ushongo local government area of Benue State. From the rainfall data, the rainfall onset, cessation and annual totals were deduced. They used Olaniran (1988) method to compute onset and cessation dates. Partial correlation and multiple linear regressions were used to analyze the data in order to determine the effect of rainfall on soya beans yield. The result showed that date of cessation and total annual rainfall had a relatively strong correlation with soya beans yield. Cessation date was found to account more for the annual variation in soya bean yield.

Osabo, Ndor and Agwale (2019) investigated the impact of rainfall onset and cessation dates and length of growing season variability on crops yield in Benue State. They employed Walter's (1967) method to compute onset and cessation dates and length of growing season. The result revealed that all the rainfall parameters except length of growing season significantly correlated with the yields of maize and sorghum in the study area.

From the above studies, it is clear that researchers have concentrated their studies majorly on onset and cessation dates and length of growing season which they have computed using Walter's (1967) and Olaniran's (1988) methods. Few have used number of rainy days and rainfall intensity. The researcher has not come across other researches that considered the effect of rainfall parameters such as: amount of rain in the months of the growing season, seasonality index, rainfall intensity and hydrological ratio on selected crops yield in the study area. This study therefore sought to fill in this gap. Methodologically, the study adopted the hybrid method to estimate rainfall onset and cessation dates which has been proposed by Ati, Stiger and Oladipo, (2002) and have not been used in the studyarea.

Benue State is blessed with fertile agricultural lands and as a result, a very high interest is placed on agricultural activities. In the course of carrying out this research, the following

questions were posed and answers to them provided more light in understanding the impact of variability of rainfall parameters on the selected crops yield. These questions include:

1. What is the trend of rainfall parameters in the study area within the study period (1990-2019)?
2. What is the trend of the yield of the selected crops in the studyarea?
3. What is the relationship between the rainfall parameters and the yield of the selected crops in studyarea?
4. What will be the yield of the selected crops by 2050 in the studyarea?

1.3 Aim and Objectives of theStudy

The global threat being posed by the problem of climate change coupled with the need for food security necessitated this study to aim at assessing the variability in rainfall parameters on the yield of the selected crops in Benue State within the period of 30 years (1990-2019). The aim of the study was achieved through the following specific objectives which include to:

i. examine the trend of rainfall parameters in the study area within the study period (1990-2019);
ii. examine the trend of the yield of the selected crops (rice, maize, sorghum and soya beans) in the study area within the studyperiod;
iii. assess the relationship between rainfall parameters and the selected crops in the study area within the study periodand
iv. forecast the yield of the selected crops in the study area for2050.

1.4 Hypothesis

H_o: There is no significant relationship between rainfall parameters and the selected crops yield in the study area.

1.5 Scope of the Study

This study is concerned with the assessment of the effects of variability in rainfall parameters in Benue State which is referred to as the Food Basket of the Nation (Nigeria). The study examined the trends of rainfall parameters and yield of selected crops, the relationship between them and forecasted the selected crops yield for 2050. The study considered the following rainfall parameters: Onset and cessation dates, length of growing season (LGS), number of rainy days, amount of rainfall in the months of the growing season, rainfall intensity, hydrological ratio and seasonality index. The study also considered the four major grown crops that are produced in the state which are; rice, maize, sorghum and soya beans as identified by Odoemenem and Asogwa, (2010); Terdoo, Gyang and Iorlamen, (2016) and Abu and Adakole, (2017) and which constitute a major staple food crops among the populace. According to Patil (2015), seasonality index could be best examined after a period of thirty years and in order that the study is contemporal and recent, it considered the period of 1990 - 2019 (30years).

1.6 Significance of theStudy

Benue state is largely referred to as the "Food Basket of the Nation" (Nigeria) because of its richness in agriculture. It is strategically located and produces both root and tuber crops – yam, cassava, cocoyam and the selected crops, - rice, maize, sorghum and soybeans which make-up major staples among the populace (Odoemenem and Asogwa, 2010).

This research will help to broaden the knowledge of farmers in Benue State about the variability of rainfall parameters and their implications on the yield of the selected crops which happen to be the major staple crops in the state. This will help to foster planning by the BNARDA and other agricultural agencies. The amount of rainfall received and the yield ofcropsgenerallyarechanging.Therefore,constantmonitoringwillhelpthefarmershave contemporalknowledgeonthisproblem.Furthermore,thisstudywillnotonlyhelpfarmers

of the selected crops, but also farmers of other crops. As the climatic condition keeps changing, this study may further ignite or catalyze other studies to be carried out in Benue State, on other agricultural products which are produced in the state such as: Cassava, beniseed (sesame) and also tree crops to foster planning so as to keep the basket consistently and constantly full.

CHAPTER TWO

CONCEPTUAL ISSUES AND LITERATURE REVIEW

2.1 Conceptual Issues

2.1.1 Rainfall

Rainfall is a form of precipitation commonly experience in the tropical regions of the world (Aphu *et al.*, 2015). Precipitation is the general name given to all forms of moisture that falls from the atmosphere on to the earth surface. Rainfall is liquid water dropping from the atmosphere to the earth surface, ranging from 1–5 mm in diameter (Chinago, 2020). For condensation and precipitation to occur there must be an appreciable ascent of an air mass. This ascent is brought about in three ways. Therefore, there are three main types of rainfall: Convectional rainfall, Orographic or relief rainfall and frontal or cyclonic rainfall. However, convectional rainfall is the type of rainfall that is predominant in the study area which falls within the tropics (Aphu *et al*., 2015). Convective rainfall is caused by natural rising of warmer, lighter air in colder, denser surroundings. On a hot day, the ground surface gets heated unequally, causing the warmer air to uplift as the colder air comes to take its place. The uplifted air, cools down adiabatically, and then condenses on the condensation nuclei in the atmosphere. When water vapor rises further, it converges and moves gradually upwards. As the air converges, it condenses to form thick cumulous clouds. The rising clouds become heavier and unstable. This unstable cloud then drops to the ground as raindrops or rainfall (Alexander, 2012 and Aphu, *et al.*, 2015). The type of rainfall produced reflects the circumstance in which it is formed. It is the major depositor of fresh water on the earth surface in thetropics.

Water provides the medium by which chemicals and nutrients from the soil are carried through the plant. Water is also the main constituent of the physiological plant tissue and a reagent in photosynthesis (Mage, Iorlamen and Orvesen, 2015). Soil moisture is the source

of water which is of primary importance to crops and the state of soil moisture is controlled by rainfall, the evaporation rate and soil characteristics. The supply of soil moisture may range from wilting point when no water is available for plant use to field capacity when the soil is fully saturated with moisture but is still well drained. When soil moisture is excessive, all the soil pores are completely filled with water and a waterlogged condition prevails. In such a situation, free movement of air within the soil is impeded and compounds toxic to the roots of plants may be formed. At the other extreme is the condition of drought in which the amount of water required for evapotranspiration exceeds the amount available in the soil. Unless this water deficit is made good by rainfall or irrigation, the plant will begin to wilt anddie.

The importance of rainfall in the tropics can never be underestimated. In fact rainfall is everything for tropical indigenous people. It determines the food they eat, clothes they wear, the types of activity and their agricultural calendar (Chinago, 2020). Rainfall provides most of the needed water for agriculture in the tropics. It is the most unreliable element and the least predictable element of climate in the humid tropics. Its role in agriculture is ever more spectacular in the tropics because of relatively high temperature throughout the year, and the rate of evaporation is constantly high. On the other hand, rainfall is highly seasonal over most parts of the tropics with exceptions of few mountain areas; the growing season/harvest unlike in the temperate region is determined by the availability of rainfall (Alexander, 2012). Rainfall occurrence however, depends on other elements of climate like wind, temperature, cloud cover, sunshine and relative humidity (Chinago, 2012).

212 Rainfallvariability

The degree to which rainfall amounts vary across an area or through time is an important characteristic of the climate of an area. This subject area in meteorology or climatology is

called rainfall variability. Rainfall variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes and so forth) of rainfall on all spatial and temporal scales beyond that of individual precipitation events (Odjugo, 2010 and Chinago, 2020). Theoretically according to National Earth Science Teachers Association [NESTA] (2003), there are three different forms of rainfall variability;

(a) Spatial,

(b) Inter-annualand

(c) Intra annualvariabilities.

Spatial variability has to do with differences in total rainfall received between places structurally located within a given region. Inter-annual rainfall variation is defined as the annual deviation from long-term averages or the differences in rainfall between years. Intra-annual rainfall variability refers to the distribution of rainfall within a year. Inter–annual and seasonal rainfall variability are key factors in the success of agricultural production, particularly where it is rain-fed (Ngetich, Mucheru-Muna, Mugwe, Shisanya, Diels and Mugendi, 2014). Rainfall variability adversely impacts crop production and imposes a major constraint on farming planning, mostly under rain fed conditions across developing countries (Bashiru, Wende, Mohammed, Mohammed, Adem and Demmisie 2020).

213 Rainfallparameters

Rainfall parameters are also referred to as ‘rainfall effectiveness indices’ or ‘precipitation effectiveness indices’. Rainfall parameters are the portion of total annual or seasonal rainfall which is useful directly or indirectly for crop production to the site where it falls (Cooper, 2009). Agriculturalists on the other hand consider rainfall parameters as the portion of the total rainfall which directly satisfies crop water needs (Bello, 2012).

According to Sawa (2019), rainfall has many variables or parameters, all of which are of great importance to agriculture. These parameters are usually derived from the amount of rainfall received. They include; Onset Date (OD), Cessation Date (CD), Length of the Growing Season (LGS), Monthly Rainfall (MR), Annual Rainfall (AR), Hydrological Ratio (HR), Number of Rainy Days (NRD), Rainfall Intensity (RI), Specific Water Consumption (SWC), Amount of Rainfall in months of the Growing Season (May, June, July, August and September) [ARMGS], Seasonality Index (SI), Index of Replicability, and Pentad Dry Spells (Sawa,2019).

2.1.4 Effect of rainfall variability on cropproduction

Generally, rainfall regime is the leading climatic factor influencing crop production. This is because rainfall has the major effect in determining the crops that can be cultivated in diverse environments, the type of agricultural system to be practiced in different parts of the world, the farming system, the sequence and timing of farming operations (Adejuwon, 2005; Ayanlade and Orimoogunje, 2010).

In respect to the above, Tunde, Usman and Olawepo (2011) and Fosu-Mensah (2012) have recognized some important factors guiding rainfall in relation to crop production. According to Tunde, Usman and Olawepo (2011) and Fosu-Mensah (2012), the number of rainy days (the length of the rainy season), time of fall (onset) and total amount of fall, cessation and the type of soil are some of the important factors guiding rainfall in relation to crop production. Therefore, a disruption in the onset and cessation dates and length of the rainy season will have an effect on soil moisture (soil moisture deficit and enhanced soil moisture), hence, crop development. According to Fosu-Mensah (2012), soil moisture deficit and also the timing of moisture deficits during growing seasons causes crop damage instagesofplantdevelopment.Assuch,wateruseforagivencropisafunctionofboth theamountofwateravailabletothecropandthetimethatsuchwaterisavailablerelative

to crop demand. On one hand, Rosenzweig, Tubiello, Goldberg and Bloomfield (2001) affirmed that enhanced soil moisture encourages the spread of nematodes and roundworms that inhabit water films or water-filled pore spaces in soils.

Moreover, increases in rainfall intensity in other regions could lead to higher rates of soil erosion, leaching to soil nutrients and agricultural pollutants, and runoff that carries soil and associated nutrients into surface water bodies leaving the soil impoverished to support plant growth (Kumar, Ashrit, Deshpande and Hansen, 2004; Gornall, Betts, Burke, Clark, Camp, Willet and Wiltshire, 2010). If erosion and leaching of soil rates go unchecked, continued soil failure would eventually force farmers to abandon their lands (Khan, Kumar, Hussain, and Kalra, 2009). From the foregoing, both direct and indirect effects of moisture stress make crops more vulnerable to damage by pests, especially in the early stages of their development. According to Cheke and Tratalos (2007) and Gornall, *et al*., (2010), rainfall variability has the tendency to cause pest migration. A typical example is the migration pattern of locusts into Sub-Saharan Africa which Mowa and Lambi (2006) believe is influenced by variability in rainfall patterns. The migration of these locusts into Sub-Sahara Africa poses danger to food security and livelihoods in theregion.

In history, many of the largest declines in crop productivity have been accredited to sudden low rainfall events (Kumar, *et al*., 2004 and Sivakumar; Das and Brunini, 2005; Gornall, *et al*., 2010). An open question is how susceptible food crop production might be to increased rainfall variability? Several studies have been carried out on specific crops in different parts of the world to assess this situation. For example, according to Osbourne and Wheeler (2013), globally, between 1960 and 2009, rice yields declined significantly as a result of low rainfall. Consideration of the observed relationship between yield and climate suggests that the significant reduction in the variability of rainfall may have contributedtothereductioninriceyield.Similarly,analysisbyAsha,GopinathandBhat

(2012) in India also concluded that the yields of sorghum, maize, pigeon pea, groundnut, wheat and onion have decreased by up to 43.03, 14.09, 28.23, 34.09, 48.68 and 29.56 kilograms per hectare respectively. The decrease in the crops yield, according to sampled farmers was attributed to the reduction of rainfall.

However, Cabas, Weershink and Olale. (2010) are of the opinion that, with prolonged rainfall, some crops may likely exhibit reduced yields while others might show improved yields. An example is a research carried out in Argentina which showed that during the last decades of the twentieth century, increases in the yield of summer crops were caused primarily by increases in rainfall (Magrin, Trabaos and Rodr'iguez, 2005). In support of the above findings, Bradford, Lauenroth, Burke and Paruelo (2006) added that in wetter areas, warmer temperatures have less influence on water availability and can increase production by promoting longer growing seasons and faster photosyntheticrates.

However, it is important to note that, minor changes in rainfall pattern during stages of crop production threaten crop productivity particularly if the rains fail to arrive during the crucial growing stage of the crops (Mowa and Lambi, 2006). Generally, at aggregated level, rainfall variability is a primary cause of inter annual yield variability (Thornton, Ericksen, Herrero, Challinor,2014).

2.2 LiteratureReview

221 Trends in rainfall and selected cropsyield

Hornby (1948) define trend as a general direction in which a situation is changing or developing. Hence, trends in rainfall and crops yield is the general direction in which rainfall and crops yield is changing over time. This change could be increasing or decreasing. There are several studies which have examined the occurring trend of rainfall parameters and crops yield. Some of these studies include but not limited to the ones discussed herein.

2.2.1.1 Trends inrainfall

Mondal, Kundu and Mukhopadhyay, (2012) in their Mann-Kendall test for annual rainfall, the Z statistics revealed the trend of the series for 40 years for individual 12 months from January to December which were 0.652, -1.56, -0.594, -0.315, 0.198, 0.804, -0.711, -1.247, 1.34, 0.408, 1.363 and -0.827 respectively. For January, May, June, September, October and November there was an evidence of increasing trend while Z value was showing negative trend in February, March, April, July, August and December. Thus Z values for six months showed a positive trend and for other six months it showed negative trend representing almost non-significant condition in North-Eastern Part of Cuttack District, Orissa, India.

Karmeshu (2012) examined the trend in annual temperature and precipitation to assess climate change on selected States in the Northeastern United States. The resultant Mann-Kendall test statistic (S) showed that precipitation of some states in Northeastern United States such as New Hampshire and Maine do not show statistically significant results, while the other states (New Jersey, Pennsylvania, New York, Connecticut, Massachusetts, Rhode Island and Vermont) showed statistically significant increasing trends. On the contrary, the linear trend line indicates a decreasing trend for Maine, while the other eight states (New Hampshire, New Jersey, Pennsylvania, New York, Connecticut, Massachusetts, Rhode Island and Vermont) have an increasing trend that ranges from 0.03 to 0.13 mm/yr.

Guhathakurta and Saji (2013) observed significant increasing trends in Seasonality Index (SI) in Mumbai, Pune, Buldhana and Amraoti districts. SI also showed increasing trend for the districts of Thane, Nandurbar, Dhule, Jalgaon, Nasik, Ahmednagar, Solapur, Satara, Sangli, Kohlapur, Ratnagiri, Sindhudurg, Akola, Washim, Yeotmal, Nanded and Gadchiroli. Significant decreasing trends were noticed in Jalna and Latur (significant)

while the districts, Raigad, Aurangabad, Beed, Osmanabad, Parbhani, Hingoli, Wardha, Nagpur, Bhandara, Gondia and Chandrapur showed non-significant decreasing trends.

Ndamani and Watanabe (2014) observed decreasing trends in both annual and average monthly rainfall totals using time series analysis in their study on rainfall variability and crop production in Lawra district of Northern Ghana. This implies that the study area is becoming drier thereby causing increase in dry spells.

Omoyo, Wakhungu and Oteng'i (2015) studied the effects of climate variability on maize yield in the arid and semi-arid lands of lower eastern Kenya. Their Rainfall trend analysis revealed that four out of the six weather stations were declining up to 3 mm pa. Hence, Kenya is becoming drier.

Using Mann Kendall trend test, Barnabas, Tumbo, Kihupi and Filbert (2017) in their study on performance of sorghum varieties under variable rainfall in central Tanzania, observed decreasing trends in onset and cessation dates and length of growing season in the study area in the years reviewed.

Nandargi, Mahto and Ram (2017) found out in their study on changes in seasonality index over sub-divisions of India during1951-2015 that the trends of seasonality index through the 65-year period was increasing in Uttaranchal, Himachal Pradesh, Gujarat Region-Dadra and Nagar Haveli; Saurashtra-Kutch and Diu, Konkan and Goa, Madhya Maharashtra, Marathwada, Chattisgarh, Tamilnaduand Pondicherry. The analysis clearly showed the climate change impact on northwest sub-divisions of the country showing increase in seasonality index (SI) values leading to dryness during the monsoon season. The negative trend in SI values was observed in Sub- Himalayan West Bengal, Haryana-Delhi-Chandigarh, Punjab, Jammu and Kashmir, West and east Rajasthan, coastal Andhra

Pradesh showing increasing wetness for an already wet months although rainfall occurs in a very short period of just a month ortwo.

Koudahe, Koffi, Kayode, Awokolaand Adebola (2018) noticed a non-significant increasing trend in annual precipitation (P>0.05) in Atakpamé, Lomé and Tabligbo, while Kouma-konda revealed a non-significant decreasing trend (P>0.05) in their study on impact of climate variability on crop yields in SouthernTogo.

Mrad, Djebbar and Hammar (2018) studied the trend of rainfall of North-Eastern Algeria using the Mann Kendall statistics. The stations with positive trends had their own specificities. Some were located between the mountains while others at low altitude near the sea. The magnitudes of positive trends in annual rainfall were recorded at Jijel station (5.915 mm), Ouled Naceur (3.445 mm), AinFakroune (5.705 mm) Helio Police (22.951 mm), Machroha (2.181 mm) and AinBerda (2.707 mm) districts while the negative trends were recorded in the districts Taoura (–5.657mm) in AinSedjra (–2.946 mm) and Foum el Khanga (–2.500 mm) at level 0.90 to –3.126 mm in Boukhadra districts at level 0.99. On an average, the annual rainfall in the region was on theincreased.

Nahayo, Habiyaremye, Kayiranga, Egide, Mupenzi and Nsanzimana (2018) studied rainfall variability and its impact on rain-fed crop production in Rwanda. The input data were the seasonal maize cropland, production and monthly maximum rainfall analyzed with use of Origin Pro Software for Statistical Analysis. The results indicated decreasing rainfall in 2015, specifically at the Kibungo-Kazo (from 273.4 to 81.3 mm), Nyagatare (from 105.8 to 52.2 mm) and Kabarondo meteorological stations (from 214.9 to 70.6 mm) in March and April, respectively. Similar rainfall decreasing trends were recorded in2016.

Chiambah and Kometa (2019) examined rainfall variability and food crop vulnerability in Ndu Sub-Division, North West Region of Cameroon. The primary data weregotten

through field surveys. A total of 200 farmers were sampled and questionnaire was administered to them. Descriptive and inferential statistical techniques were employed to analyze the data. Result revealed a decreasing trend in rainfall. Also from the data collected, 197 respondents agreed that there has been a decreasing trend in onset (early start) of rains and decreasing trend in cessation (early end) of rains whereas 65 respondents were of the opinion that there has been increasing onset (late start) of rains and increasing cessation (late end) of rains in the studyarea.

The Mann Kendall trend result of Sharma and Singh (2019) showed that the seasonality index exhibits a decreasing trend for the northeast of Jharkhand in India, though the magnitude was very small. The maximum declining trend for seasonality index was observed over the northeast and the minimum over the southwest of Jharkhand.

Rainfall characteristics in Nigeria have been examined for dominant trend. They include but not limitedto:

Adefolalu (1986) studied the rainfall trends for periods of 1911–1980 over 28 meteorological stations in Nigeria with 40 years moving average showing appearance of decliningrainfall.

The studies of Olaniran and Sumner (1989) and Oluwasegun and Olaniran, (2010) showed that there has been a progressive early retreat of rainfall over the whole country (Nigeria) and consistent with this pattern, they reported a significant decline of rainfall frequency in September and October which respectively coincide with the end of the rainy – season in the northern and central parts of the country.

Oguntunde, Abiodun and Lischeid (2011) analyzed rainfall trends over Nigeria using 1901–2002 rainfall data from Global Gridded Climatology of Climate Research Unit Time

series (CRU TS.2.1). They concluded that annual rainfall has been reduced significantly over 20% of the landscape and the amount of annual rainfall reduced by 50–350 mm in 64% portion of Nigeria.

The study of Akinsanola and Ogunjobi (2014) indicated that there have been statistically significant increases in precipitation and air temperature in vast majority of the country (Nigeria). Analyses of long-time trends and decadal trends in the time series further suggested a sequence of alternately decreasing and increasing trends in mean annual rainfall and air temperature in Nigeria during the study period (1971 – 2000).

Ogungbenro and Morakinyo (2014), worked on rainfall distribution and change detection across climatic zones in Nigeria. Statistical methods were utilized to justify any change in the average monthly and annual rainfall trend using probability density function and non-parametric tests such as the Pettitt test, Wilcoxon signed-rank test and paired sample test. Results showed common change points and transitions from dry to wet (upward shift) in all climatic zones. Statistical tests performed on the data showed that rainfall variation over each climatic zone is significant ($p<0.05$) between pairs of climateperiods.

Trends and spatial analysis of temperature and rainfall on rice yield in Nigeria was carried out by Akinbile, Ogunmola, Abolude and Akande (2020). Geographic information systems mapping for spatial analysis of temperature and rainfall over Nigeria was carried out. Mann–Kendall, Sens' tests, Pettitt's, and Buishand's tests and multiple linear regressions were used as statistical tools for analysis. Increasing rainfall trends in Enugu, Calabar, and Ikeja but decreasing trends were observed in Ilorin Kaduna and Maiduguri while temperature showed increasing trends in all the cities in the last four decades.

Hess (2000) observed that over the period of 1961-1990, the northeast arid- zone of Nigeria experienced a decline in the trend of annual rainfall which led to decline in millet yields in the studyarea.

Aliyu (2009) carried out a research on the consequence of the recent trends and variability in the duration of the growing season for food crop production in Northern Nigeria and observed a downward trend in the duration of the growing season in some locations from 1978 - 2007, with a significant variability in most of the stations north of latitude 9^{o}N of Nigeria even though he did not relate the trends of the growing season and monthly rainfall with current trends of yields of some major crops grown in the studyarea.

Sawa and Adebayo (2011) studied the impact of precipitation effectiveness indices on crops yield in northern Nigeria. The Six precipitation indices examined were; onset, Cessation and length of rainy season, hydrology ratio, seasonality index and occurrence of pentad dry spells. Results of the analysis showed that the onset date was increasing with a trend line equation of $y = 0.1711x + 40315$, the cessation was decreasing with a negative trend line equation of $y = -0.2218x + 40.452$ and as a result, length of the rainy season was decreasing with a negative trend line equation of $y = -0.3758x + 138.06$. Northern Nigeria is becoming drier as the rainy season is now spread within fewer months. The seasonality of rainfall was shortening. The negative best fit line equation agrees with the shorting of the rainy season in the region.

Sawa and Adebayo (2011) considered the impact of climate change on precipitation effectiveness indices in Northern Nigeria and noticed the decrease in length of rainy season, as northern Nigeria gets drier, the rainy months get fewer and dry spell incidents are on the increase, posing an imminent threat to crop production in the region.

Abaje, Ati and Iguisi (2012) studied the recent trends and fluctuations of annual rainfall in the Sudano-Sahelian Ecological Zone of Nigeria. They found out that the trend of rainfall within the study area was increasing. They further highlighted on the positive and negative implications of such increase to the study area.

Chinago (2015) in his study on length of rainfall season and its implication over Enugu South - East Nigeria, observed an increase in the trend of onset and a decrease in the trend of cessation dates respectively over the region. This means that the study area is becoming dryer as the rainy season is starting late and stopping early.

Chikezie, Ibekwe, Ohajianya, Orebiyi, Ehirim, Henri-Ukoha, Nwaiwu, Ajah, Essien, Anthony and Oshaji (2015) observed a decreasing trend in the number of rainy days in their study on the effect of climate change on food crop production in southeast, Nigeria within 1984 to 2014.

Dammo, Ibn Abubakar and Sangodoyin (2015) quantitatively analysed the rainfall variations in North-eastern region of Nigeria for 30 years (1981 to 2010). Rainfall in the study area was analysed for Yobe, Borno, Bauchi, Adamawa, Gombe and Taraba. Yobe recorded the least average rainfall over the years across the study area while the highest average rainfall was recorded in Taraba State. There was visible pattern of rainfall fluctuations with periodic trends in all the locations. Quantitatively rainfall increased at the rate of 40.59 to 132.67 mm/month and decreased at a rate of 2.918 to 9.673 mm/month in the study area. Therefore, rainfall was on the increase within the duration of consideration. The decadal means were compared. Evidence from the six stations considered showed that there was also a significant increase in annual rainfall amount in the last decade of the study. It means, therefore, that north eastern zone of Nigeria was experiencing wetter conditions.

Atedhor (2016) carried out a research on the planting season's rainfall trends and droughts in the forest belt of Nigeria. The results revealed declining trends of the annual rainfall in Warri, Port Harcourt, and Calabar, with regression coefficients of -0.71, -1.94 and -0.31 respectively, while Ondo and Benin showed increasing trends with regression coefficients of 0.17 and 0.11 respectively. Warri, Ondo, Port Harcourt and Calabar revealed decreasing trends of the number of rain-days with -0.07, -0.09, -0.12 and -0.05 regression coefficients respectively while only Benin showed increasing trends with regression coefficients of 0.02.

Ntat *et al.,* (2018) observed that the annual rainfall amount experienced in North-Central Nigeria was between 1100 mm and 1700 mm. Out of the six stations studied; only Abuja indicated statistically significant increased trend while the other five stations (Ilorin, Jos, Lokoja, Makurdi and Minna) in the region showed no significant trend using the Mann Kendall statistics. They also noted that rainfall distribution in the region was largely influence by the Jos Plateau rather than Latitudes or Longitude. Ntat, *et al.,* (2018) also studied on rainfall variability and the impact on maize and rice yields in North – Central Nigeria using Mann-Kendal test and Kriging methods. The result revealed a statistically significant increasing trend in annual rainfall amount in Abuja, Lokoja and Ilorin while Jos, Makurdi and Minna showed statistically non-significanttrends.

Adamgbe and Ujoh (2012) in their study on variations in climatic parameters and food crop yields in Benue State, Nigeria observed that onset and cessation dates of the rainy season, duration of the rainy season and number of rainy days were on downward trend whereas annual rainfall total was on an upwardtrend.

Ayinde, Ojehomon, Daramola and Falaki (2013) in their research on evaluation of the effects of climate change on rice production in Niger State, Nigeria observed and

increasing trend in annual rainfall using line graphs in the study area within the study period of 1981 – 2010.

The study of Oruonye (2014) examined the trends of climatic variables in Taraba State. The result using simple correlation coefficient showed that all the stations exhibited a similar trend of increasing temperature with exception of Gembu where the temperature is decreasing. Annual rainfall showed increasing trend in the southern and central part of the state with exception of Lau in the northern part of the state. All the four stations where synoptic data were obtained (Gembu, Gassol, Ibi and Lau) showed increasing trends of onset (late onset) of rain, while only Ibi showed increasing cessation (late cessation) of rains. Length of rainy season in the study area showed decreasing trend in all the stations with the exception of Ibi, where it was relatively stable. According to him, the implication of such a trend, mean a reduction in annual rainfall, and hence reduced crop yield, especially if the trend persisted for a long period of time, which can lead to a tendency towards a drier condition.

Okeowo, Ogunbameru and Ogunyemi (2015) in their study on the effect of rainfall variability on Maize Production in Lagos state employed the use of secondary data of rainfall and maize yield spanning for 10 years from 1997 to 2006. The data were analyzed using descriptive statistics and simple linear regression. The results also showed an increasing trend in annual rainfall within the study area.

Akinbobola, Okogbue and Ayansola (2018) reported the work of Adeleke and Abiodun (2017) on statistical analysis of rainfall trend in Akure and Ondo states, Nigeria. Descriptive statistics (mean and standard deviation) and inferential statistics (time series and correlation analysis) were used. The results from time series analysis showed that rainfall fluctuated in an upward trend through the period of study. The predicted rainfall

for 2016-2045 indicated a positive trend of (+0.274); meaning that rainfall will increase in intensity, number of raining-days and duration. The study equally revealed a significant increase in rainfall trend for Akure between 1966 and 2015.

Agidi, Hassan, Baleri and Yilgak, (2018) in their study on the effect of inter-annual rainfall variability on precipitation effectiveness in Nasarawa State, Nigeria observed increasing trend of onset date in Toto,Wamba, Akwanga, Nasarawa, Awe, Obi, Keana, Kokona, Nasarawa-Eggon and Keffi local governments, increasing trend of cessation date in Nasarawa, Nasarawa-Eggon, Kokona, Obi, Keana, Awe, Karu and Keffi Local governments and increasing length of growing season in Keffi, Lafia and Doma local governments. The result implied that, most of the local governments in the state will witness delayed onset, late cessation date and long length of growingseason.

Itiowe, Hassan and Agidi, (2019) analyzed rainfall trends and patterns in Abuja, Nigeria. Daily rainfall data for 31 years was used for the study. The daily rainfall data was subjected to several analyses. The result obtained indicated that there is a downward trend in the rainfall amount received in Abuja over the last 31 years. Also, a gradual decadal decline in rainfall was observed using the Standard Precipitation Index (SPI) to compare the three decades underreview.

Haruna and Murtala (2019) did a comparative study between length of the growing season and millet and sorghum yields in Kano state Nigeria. The result of their trend analysis with least square regression model revealed that the trend of length of the growing season in the study area was positive, meaning that the trend was increasing with a linear trend line equation $y = 0.5517x - 968.43$.

Chinda (2019) observed an increasing trend in onset date with the trend line equation; y = 0.034x + 42839, increasing trend in cessation date with the trend line equation y = 0.7354x

+ 42984 and an increasing length of rainy season with the trend line equation of y = 0.7644x+143.29 in Jos South local government area of Plateau State, Nigeria. This implies that, the rains has been starting late and also ending late thereby leading to longer length of the growing season.

Idumu, Ishaya, Bello and Ifeka (2020) in their studies on evaluation of onset and cessation of rainfall and temperature observed an increasing trend of Onset, cessation and length of growing season in Akure, Ondo State, Nigeria.

Ekoh (2020) analysed rainfall trends in Sokoto State between 1987– 2016. He found out that the trend of onset date was decreasing whereas the trends of annual rainfall, cessation date and length of growing season was progressively increasing within the study area.

Onyeneke, Amadi, Njoku and Emenekwe (2020) studied the empirical trend analysis of climate variability in Ebonyi state, Nigeria. They found out that there was no Significant decreasing trend at 0.43% per annum for rainfall in the area during the period under study using nonparametric Man Kendall trend test.

The study of Abulhamid and Abubakar (2002) found that Katagum Zone, Bauchi State have a high hydrologic ratio and low seasonally index due to long dry season of at least seven months.

The study of Abaje, Ishaya and Usman (2010) on analysis of rainfall trends in Kafanchan, Kaduna State revealed a decreasing trend in annual rainfall over the region within the period of 1974-2008. This means that Kafanchan is becoming dryer.

Ocholi, Ocholi and Isah (2016) conducted a study on trends analysis of rainfall features and its influence on the socio-economic development of Anyigba, Kogi state - Nigeria. ThreeyearsrainfalldataofAnyigbacovering2008,2009and2010wereassessed.The

data were analyzed with time series statistics to determine the changing pattern of rainfall for the study period. The summary of the analysis however showed a decline in rainfall intensity from 2008 to 2010. This can be interpreted according to them to mean a decline in available moisture for cropping, low crop yields and reduced farmingactivities.

Oruonye, Ahmed, Gambo and Tukura (2016) examined the impact of rainfall variability on maize yields in Gassol LGA of Taraba State. Specifically, the study examined the trend of rainfall variability on maize crop production and the relationship between rainfall variability and maize yield in the study area using time series, regression and correlation statistical analyses. Their observation showed that there was increase in the trends of annual rainfall and onset date of rain and decrease in the trends of cessation date and length of the growing season in GassolLGA.

Isioma, Rudolph, Omena (2018) using Mann – Kendall test discovered that the rainfall data of Benin City shows statistical significant evidence of an increasing trend with a computed M-K trend value of +124 while the rainfall records from Warri did not have sufficient statistical evidence of a significant trend, the computed M-K trend value was -96 which showed evidence of decreasingtrend.

Oloruntade, Mogaji and Imoukhuede, (2018) in their study on rainfall trends and variability over Onitsha on annual basis, an insignificant negative trend was observed for the studyperiod.

2.2.1.2 Trends in cropsyield

Omoyo, *et al.,* (2015) found out in their study on the effects of climate variability on maize yield in the arid and semi-arid lands of lower eastern Kenya that maize yields were declining at high levels in Machakos County followed by Kitui, Mwingi, and Makueni Counties.

Raju and Phanindra (2020) examined the effects of climatic factors on mean yields and yield variability of four primary crops (rice, cotton, jowar and groundnut) in Telangana state, india. The result of their study revealed increasing trends of rice and groundnut yields in the studyarea.

Bamiro, Adeyonu, Babatunde, Solaja, Sanni, Faronbi and Awe (2020) studied the effects of climate change on grain productivity in Nigeria. The result of their trend equations showed that there were positive trends in the outputs of all the grain crops (maize, millet, rice and sorghum) in the years under review (1970-2014) with the exception of rice which shows a downwardtrend.

Haruna (2014) examined the relationship between rainfall variability on millet (*Pennisetum americanum l.*) and sorghum (*Sorghum bicolor (l) moench*) yields in the Sudan savanna ecological zone of Nigeria using ogive of cumulative pentad rainfall, trend lines and linear trend line equations, product- moment correlation coefficient (r) bar chart and stepwise multiple regression analyses. There was an increasing trend in millet and sorghum yields in the studyarea.

Hassan (2014) evaluated the pattern of rice production in the Federal Capital Territory (FCT), Nigeria. The study relied essentially on secondary data hence data on rice yield were obtained from Abuja Agricultural Development Project (AADP), rainfall and temperature from NiMet all in the FCT. The data obtained were subjected to descriptive statistic such as bar charts, pie charts and line graphs. The result also shows that the trend of rice production in the FCT is increasing which implies there is a positive linear trend along with cultivated area which means that there is room for future increase and even production of rice for export.

Chikezie *et al.,* (2015) discovered a decreasing trend in maize yield in their studies on effect of climate change on food crop production in Southeast, Nigeria.

Adamgbe and Ujoh (2012) in their study on variations in climatic parameters and food crop yields in Benue State, Nigeria observed that the trends of cassava, yam, groundnut, sorghum and soya beans yields were increasing while the trends of rice and maize yields weredecreasing.

Ayinde *et al.,* (2013) in their research on the evaluation of the effects of climate change on rice production in Niger State, Nigeria observed and increasing trend in rice yield using line graphs in the study area within the study period of 1981 – 2010.

Emeghara (2015) studied the effect of precipitation effectiveness indices on the yield of some selected cereal crops in Sokoto state, Nigeria. The findings revealed that the trends of rice and maize yields in the study area within the study period were increasing using time seriesanalysis.

Okeowo *et al.,* (2015) in their study on the effect of rainfall variability on Maize Production in Lagos state employed the use of secondary data of rainfall and maize yield spanning for 10 years from 1997 to 2006. The data were analyzed using descriptive statistics and simple linear regression. The results also showed an increasing trend in maize yield within the studyarea.

Agidi, Hassan and Baleri (2017) studied the trends of staple crops yields in Nasarawa state, Nigeria. Crop yields data were collected from the archives of Nasarawa Agricultural Development Programme for the years 1998-2016. The yields were subjected to simple regression analysis in order to determine the trends of the yields. Results showed that maize and yam yields were on the positive trends with trend lines Y= 0.0024x+2.1391and

Y=0.391x +13.58 respectively while rice yield was on the decrease all over the state with the trend line Y= -0.00309x +2.5312.

Haruna and Murtala (2019) did a comparative study between length of the growing season and millet and sorghum yields in Kano state Nigeria. The result of their trend analysis with least square regression model revealed that the trends of millet and sorghum in the study area were negative, meaning that the trends were decreasing with linear trend line equations = −0.0979 − 197.88 for millet and = −0.0526 − 107.27 for sorghum. This means that as the trend of length of growing season increases the trends of millet and sorghum yields decreases in the study area over the studyperiod.

Oruonye, *et al.*, (2016) examined the impact of rainfall variability on maize yields in Gassol LGA of Taraba State. The employed time series analyses to observe the trend of maize yield. They found out that the trend of maize yield in the study area was decreasing with a trend line equation of = −0.0069 + 1.8643.

Akinbile, *et al.*, (2020) observed increasing trend of rice yield in Ikeja and Maiduguri using Mann Kendall statistics in their studies on trends and spatial analysis of temperature and rainfall patterns on rice yields inNigeria.

Idumu, Ishaya, Bello and Ifeka (2020) in their studies on evaluation of onset and cessation of rainfall and temperature observed an increasing trend of maize yield in Akure, Ondo State, Nigeria.

222 Crop – climate relationshipstudies

Climate plays a very significant role at every stage of crop production. Hence, there exist a relationship between crop production and climate. According to Olaniran (1981), this

relationship could be studied in three approaches namely; fundamental, empirical and controlled environment approaches.

2.2.2.1 Fundamentals of crop – climaterelationship

According to Ogutoyinbo (1972), few studies on the fundamental approach on crop-climate relationships in Nigeria exist due to limitations of data. Some of these studies include:

Kowal and Kassem (1973) computed gross and net photosynthesis for both the forest and Savanna zones of Nigeria, and reported that mean at photosynthesis throughout the year in the Savanna zone is 20-40% was greater than in the forest and 19-34% greater than in the forest during the growing season. They also computed the rates of dry matter production and yield of different cereal crops for the two zones and observed the rates of dry matter production are nearly twice as high in the Savanna zone as in the forest zone, and yield for all crops are over 70% greater in the Savanna zone.

Kowal and Andrews (1973) investigated the pattern of water requirements for two varieties of Sorghum (short kaura and American hybrid) at Samaru in Zaria Local Government Area, Nigeria. Their result indicated that the American hybrid had a shorter growing season and gave higher grain yield but of low quality because it matured during a period of high rainfall andhumidity.

2.2.2.2 Empirical approach to crop – climaterelationship

An empirical approach is one in which crop-climate relationships are studied for a number of places within a given area for a long period of time where records of both climate and agriculture are available and agro – climatological relationships can be deduced from the data. There are several empirical studies on crop-climate relationships. Some of which include;

Rowhani, Lobeu, Linderman and Ramankutty (2011) studied climate variability and crop production in Tanzania. They found out that inter and intra-seasonal changes in precipitation and temperature are associated with changes in maize, sorghum and rice yields. However, increased precipitation variability during the growing season reduced the yields of maize, rice and sorghum in the study area within the study period (1992 – 2005) using regression model.

Rashia and Rasul (2013) found out from their study on rainfall variability and maize production over Potohar plateau of Parkistan that excess or deficit rain badly affects grain yields especially at early and reproductive stages. The Polynomial regression technique was employed to study the relationship of rainfall received at different stages and coefficients of correlation R^2. The analysis revealed that increase in rain enhances the yield up to certain limits afterward the grain yield decreases. They concluded on the average that in Potohar Zone, 300 mm of rainfall is required during growing season, 250 mm during vegetative phase and 200 mm during reproductive phase to obtain the best yield. The relation of rainfall and the yield obtained in Potohar zone was57%.

The correlation result of Ndamani and Watanabe (2014) in Lawra district of Northern Ghana showed that maize, sorghum, millet, cowpea and groundnut had negative correlations with annual rainfall. However, with seasonal rainfall, sorghum, millet and groundnut showed negative correlations. Only maize and cowpea showed positive correlations with seasonal rainfall. Correlations for sorghum and groundnut were found to be statistically significant while that for maize, millet and cowpea were not statistically significant.

Rashida (2016) examined the effect of climate variability on food crop production in the Bawku Municipality, Ghana. Five farming communities were selected in the Bawku

Municipality as the study sites. Quantitative and qualitative data were sourced from both primary and secondary sources. Questionnaires, focus group discussions and oral narratives were used as data collection tools to assess the situation. Quantitative data were analyzed with SPSS and E-views and the results presented in the form of charts and tables whiles qualitative data were analyzed thematically to support the quantitative data. The results indicate a significant variation in annual rainfall for the 15 year period (1999 to 2013) but mean temperature variation in the Municipality was relatively stable. The results of the regression model revealed that rainfall significantly explains variation in maize production while temperature was not significant in explaining the variation of rice, maize and milletproduction.

The study of Barnabas, Tumbo, Kihupi and Filbert (2017) confirmed that rainfall variability indeed affects yields of improved sorghum varieties. Further analyses of simulated sorghum yields based on seasonal rainfall distribution indicate the concurrence of lower grain yields with the 10-day dry spells during the cropping season in central Tanzania.

The study of Mugiyo, Mhizha and Mabhaudhi (2018) involved a survey of current farmers' cropping practices, analyses of climatic data (daily rainfall and daily minimum and maximum temperature) of Hwedza (Zimbabwe) station and simulation of maize yield response to climate change using DSSAT CERES crop growth simulation model. The climatic and maize yield data was analysed using mean correlation and regression analyses to establish relationships between rainfall characteristics and maize yield in the study area. Survey results showed that maize was the staple food grown by 100% of the farming households while 8.7% also grew sorghum. The result of the correlation analysis of climatic data and maize yield showed that number of rain days hadstrong positive

relationship (r = 0.7) with maize yield. Non-significant yield differences ($p > 0.05$) between maize cultivar and planting date criteria wereobtained.

The study of Ali (2018) assessed the impact of climate variability on staple food crops production in the Northern regions of Togo using cereal and climate data over the period of 1972-2013. The linear mixed model and generalized linear mixed model were used. The results indicated that maize was the most vulnerable food crop affected by the inter-seasonal and the intra-seasonal variability of temperature and precipitation compared to sorghum and rice in the study area. He concluded that encouraging rain-fed water management would increase the rice production in the studyarea.

Tiamiyu, Eze, Yusuf, Maji and Bakare (2015) researched on rainfall variability and its effect on yield of rice in Nigeria. The mean annual rainfall data from major rice producing states and national average rice yields were analysed using descriptive statistics and regression models. Results of the analysis revealed a significant variation in mean annual rainfall across vegetation groupings in a descending order from swamp forest to Sudan savanna. Mean rainfall was adequate for rice production in all vegetation groupings except Sudan savanna where rainfall was less than the prescribed minimum quantity for rice production. Rainfall was positively related to yield of rice in all vegetation grouping except Sudan savanna but relationship was not statistically significant at 5% level. It was concluded that annual rainfall variability had statistically negligible effect on national average riceyield.

Agba, Adewara, Adama, Adzer, and Atoyebi (2017) found out that only rainfall tested significantly positive to crop output among the climate change factors in the short-run but all the factors had evidence of significant effect in the long-run in Nigeria.

Abu, Okpe, Abah (2018) observed the effects of climate and other selected variables on rice output response in Nigeria from 1966 to 2015 using an error correction model. The results showed that temperature and rainfall adversely affected rice output in Nigeria during the period studied. Also, the variance decomposition result showed that rainfall had the most drastic effect on rice output. Consequently, in order for Nigeria to mitigate the negative consequence of climate change on rice output, there is a need for the promotion of irrigationsystems.

Bamiro *et al.,* (2020) found out that more rainfall increases the yield variability on sorghum, maize, millet and rice in Nigeria. The increasing variation on rainfall also increased crop yield variability on rice. Based on the empirical findings they concluded that climate change, through an increase in actual average temperature and changing rainfall pattern has resulted to a decline in productivity of most food graincrops.

Akinola (1983) analysed the effects of climate on production of food crops in Ibadan, Nigeria and observed that agro-climatic factors correlated with the yields of maize, rice andcowpea.

Adebayo and Adebayo (1997) reported that, four critical climatic factors: hydrological ratio, onset dates of rains, number of dry spells (in pentads) during the growing season and rainfall in June influence rice yields in Adamawa State.

Abdulhamid and Adebayo (2006) observed that total rainfall, relative humidity and seasonality index together accounted for about 76% of the variation of sorghum yield at Wailo (Bauchi State). Also Adebayo, Binbol and Kwon-Ndung (2006) in their study of the influence of climatic factors on the growth of sugar cane at Numan observed total rainfall, relative humidity; minimum temperature and evaporation are critical to sugar cane growth and yield at various stages of development.

Bello (2012) studied precipitation effectiveness indices and millet yield in two Local Government Areas of Kano State, Nigeria. Their results showed that the coefficients of the four variables were significant in the analysis. The four variables; total annual rainfall (r =0.730), hydrologic ratio (r=0.787), length of the rainy season (r=0.734) and onset dates of rains (0.643) accounted for 62% of the variation in the yield of millet at Kura. While at Dambatta, the four variables, total annual rainfall (r=0.713), hydrological ration (r = 0.798), length of growing season (r = 0.718) and June rainfall (r = 0.705) accounted for 73.5% of the variation in the yield ofmillet.

Aondoakaa (2012) used simple regression, correlation and multiple regression model to correlate the relationship among temperature and rainfall on crops yield and found out that a correlation between the climatic data (rainfall and temperature) and crops yield existed. Regression value for the crops investigated were: maize 0.11, rice 0.67, cassava 0.14, ground nut 0.37 and garden egg 0.57. It was positively significant though weak and showed that rainfall and temperature influence crop yield in theFCT.

Okeowo, Ogunbameru and Ogunyemi (2015) in their study on the effect of rainfall variability on Maize Production in Lagos state employed the use of secondary data of rainfall and maize yield spanning for 10 years from 1997 to 2006. The data were analyzed using descriptive statistics and simple linear regression. The results showed that average change in rainfall impacted positively on maize yield throughout the period with a slope coefficient of 0.192 which means a unit increase in rainfall will lead to 0.192 unit increase in maize yield. The farmers were encouraged to adopt drought resistance maize varieties and collective irrigation facilities to cope with climate change phenomenon.

Oruonye *et al.*, (2016) examined the impact of rainfall variability on maize yields in GassolLGAofTarabaState.Specifically,thestudyexaminesthetrendofrainfall

variability and maize crop production and the relationship between rainfall variability and maize yield in the study area using trend, regression and correlation statistical analyses. The study finding observed that onsets of rainfalls are becoming more uncertain and unpredictable with dry spells after planting in the study area. The result shows that there is a low relationship between maize yield and rainfall variability in the study area. Rainfall variability amounts only to 23% of the total variance influencing maize yield per hectare in the past 30 years in the studyarea.

Iortyom, Iorsamber, and Adelabu, (2017) examined the effect of onset and cessation of raining season on crops yield in Lafia. The result of their regression analysis of rainfall onset and cessation revealed the values of 0.349 and -0.286 respectively on sorghum yield. This means that late rainfall onset results to more sorghum yields while late cessation result to poor yields. Regression analysis on the effect of onset and cessation of rainfall on millet yield revealed the values of 0.065 and -0.16 respectively. This shows that late onset of rainfall in Lafia increases millet yield while late cessation reduces yield. Hence, years with early cessation tend to have moreyields.

Osabo, Ndor and Agwale (2019) analysed the impact of rainfall onset, cessation and length of growing season on crop yields in Benue state, Nigeria. They made use of rainfall data and crop yields (maize, rice, sorghum, yam and cassava) data. Pearson correlation technique was used to establish relationship between crops yield and rainfall indices. The findings revealed both temporal and spatial variation in the rainfall indices of amount, onset, cessation and length of growing season. These variations were found to have impact on food production of the study area in various dimensions. Pearson correlation result showed that the rainfalls correlated perfectly with the yield of maize, sorghum and yam in the study area, but with less correlation with the length of growing season.

The study of Ibrahim (2020) focused on rainfall trend within 2010 - 2018 as it affects crop production in Keffi, Nasarawa State, Nigeria. The time series analysis was conducted by using appropriate techniques of data collection and analysis. The linear integration model, quadratic trend model, growth curve model and regression analysis was applied to show the correlation between the rainfall and crop production in the study area. It was discovered that the period of rainy months has high correction and significantly fitted the model which indicated high crop yields perharvest.

2.2.2.3 Crop – climate study under controlledenvironment

A crop climate study under controlled environment involves adjusting climatic conditions in the climate control chamber in other to study the relationship between crops and climate. Very few studies exist on this subject matter and someinclude;

Okigbo, (1966) studied the effect of light on bitter leaf growth and development. He found out that there is a significant relationship between photo periodism, light and leaf area development.

Cadidell and Wibel (1971) investigated the effect of photo period and temperature on the development of sorghum. They identified that flowering or panicle initiation in sorghum is highly influenced by photoperiodism and temperature.

Babalola (1972) varied the soil moisture regime inside a greenhouse with relative humidity averaging 80 per cent and air temperature of 260 to study the effect of different soil moisture status on the root and aerial development of young plants of cocoa, kola and coffee. He asserts that an increase in soil moisture level will encourage increment in height, root and leaf area of coffee and cocoa than it does for the kolaplant.

Ajadi, Adeniyi and Afolabi (2011), evaluated the influence of climate on urbanagriculture in Ilorin city from 1991 to 2000. They considered the correlation between climatic

elements like rainfall, evaporation, relative humidity, temperature and sunshine and some crops which include rice, sorghum, maize, cowpea and yam. Their findings showed that the selected climatic parameters have a very minimal effect on urban agriculture in the studyarea.

223 Agro – climaticderivations

Detailed methods of deriving the required rainfall parameters are discussed in this section.

2.2.3.1 Onset, cessation and length of growingseason

The onset and cessation dates of rain have both been defined in various ways for different purposes by researchers (Sawa and Adebayo, 2011). According to Sawa and Adebayo, (2011) Onset is the time in which the accumulated rainfall received over a place is adequate for crop germination and growth. Omotosho (1990) defined onset as the first three or four rainfalls of at least 10 mm of rainfall with not more than 7 days between them. Generally, onset date is defined by most authors as the time a place receives an accumulated amount of rainfall sufficient to support growing of crops (Matthew, Imasogie, Ayoola, Abiye and Sunmonu, 2017). Rainfall cessation can be defined as the period towards the end of the rainy season, when the distribution of rainfall is no longer sufficient to sustain crop growth (Walter, 1967; Ilesanmi, 1972a; Olaniran, 1988; Odekunle, Balogun and Ogunkoya, 2005). The length of the rainy season is simply the period between the onset and cessation dates (Walter, 1967; Ilesanmi, 1972a; Adefolalu, 1993; Sawa and Adebayo, 2011). The length of rainy season determines the type and variety of crops that can be grown in any environment (Mubvuma, 2013). Detailed methods of deriving the onset and cessation dates and length of the growing season are discussedbelow;

2.2.3.1.1 Traditionalmethods

The traditional methods are employed by traditional farmers. Traditional farmers have several methods of determining the onset date of growing season rainfall. This involves the use of traditional weather lore, behavior of heavenly bodies like stars, change in wind direction, arrival of seasonal migratory birds and ``Ramadan`` month (Haruna, 2014 and Ati, 1995). These methods lack scientific backing as they are based on poor knowledge of decision making of traditionalfarmers.

2.2.3.1.2 Semi-empiricalmethods

The semi-empirical methods are based on accumulated rainfall totals. The use of accumulated rainfall total is based on the assumption that after a particular amount of rainfall is received, the probability of a long dry spell sufficient to lead to crop failure is small. Some of these methods include; Walter (1967), Olaniran (1988), Sivakumar (1988) and so forth.

2.2.3.1.3 Scientificmethods

The scientific methods are based on rainfall and evapo-transpiration relationships. The rainfall and evapo-transpiration relationships assume that rainfall equal to or more than half the potential evapo-transpiration and maintained throughout the season would be enough to sustain crop growth. An example of this method is the rainfall evapo-transpiration relation method postulated by Cocheme and Franquin, (1967) and Benoit (1977).

2.2.3.1.4 Walter's (1967)method

Walter(1967)developedthismethod.Accordingtohim,thethresholdofmoistureindex that supports plant germination and growth is 51mm. Therefore, the month whose cumulativerainfallis≥51mmisreferredtoasMonthwithEffectiveRainfall(MER).This method is thereby summarizedbelow;

$$OD = \frac{T_R(51-T_M)}{T_T} \quad \text{.....(2.1)}$$

Where: OD = Onset Date,

T_R = Number of days in the MER,

T_M = Total amount of rainfall of the month before the month with cumulative rainfall of ≥ 51mm,

T_T = Total amount of rainfall in the MER

In calculating cessation date, the procedure is worked backwards starting from December. Finally, the length of rainy season is therefore the difference in days between onset and cessation dates.

2.2.3.1.5 Olaniran's (1988)method

This is a modified form of Walter's (1967) method. Olaniran (1988) suggested that the model proposed by Walter (1967) can be accepted if the 51mm threshold index is not followed by a month with less than 51mm of rainfall. This method is summarized thus;

$$\text{OnsetDate} = \frac{\text{DaysinMER}(51-\text{RainfallofSucceedingMonthtoMER})}{\text{Rainfall of the second Month after MER}} \quad \text{.....(2.2)}$$

To determine the cessation date of rainy season, the procedure is worked backwards from December. The number of days between the onset and cessation dates becomes the length of the growing season (Sawa, 2007).

2.2.3.1.6 Adefolalu's (1993) ogive method

This method was postulated by Adefolalu (1993). Firstly, the twelve months of the year are divided into pentads, using the pentad calendar. This gives us a total of 73 pentads. Secondly, pentad rainfall is calculated for each pentad and cumulated. Then, the cumulated rainfall is plotted against pentad to give an Ogive. Thirdly, to determine the onset and cessation dates, the points on the pentad axis corresponding to the first and the last point of maximum curvature on the Ogive, gives the onset and cessation pentad respectively(Sawa

and Adebayo, 2011; Sawa, 2016). The last date in the onset pentads gives the exact date of the onset of rains, while, the cessation of rainy season is given by the first date of the cessation pentad. Finally, the length of rainy season is derived by subtracting the onset pentad from the cessation pentad and multiplying the answer by five (5) which is the number of days in a pentad (Sawa, 2007).

2.2.3.1.7 Inter – tropical discontinuity rainfallmethod

This method was authored by Ilesanmi, (1972a) and Kowal and Knabe (1972). The movement of the Inter Tropical Discontinuity (ITD) in West Africa is used to determine the Onset and Cessation dates and the length of growing season. It is very important to note down that the occurrence, amount and variations of rainfall within West Africa Nigeria inclusive, follows the movement of the (ITD) (Ilesanmi, 1972a; Emeghara, 2015). Places located north of the (ITD) are dominated by the hungry dry harmattan wind from the Sahara desert. This gives the area a vapour pressure less than 15 millibars (mb) causing rainless conditions and clear skies (Bello, 1995; Emeghara, 2015). On the contrary, places located South of the (ITD), have a vapour pressure above 15mb which causes rainfall due to the presence of the moisture laden south west trade winds which emanates from the vast Atlantic Ocean (Ilesanmi, 1972a; Emeghara,2015).

It is important to note that places located south of the ITD at any given season are always under the influence of low pressure condition that brings rainfall. At the end of the last quarter of the year and beginning of the first quarter of the subsequent year around December to January, the coastal areas like Brass, Bonny and Southern Cross River state falls within the zone with prevalence of rainfall while the rest of Nigeria will fall within the zone with dominance of dust-laden-arid harmattan winds which pervades rainless conditions (Bello, 1995; Emeghara, 2015). During the month of February, the ITD will be locatedaroundlatitude17^{o}Nsubsequentlyareaswithintheabovestatedzoneswillbe

located outside Nigeria towards Northwestern part of West Africa, leaving the whole of Nigeria under the influence of the rain bearing maritime air mass from the Atlantic, producing clouds of great vertical extent like cumulus, cumulonimbus and low clouds like nimbostratus (Kowal and Knabe, 1972; Emeghara, 2015). Therefore by July all of Nigeria would be under wet season. This sequence is repeated year after year providing an avenue for the determination of Onset and Cessation dates using the seasonal fluctuation of the ITD (Bello, 1995; Emeghara, 2015).

2.2.3.1.8 Rainfall evapo – transpiration relation method

Cocheme and Franquin, (1967) and Benoit (1977), developed this method. In determining the onset, cessation dates of rainfall and the length of rainy season. It uses the balance between water received from rainfall and water lost to evapo-transpiration to determine these indices. This method involves the use of climatic data to predict potential evapo-transpiration which will be related to rainfall (Cocheme and Franquin, 1967).

Firstly, climatic parameters like sunshine hours, wind speed, vapor pressure and other meteorological manifestations are measured using relevant instruments. The Potential Evapo-Transpiration (PET) is predicted using either the Howard Penman's 1948 method or the Thornthwaite's 1948 method (Benoit, 1977). After the PET has been estimated, the mean monthly rainfall amount for the study area will be plotted for each month in a year. Furthermore, the mean monthly predicted PET values will be superimposed on the plotted mean monthly for each month (Odekunle, 2006). A PET scale of 0.1 to 1.0 will be used to determine the yearly onset date, cessation date and length of rainy season. Thus the period between 0.1 and 0.5 is rainless while the periods between 0.5 to 0.9is the period of intermittent light shower. The period from 1.0 and above is the period of steady and reliable rain. Subsequently, where the rainfall curve crosses the PET at 1.0 upwards during theperiodofsteadyandreliablerainfallmarkstheonsetwhilewhereitcrossesit

downwards into the period of intermittent light shower marks the cessation date. The period between the onset and cessation date on the PET scale marks the length of rainy season (Cocheme and Franquin, 1967; Benoit, 1977; Bello. 1997; Odekunle, 2006). It is however rare and difficult to obtain an accurate field measurement of PET. In addition the available empirical formulae adopted to predict PET are many and the choice of formulae depends on available climatic data. Generally, no specific guideline is given for selecting a particular method over the others in predicting PET.

2.2.3.1.9 Percentage cummulative mean method

The proponents of this method for determining rainfall onset and retreat dates include Ilesanmi (1972a; 1972b), Rao (1976), Adejuwon (1988) and Adejuwon, Balogun and Adejuwon, (1992) and was adopted by Adefolalu, (1993). The first essential step in this method is to derive the mean annual rainfall that occurs at each 5-day interval of the year. This is followed by computing the percentage of the mean annual rainfall that occurs at each of the 5-day interval throughout the year. The next step involves cumulating the percentages of the 5-day periods. Finally, when the cumulative percentage is plotted against time through the year, the first point of maximum curvature of the graph corresponds to the time of rainfall onset, while the last point of maximum negative curvature corresponds to rainfall retreat date (Ilesanmi, 1972a; Emeghara, 2015).This method is widely adopted, because as observed by several scholars, it provides mean onset of rains that do not differ significantly from the mean start of the growing season for all locations in the country. Furthermore, it uses rainfall data, which is a readily available by direct measurement, rather than some other rainfall associated factors (Odekunle,2006).

2.2.3.1.10 Hybridmethod

The hybrid method was proposed by Ati, Stiger and Oladipo (2002). According to this method, the onset date should be the 10 day period in which rainfall is greater than 25mm

and where a subsequent 10 day rainfall total is greater than 0.5 of the potential evapo-transpiration (the actual date, for the purpose of calculation be taken to be 6 days from the start of that 10 day period) and where there is no dry spell of more than 7 days within the next 30 days from the date as determined. If such a dry spell occurred, a new onset was determined as the date satisfying the Kowal rainfall criterion after the dry spell. Potential evapo-transpiration was obtained using the Blaney-Morin-Nigeria method which was developed by Duru (1984) by the use of formula 3.

$$\square\square = \frac{\square\square(0.45\square+8)(\square-\square^{\square})}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where: H = 520, m = 1.31

Where, □□ is the ratio of monthly radiation to annual radiation, □□ the mean monthly temperature (°C), □ the mean monthly relative humidity, *H* and *m* are model constants given by Duru (1984) as 520 and 1.31 respectively. To obtain the cessation date, the year is divided into decades. The 6th-day in the decade before a dry spell of more than seven days corresponds to the cessation date. Any rain that falls after such dry spell is not likely to be followed by series of rains that could keep the ground wet. The period between the onset and cessation dates is the length of rainy season.

2.2.3.1.1.1 The traditional Ramadanmethod

According to Ati, Stiger and Oladipo, (2002), the traditional Ramadan method used in the Kano region was named after the Muslim fasting period. This rule states that planting can begin with the first good rain after Ramadan provided that it is at least 7 months from the last effective rain of the previous season. If these dates are not close, a 7 months rule is applied and planting is advised to be 7 months after the last effective rain of the previous season.

2.2.3.2 Number of rainydays

The number of rainy days is determined only after a threshold value has been defined after which a day will be considered wet and below which a day will be considered dry (Sawa, 2016). The World Meteorological Organization (WMO) stipulated that a day should be considered wet only if it has a minimum rainfall of 0.25mm. However, the Nigerian Meteorological Agency (NiMet) defined a wet day as any day that has a minimum rainfall of 1mm (Sawa, 2016; Chinda, 2019). This means that a day recording Trace Rainfall (T.R) or 0.99mm of rainfall is referred to by NiMet as a dry day in Nigeria.

2.2.3.3 Amount of rain in the months of the growingseason

This is referred to as the total amount of rainfall recorded in each of the months of the rainy season or growing season. It is hence obtained by taking the sum of the amount of rainfall recorded in each month of the growing season. These months include; May, June, July, August and September (Sawa, 2016; Chinda,2019).

2.2.3.4 Rainfall intensity

This is referred to as the amount of rainfall per unit time. It is obtained by taking the amount of rainfall of a rain and dividing it by the duration (minutes or hours) of the rain. This is usually done immediately after the time of rain to get accurate result. The duration could be in a day, month or a year (Sawa, 2016; 2019).

2.2.3.5 Seasonalityindex

Seasonality index is the measure of the spread of rainfall or how steady the rainfall has been in the year (Sawa, 2016; Chinda, 2019).This attribute was determined first by Walsh and Lawler (1981). According to them, the Seasonality Index (SI) is the sum of the absolute deviations of the mean monthly rainfall from the overall monthly mean multiplied by the exponent of the mean annual rainfall. This is summarized in the following equation:

2.2.3.6 Hydrologicalratio

This is referred to as the ratio of the mean annual rainfall (P) to the Potential Evapotranspiration (PE). It symbolizes soil moisture deficiency or surplus as documented by Duckam (1976) and applied by Adefolalu (1988). According to Sawa and Adebayo (2011), it is one of the best methods of estimating water availability as soil moisture. It is the most suitable drought pointer, which not only gives an indication of the adequacy of rainfall but also serves as an empirical measure of the contribution of drought 'tendency' in the desertification process. It provides a guide as to not only where a particular crop will thrive but also how much water is needed to augment soil moisture deficiency. This however increases with latitude (Sawa, 2016). It is computedthus;

2.2.4 Crops yieldforecast

Among the meteorological variables, rainfall parameters, temperature, sunshine hours, relative humidity, wind velocity and soil moisture are some of the most important factors which affect crop yield significantly. Most of the developed forecasting models for crop yields were based on weather variables (Amrender and Lalmohan, 2005). Few of these models include;

Adebayo and Adebayo (1997) developed double log multiple regression model to predict rice yield in Adamawa State, Nigeria. The general form of his model was expressed as*:*

$$Y=a+b_1 log x_1+b_2 log x_2+b_3 log x_3+b_4 log x_4+\ldots\ldots\ldots\ldots b_n log x_n \quad (2.4)$$

Whereby: Y= predicted yield in kg/ha (log_{10}),

x_1= hydrological ratio,

x_2= onset of the rain,

x_3= number of pentad dry spells between May and September,

x_4= total rainfall in June

a, b_1, b_2, b_3, b_4 ---------- b_n are the coefficients of double log multipleregression.

Adejuwon (2005) in the study of food crop production and present effects of climatic variables in Nigeria adopted a forecast model for the yields of cowpeas, groundnut, millet, maize and sorghum in Potiskum and Maiduguri using bivariate correlation and stepwise multiple regression analysis techniques. The form of his model was mathematically expressed as:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 \ldots\ldots\ldots\ldots + b_nx_n \quad (2.5)$$

Whereby: Y = Crop yield,

a, $b_1 - b_n$ are the coefficients of stepwise multiple Regression,

$x_1 - x_n$ are rainfall parameters (predictors variables).

He used the equation to develop four yield forecast models of cowpea, groundnut, millet and sorghum in the Nigerian Arid Zone. He reported that the predicted models generated for the yield of cowpeas, groundnut, millet and sorghum were statistically significant with $\alpha \leq 0.05$. Among more powerful determinants of crop yield were rainfalls at the onset and at the cessation of months of the growing season.

Abdullahi, Iheanacho and Ibrahim (2006) in their study on econometric analysis of the relationship between drought and millet production in the Arid Zone of Nigeria: A case study of Borno and Yobe States, used a supply response model. They used this model to isolate the systematic effect of rainfall on millet production using ordinary lease squares (OLS) estimate. Linear and double log functions were lead equations for the production and yield, with coefficient of determination (R^2s) of 0.86 and 0.77 respectively. They observed that rainfall and trend variables were significant ($p \leq 0.01$) for both production and yieldfunction.

Sawa and Ibrahim (2011) presented models for the prediction of millet and sorghum yields in the face of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15

consecutive days during the growing season. Daily rainfall records and crop yield per hectare for three decades (1976-2005) were used to develop forecast models for the yield of millet and sorghum in the semi-arid region of Northern Nigeria on the basis of dry spell parameters. Employing bivariate correlation analysis, stepwise regression (forward selection) and double log multiple regression statistical methods; they developed models for the prediction of the yield of millet and sorghum. Stepwise multiple regression identified total dry spells during the growing season as being critical to millet yield while 5-day dry spells in May and total dry spells in the growing season were picked for sorghum. The model for millet yield was $\log Y = 0.0715\text{-}0.0817 \log X_2$, inferring that, the yield of millet would be reduced by about 0.0817 ton/ha in the study area, if the occurrence of total dry spells during the growing season was unity. That for sorghum was $\log Y = 0.170 + 0.0629 \log X_1 – 0.141 \log X_2$, signifying that the occurrence of a single 5-day dry spell in May would increase sorghum yield by about 0.0629 ton/ha however that of total dry spells would reduce it by 0.141 ton/ha. About 54.5% disparity in millet yield was accounted for by incidences of total dry spells during the growing season whereas 63.2% of the variation in sorghum yield was mutually due to the occurrence of 5-day dry spells in May and total dry spells in the growing season. Both the forecast error and the linear graph of observed and predicted yields proposed that the models were adequate for the forecast of millet and sorghum yield in the studyarea.

Adamgbe and Ujoh (2013) in their study on effect of variability in rainfall characteristics on maize yield in Gboko, Nigeria employed the mean, standard deviation and coefficient of variability in analyzing the variations in the study variables (onset and cessation dates, duration of rainy season and Annual rainfall amounts). Partial correlation and multiple linearregressionanalysiswerethestatisticaltoolsusedtoestablishtherelationshipand

effect of rainfall characteristics on maize yield. The regression model for the study was also computed as:

$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_nx_n + e$ …..……...……(2.6) where; *Y* = the value of the dependent variable (maize yield/ha);

a = *Y*intercept,

$b_1 - b_n$= regression coefficients (each b represents the amount of change in *Y* (Maize yield/ha) for one unit of change in the corresponding *x*-value when the other *x* values are heldconstants),

$x_1 - x_n$ = the independent variables (*i.e.* rainfall onset, cessation, duration, annual totals and annual number of rain days respectively); and, *e* = the error of estimate or residuals of the regression. Apart from the coefficients of the independent variables (rainfall characteristics), coefficient of multiple determinations (R^2) was used to determine the percentage explanation achieved jointly by the rainfall characteristics. The regression equation or predictor model of the study was stated thus:

$Y = -4790.90 - 2.723x_1 + 5.233x_2 + 9.797x_3 + 48.650x_4 + 1.107x_5 + 291$……(2.7)

Where; *Y* = Predicted yield of maize in the area and

$x_1 - x_5$ = the independent variables (*i.e.* rainfall onset, cessation, duration, annual totals and annual number of rain days respectively)

The model showed that given a unit change in any of the rainfall characteristics while holding others constant, the highest variation in the yield of maize in the area will be accounted for by annual rainy days (48.650 kg/ha), followed by duration of rainy season (9.797 kg/ha), cessation date (5.233 kg/ha), annual total (1.107 kg/ha) and the least change in yield was from onset date (−2.7233 kg/ha). These showed that among the rainfall characteristics, annual number of rainy days (x_4) was the most important variable for the variation in maize yield in the study area indicating that the yield of maize was higher

when annual number of rain days is higher. This is followed by annual rainfall totals (x_5), meaning that there was higher yield of maize under years with higher rainfall amount than those with lower amount.

Haruna and Tasi'u (2017) modeled the relationship between rainfall variability on millet (*pennisetum americanum* l.) and sorghum (*sorghum bicolor* l. *Moench.*) yields in the Sudan savanna ecological zone of Nigeria. Adopting the model of Adebayo and Adebayo (1997) developed four forecasting models for millet and sorghum using stepwise multiple regressionanalyses.Thefour modelsinclude;$Y=-0.733AR_{10}+2.483$milletmodel forKano,$Y=0.503AR_{10}-1.292$modelforKatsina,$Y=-0.185AR_{10}+0.529$ maize forecastmodel for Potiskum and $Y=-0.008AR_{10}-0.018$sorgum model for Potiskum. Where AR=log10 Annual Rainfall, M=log10 rainfall in May and Y=millet/sorghum yields in ton/ha. They however recommended after carrying a test of validity for the four forecast models that maize forecast model for Katsina ($Y = 0.503AR_{10}-1.292$)and sorghum forecastmodel for Potiskum ($Y=-0.008AR_{10}-0.018$)be used to forecastthe yieldsof maize and sorghum in the Sudan Savanna Ecological Zone ofNigeria.

Bekele, Korecha and Negatu (2017) demonstrated the effect of rainfall characteristics on wheat yield in Sinana districts, South Eastern Ethiopia. Using the stepwise regression equation of the form;

$Y=a+b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_nx_n+e$……..……..……..…...(2.8) where;

Y = the value of the dependent variable (wheat inqt/ha),

a = Y intercept,

$b_1 – b_n$ = regression coefficients,

$x_1 – x_n$= the independent variables (rainfall features such as rainfall onset, cessation, duration, seasonal rainfall total, number of rain days and yearly total rainfall respectively);

and, e = the error of estimate or residuals of the regression, they developed two forecast models for predicting wheat yield for Robe and Sinana meteorological stations. The developed models include: *Y* (Wheat) = 30.02 + 0.062 Total Kiremt (seasonal) Rain − 0.358 Kiremt Rainy Day for Robe and Y (Wheat) = 36.681 + 0.032 kiremt rain – 0.133 duration for Sinana. The result of their projected wheat yield using the above models indicated that there will be a slight decrease (qt/ha) after the year 2030 due to the impact of expected weakening of kiremt rainfall total.

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 The StudyArea

3.1.1 Location and size

Benue State is located in the North Central geopolitical zone of Nigeria. It lies between latitudes 6°30'N and 8°10'N of the Equator and between longitudes 7°50'E and 10°E of the Greenwich Meridian. Its capital is Makurdi. It is situated at 164 m above sea level and occupies a landmass of 34,059 square kilometres *(*Abu and Adakole, 2017*).* It is surrounded by six states, namely, Nassarawa to the north, Taraba to the northeast, Cross River and Ebonyi to the south, Enugu to the southwest, and Kogi to the west. There is also a short international boundary between the state and the Republic of Cameroun along Nigeria's South-East border. Benue State is made up of 23 Local Government areas (LGAs) (Abu, Madu and Ajaero, 2015). Map of the study area is shown in Fig. 3.1. The size of the state gives vast lands for agricultural purposes and hence the production ofcrops.

3.1.2 Climate

Benue State has a tropical sub-humid climate. Based on Koppen's climate classification, Benue State lies within the Aw climate (Adamgbe and Ujoh, 2012, Halima and Edoga, 2016). There are two distinct climatic seasons in the state; rainy season which occurs from March to October and dry season which occurs from November to February. The seasonality in rainfall is largely determined by the movement of the Inter-tropical Convergent Zone (ITCZ) or the Inter-tropical Discontinuity (ITD) across Nigeria. This ITCZ/ITD is the zone where the two prevalent air masses; Tropical Continental (cT) which originates from the North-East and Tropical Maritime (mT) which originates from the South West meet (Ayoade, 1988, Halima and Edoga, 2016, 2012).



Figure 3.1: Map of the Study Area: Benue State
Source: Modified administrative map of Benue state.

The total annual rainfall ranges from 1,200 mm - 1,500 mm (Akintola, 1986, Anonymous, 2003). The month of September usually experience the peak rainfall and October usually experience the least rainfall during the wet season. Rainfall in the State

is usually associated with heavy wind, lightning and thunder. Agricultural activities are performed more during the wet season due to sufficient moisture. Fig. 3.1 shows the rainfall pattern in the study area.

Temperatures are constantly high averaging between 28^{o} – 32^{o}C and sometimes rising to 37^{o}C (Fig. 3.2) especially within Makurdi the state headquarters (Halima and Edoga, 2016). This promotes the activities of photosynthesis which gives rise to greater yield of crops.

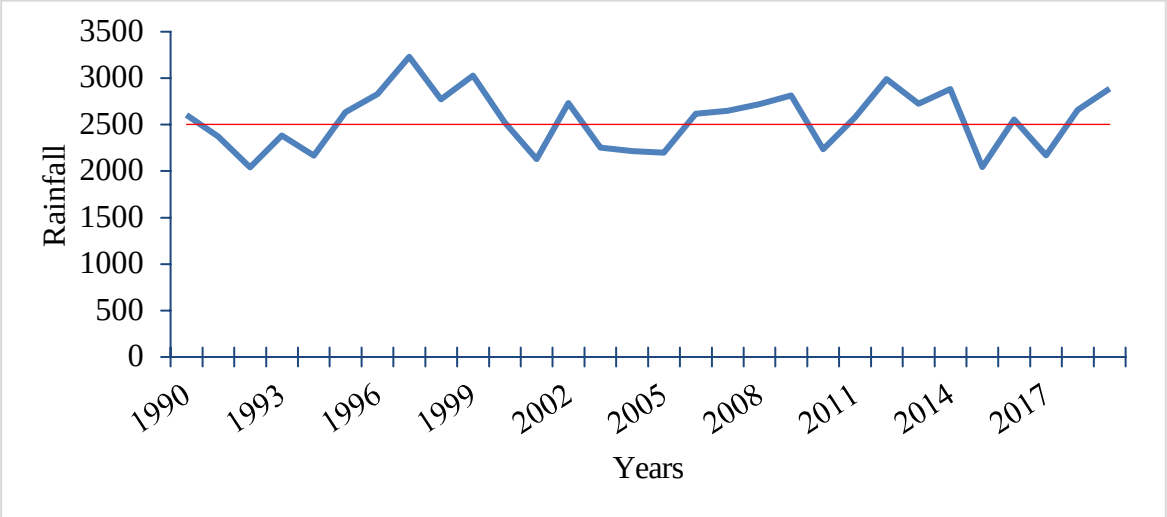


Figure 3.2: Pattern of Rainfall in Benue State.
Source: Author's Analysis (2021).

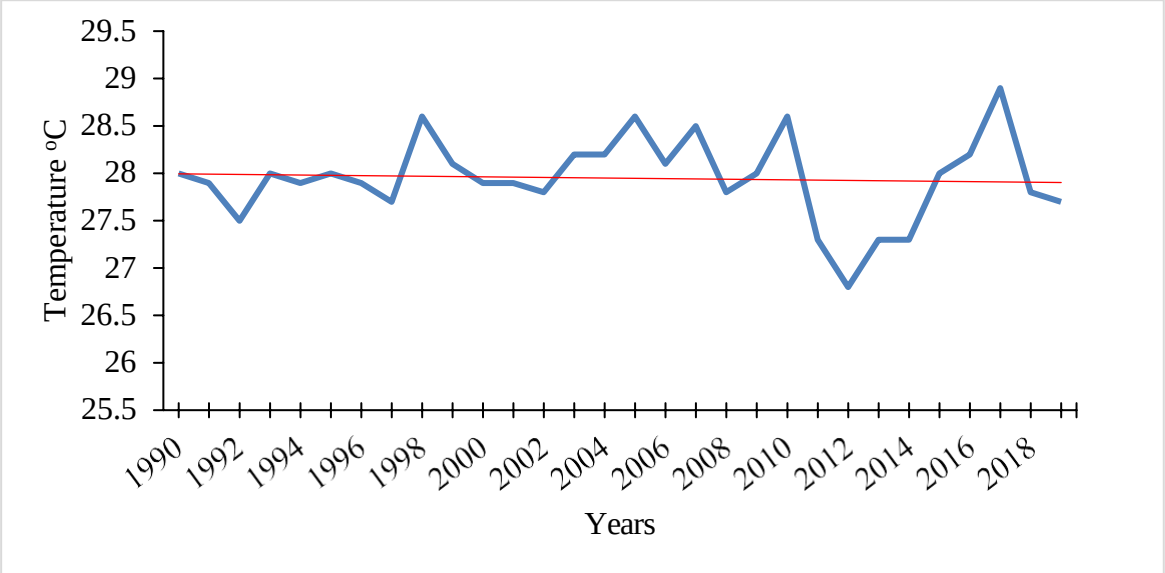


Figure 3.3: Pattern of Temperature in Benue State.
Source: Author's Analysis (2021).

3.1.3 Soils andvegetation

The soils are mainly Oxisols and Ultisols (tropical ferruginous) which vary over space with respect to texture and structure (Halima and Edoga, 2016). A typical profile is highly weathered with sandy surface layer overlying clay mottled subsoil (Anonymous, 2003). In the southern part of the state, around Vandeikya, Oju, Obi, Oturkpo, Ogbadibo LGAs, well developed lateritic profiles with pallid zones exist. Deep seated lateritic crusts occur over extensive areas on the plains. The agronomic significance of this subsoil crust is that it often produces a perched water table which is an important source of capillary water, which keeps the surface moist long after the end of the rainy season (Charles, 1985, Anonymous, 2003, Halima and Edoga, 2016). Entisols and Inceptisols also occur associated with young soils on hill slopes and recent alluvium on flood plains. Around Gbajimba in Guma LGA, Euthropic Brown Earths occur associated with the volcanic parent materials season (Charles, 1985, Anonymous, 2003, Halima and Edoga, 2016).

Sheet erosion is the dominant form of water erosion in the State. Deep gullies occur in Ogbadibo LGA and represent a northern extension of the Eastern Nigerian meta-sedimentary deep gully system. Other gullied areas in the state include Makurdi North Bank area, Tse-Mker and Gbem in Vandeikya LGA, Gbajimba town, stream bank erosion in Gboko town, incised streams on sloppy ground coterminous to Anwase, Kyogen, Abande ranges in Kwande LGA, (Anonymous, 2003).

Benue State lies in the southern Guinea Savanna. Persistent clearance of the vegetation has led to the development of re-growth vegetation at various levels of serial development, but more importantly, parklands with grasses ideal for animal grazing during their early growth (Halima and Edoga, 2016). These succulent grasses can be cut with machinery, dried and baled for dry season livestock feeding. The grasses however

grow very tall, coarse and tough on maturity. The scattered trees are mainly those of economic value and include locust bean (*Parkia biglobosa*), shea butter (*Vitellaria paradoxa*), mango (*Mangifera indica*), silk cotton (*Ceiba pentandra*), orange *(Citrus aurantium),* baobab *(Adansonia digitata),* cashew (*Anacardium occidentale*), oil palm (*Elaeis guinensis*) and so forth (Anonymous, 2003, Halima and Edoga, 2016). These trees produce valuable fruits, wood and fibre which can be utilized for small scale cottageindustries.

In the southern part of the State, particularly in Oju, Ado, Obi, Ogbadibo and Okpokwu LGAs, the vegetation is mainly oil palm bush. The oil palm (Elaeis guinensis) is utilized for its palm oil, palm kernel, palm wine, broom sticks and several other products. Dense forests are few and far apart, except in a few LGAs such as Vandeikya, Kwande and Okpokwu (Anonymous, 2003). The type of soil usually determines the type of vegetation it can support and hence, the type of crops that can be cultivated in an area. Hence, the type of soil in the study area supports the production of tubers, grains and tree crops (Adamgbe and Ujoh, 2012, Halima and Edoga,2016).

3.1.4 Geology

Much of Benue State falls within the Benue trough which is believed to be structurally developed. During the tertiary and possibly the interglacial periods of the Quaternary glaciation, the Benue and Niger valleys, otherwise known as the Niger/Benue trough, were transgressed by the waters of the Atlantic Ocean. As a result, marine sediments form the dominant surface geology of much of Benue State. These sediments have undergone varying degrees of metamorphism. The state is underlain at variable depth by basement complex rocks. In the southern LGAs such as Ado, Ogbadibo and Okpokwu, the meta-sediments may be more than 20m thick (Charles, 1985, Anonymous, 2003).

Benue State geology can, therefore, be broadly divided into (1) meta-sediments occurring in more than 75% of the state, associated with the Benue trough (2) basement complex rocks occurring in higher ground further away, particular in Kwande and the eastern part of the state. The meta-sediments are dominantly sandstone, but also contain shale, siltstone, limestone and quartzite. On the flood plains of the Benue and Katsina-Ala Rivers and other smaller rivers are alluvial deposits, comprising an assortment of clays, sand, gravels and pebbles, overlying the meta-sediments and form the superficial geology. In Benue State, volcanic materials are well represented in Guma LGA around Gbajimba. These volcanoes are thought to be responsible for some economic mineral formations of the area including the salt springs. Basement complex rocks comprising ancient igneous and metamorphic rocks occur mainly in Kwande LGA and the eastern part of Oju LGA. The materials also outcrop in widely scattered locations as upland residuals, such as inselbergs, knolls and ruwares and underlie all of the meta-sediments (Charles, 1985, Anonymous, 2003).

The basement rocks are dominated by porphyritic granites, migmatites, diorites, pegmatites and gneisses. In much of Benue State, both the tertiary and sedimentary rocks and the basement complex have been deeply weathered to produce regolith and saprolite several metres deep. These rocks are rich in solid minerals, such as limestone, barite, coal, gypsum, salt, shales, silica, sand and kaolin which are currently being mined (Anonymous, 2003). The Geology of an area usually determines the type of soil. Hence, the geology of the study area is responsible for the type of soil and hence the agricultural significance of the state.

3.1.5 Relief and drainage

The land is generally low-lying (averaging 100 m – 250 m) above sea level and gently undulating with occasional inselbergs, knolls, ruwares laterite capped mesas and buttes.

It is only at the boundary area with Cameroun Republic in Kwande and Oju LGAs that hilly terrain with appreciable local relief is encountered. Here, the terrain is characterized by steep slopes, deep incised valleys and generally rugged relief. Elsewhere, gradients average less than 4m. Such areas are made up of interfluves, broad open valleys and flood plains (Anonymous, 2003).

River Benue is the dominant geographical feature in the state. It is one of the few large rivers in Nigeria not plagued with waterfalls and rapids. The Katsina-Ala River is its largest tributary, while the smaller rivers include Mkomon, Amile, Duru, Loko Konshisha, Kpa, Okpokwu, Mu, Be, Aya, Apa Ogede and Ombi. The flood plains which are characterized by extensive swamps and ponds are good for dry season irrigation farming. Elsewhere, surface drainage is generally good (Anonymous, 2003).

Though Benue State has high drainage density many of the streams are ephemeral. The water table in many parts of the state is very low, as a consequence of the thick overlying permeable meta-sediments and the great depth to which weathering has reached. Hence, there is an acute water shortage in the dry season in LGAs such as Guma, Okpokwu, Ogbadibo, Gwer-West and Oju (Anonymous, 2003). With the availability of good drainage system, the soil of the study area is adequately drained to prevent waterlogged situations that could harm the cultivated crops.

3.1.6 Population andpeople

According to Nigeria Bureau of Statistics (NBS) (2020) the projected population of Benue State for 2019 stands at 5,787,706 (NBS, 2020).

There are three major ethnic groups inhabiting the state. The Tiv form about two thirds of the population and are found in 14 out of the 23 LGAs. The Idomas and the Igedes occupytheremaining9LGAs.OtherethnicgroupsincludetheEtulo,whoaremainly

found in Katsina-Ala and Buruku LGAs, the Afia in Ado, the Nyifon in Buruku, and the Jukun in Makurdi and Guma LGAs (Abu, Madu and Ajaero, 2015). The Tiv and Idoma ethnic groups are good farmers whereas the Jukuns are good fishers.

3.1.7 Economicactivities

The State at large is an agrarian based economy as agriculture is the major economic activity and serves as the bedrock of other activities. These activities include: food and tree crop production, poultry, trading and craft making. The major crops produced in the study area include; yam, cassava, potato, rice, maize, sorghum, soyabeans, beniseed, melon, groundnut, oranges, cashew, mangoes and so forth (Anonymous, 2003).

3.2 Methodology

3.2.1 Reconnaissancesurvey

The researcher having done his Student Industrial Work Experience Scheme (SIWES) with the Nigerian Meteorological Agency (NiMet) Makurdi, surveyed the rainfall data available through his practical and interaction with the Officer-in-charge of synoptic station, Mall. Adaji. The crop yield data available from BNARDA through the Director of Agricultural services, Mr. Pine Celestine was also surveyed. The researcher further surveyed the available literature to catch a glimpse at the wealth of knowledge available on rainfall and crop yield. The aim of the above was to enable the researcher get acquainted with the study and the study area.

3.2.2 Types of data

The types of data the researcher used include:

i. Rainfall data for 30 years(1990-2019).

ii. Yield of selected crops (rice, maize, sorghum and soyabeans) for 30 years(1990-2019).

323 Sources of data

The mentioned data were of secondary source. Rainfall data for Benue Sate was obtained from NiMet Makurdi and Akperan Orshi College of Agriculture, Yandev while crops yield data was obtained from Benue State Agricultural and Rural Development Agency (BNARDA).

324 Harmonization of data

According to FAO (1998) harmonization seeks to bring together various types, levels and sources of data in such a way that they can be made compatible and comparable, and thus useful for decision making. Data harmonization is the process of bringing together data of varying file formats, naming conventions, and columns, and transforming it into one cohesive data set. Several methods are used for data harmonization, some of which are: Logarithm, square root, power, multiplicative inverse, MINMAX, Fisher, Log_{10} among others. However, for the purpose of this study, Log_{10} harmonization was used to harmonize rainfall parameters and the yield selected crops (mt/ha) using the Statistical Package for Social Sciences(SPSS).

325 Agro-climaticderivations

Methods employed in the derivation of selected rainfall parameters (onset and cessation dates, length of growing season, number of rainy days, amount of rain in the months of the growing season, rainfall intensity, hydrological ratio and seasonality index) are discussed in this section.

3.2.5.1 Onsetdate

The hybrid method was adopted in estimating the onset dates of rain in the study area. The hybrid method was adopted because it was derived to be used in Northern Nigeria by Ati, Stiger and Oladipo (2002). It is also a better method according to Ati, Stiger and Oladipo (2002), as it deals with the problem of false onset unlike the othermethods.

According to this method, the onset date should be the 10 day period in which rainfall is greater than 25mm and where a subsequent 10 day rainfall total is greater than 0.5 of the potential evapo-transpiration (the actual date, for the purpose of calculation be taken to be 6 days from the start of that 10 day period) and where there is no dry spell of more than 7 days within the next 30 days from the date as determined. If such a dry spell occurred, a new onset was determined as the date satisfying the Kowal rainfall criterion after the dry spell. Potential evapo-transpiration was obtained using the Blaney-Morin-Nigeria method which was developed by Duru (1984) by the use of formula3.1.

$$E_t = \frac{R_s(0.45T+8)(H-R^m)}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots....(3.1)$$

Where: H = 520, m = 1.31

Where, R_s is the ratio of monthly radiation to annual radiation, T_m the mean monthly temperature (°C), R the mean monthly relative humidity, *H* and *m* are model constants given by Duru (1984) as 520 and 1.31 respectively

3.2.5.2 Cessation date

The hybrid method was adopted in estimating the cessation dates of rain in the study area. To obtain the cessation date, the year is divided into decades. The 6th-day in the decade before a dry spell of more than seven days corresponds to the cessation date. Any rain that falls after such dry spell is not likely to be followed by series of rains that could keep the ground wet. This method was adopted because it was derived to be used in Northern Nigeria by Ati, Stiger and Oladipo(2002).

3.2.5.3 Length of growingseason

The length of growing season was derived by counting the number of days between the onset and cessation dates. This is the actual method of estimating length of the growing season (Sawa, 2016; 2019, Chinago, 2019).

3.2.5.4 Number of rainydays

This study adopted the threshold value as defined by NiMet which is 1 mm of rainfall. This is because as a Nigerian agency, it has a better knowledge of the nature of rains or climate generally in the study area. Hence, all the days with rainfall records of 1 mm and above were counted and the total recorded for all the years under review (Sawa, 2016; Chinda, 2019).

3.2.5.5 Amount of rain in the months of the growingseason

This was obtained by taking the sum of the amount of rainfall recorded in each month of the growing season. These months include; May, June, July, August and September (Sawa, 2016; Chinda, 2019). These are the months that make-up the rainy season in the study area. This is fully discussed in section 2.2.3.3

3.2.5.6 Rainfallintensity

This was obtained by dividing the total amount of rain in the months of the growing season by the length of the growing season. (Sawa, 2016; 2019, Chinago, 2019). This is better discussed in section2.2.3.4.

3.2.5.7 Hydrologicalratio

Hydrological ratio which is the ratio of the mean annual rainfall (P) to the Potential Evapotranspiration (PE). It symbolizes soil moisture deficiency or surplus as documented by Duckam (1976) and applied by Adefolalu (1988).

$$H.R = \frac{P}{P.E} \qquad \text{……..(3.2)}$$

Where; **H. R** is Hydrological ratio,

P is Mean annual Rainfall and

P. E is Potential Evapo-transpiration. The higher the value derived the drier the wet season and vice versa.

3.2.5.8 Seasonalityindex

Seasonality index which is the measure of the spread of rainfall or how steady the rainfall has been in the year (Sawa, 2016; Chinda, 2019) was estimated using formula

$$SI = \frac{1}{R}\sum \left| x_i - \frac{R}{12} \right| \quad \text{.....(3.3)}$$

Where: SI = Seasonality index,

R = Annual Rainfall,

x_i = Mean rainfall of eachmonth.

Interpretation table for seasonality index was provided by Walsh and Lawler (1981) and is shown in Table 3.1.

The higher the S.I value, the shorter the spread of the rainy season, implying the drier the place, and vice versa.

Table 3.1: **Seasonality Index Interpretation Table**

S/No	Class of index	Rainfall regime
1.	≤ 0.19	Very equitable. Rainfalls throughout the year and hence, no dry season.
2.	0.20 – 0.39	Equitable. Rainfalls throughout the year, but with a definite wetter season (Calabar, Cameroon regions).
3.	0.40 – 0.59	Rather seasonal with a short drier season (Lagos, P/Harcourt, Bayelsa regions).
4.	0.60 – 0.79	Seasonal rainfall (Guinea savannah regions).
5.	0.80 – 0.99	Markedly seasonal with a long dry season (Kaduna, Gusau, Kano and other regions around the Sudan savannah).
6.	1.0 – 1.19	Most rainfall in less than 3 months or less (Borno, Yobe and areas around the Sahel savannah)
7.	≥1.20	Extremely seasonality, with almost all rainfall in 1 or 2 months (Niger Republic).

Source: (Patil, 2015; Sawa, 2016).

3.2.6 Dataanalysis

3.2.6.1 To examine the trends in rainfall parameters.

The derived rainfall parameters (Onset and cessation dates, length of the growing season, number of rainy days, amount of rain in the months of the growing season, rainfall

intensity, hydrological ratio and seasonality index) and crops yield (Rice, maize and sorghum) were subjected to Mann Kendall test. The Mann–Kendall trends test (Mann, 1945) and (Kendall, 1975) is one of the widely used non-parametric tests also called Kendall's tau test. It is used to detect significant trends in time series data (Basistha, Arya and Goel, 2009; Oguntunde, Abiodun, Olukunle and Olufayoa, 2011). The Mann Kendal test($\square$)statisticisgiven by:

$$\square = \sum_{\square=1}^{\square-1} \sum_{t=\square+1}^{\square} \text{Sign}(\square_j - \square_k) \quad \text{.....(3.4)}$$

Where $\square_j$and $\square_k$are the sequential data *j* greater thank *k*, *n*

is the duration of the data set.

$$\square\square\square\square(\square_j - \square_k) = \begin{cases} +1, > (\square_j - \square_k) \\ 0, = (\square_j - \square_k) \\ -1, < (\square_j - \square_k) \end{cases} \quad \text{……..…....(3.5)}$$

Mann (1945) and Kendall (1975) documented that the statistic $\square$ is approximately normallydistributedwhen$n$≥10,withthemeanandthevarianceofstatistics$\square$as follows:

$$\square(\square) = 0$$

$$\square\square\square(\square^2) = \frac{\square(\square-1)(2\square+5) - \sum_{\square} \square(\square)(\square-1)(2\square+5)}{18} \text{……}\ldots(3.6)$$

Where $\square_\square$denotes the number of ties to extent *j*. The ∑term in the numerator is used only if the data series contains tied values. The standard test statistic Z is calculated as follows:

$$Z = \begin{cases} \frac{\square - 1}{\sqrt{\square}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{\square + 1}{\sqrt{\square}} & \text{if } S < 0 \end{cases} \quad \text{……..……..…....(3.7)}$$

A positive *Z* value indicates an increasing trend while a negative *Z* value indicates a decreasing trend. The null hypothesis, H_o, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or greater than the critical value of Z statistics obtained from the normal distribution Table. If Z is greater than $Z_{(1-\alpha/2)}$ [1.96), the trend is said to be significant whereas if Z is less than $Z_{(1-\alpha/2)}$ [1.96], the trend is said to be insignificant, where α represent the statistically significant level of 5%. Summary *of* trend classification according *to the* value *of* Z for $\alpha = 0.05$ (5%) is shown in Table3.2.

However, Microsoft Excel XLSTAT 2021 software which was used to examine the trends of rainfall parameters and selected crop yields usually deals with the problem of ties in data and give the Tau (τ)value whose significance is interpreted using the p-value at statistically significant level of 5% (0.05).

Table 3.2: Classification of Trend according to the value of Z

S/No	Categories	Scale
1.	Significanttrend (increase)	Z >1.96
2.	Non-Significanttrend(increase)	0 < Z >1.96
3.	Notrend	Z =0
4.	Non-Significanttrend(decrease)	-1.96 < Z <0
5.	Significanttrend (decrease)	Z <-1.96

Source: Adapted from: Shadmani, Marofi and Roknian (2012).

The Tau (τ)value usually indicate the direction of the trend: negative Tau (τ)value indicatesdecreasingtrendsandpositiveTau(τ)valueindicatesincreasingtrendwhereas the p-value indicates the significance in the trend (Brossart, 2018). This was used to interpret the trend in this study instead of theZ-values.

3.2.6.2 *To examine the trends in selected cropsyield*.

The selected crops yield (Rice, maize, sorghum and soyabeans) were subjected to Mann Kendall test. The same process procedure in 3.2.6.1 was employed.

3.2.6.3 To assess the relationship between rainfall parameters and cropsyield.

The derived rainfall parameters (Onset and cessation dates, length of the growing season, number of rainy days, amount of rain in the months of the growing season, rainfall intensity, hydrological ratio and seasonality index) and selected crops yield (Rice, maize, sorghum and soyabeans) the harmonized data to Log_{10} were subjected to the Pearson's product momentum correlation to show the relationship between rainfall parameters and crops yield in the study area. Correlation is a statistical method that determines the degree of relationship between different variables (Chee, 2015). The Pearson Product-Moment Correlation is the single most common type of correlation which measures the degreeofrelationshipbetweentwocontinuousvariables.Itscoefficient(r)isestimated using the formula;

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \quad \text{.....(3.8)}$$

Where $\bar{x}$ and $\bar{y}$are the sample means of x and y respectively.

The correlation coefficient, *r*, is a summary measure that describes the extent of the statistical relationship between two interval or ratio level variables. The correlation coefficient is scaled so that it is always between -1 and +1. If the two variables are in perfect linear relationship, the correlation coefficient will be either 1 or –1. When *r* is close to 0 this means that there is little relationship between the variables and the farther away from 0 *r* is, in either the positive or negative direction, the greater the relationship between the two variables. In summary, there is a positive relationship between variables when *r* is positive and a negative relationship when *r* is negative (Chee, 2015). The

Pearson Product-Moment Correlation was also used to test the stated hypothesis that, there is no significant relationship between rainfall parameters and crops yield. The Statistical Package for Social Science (SPSS) software was employed here.

3.2.6.4 To forecast the yield of selected crops for2050

Rainfall parameters with significant relationship with the selected crops from the correlation result were further subjected to stepwise multiple regressions. The statistical goal of multiple regression analysis is to produce a model in the form of a linear equation that identifies the best weighted linear combination of independent variables in a study so as to optimally predict the criterion variable. The multiple regressionequation is in the form;

$$Y = a + bx \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.9)$$

Where Y is the predicted score on the criterion variable,

x is the predictor variables in the equation,

b is the coefficients associated with the predictors and are also referred to as partial regression coefficients because each reflects the relative contribution of its independent variable and

a is a constant (Kachigan, 1991). A positive sign in the equation implies an increasing pattern whereas a negative sign in the equation depicts decreasing pattern (Kachigan, 1991, Chee, 2015). The Statistical Package for Social Science (SPSS) software was utilized here.

The developed models were subjected to confirmation test. Not all the crops yield data were used in developing the models. The last two years' records (2018 and 2019) were deliberately used for the confirmation test by obtaining the predicted yield values using the developed models. To check the appropriateness of the developed models, the differences between the observed and predicted values were examined. The goodness of

fit of the models were confirmed by the coefficient of determination (R^2). The precision of the forecast models was tested by the Forecast Error Percentage [FE] (%) which was computed using the equation:

$$\text{FE} = \frac{\text{Predicted value} - \text{Observed value}}{\text{Observed value}} \times 100 \quad \text{.....(3.10)}$$

For goodness of fit, the percentage errors should not vary significantly one from another. FE should not exceed 25% else the models were not suitable for forecasting the yield of the selected crops yield in the study area (Sawa and Ibrahim, 2011).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Derived RainfallParameters

This study derived the needed rainfall parameters for the two stations in the study area: Akperan Orshi Polytechnic station (AOPOLY) Gboko and Nigerian Meteorological Agency station (NiMet), Makurdi. They derived rainfall parameters for Makurdi station are presented in Table 4.1

Table 4.1 shows that the earliest onset date at Makurdi was on 31 March 1990 and was recorded in 2014 while the latest onset date at Makurdi was observed in 2018 (23 June). The mean onset date was on 18th May. There was fluctuation in the onset dates within the period. The onset dates were within the months of March and June.

The earliest cessation date was on 6th October 2000 and 2017. The latest cessation date was observed on 6th of November in the years 1997, 2012 and 2014 respectively. The mean cessation date was however estimated to be on 19th October. The cessation dates fluctuated between the months of October and November.

The year with the shortest length of growing season (LGS) was 2011 (103 days) and the longest was observed in the 2014 (220 days). The mean LGS at Makurdi was 162 days.

The number of rainy days (NRD) varied across the period with the year 2017 having the least number of rainy days of 60days and the year 2013 had the highest number of rainy days of 84 days. The mean number of rainy days however was 73 days in the study area.

Amount of rain in the months of the growing season (ARMGS) was highest in 1998 with 1328mm and the lowest in 2003 with 631.6mm. The mean ARMGS was 984mm.

Rainfall intensity (RI) was lowest in 2003 with 12.3 and highest in 1998 with 21.9. The mean RI was 16.3. The hydrological ratio (HR) was highest in 2006 (1.1) and lowest by 0.5 in many of the years. The mean HR however was 0.7.

The seasonality index (SI) was uniform throughout the period of study with 0.88 meaning, there has not been change in climatictype.

The derived rainfall parameters for Gboko are presented in Table 4.2.

The earliest onset date (OD) was observed on 17th April in 1991 at Gboko as seen in Table 4.2 and the latest was observed on 24th June, 2018. The OD however fluctuated within the months of April – June. The mean OD was 17th May.

The earliest cessation date (CD) was 16th October for many of the years under review and latest CD was on 6th November. The CD fluctuated between the months of October and November. The mean CD was estimated on 19thOctober.

The length of growing season (LGS) was longest in 1997 (199 days) and lowest in 2005 (112 days). The mean LGS was 152 days.

There was variation in the number of rainy days (NRD) in Gboko station with the year 2005 recording the least number of rainy days of 59 days. The year 2014 recorded the highest number of rainy days of 88 days. The mean NRD in the study area was 70 days.

Amount of rain in the months of the growing season (ARMGS) was highest in 2008 with 1245mm and lowest in 2019 with 752mm. The mean ARMGS was 985mm.

Table 4.1: Derived Rainfall Parameters of NiMet, Makurdi Station

Year	OD	CD	LGS	NRD	ARMGS	RI	HR	SI
1990	14-Jun	26-Oct	134	73	910.8	15.4	0.5	0.9
1991	19-Apr	26-Oct	190	73	871.6	16.2	0.6	0.9
1992	20-Apr	16-Oct	179	78	781.1	12.5	0.5	0.9
1993	28-Apr	26-Oct	181	67	974.1	18.2	0.6	0.9
1994	22-Apr	26-Oct	187	69	738.4	14.1	0.5	0.9
1995	29-Apr	16-Oct	170	77	951	15.2	0.6	0.9
1996	5-May	26-Oct	174	70	1115.9	18.9	0.7	0.9
1997	22-Apr	6-Nov	198	81	881.4	16.5	0.7	0.9
1998	29-Apr	16-Oct	170	71	1328.5	21.9	0.8	0.9
1999	22-Apr	26-Oct	187	79	1307.4	20.5	0.9	0.9
2000	5-Jun	6-Oct	123	65	998.3	18.1	0.7	0.9
2001	13-Jun	16-Oct	125	69	946.6	15.7	0.7	0.9
2002	15-Jun	16-Oct	123	71	1037.5	18.0	0.8	0.9
2003	10-Jun	16-Oct	128	62	631.6	12.3	0.5	0.9
2004	6-May	26-Oct	173	63	755.6	14.6	0.6	0.9
2005	17-Jun	16-Oct	121	69	714.8	12.6	0.7	0.9
2006	24-Apr	26-Oct	185	78	1153.1	17.2	1.1	0.9
2007	28-Apr	26-Oct	181	76	985.6	17.6	0.7	0.9
2008	22-Apr	16-Oct	177	72	881.4	14.6	0.6	0.9
2009	12-Apr	26-Oct	197	82	931.8	17.1	0.8	0.9
2010	9-Jun	26-Oct	139	74	930.5	15.1	0.6	0.9
2011	17-Jun	26-Oct	103	64	779.6	18.0	0.7	0.9
2012	24-Apr	6-Nov	196	81	1122.7	18.4	0.9	0.9
2013	25-May	16-Oct	144	84	985.1	15.3	0.7	0.9
2014	31-Mar	6-Nov	220	79	1036.3	16.0	0.7	0.9
2015	1-Jun	26-Oct	147	61	766.9	16.4	0.5	0.9
2016	12-Apr	16-Oct	187	76	985.7	16.3	0.7	0.9
2017	25-Apr	6-Oct	164	60	848.4	16.9	0.5	0.9
2018	23-Jun	26-Oct	125	75	948.4	15.4	0.6	0.9
2019	5-Jun	26-Oct	143	76	1015.9	21.0	0.9	0.9
MEAN	**18-May**	**19-Oct**	**162**	**73**	**984**	**16.3**	**0.7**	**0.9**

Where: OD = onset date, CD = cessation date, LGS = length of growing season, NRD = number of rainy days, ARMGS = amount of rain in the months of the growing season, RI = rainfall intensity, SI = seasonalityindex.

Source: Author's Computations(2021).

Table 4.2: Derived Rainfall Parameters of AOPOLY, Gboko Station

Year	OD	CD	LGS	NRD	ARMGS	RI	SI
1990	17-Jun	26-Oct	131	69	1064.5	21.5	1.0
1991	17-Apr	26-Oct	192	80	844.3	14.9	1.0
1992	7-Jun	16-Oct	131	66	756.2	16.2	1.0
1993	21-Jun	16-Oct	117	62	900	18.8	1.0
1994	19-Jun	26-Oct	129	69	968.6	17.3	1.0
1995	16-Apr	6-Nov	174	78	975.5	18.8	1.0
1996	11-Jun	26-Oct	137	65	1111.8	23.1	1.0
1997	21-Apr	6-Nov	199	83	1558.2	22.8	1.0
1998	29-Apr	26-Oct	180	61	967.1	19.9	1.0
1999	29-May	26-Oct	150	70	1065.7	20.1	1.0
2000	11-Jun	16-Oct	127	62	1029.9	21.8	1.0
2001	23-Jun	16-Oct	115	62	885.1	16.9	1.0
2002	15-Jun	26-Oct	133	68	1027.4	21.3	1.0
2003	12-Jun	6-Nov	147	64	1176.3	23.3	1.0
2004	6-May	6-Nov	184	64	981.8	20.3	1.0
2005	26-Jun	16-Oct	112	59	919.1	22.5	1.0
2006	20-May	26-Oct	159	76	935.4	16.8	1.0
2007	26-Apr	6-Nov	194	76	913.5	17.2	1.0
2008	24-Apr	16-Oct	175	74	1245.2	22.6	1.0
2009	21-Apr	26-Oct	188	84	982.5	16.8	1.0
2000	8-Jun	26-Oct	140	66	777.9	17.0	1.0
2011	13-May	26-Oct	166	63	982.1	22.6	1.0
2012	1-Jun	26-Oct	147	87	1164.4	17.2	1.0
2013	18-Apr	16-Oct	181	69	854.3	20.8	1.0
2014	19-Apr	26-Nov	221	88	1044	18.4	1.0
2015	10-May	26-Oct	169	64	843.6	16.3	1.0
2016	5-Jun	26-Nov	174	82	887.9	16.0	1.0
2017	14-Jun	26-Oct	134	66	883.4	17.6	1.0
2018	24-Jun	6-Nov	135	75	1052.6	20.0	1.0
2019	19-Jun	6-Nov	140	60	752	21.5	1.0
Mean	**17-May**	**19-Oct**	**152**	**70**	**985**	**16.3**	**1.0**

Where: OD = onset date, CD = cessation date, LGS = length of growing season, NRD = number of rainy days, ARMGS = amount of rain in the months of the growing season, RI = rainfall intensity, SI = seasonalityindex

Source: Author's Computations(2021)

Rainfall Intensity (RI) was observed to be highest (23.3) in 2003 and lowest in 1991 (14.9) and the mean of RI was 19.3. SI was uniform throughout the years under review with 1.0 implying no change in climatic type.

4.2 CropsYield

The selected crops yield per hectare for this study (maize, rice, sorghum and soyabeans) as obtained from BNARDA from 1990 to 2019 are presented in appendix 1.

4.3 Trends in Rainfall Parameters and Crops Yield

4.3.1 Trends of rainfallparameters

The trend of rainfall parameters is presented on Table 4.3.

4.3.1.1 Trends in onset dates(OD)

The trends in onset dates for the two stations in the study area are shown in Table. 4.3. The onset date depicted a positive increasing non-significant trend, with p-value of 0.968 at Gboko station as illustrated on Figure 4.1. This entails that the onset dates of rainfall were coming late at Gboko. This could pose a serious threat to crops in the long run if cessation dates come early.

Similarly, in Table 4.3 the trend of onset shows a positive increasing non-significant trend with p-value of 0.418 at Makurdi as shown on Figure 4. 2. This means that the onset dates were also continuously coming late and could have the tendency of affecting the farmers negatively.

The result of the positive increase in the trends of onset dates of rains for the two stations is in agreement with the studies of Sawa and Adebayo (2011), Oruonye (2014), Chinago (2015), Oruonye *et al.,* (2016), Agidi *et al.,* 2018 and Chinda (2019), who also analysed trends in onset dates in Northern Nigeria, Taraba State, Enugu State, Gassol LGA in Taraba State, some parts of Nasarawa state and Jos in Plateau state respectively.

Table 4.3: Trends of Rainfall Parameters

S/No	Rainfall Parameter	□ -Value		p-Value	
		Makurdi	Gboko	Makurdi	Gboko
1	Onset date (OD)	0.122	0.009	0.418	0.968
2	Cessation date (CD)	0.101	0.227	0.534	0.148
3	Length of growing season (LGS)	-0.088	0.132	0.509	0.317
4	Number of rainy days (NRD)	0.042	0.061	0.761	0.655
5	Amount of rain in the months of growing season (ARMGS)	0.046	-0.113	0.735	0.392
6	Rainfall intensity (RI)	0.065	-0.037	0.630	0.789
7	Seasonality index (SI)	-	-	-	-
8	Hydrological ratio (HR)	0.180	-	0.203	-

***** Trend statistically significant at 0.05 level (2-tailed)

Source: Author's computations (2021)

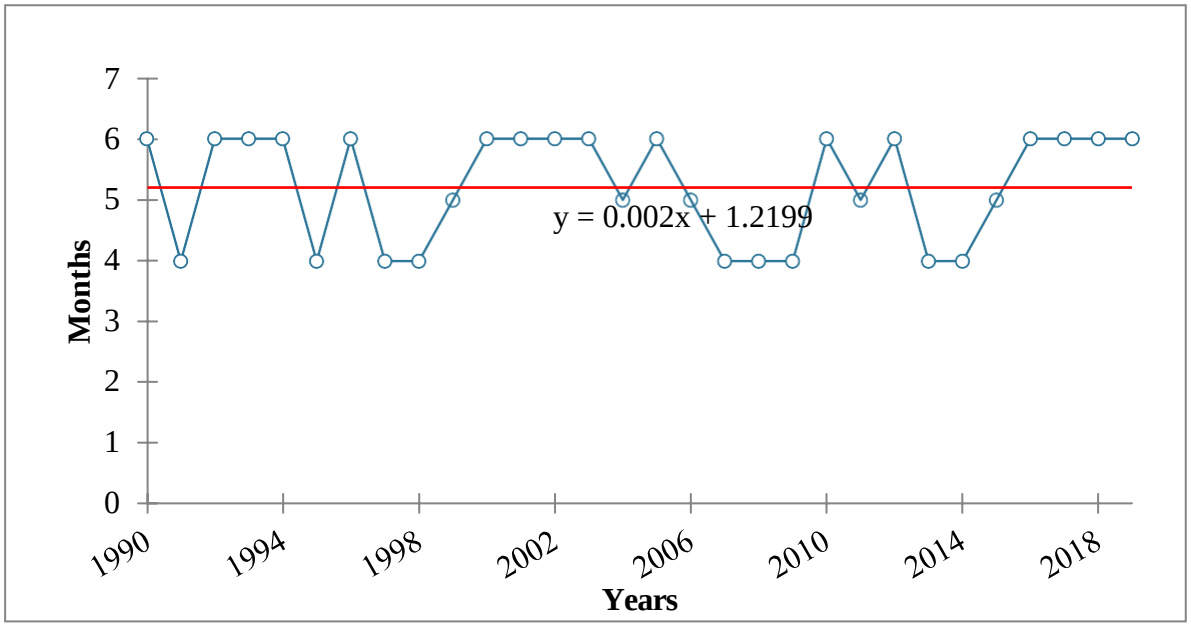


Figure 4.1: Trend in Onset Date at Gboko.

Source: Author's Analysis

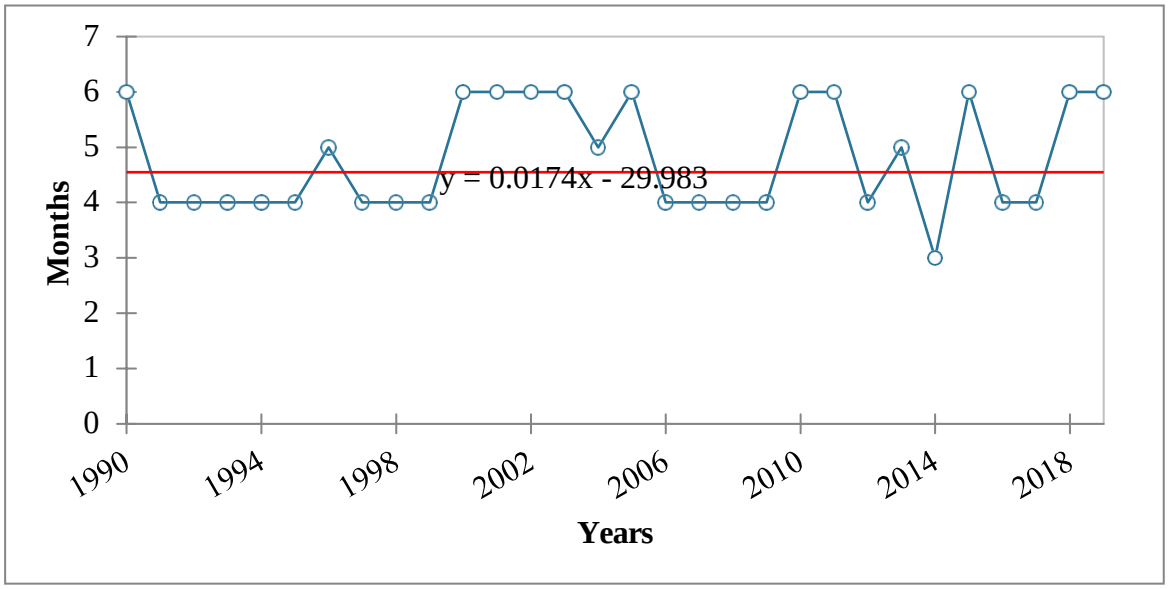


Figure 4.2: Trends in Rainfall at Makurdi.

Source: Author's Analysis

It is however contrary to the researches of; Barnabas *et al*. (2017), Adamgbe and Ujoh (2012) and Ekoh, (2020), who examined the trend in onset dates in Tanzania, Benue State and Sokoto state respectively. It is worthy to note that late onset dates, if coupled with early cessation would affect crops yield. This means that the amount of water required by crops for growth and proper yielding will be shortened and hence affect its yield. If this scenario continues for a long time, food insecurity would likely be experienced in the study area.

4.3.1.2 Trends in cessation dates(CD)

The trend in cessation date is shown in Table 4.3, Figure 4.3 and Figure 4.4. A positive increasing trend in cessation date with p-value of 0.148 at Gboko was observed. This means that the positive increasing trend as shown in Figure 4.3 is significant. An increasing positive trend as shown in Figure 4.4 was also observed at Makurdi station with p-value of 0.538 which mean that the increasing positive trend was non-significant. An increasing positive trend in cessation date implies that the rains are ending late.

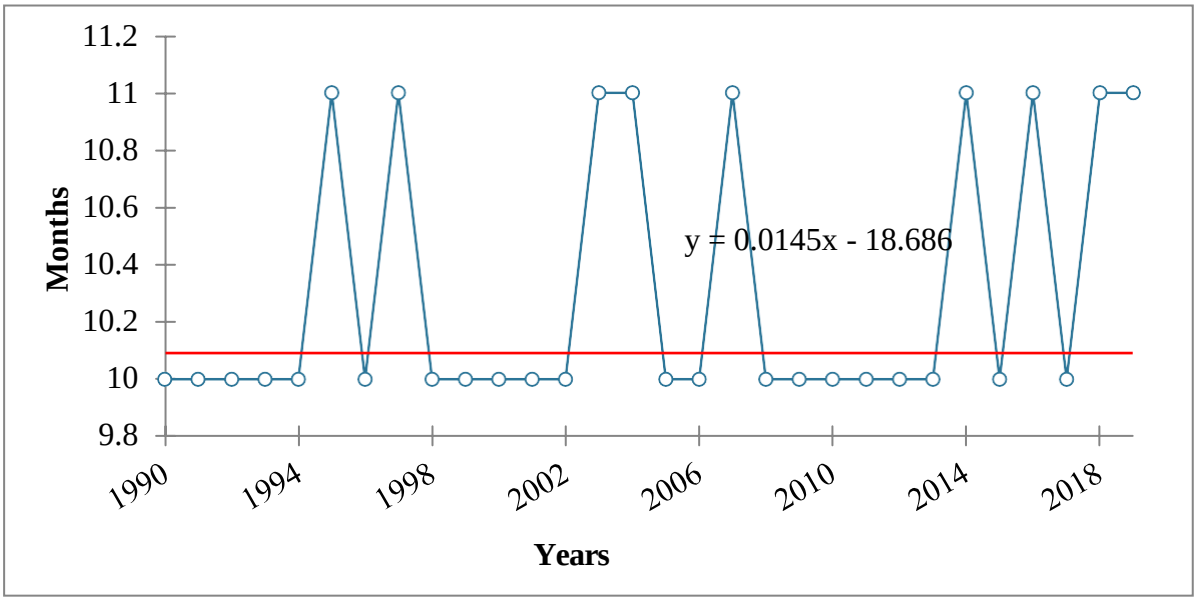


Figure 4.3: Trend in Cessation at Gboko.

Source: Author's Analysis

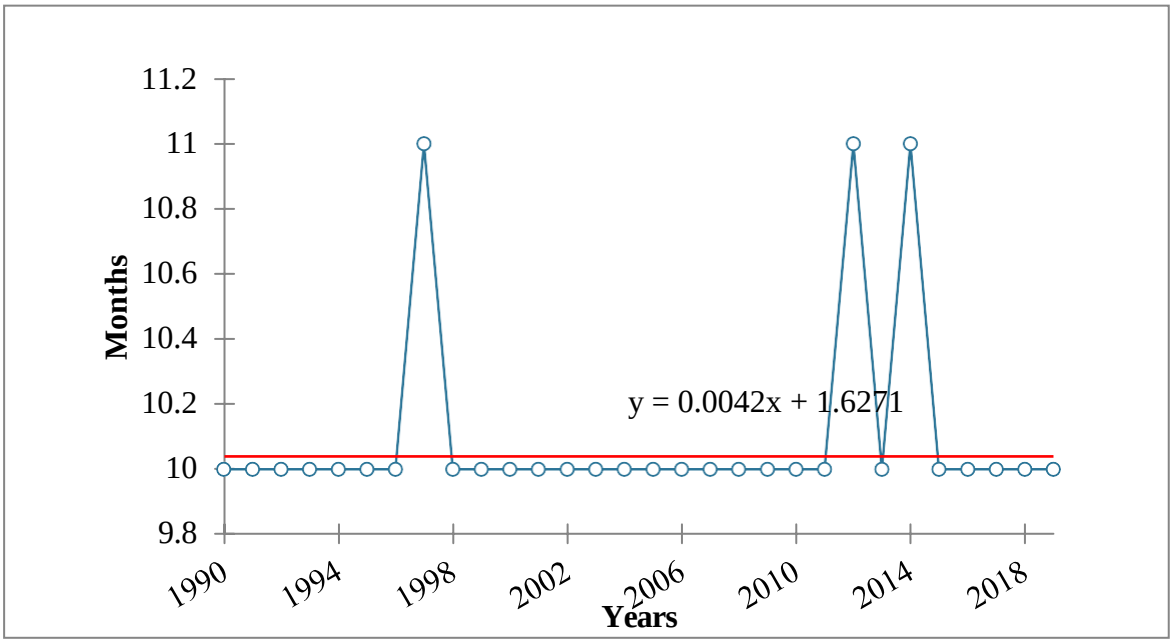


Figure 4.4: Trend in Cessation Date at Makurdi.

Source: Author's Analysis

The increasing trends in the cessation dates from the results in Table 4.3 are in agreement with the studies of Oruonye (2014), Agidi, *et al*., (2014), Chinda (2019) and Ekoh (2020) in some parts of Taraba State, Nasarawa State, Jos in Plateau state and Sokoto States

respectively. It is however contrary to the studies of Sawa and Adebayo (2011), Adamgbe and Ujoh (2012), Chinago (2015) and Barnabas, *et al*., (2017) who found out that the trend in cessation dates were rather decreasing in Northern Nigeria, Benue State, Enugu State and Tanzania respectively. The implication of increasing cessation date is longer LGS so if farmers do not harvest their drops in time, they are likely to be destroyed.

4.3.1.3 Trends in length of growing season(LGS)

The length of growing season as shown in Table 4.3 and Figure 4.5 depicted an increasing positive non-significant trend at Gboko station with the p-value of 0.317. This is advantageous to farmers in the sense that they can grow crops that take longer time to mature. This finding was in agreement with Akinbobola, Okogbue and Ayansola (2018), Agidi, *et al*., (2018), Haruna and Murtala (2019), Chinda (2019) and Ekoh (2020) who also observed increase in the trend of LGS in Ondo and Akure, some parts of Nasarawa state, Kano state, Jos in Plateau state and Sokoto state respectively. This finding is however contrary to Sawa and Adebayo (2011), Adamgbe and Ujoh, (2012), Aliyu (2009), Oruonye (2014), Oruonye, *et al.,* (2016) and Barnabas, *et al*., (2017) whose researches found out rather decreasing trends in Northern Nigeria, Benue State, Northern Nigeria, Taraba state, Gassol LGA in Taraba State and Tanzania respectively. Increasing trend in LGS will provide the farmers' opportunities to plant 2 – 3 crops of different lifecycle in a season. This in the long run would lead to foodsecurity.

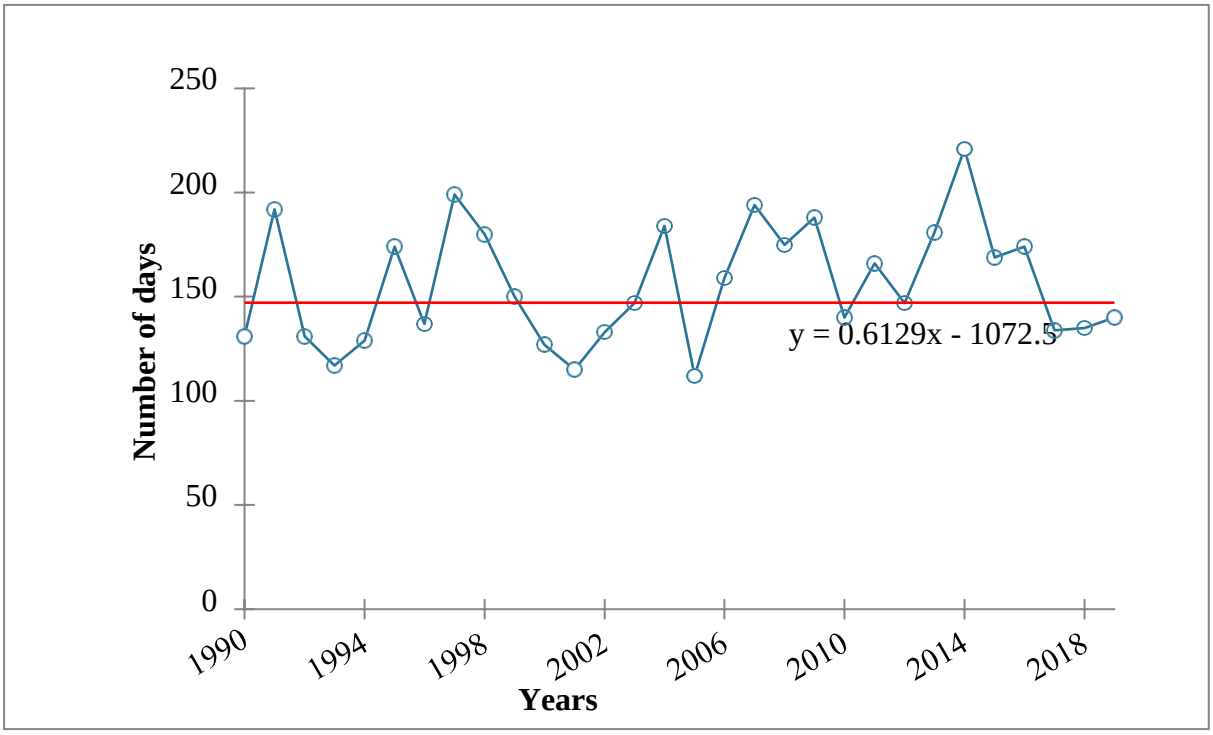


Figure 4.5: Length of Growing Season at Gboko

Source: Author's Analysis

Table 4.3 and Figure 4.6 also showed a negative trend (= -0.088) in LGS at Makurdi station with the p-value of 0.509 which showed that the negative trend was non-significant. Decreasing trend in LGS means that the rainy season is becoming shorter and this could be detrimental to farmers because there may not be sufficient moisture for their crops. In this situation, farmers could begin to think of an alternative, probably irrigation in order to complement the moisture insufficiency. This finding is in agreement with Sawa and Adebayo (2011), Adamgbe and Ujoh, (2012), Aliyu (2009), Oruonye (2014), Oruonye, *et al*., (2016) and Barnabas, *et al.*, (2017) whose researches found out a decreasing trend in LGS in Northern Nigeria, Benue State, Northern Nigeria, Taraba state, Gassol LGA in Taraba State and Tanzania respectively. It is however contrary to Akinbobola, Okogbue and Ayansola (2018), Agidi, *et al*., (2018), Haruna and Murtala (2019), Chinda (2019) and Ekoh (2020) who observed increase in the trend in LGS in Ondo and Akure, some parts of Nasarawa state, Kano state, Jos in Plateau state and Sokoto staterespectively.

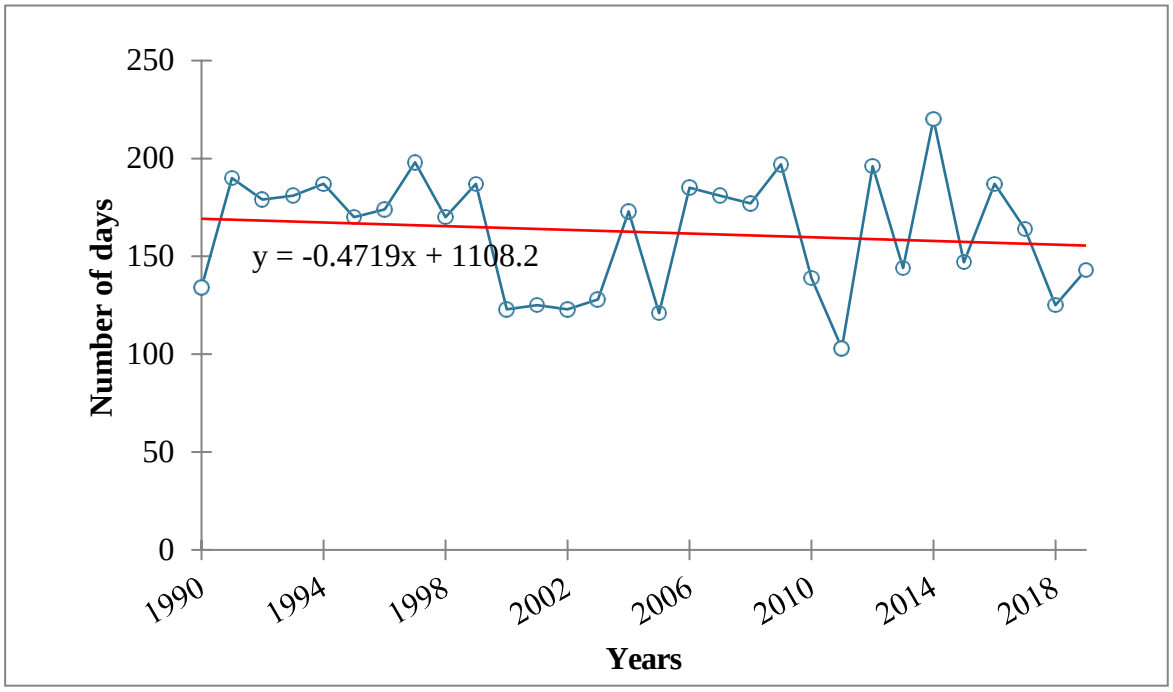


Figure 4.6: Trend in Length of Growing Season in Makurdi.

Source: Author's Analysis

4.3.1.4 Trends in number of rainy days (NRD)

The trend of number of rainy days at Gboko station is shown on Table 4.3 and Figure 4.7. NRD depicted a positive increasing non-significant trend with p-value of 0.655. Increase in the number of rainy days is advantageous to farmers as there will be sufficient moisture available for crops use. An increase in the number of rainy days also leads to increase in the LGS.

The trend in NRD at Makurdi station indicated a similar increasing trend (Figure 4.8) as that of Gboko with the p-value of 0.761 which however shows that the increasing trend was non-significant. The Positive trend in NRD is advantageous to farmers as it makes more water available for crop use. It could however be disastrous also because certain crops, soyabeans for instance, could be destroyed with prolonged number of rainy days beyond threemonths.

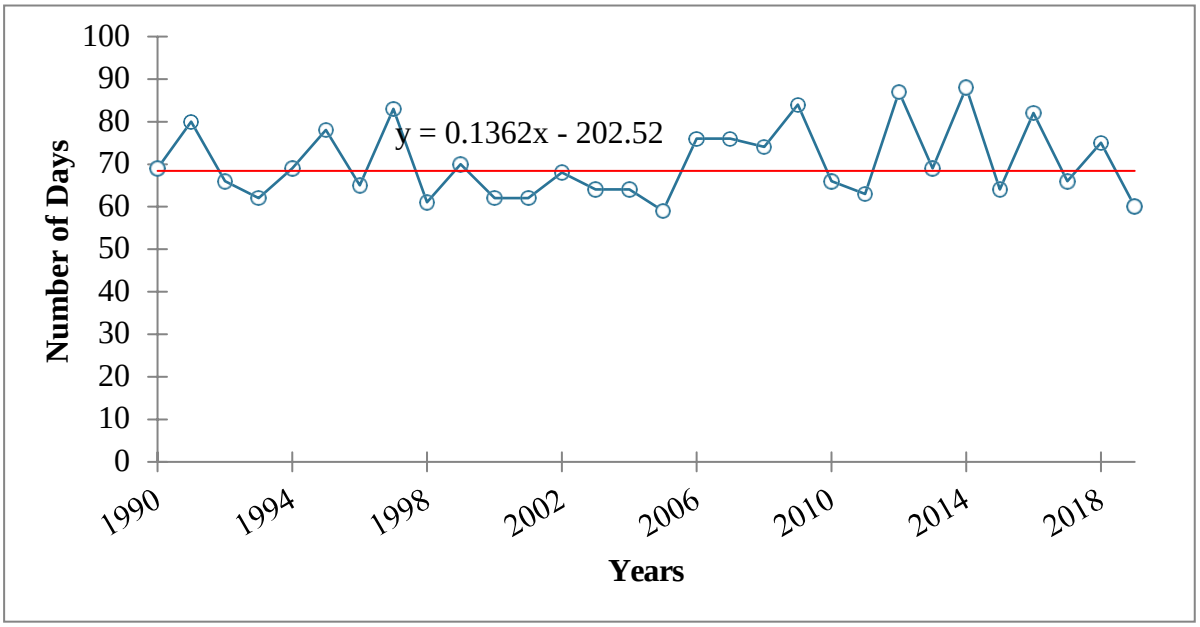


Figure 4.7: Trend in Number of Rainy Days (NRD) in Gboko.

Source: Author's Analysis, (2021)

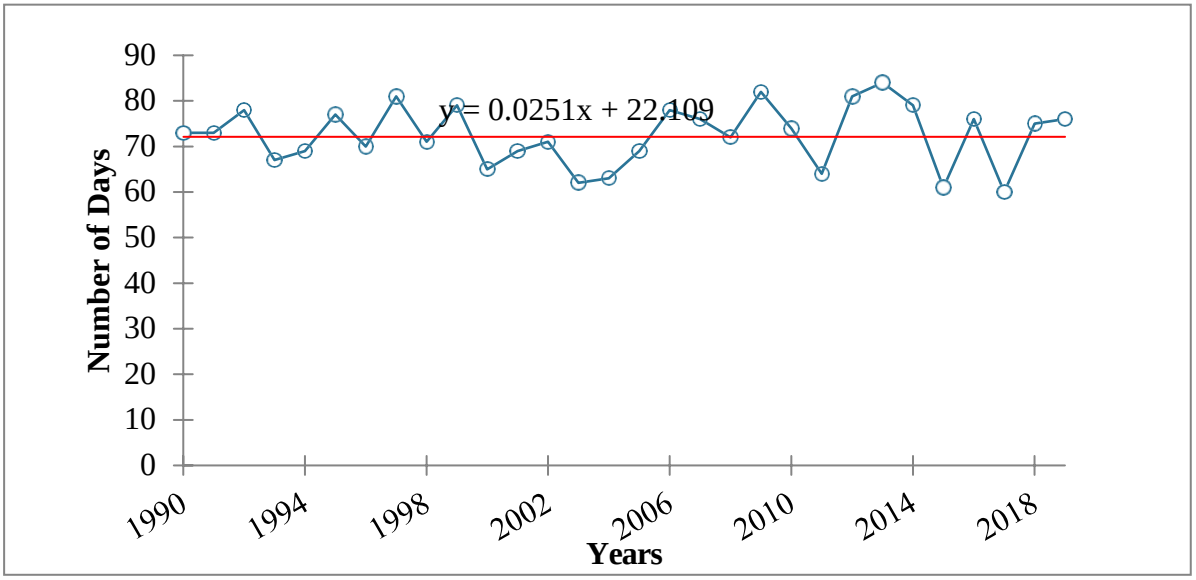


Figure 4.8: Trend in Number of Rainy Days in Makurdi.

Source: Author's Analysis, (2021).

The finding of this study is in agreement with Akinbobola, Okogbue and Ayansola (2018) who also predicted an increasing trend in NRD in Ondo and Akure and Atedhor (2016) who observed an increasing trend in NRD in Benin and a decreasing trend in Warri, Ondo,Port-

Harcourt and Calabar. It is contrary to studies of Adambge and Ujoh (2012) who observed rather a decreasing trend in NRD in Benue Sate.

4.4.1.5 *Trends in rainfall intensity (RI)*

The trend of rainfall intensity shown in Table 4.3 and Figure 4.9 indicated a decreasing (= -0.037) non-significant trend at Gboko with the p-value of 0.789. In contrast, the trend of RI shown in Table 4.3 and Figure 4.10 indicated an increasing non-significant trend at Makurdi with the p-value of0.630.

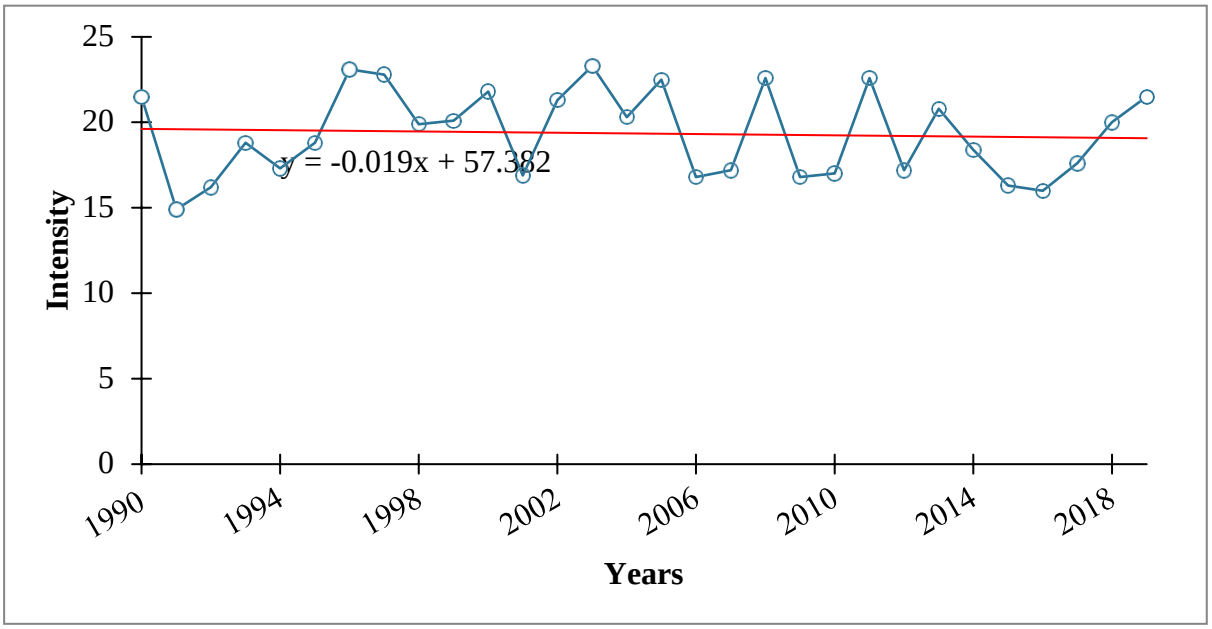


Figure 4.9: Trends in Rainfall Intensity at Gboko

Source: Author's Analysis

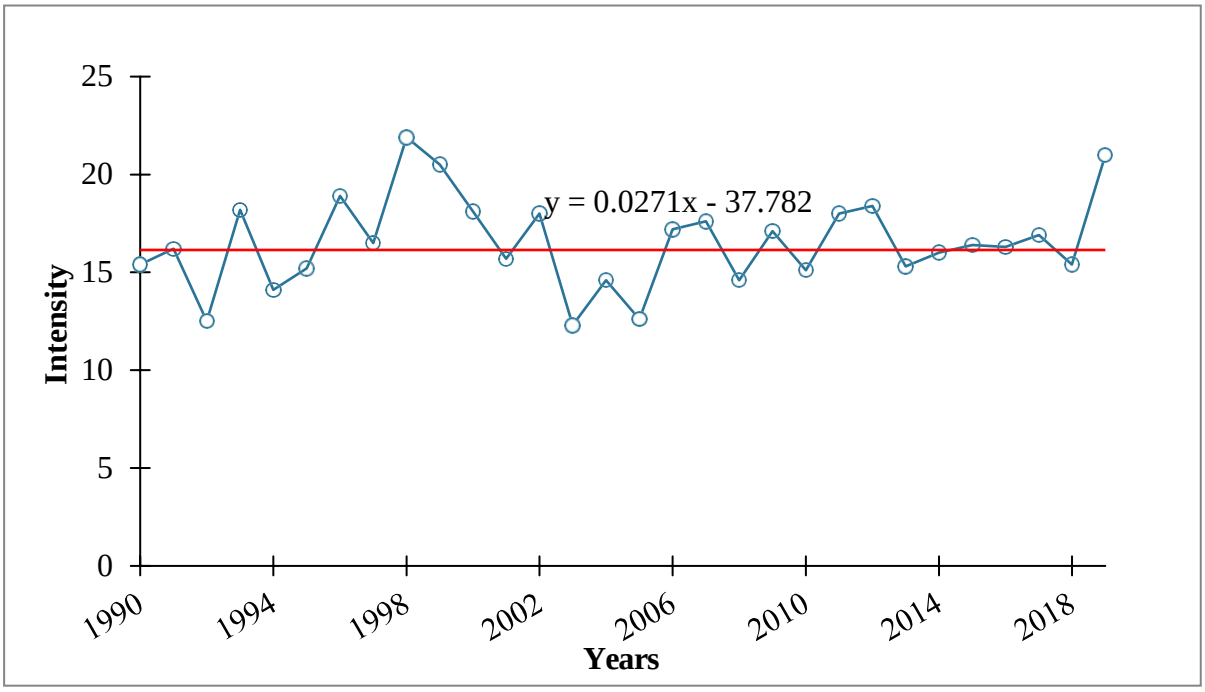


Figure 4.10: Trend in Rainfall Intensity at Makurdi.

Source: Author's Analysis (2021).

The lower the intensity of rainfall per time, the more useful it will be to crops. This is because high intensity leads to sheet erosion but low intensity encourages infiltration.

This finding is in agreement with that of Ocholi, Ocholi and Isah (2016) and Akinbobola, Okogbue and Ayansina (2018) whose researches also observed a decreasing trend in RI in Ayigba, Kogi state and Akure in Ondo state respectively.

4.3.1.6 Trends in hydrological ratio(HR)

The trend in hydrological ratio is shown in Table 4.3 and Figure 4.11. It showed an increasing non-significant trend in HR with the p-value of 0.203. This conforms with the study of Abdulhamid and Abubakar, (2002) who observed an increasing trend of HR in Katagum zone of Bauchi state. A high value of HR depicts a drier rainy season. The increasing trend in HR therefore shows that the wet season is becoming drier. This could be detrimental to crops because, moisture will become insufficient for the crops. Farmers will therefore have to look for possible means to augment soil moisture deficiency fortheir

crops, precisely irrigation. This drier condition will further inform the farmers to change their types of crops in order to cope with the drier conditions being experienced in the study.

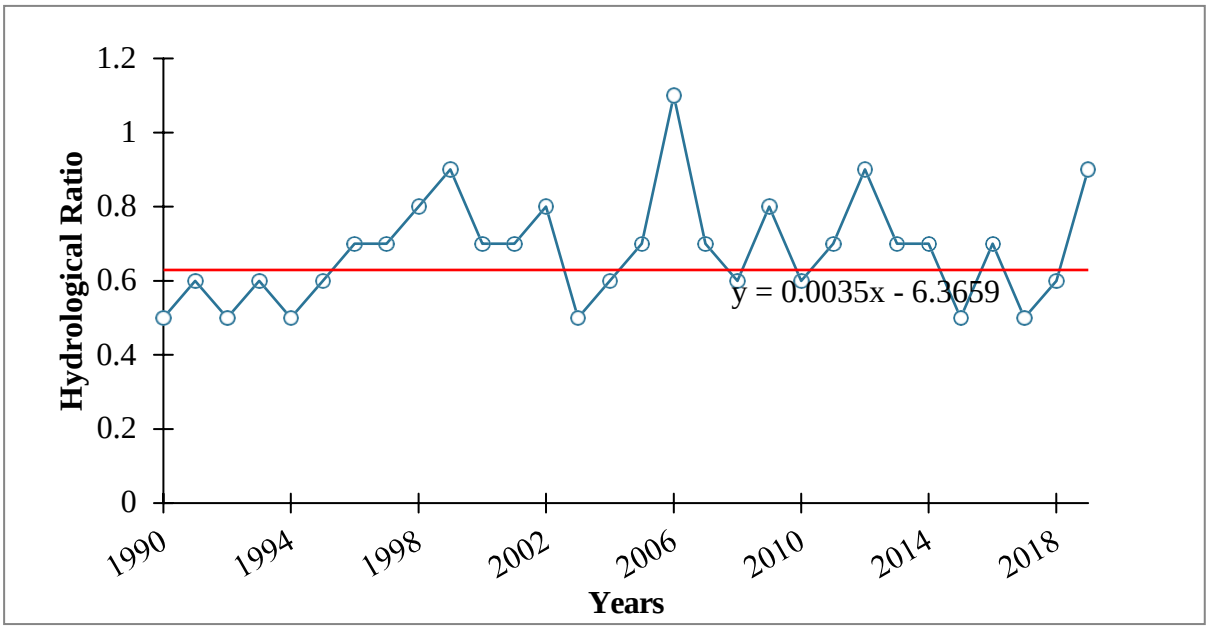


Figure 4:11: Trend in Hydrological Ratio in the at Makurdi.

Source: Author's Analysis (2021).

4.3.1.7 Trends in seasonality index(SI)

The trends of seasonality indices for Gboko and Makurdi stations were not calculated. This was because both stations maintained constant values of 0.97 and 0.88 respectively. Due to the constant values, their □ and p-values could not be computed by the software. However, Figures 4.12 and 4.13 gives a pictorial illustration in thetrends.

The trend of SI showed stability in the two stations. This result was contrary to Guhathakurta and Saji (2013) who in their research observed increasing trends of SI in some parts of Maharashtra State and an increasing trend in others, Nandargi, Mahto and Ram (2017) also observed increasing trend in India and Sharma and Singh (2019) observed decreasing trend in SI in North EastJharkhand.

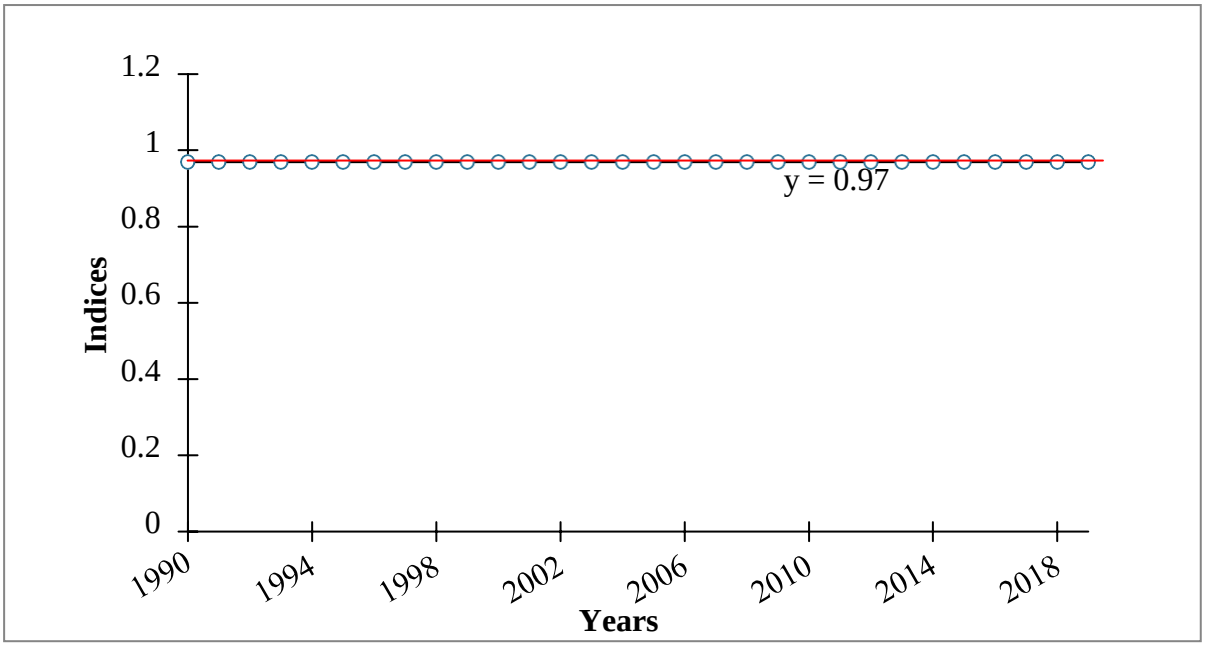


Figure 4.12: Trend in Seasonality index at Gboko

Source: Author's Analysis (2021)

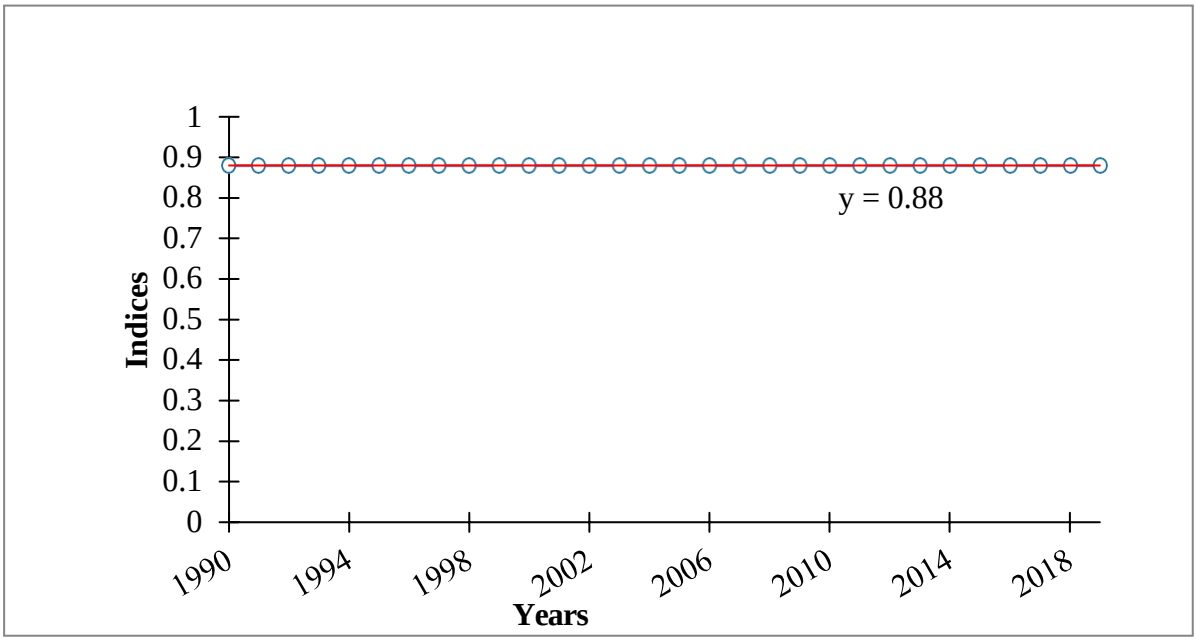


Figure 4.13: Trend in Seasonality Index at Makurdi.

Source: Authors' Analysis (2021).

The SI interpretation values in Table 3.1 indicated that the SI values for the study area falls within the Sudan Savanna, in contrast to the Guinea Savanna where the study area falls. This could be attributed to variability in rainfall being mostly caused by climate change.

This also agrees with the revelation of Franchito, *et al*., (2010) that Climate variability in the tropics is usually revealed by rainfallvariability.

4.4.1.8 *Trends in amount of rain in the months of the growing season(ARMGS)*

The trend for amount of rain in the months of the growing season at Gboko station as shown in Table 4.3 and Figure 4.14 depicted a decreasing non-significant trend with the P-value of -0.113. This implies that the amount of rainfall received within the months of the growing season was decreasing. The implication of this is that the amount of moisture that is available for plant uptake is decreasing. If this decreasing trend continues, it will be a threat to future food security because of moisturedeficiency.

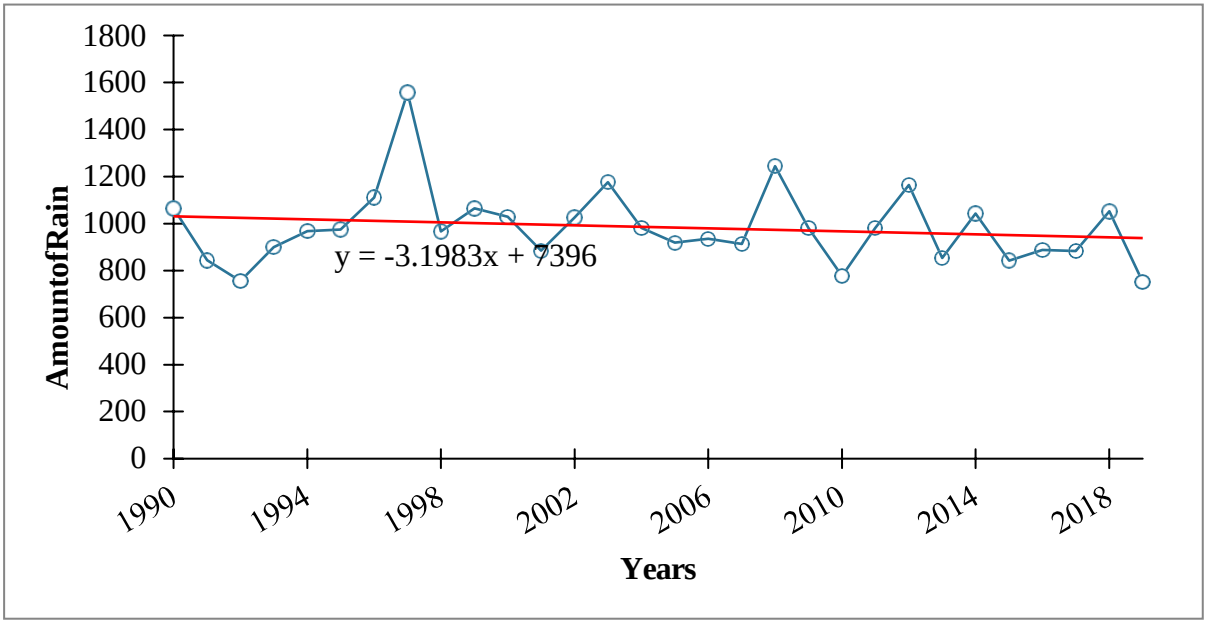


Figure 4.14: Amount of Rain in the Months of the Growing Season at Gboko

Source: Author's Analysis (2021).

On the other hand, the ARMGS at Makurdi station depicted an increase (Figure 4.15) which was non-significant with the p-value of 0.046. An increase in the amount of rain in the months of the growing season is advantageous to crops. It signifies sufficient moisture for plantuse.

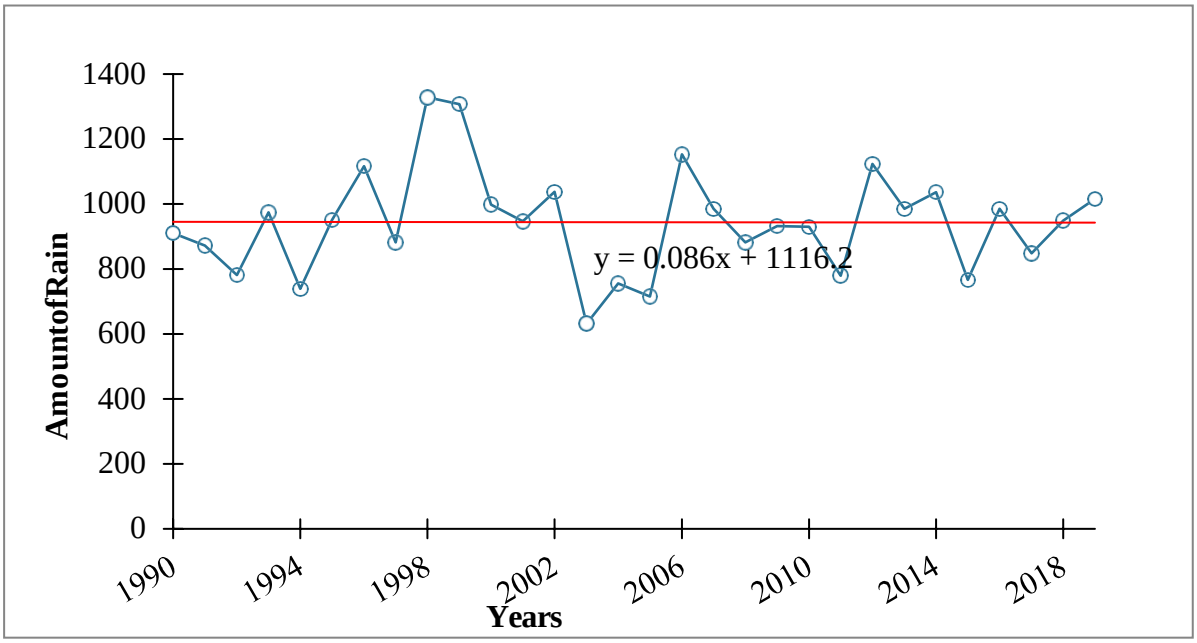


Figure 4.15: Amount of Rain in the Months of the Growing Season at Makurdi

Source: Author's Analysis (2021).

4.3.2 Trends of crops yield

The trends of the selected crops yield are presented in Table 4.4

4.3.2.1 Trends in maizeyield

The trend in maize yield presented in Table 4.4 showed an increasing trend with a computed p-value of 0.003. This value depicted that the positively increasing trend of the yield of maize as shown in Figure 4.16 was significant at 0.01 significant level. This finding is in agreement with the studies of Okeowo, *et al*, (2015), Emeghara (2015) and Bamiro *et al.*, (2020) whose researches found out an increasing trend in the yield of maize in Lagos state, Sokoto state and Nigeria respectively. It is however contrary to the findings of Omoyo *et al.*, (2015), Chikezie *et al.*, (2015) and Oruonye *et al*, (2016) in Eastern Kenya, South-Eastern Nigeria and Gassol LGA in Taraba state respectively.

This is a welcome development as maize will continue to be in abundance and available for humanconsumption.

Table 4.4: Trends of Crops Yield

S/No	Selected crops	□ -Value	p-Value
1	Maize	0.394	0.003**
2	Rice	0.176	0.192
3	Sorghum	0.367	0.007**
4	Soyabeans	0.519	<0.0001**

**Trend statistically significant 0.001 level (2-tailed)
***** Trend statistically significant at 0.05 level (2-tailed)
Source: Author's Computations (2021)

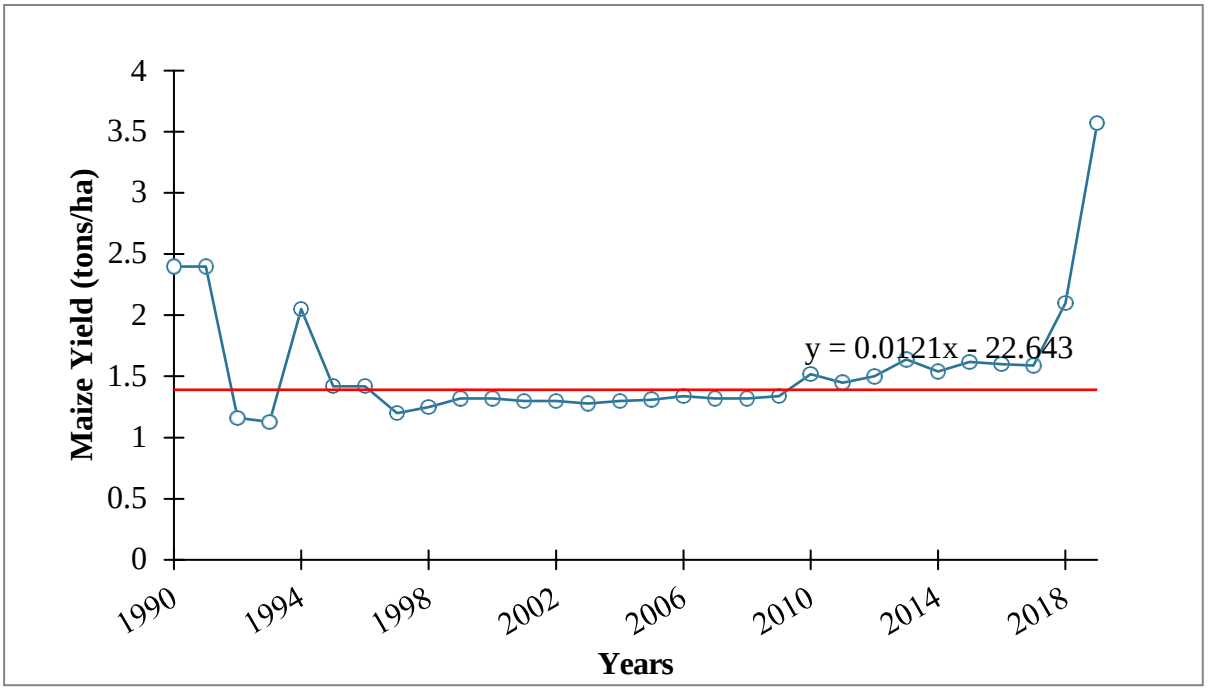


Figure 4.16: Trend in Maize Yield

Source: Author's Analysis (2021)

4.3.2.2 Trends in riceyield

The trend in rice yield as presented in Table 4.4 and shown in Figure 4:17 depicted an increasing trend. The computed p-value is 0.192 and showed that the increasing trend in rice yield was non-significant. This means that rice is becoming more abundant in the studyarea.

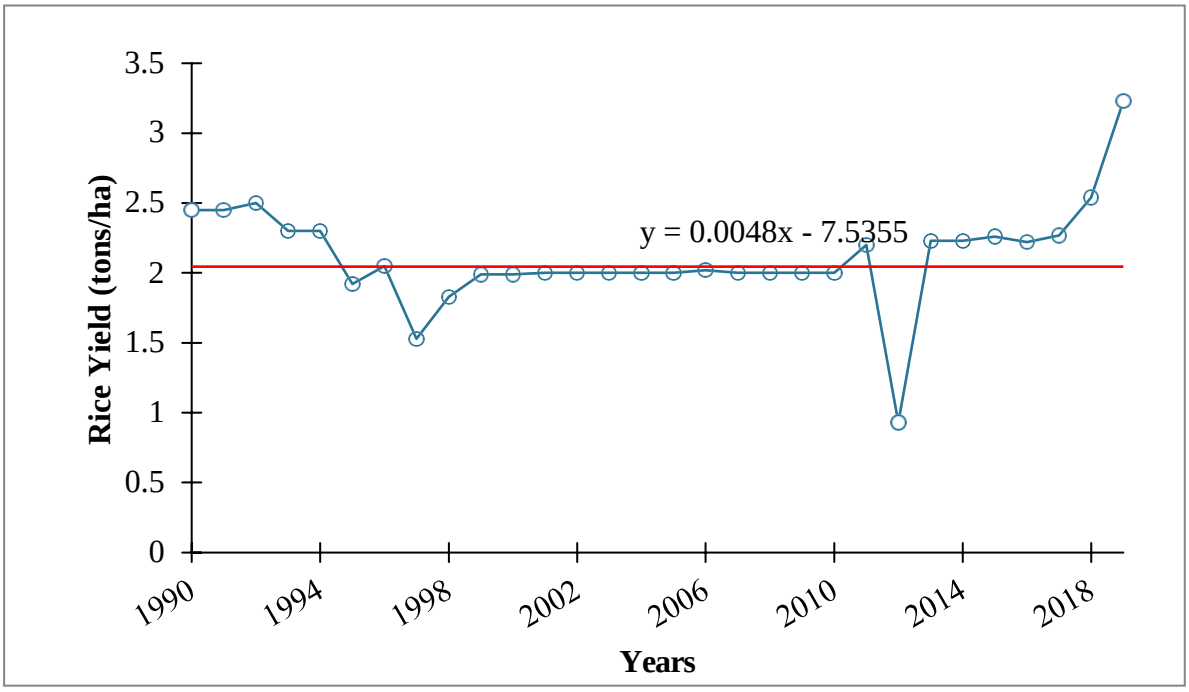


Figure 4.17: Trend in Rice Yield

Source: Author's Analysis (2021)

This finding conforms to the researches of Ayinde, *et al.*, (2013), Haruna (2014), Emeghara (2015) and Raju and Phanindra (2020) also found out an increasing trend in the yield of rice in Niger state, FCT, Sokoto state and Telangana state in India respectively. It is however contrary to Agidi, Hassan and Baleri (2017) and Bamiro *et al.*, (2020) in Nasarawa state and Nigeriarespectively.

4.3.2.3 Trends in sorghumyield

The trend in the yield of Sorghum showed an increasing trend as shown in Table 4.4 and Figure 4.18. The computed p-value of 0.007 indicated that the trend is significant at 0.01 significant level. This finding was in agreement with that of Haruna (2014) and Adamgbe and Ujoh (2012). It is however contrary to Haruna and Murtala (2019).

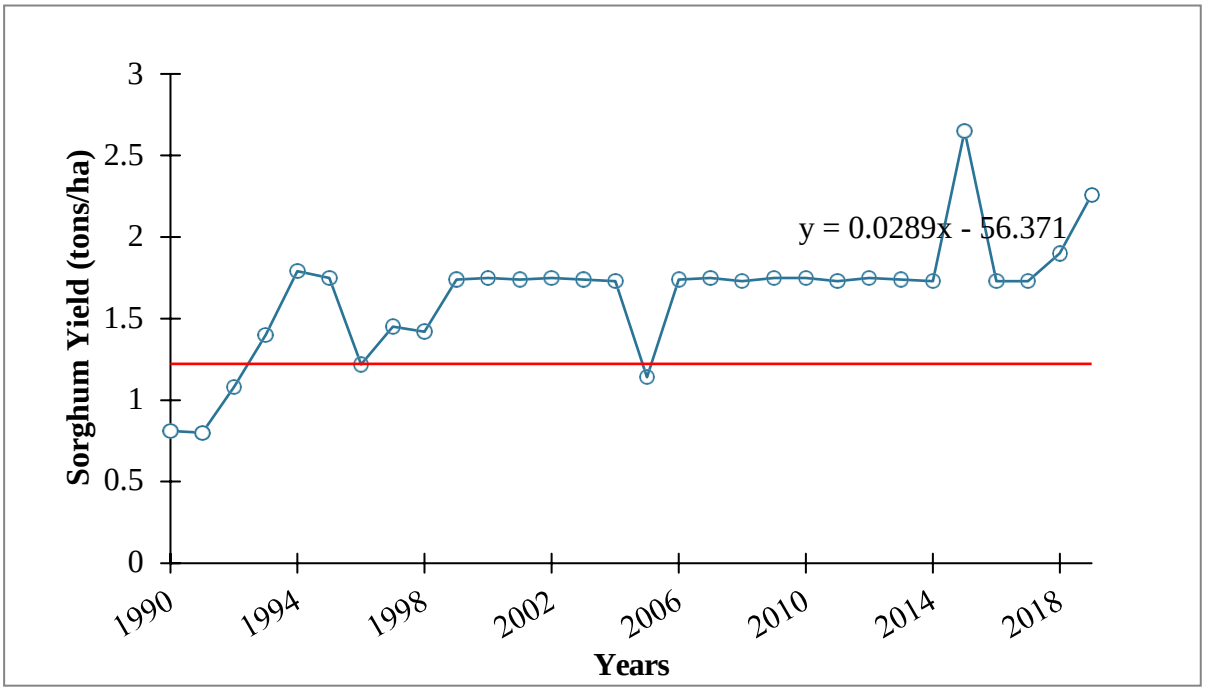


Figure 4.18: Trend in Sorghum Yield

Source: Author's Analysis (2021).

4.3.2.4 Trends in soya beans yield

The trend in soya beans yield is shown in Table 4.4 and Figure 4.19. It depicted a positively significant increasing trend with the computed p-value of <0.0001 at 0.01 significant level. Hence, the stated hypothesis was rejected meaning that there is significance in the trend of soyabeans yield in the study area within the study period which is in agreement with the study of Adamgbe and Ujoh (2012) who observed an increasing trend of Soyabeans in Benue state.

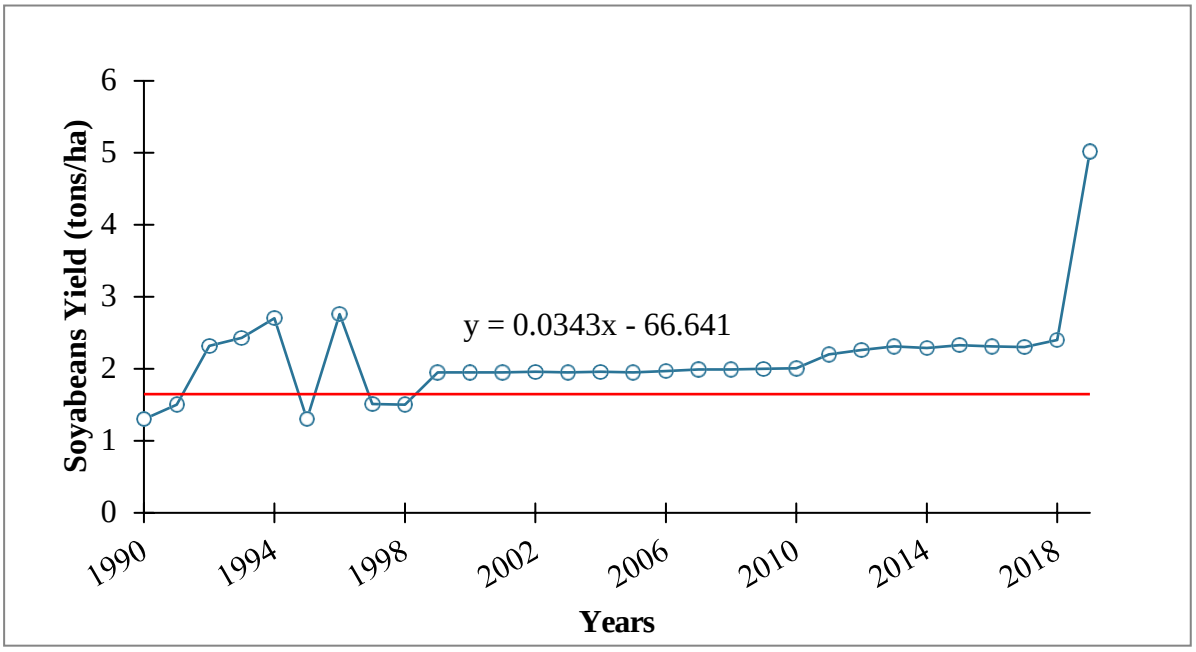


Figure 4.19: Trend in Soya Beans Yield

Source: Author's Analysis (2021).

4.4 Relationship Between Rainfall Parameters and CropsYield

Rainfall parameters and the selected crops yield were first harmonized into $\log_{10}$ base and subjected to Pearson's Product Momentum Correlation. This tool was also used to test the stated hypothesis that; there is no significant difference between rainfall parameters and crops yield in the study area, at 0.01 and 0.05 significant levels.

441 Relationship between rainfall parameters and crops yield atGboko

Table 4.5 shows the relationship between rainfall parameters and the selected crops yield at Gboko. It was observed from Table 4.5 that maize had a positive non-significant relationship with OD, CD and NRD at 0.01 and 0.05 significant levels. It also showed a negative non-significant relationship with LGS, ARMGS and RI at 0.01 and 0.05 significantlevels.

Table 4.5: Relationship between Rainfall Parameters and Crops Yield at Gboko

Parameters	Maize	Rice	Sorghum	Soyabeans
OD	0.148	0.120	0.000	0.412*
CD	0.151	0.102	0.274	0.085
LGS	-0.037	-0.137	0.129	-0.252
NRD	0.027	-0.375*	-0.020	-0.250
ARMGS	-0.302	0.551**	-0.044	-0.363*
RI	-0.079	-0.014	-0.019	0.019
SI	0.0[b]	0.0[b]	0.0[b]	0.0[b]

** Correlation is Significant at the 0.01 level (2-tailed).

* Correlation is Significant at the 0.05 level (2-tailed).

[b] Cannot be computed because at least one of the variables is constant

Where: OD = onset date, CD = cessation date, LGS = length of growing season, NRD = number of rainy days, ARMGS = amount of rain in the months of the growing season, RI = rainfall intensity, SI = seasonality index

Source: Author's Computations (2021)

Hence the null hypothesis that there is no significant relationship between maize yield and rainfall parameters was accepted. This finding is contrary to Bello, (2012) who observed positive and significant relationship between millet yields with OD, LGS and HR with r values of 0.643, 0.734 and 0.787 respectively and Osabo, Ndor and Agwale, (2019) which showed a perfect correlation with ARMGS.

Rice yield showed a positive relationship with OD, CD and ARMGS and a negative relationship with LGS, NRD and RI in Table 4.5 which were non-significant at 0.01 and 0.01 and 0.05 significant levels. However, the relationship was significant with ARMGS and NRD at 0.01 and 0.05 significant levels respectively. Hence, the stated null hypothesis was accepted in regards to the relationship between rice yield and NRD and ARMGS. However, the stated null hypothesis that; there is no significant relationship between rice yield and other rainfall parameters of OD, CD LGS and RI was rejected.

This finding is contrary to the study of Adebayo and Adebayo (1997) who observed that OD and HR influenced the yield of rice in Adamwa state.

Sorghum showed a positive relationship with OD, CD and LGS in Table 4.5. It also showed a negative relationship with NRD, ARMGS and RI at Gboko station. Both relationships were non-significant at 0.01 and 0.05 significant levels. Hence, the stated null hypothesis was accepted that there is no significant relationship between sorghum yield and rainfall parameters in the studyarea.

Soyabeans showed a positive relationship with OD, CD and RI and a negative relationship with LGS, NRD and ARMGS at Gboko station as shown in Table 4.5 which were non-significant at 0.01 and 0.05 significant levels. However, the relationship was significant with OD and ARMGS both at 0.05 significant level. Hence, the stated null hypothesis was accepted in respect to the relationship between soyabeans yield and OD and ARMGS. The relationship was non-significant with the other rainfall parameters hence, the stated hypothesis was rejected.

The relationship between crops yield with SI was not computed as a result of their constant variables at both stations. Hence, no relationship could be determined.

4.4.2 Relationship between rainfall parameters and crops yield atMakurdi

Table 4.6 shows the relationship between rainfall parameters and the selected crops yield at Makurdi. It was observed that maize had positive non-significant relationship with OD, NRD and RI and negative non-significant relationship with CD, LGS, ARMGS and HR at both 0.05 and 0.01 significant levels. Hence, the stated hypothesis that there is no significant relationship between maize yields with rainfall parameters at Makurdi station was accepted at both significant levels.

Table 4.6: Relationship between Rainfall Parameters and Crops Yield in Makurdi

Parameters	Maize	Rice	Sorghum	Soyabeans
OD	0.226	0.226	0.112	0.136
CD	-0.098	-0.589**	0.034	-0.060
LGS	-0.117	-0.242	-0.093	-0.044
NRD	0.090	-0.195	-0.112	-0.051
ARMGS	-0.027	-0.225	0.054	-0.011
RI	0.125	-0.104	0.210	0.190
SI	0.0[c]	0.0[c]	0.0[c]	0.0[c]
HR	-0.075	-0.321	0.212	0.148

** Correlation is Significant at the 0.01 level(2-tailed).
* Correlation is Significant at the 0.05 level(2-tailed).
[c] Cannot be computed because at least one of the variables is constant
Where: OD = onset date, CD = cessation date, LGS = length of growing season, NRD = number of rainy days, ARMGS = amount of rain in the months of the growing season,RI = rainfall intensity, SI = seasonality index

Source: Author's Computations (2021)

This finding agrees with the study of Mugiyo, Mhizha and Mabhaudhi (2018) whose study also observed a strong positive but non-significant relationship between maize yields with NRD in Hwedza, Zimbabwe. However, this finding is contrary to Bello, (2012) who observed positive and significant relationship between millet yields with OD, LGS and HR with r values of 0.643, 0.734 and 0.787 respectively and Osabo, Ndor and Agwale, (2019) which showed a perfect correlation withARMGS.

Rice yield recorded a positive non-significant relationship with OD and negative non-significant relationship with LGS, NRD, ARMGS, RI and HR at 0.01 and 0.05 significant levels. Cessation date (CD) however showed a negative but significant relationship with rice yield at 0.01 significant level in Table 4.6. Hence, the stated null hypothesis was accepted for the relationship between rice yield and CD and was rejected for rice yield and other rainfall parameters (OD, LGS, NRD, ARMGS, RI, SI and HR) at 0.01 and 0.05 significant levels at Makurdistation.

This finding is in disagreement with Adebayo and Adebayo (1997) who observed that OD and HR influenced the yield of rice in Adamawa state.

Soyabeans showed a positive relationship with OD, RI and HR and negative relationship with CD, LGS, NRD and ARMGS at Makurdi as shown in Table 4.6. Both positive and negative relationships were of non-significance at 0.01 and 0.05 significant levels. Hence, the stated null hypothesis that there is no significant relationship between soyabeans yield and rainfall parameters was accepted.

Sorghum recorded a positive non-significant relationship with OD, CD, ARMGS, RI and HR at Makurdi station as shown in Table 4.6. It also showed a non-significant negative relationship with LGS and NRD. The relationships were non-significant at 0.01 and 0.05 significant levels. Hence, the stated null hypothesis that there is no significant relationship between sorghum yields with rainfall parameters was accepted at Makurdi station.

This finding is in agreement with the studies of Iortyom, Iorsamber and Adelabu, (2017) who observed a positive non-significant relationship between sorghum and onset dates (OD), and negative non-significant relationship between sorghum and cessation dates (CD) in Lafia. It was however contrary to Osabo, Ndor and Agwale, (2019) which showed a perfect correlation with OD and CD Benuestate.

The relationship between crops yield with SI was not computed as a result of their constant variables at both stations. Hence, no relationship could be determined.

Generally, as observed above, the variability in rainfall parameters affected crops yield differently at the two locations. The findings of Akinola (1983) showed that agro-climatic factors correlated with the yields of maize and rice yields in Nigeria. Maize yield was affected by rainfall variability from the researches of: Aondoakaa, 2012; Rashia and

Rasul, 2013; Okeowo, Ogunbameru and Ogunyemi, 2015; Rashida, 2016; Ali, 2018; Mugiyo, Mhiza and Mabhaudhi, 2018. It also affected rice yield in Nigeria (Tiamiyu, *et al.*, 2015; Bamiro, *et al.*, 2020).

4.5 Prediction of Selected Crops Yield by2050

The method of Adebayo and Adebayo (1997) was used to build yield forecast models for the four crops in each location. The correlation results in Tables 4.5 and 4.6 showed however that three rainfall parameters (OD, NRD and ARMGS) were significantly correlated with the yield of two of the selected crops (rice and soyabeans) in Gboko and only one rainfall parameter (CD) correlated significantly with the yield of one of the selected crop (rice) in Makurdi. These were further subjected to Stepwise Multiple Regression. At the end of the stepwise multiple regression analysis, NRD was excluded from the model probably as a result of weak correlation and hence was not part of the developed equation for predicting rice yield in Gboko. CD on the other hand formed the model for predicting rice yield inMakurdi.

The results of the analysis therefore produced three yield forecast models; one each for rice and soyabeans at Gboko and one for rice at Makurdi respectively. The formed yield forecast models are presented in Table4.7.

Table 4.7: Crops Yield Forecast Models

Crop	Location	YieldforecastModel	R^2	R^2(%)
Rice	Gboko	$Y = 2.214 – 0.637LogX_1$	0.27	27
Soyabeans	Gboko	$Y = 0.005 + 0.418LogX_2$	0.16	16
Rice	Makurdi	$Y = 4.130 – 3.805LogX_3$	0.39	39

Source: Author's computations (2021)

Where: $Y = Log_{10}$ Crops yield [Rice and Soyabeans] (tons/ha)

X_1 = Amount of rain in the months of the growing season

X_2 = Onset Date (OD)

X_3 = Cessation Date (CD)

The R^2 is the degree by which the rainfall parameters account for the total variations of the crops yield. Hence, it was observed that 27% of the variation in rice is accounted for by variation in the amount of rain in the months of the growing season (ARMGS) at Gboko, 16% variation in soyabeans is accounted for by variation in onset date (OD) and 39% variation in rice is account for by variation in cessation date (CD) at Makurdi. This could mean that the variation in crops yield could also be accounted for by other factors. According to Adebayo and Adebayo (1997), Folorunsho *et al*., (1998) and Sawa and Ibrahim (2011), other factors that could cause variations in crop yield could be climatic and agronomic. The climatic factors include wind, radiation, specific water consumption, onset dates of the rain, annual rainfall, dry spells and so forth. The agronomic factors could include varieties of seed, use of fertilizers (type and time of application), differentials in soil fertility, weeding practices, animals' interference, occurrence of pests and diseases, and time of harvest which were not reflected in this study. These factors could account for 70%, 84% and 71% of the variations in the yield of rice and soyabeans in Gboko and also rice in Makurdi respectively in Benuestate.

Not all crop yield data were used in formulating the models. The last two years data (2018 and 2019) were preserved to be used to verify or confirm the goodness of fit of the developed models. The result of the confirmation is shown in Table 4.8

It could be observed from Table 4.8 which shows the validity of the developed crop yield forecast models that -453% and -151% indicate the ratios of Forecasting Error (FE) percentages of 2018 and 2019 for developed rice and 97% and 81% for soyabeans yield forecast models in Gboko. These values are in the range of FE ≤ 25% for rice and FE ≥ 25%forsoyabeans.Thesefindingspointoutthatthedevelopedriceyieldforecastmodels werevalidforGbokowhereasthatofsoyabeanswasnotvalid.Hence,theforecastmodel

for rice can be used to forecast the yield of rice in Benue state on the basis of ARMGS whereas, that for soyabeans cannot be used on the basis of OD.

Table 4.8: Validity of Developed Crops Yield Forecast Model for Benue State

Crop	Location	Model	R^2 (%)	Year	Observed yield (tons/ha)	Forecast Yield (tons/ha)	FE (%)
Rice	Gboko	$Y = 2.214 - 0.637\log X_1$	27	2018	0.40 {2.54}	2.21	-453
				2019	0.51 {3.23}	2.02	-151
Soyabean		$Y = 0.005 + 0.418\log X_2$	16	2018	0.38 {2.40}	0.01	97
				2019	0.70 {5.02}	0.13	81
Rice	Makurdi	$Y = 4.130 - 3.805\log X_3$	39	2018	0.40 {2.54}	4.13	-932
				2019	0.51 {3.23}	3.2	-527

Figures in parenthesis { } are observed yield values
Figures not in parenthesis under Observed yield column are Log_{10} values
Source: Author's computations (2021)

Where, Y = Log_{10} crops yield (Rice and Soyabean)

X_1 = Amount of rain in the months of the growing season (ARMGS)

X_2 = Onset date (OD)

X_3 = Cessation date (CD)

For Makurdi, -932% and -527% were the FE percentages of 2018 and 2019 for rice yield. These values are in the range of FE $\leq$ 25% meaning that this model is valid. It can therefore be used for forecasting rice yield on the basis of CD in BenueState.

Using the validated rice yield forecast models for Gboko and Makurdi, Table 4.9 presents the rice yield forecast for 2050.

Table 4.9: Rice Yield Forecast for 2050

Location	Crops	Forecast Model	Yield for 2003 (tons/ha)	Yield for 2050 (tons/ha)	% reduction
Gboko	Rice	$Y = 2.214 - 0.637X_1$	2	1.26	37
Makurdi	Rice	$Y = 4.130 - 3.805X_3$	2	-1.54	23

Source: Authors Computation (2021)

Where, Y = Log_{10} Rice yield

X_1 = Amount of rain in the months of the growing season (ARMGS)

X_3 = Cessation date CD

It was projected by Jones (2003), IPCC (20027) and re-emphasized by Nwaobiala and Nottidge (2012) that crop yield in Africa may fall by 10 – 20% by the year 2050 or even up to 50% due to climate change. Table 4.9 therefore shows that the prediction made by Jones (2003) was accurate for rice using the developed yield forecast model for rice in Benue State. Using the rice yield forecast model for Gboko, rice yield has reduced by 37%, whereas using that of Makurdi, rice yield has reduced by 23%, all of which are in agreement with the predictions of Jones (2003), IPCC (2007) and Nwaobiala and Nottidge (2012).

The result of the prediction portrays serious threat as rice is one of the major consumed crops in the state. If this situation is not reverted it could lead to food insecurity in the studyarea.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

This study aimed at accessing the variability in rainfall parameters on crops yield in Benue state. The study used daily rainfall data (mm) and annual crops yield for maize, rice, sorghum and soyabeans (tons/ha) from 1990 to 2019 (30 years). They were obtained from Nigerian Meteorological Agency (NiMet) Makurdi station, Akperan Orshi Polytechnic (AOPOLY) Gboko station and Benue State Rural Development Authority (BNARDA) respectively. The required rainfall parameters (Onset date [OD], Cessation date [CD], Length of the Growing Season [LGS], Hydrological Ratio [HR]s, number of Rainy Days [NRD], Rainfall Intensity [RI], Amount of rainfall in months of the growing season (May, June, July, August and September) [ARMGS] and Seasonality Index [SI]) were derived from the daily rainfall data obtained.

The trends of rainfall parameters and crops yield were analysed using Mann Kendall test, relationship between rainfall parameters and crops yield were analysed using the Pearson Product Momentum Correlation Coefficient and the forecast model was developed using stepwise multiple regression.

Results of the Mann Kendall trend test for Gboko showed that OD had a positively increasing non-significant trend with p-value of 0.968; CD had a positive non-significant increasing trend with p-value of 0.148; LGS had a positive increasing but non-significant trend with p-value of 0.317. Results also showed that NRD had a positive increasing trend with p-value of 0.655 which however, indicated that the positively increasing trend was of no significance; RI indicated a negatively decreasing (= -0.037) trend with the p-value of 0.789 which was non-significant; SI showed a constant value y = 0.97. Lastly, ARMGS had

a decreasing trend (= -0.113) which was not significant with p-value of 0.392. The observations were at 0.01 and 0.05 significant levels.

The results of the Mann Kendall trend test for Makurdi revealed a positive increasing non-significant trend with p-value of 0.418 for OD. An increasing positive trend was also observed with CD whose p-value of 0.534 was non-significant; LGS showed a negatively decreasing(=-0.088)trendwithp-valueof0.509whichwasnon-significant.Thetrendof NRD indicated a positively increasing non-significant trend with p-value of 0.761. RI indicated a positively increasing trend with p-value of 0.630 which was non-significant. HR showed a positively increasing non-significant trend with p-value of 0.203. SI showed a constant value y = 0.88 and ARMGS showed a positively decreasing trend which was non-significant given p-value of 0.735. The observations were at 0.01 and 0.05 significant levels.

Maize yield in Benue state showed an increasing positive trend which was significant with a computed p-value of 0.003; rice yield showed a positively increasing trend whose computed p- value of 0.192 showed however that the positively increasing trend was non-significant. Sorghum had a significant positively increasing trend with p-value of 0.007 and Soyabeans had a positively significant increasing trend with a p-value of <0.0001. The observations were at 0.05 significant level.

It was observed from the correlation results that onset date (OD) had a significant relationship with soyabeans at the 0.01 significant level, CD, LGS and RI had no significant relationship with any of the crops, NRD only had a negative significant relationship with rice yield at 0.01 significant level and ARMGS had a positive significant relationship with rice yield and soya beans at 0.05 and 0.01 significant levels respectively at Gboko station. The stated hypothesis that there is no significant relationship between rainfall parameters

and crops yield was rejected for; OD and ARMGS with Soya beans, NRD with rice yield and was accepted for CD, LGS and RI with all the crops yield at Gboko station. The relationship between SI and crops yield was not computed as a result of their constant variables in Gboko station. Hence, the relationship between SI with crops yield could not bedetermined.

The correlation result for Makurdi station revealed that all the rainfall parameters had no significant relationship with crops yield except cessation date (CD) which had a significant negative relationship only with rice yield at the 0.01 significant level. Hence, the stated hypothesis that; there is no significant relationship between rainfall parameters and crops yield was accepted for OD, LGS, ARMGS, NRD, HR and RI with the entire crops yield but was rejected for CD with rice yield. The relationship between SI could not be computed as a result of it constant variables. Hence no relationship was determined between SI and crops yield in Makurdistation.

Results for stepwise multiple regression analysis gave three (3) yield forecast models, two (2) for Gboko for rice and soya beans each and one (1) for Makurdi for rice yield. The forecast model for rice yield at Gboko was $Y = 2.214 – 0.637LogX_1$ whose R^2 was 27% and that for Soya beans was $Y = 0.005 + 0.418LogX_2$ whose R^2 was 16%. The forecast model for rice yield at Makurdi station was $Y = 4.130 – 3.805LogX_3$ whose R^2 was 39%. The forecast models that passed the validity test and were best fitted for the forecast of crops yield in Benue state were two; $Y = 2.214 – 0.637LogX_1$ for rice in Gboko on the basis of ARMGS and $Y = 4.130 – 3.805LogX_3$ for rice in Makurdi on the basis of cessation date(CD).

The two best fitted models for crops yield forecast were used to forecast the crops yield for 2050 in order to check their accuracy. The models performed excellently in the prediction of yield in the future for the study area.

5.3 Conclusion

The study concludes that no rainfall parameter had significant trend at Gboko and Makurdi stations.Amongthecrops,Maize,sorghumandsoyabeansyieldhadsignificanttrendsat 0.01 significant level. Among the rainfall parameters, OD had significant relationship with soyabeans, NRD and ARMGS had significant relationship with rice yield at Gboko at 0.05, 0.05 and 0.01 significant levels while only CD had significant relationship with rice yield at Makurdi at 0.05 significant level.. Two models were best fitted for the forecast of crops yield in Benue state which are; $Y = 2.214 – 0.637LogX_1$ for rice in Gboko on the basis of ARMGS and $Y = 4.130 – 3.805LogX_3$ for rice in Makurdi on the basis of cessation date (CD).

5.4 Recommendations

The following recommendations are hereby made based on the findings of this study;

1. Since the trend of hydrological ratio is increasing and the amount of rain in the months of the growing season is decreasing, government should make provision for irrigation facilities to complement moisturedeficiency.
2. Farmers should apply the two developed forecast models for rice yieldforecast.

5.5 Suggestions for FurtherStudies

1. Researches should be conducted to consider other factors such as: specific water consumption, annual rainfall, dry spells, wind, temperature, evaporation and radiation on cropsyield.
2. A comparative study on Walter's (1967), Adefolalu's (1993) and Hybrid methods of onset, cessation dates and length of growing season should be carriedout.

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Appendix 1:
Crops Yield Data

Years	Maize yield (tons/ha)	Rice yield (tons/ha)	Sorghum yield (tons/ha)	Soyabeans yield (tons/ha)
1990	2.4	2.45	0.81	1.3
1991	2.4	2.45	0.8	1.5
1992	1.16	2.5	1.08	2.32
1993	1.13	2.3	1.4	2.43
1994	2.05	2.3	1.79	2.7
1995	1.42	1.92	1.75	1.3
1996	1.42	2.05	1.22	2.76
1997	1.2	1.53	1.45	1.51
1998	1.25	1.83	1.42	1.5
1999	1.32	1.99	1.74	1.95
2000	1.32	1.99	1.75	1.95
2001	1.3	2	1.74	1.95
2002	1.3	2	1.75	1.96
2003	1.28	2	1.74	1.95
2004	1.3	2	1.73	1.96
2005	1.31	2	1.14	1.95
2006	1.34	2.02	1.74	1.97
2007	1.32	2	1.75	1.99
2008	1.32	2	1.73	1.99
2009	1.34	2	1.75	2
2010	1.52	2	1.75	2.01
2011	1.45	2.2	1.73	2.2
2012	1.5	0.93	1.75	2.26
2013	1.64	2.23	1.74	2.31
2014	1.54	2.23	1.73	2.29
2015	1.62	2.26	2.65	2.33
2016	1.6	2.22	1.73	2.31
2017	1.59	2.27	1.73	2.3
2018	2.1	2.54	1.9	2.4
2019	3.57	3.23	2.26	5.02

Source: BNARDA, 2020

Appendix II:
Correlation Analysis Result for Gboko

		Log10Onset	Log10Cessation	Log10LGS	Log10NRD	Log10ARMGS	Log10ARI	Log10SI	Log10MAIZE	Log10RICE	Log10SORGHUM	Log10SOYABEANS
Log10Onset	Pearson Correlation	1	-.178	-.860**	-.477**	-.212	.066	.b	.148	.120	.000	.412*
	Sig. (2-tailed)		.347	.000	.008	.260	.731	.	.436	.529	1.000	.024
	N	30	30	30	30	30	30	30	30	30	30	30
Log10CESSATION	Pearson Correlation	-.178	1	.416*	.309	.196	.127	.b	.151	.102	.274	.085
	Sig. (2-tailed)	.347		.022	.097	.300	.503	.	.426	.590	.143	.654
	N	30	30	30	30	30	30	30	30	30	30	30
Log10LGS	Pearson Correlation	-.860**	.416*	1	.616**	.220	-.144	.b	-.037	-.137	.129	-.252
	Sig. (2-tailed)	.000	.022		.000	.243	.448	.	.845	.471	.496	.178
	N	30	30	30	30	30	30	30	30	30	30	30
Log10NRD	Pearson Correlation	-.477**	.309	.616**	1	.372*	-.371*	.b	.027	-.375*	-.020	-.250
	Sig. (2-tailed)	.008	.097	.000		.043	.043	.	.888	.041	.918	.182
	N	30	30	30	30	30	30	30	30	30	30	30
Log10ARMGS	Pearson Correlation	-.212	.196	.220	.372*	1	.547**	.b	-.302	-.551**	-.044	-.363*
	Sig. (2-tailed)	.260	.300	.243	.043		.002	.	.105	.002	.818	.049
	N	30	30	30	30	30	30	30	30	30	30	30
Log10ARI	Pearson Correlation	.066	.127	-.144	-.371*	.547**	1	.b	-.079	-.014	-.019	.019
	Sig. (2-tailed)	.731	.503	.448	.043	.002		.	.679	.941	.921	.920
	N	30	30	30	30	30	30	30	30	30	30	30
Log10SI	Pearson Correlation	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b
	Sig. (2-tailed)	.	.	.	.	.	.		.	.	.	.
	N	30	30	30	30	30	30	30	30	30	30	30
Log10MAIZE	Pearson Correlation	.148	.151	-.037	.027	-.302	-.079	.b	1	.501**	-.038	.380*
	Sig. (2-tailed)	.436	.426	.845	.888	.105	.679	.		.005	.843	.038
	N	30	30	30	30	30	30	30	30	30	30	30
Log10RICE	Pearson Correlation	.120	.102	-.137	-.375*	-.551**	-.014	.b	.501**	1	-.066	.358
	Sig. (2-tailed)	.529	.590	.471	.041	.002	.941	.	.005		.729	.052
	N	30	30	30	30	30	30	30	30	30	30	30
Log10SORGHUM	Pearson Correlation	.000	.274	.129	-.020	-.044	-.019	.b	-.038	-.066	1	.466**
	Sig. (2-tailed)	1.000	.143	.496	.918	.818	.921	.	.843	.729		.009
	N	30	30	30	30	30	30	30	30	30	30	30
Log10SOYABEANS	Pearson Correlation	.412*	.085	-.252	-.250	-.363*	.019	.b	.380*	.358	.466**	1
	Sig. (2-tailed)	.024	.654	.178	.182	.049	.920	.	.038	.052	.009	
	N	30	30	30	30	30	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
b. Cannot be computed because at least one of the variables is constant.

Appendix III:

Correlation Analysis Result for Makurdi

		Log10Onset	Log10Cessation	Log10LGS	Log10NRD	Log10ARMGS	Log10RI	Log10SI	Log10HR	Log10MAIZE	Log10RICE	Log10SORGHUM	Log10SOYABEANS
	Pearson Correlation	1	-.419*	-.911**	-.433*	-.316	-.124	.c	-.140	.226	.226	.112	.136
Log10Onset	Sig. (2-tailed)		.021	.000	.017	.089	.516	.	.462	.229	.231	.555	.473
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.419*	1	.433*	.388*	.160	.081	.c	.221	-.098	-.589**	.034	-.060
Log10Cessation	Sig. (2-tailed)	.021		.017	.034	.400	.672	.	.241	.605	.001	.857	.754
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.911**	.433*	1	.462*	.314	.140	.c	.144	-.117	-.242	-.093	-.044
Log10LGS	Sig. (2-tailed)	.000	.017		.010	.092	.461	.	.448	.538	.197	.626	.819
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.433*	.388*	.462*	1	.511**	.131	.c	.505**	.090	-.195	-.112	-.051
Log10NRD	Sig. (2-tailed)	.017	.034	.010		.004	.489	.	.004	.636	.301	.554	.787
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.316	.160	.314	.511**	1	.788**	.c	.713**	-.027	-.225	.054	-.011
Log10ARMGS	Sig. (2-tailed)	.089	.400	.092	.004		.000	.	.000	.888	.232	.778	.955
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.124	.081	.140	.131	.788**	1	.c	.629**	.125	-.104	.210	.190
Log10RI	Sig. (2-tailed)	.516	.672	.461	.489	.000		.	.000	.511	.583	.265	.315
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c
Log10SI	Sig. (2-tailed)	.	.	.	.	.	.		.	.	.	.	.
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	-.140	.221	.144	.505**	.713**	.629**	.c	1	-.075	-.321	.212	.148
Log10HR	Sig. (2-tailed)	.462	.241	.448	.004	.000	.000	.		.692	.084	.260	.434
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	.226	-.098	-.117	.090	-.027	.125	.c	-.075	1	.501**	-.038	.380*
Log10MAIZE	Sig. (2-tailed)	.229	.605	.538	.636	.888	.511	.	.692		.005	.843	.038
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	.226	-.589**	-.242	-.195	-.225	-.104	.c	-.321	.501**	1	-.066	.358
Log10RICE	Sig. (2-tailed)	.231	.001	.197	.301	.232	.583	.	.084	.005		.729	.052
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	.112	.034	-.093	-.112	.054	.210	.c	.212	-.038	-.066	1	.466**
Log10SORGHUM	Sig. (2-tailed)	.555	.857	.626	.554	.778	.265	.	.260	.843	.729		.009
	N	30	30	30	30	30	30	30	30	30	30	30	30
	Pearson Correlation	.136	-.060	-.044	-.051	-.011	.190	.c	.148	.380*	.358	.466**	1
Log10SOYABEANS	Sig. (2-tailed)	.473	.754	.819	.787	.955	.315	.	.434	.038	.052	.009	
	N	30	30	30	30	30	30	30	30	30	30	30	30

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

c. Cannot be computed because at least one of the variables is constant.