INVESTIGATING THE VARIATION OF INTRA-SEASONAL RAINFALL CHARACTERISTICS IN SIERRA LEONE

BY

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DECLARATION

This project is my original work, except where duly acknowledged and has not been presented for a degree in this or any other university.

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DEDICATION

I dedicate this project to my beloved family: my late father and mother (Mr.Thaimu Yangbay Kamara and Madam Marie Thaimu Kamara), my wife Fatimeh Kamara, our daughter, Mariama Mohamed Yangbay Kamara and my brothers and sisters.

ABSTRACT

The rainy season in Sierra Leone is unimodal from April to October; an understanding of the inter-annual variability of rainfall in Sierra Leone is of importance to economic sectors such as fisheries, agriculture, infrastructure, hydro-electric power generation (HEP) and water resources. This study investigated the variation of the intra-seasonal rainfall characteristics in Sierra Leone. Daily rainfall data from 4 synoptic stations was obtained from the Sierra Leone Meteorological Department from 1990-2014.

The relationship between onsets, cessation, and duration to seasonal totals was determined using Pearson correlation, variability of intra-seasonal rainfall characteristics was determined using coefficient of variation. The magnitudes of the intra-seasonal rainfall characteristics were obtained from the slopes of linear regression lines and the statistical significance was obtained by non parametric method (Mann-Kendall).

The results from the study showed that the onset of the rainy season starts early and ends late in the Freetown and Lungi stations resulting to longer durations. The seasonal total of rainfall was also higher at Freetown ranging from 3000-3500mm. On the other hand, at BO station the rainy season starts a bit late and ends late while at Daru, the onset start late and ends early indicate a short duration with seasonal totals of rainfall ranging from 1500-2500mm. The observed phenomenon can be attributed to the fact that Freetown and Lungi are near the coastline hence there is enough source of moisture, while BO and Daru are further inlands hence somehow dry.

The results for the correlation analysis indicated negative and significant coefficients for the onsets at Daru. Implying that early onsets results to higher amounts of rainfall and late onsets results to lower amount of rainfall. Both BO and Daru stations depicted positive and significant correlation coefficients between duration of the rains and seasonal rainfall totals. This suggests that as the duration increases the seasonal rainfall amounts increases and vice versa.

The spread of onset dates at BO is considerably larger compared to the other three stations hence it is variability is slightly higher (12.4%) compared to the three other stations. The onsets are skewed to the right that is most of the onsets occurs much later. At Freetown the variability of cessation is considerably larger compared to the other three stations. The cessation dates are skewed to the right that is most of the cessation dates occur much later. The spread of duration at

Daru is considerably lower with a variability of 4.4%. The variability of seasonal rainfall at Freetown is slightly higher than the other three stations, with a variability of 9.9%. It is also further noted that the variability of the intra-seasonal rainfall characteristics at BO station was slightly higher as compared to the other stations though not significant.

The observed trends for onset and cessation dates, as well as duration of the season were not statistically significant except for cessation dates at BO station. The seasonal rainfall totals depicted insignificant decreasing trends for all the stations except Freetown station which indicated an insignificant increasing trend.

The results from this study will be useful in addressing the problems associated with late **o**nset and early cessation of rains which has a detrimental effect to farmers in the area of agriculture in terms of food security in the country and also combating the problem of water shortage in industries, dams, reduced stream flow in rivers and watercourses and many more among others.

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LIST OF ABBREVIATION

AEJ	African easterly jet
ARIMA	Auto Regression Integrated Moving Average Model
AWJ	African Westerly Jet
CV	Coefficient of Variation
DARC	Debrezeit Agricultural Research Center
ENSO	El Niño–Southern Oscillation
GES-DAAC	Goddard Earth Sciences, Distribution Active Centre
HEP	Hydro Electric Power
ITCZ	Inter Tropical convergence Zone
ITD	Inter Tropical Discontinuity
KADP	Kwara state Agricultural Development Project
LGS	Length of Growing Season
MAM	March April May
MK	Mann-Kendall
NCEP-CRU	National Centre for Environmental Prediction and Climate Research Unit
NCEP-NCAR	Environmental prediction-National Centre for Atmospheric Research
NE	Northeast
NIMETA	Nigeria Meteorological Agency
NMA	National Meteorological Agency
PBL	Planetary Boundary Layer
PC	Principal Component
PCA	Principal Component Analysis
PET	Potential Evapotranspiration
RD	Rainy Days

RD J-S	Rainy Days during June to September
ROC	Rainy season Cessation Dates
ROD	Rainy season Onset Dates
SD	Standard Deviation
SST	Sea Surface Temperature
TEJ	Tropical Easterly Jet
TMRF	Mean of Total month of Rainfall
TMRF J-S	Mean of Total month Rainfall during June to September

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

An understanding of the inter-annual variability of rainfall in Sierra Leone is of importance to sectors such as fisheries, agriculture, infrastructure, hydro-electric power generation (HEP) and water resources. The variability in rainfall in Sierra Leone caused water shortage problem for both the industries and domestic used, reduced the flow of water in rivers, dam leading to cut-off in electricity and also caused health related problems associated with water borne diseases (Mcsweeney *et al* (2010)).

Climate change is expected to modify intra-seasonal variability, arising from shifts in rainfall frequency, intensity and seasonality which is likely to have important ecological impacts on the ecosystem, yet, quantifying these impacts across biomes and large climate gradients is largely missing (Guan *et al*., 2014). The impact of climate change on agriculture in developing countries has been increasing and this impact could influence agriculture in a variety of ways Lemma *et al* (2016).

Rainfall varies greatly on a spatial and temporal scale, hence affecting agricultural activities (Tveito *et al.,* 2005; Moeletsi *et al*., 2011). Rainfall is a major climatic factor that determines crop choice as well as, success of other socio-economic activities in West Africa (Mensah *et al.*, 2016). For better planning of farming activities such as when to plant and the choice of the right cultivar suitable for a particular region, it is always important to determine at a reasonable accuracy the probability levels of the onset, cessation and duration of seasonal rainfall, as well as their inter-relationships (Sivakumar, 1988, Mugulavai *et al.*, 2008, Tadross *et al*., 2005).

According to Moeletsi *et al*., (2011), one of the most important occurrences to the farmer is the onset of rainfall. Farmers benefit from lower rates of evaporation during an early onset since they are able to plough land and plant earlier. Late onset on the other side can result to the critical stages of the plant which are sensitive to water stress to be aligned with months of lower rainfall and higher evaporative demand. The timing of the occurrence of onset of rains can have an impact on agricultural productivity with late onsets resulting in decreased yields (Camberlin and Okoola, 2003). Planting after early onset of rains can improve agricultural productivity potential due to a longer growing period.

Cessation of rains is the other important intra-seasonal rainfall index of importance to agriculture. Early cessation may result in short growing period affecting long season crop varieties while late cessation favors long season crop varieties. Availability of agro meteoro-logical information about the behavior of the seasonal rainfall should be able to minimize crop losses (Sivakumar, 1990; Raes *et al.*, 2004).

1.2 Problem Statement

The uncertainty on the onset, cessation and the length of the rainy season affect farm operations such as, land preparation, choice of crops to grow, sowing, weeding, spraying, irrigation etc., which in turn undermines the food security situation in Sierra Leone.

The country is highly dependent on rainfall for hydro-power generation. The variability in rainfall causes fluctuations in hydro-electric power generation, leading to huge economic losses by the government as well as the private sector. More importantly, the constant power outages in the city and many other parts of the country undermine investor confidence thereby accentuating the problem of capital flight, unemployment and loss of tax revenues that are crucial for the development of the country. Costs of production are also likely to rise among small and medium sized entrepreneurs who have to utilize alternative sources of energy which cause serious environmental damage to society.

Besides the economic concerns associated with high variability in rainfall patterns in Sierra Leone, there are also environmental issues that need to be addressed. For instance, the use of diesel thermal power plants generators for power supply causes pollution to the environment that affect human health through the respiratory track in the form of allergies, irritation of the eyes, asthma and other forms of respiratory infections. It also affects the health of animals through acid rains that change the composition of streams, rivers and seas making them toxic for fish and other aquatic lives. In addition the deposition of pollutants on the surface can lead to subsequent poisoning of the animals when they eat contaminated vegetation, if the animal is eaten by human beings, the pollutant will travel in the form of food chain affecting human health.

The change in rainfall patterns also causes acute or chronic water shortages which aggravate the problems of cholera and related water borne epidemics in the country. Furthermore, variations in water supply for both domestic and industrial use thereby affect the operations of firms and households. Lastly, reduced rainfall also adversely affects aquatic lives through reduced stream flow in rivers and other water courses. In spite of these enormous challenges facing the country, there is little or no literature on the subject. It is against this backdrop that this study is designed to bridge the gap in literature by investigating the intra-seasonal variability of rainfall in Sierra Leone.

1.3 Justification

The yearly variation on the onset, cessation, duration, and the seasonal totals of the rainy season makes the planning of agricultural activities very difficult for farmers to know when to start land preparation, the selection of the type of crop, the planting of their crops and varieties to be grown. As a result of such abnormalities, yield may suffer significantly with either a late onset or early cessation with a great predictability of destructive dry spell within the vegetative period that will cause crop failure and water management stress that lead to food insecurity in the country. It is therefore important to determine the onset, cessation, duration and seasonal totals of the rainy season for planning purposes to enhance a better crop production in agriculture. It is therefore hoped that a study of this nature will guide in the formulation and implementation of policies related to weather impact in Sierra Leone.

The variability in rainfall also causes fluctuation on the hydro-electric power supply is the main source of electricity in the country. In this regard, findings of this research shall inform policy making in the Ministry of Energy and Power regarding the causes, and impacts of intra-seasonal variation in rainfall patterns in the country. As a result of such abnormalities on electricity power supply in the country, most foreign investors doing businesses in the country relocates their investments to other place that leads to a loss in the national economy and job scarcity for the people. Therefore, determination of the onset dates, cessation dates, duration and seasonal totals of the rainy season shall address the issue of the hydro-electric power in the country which requires less maintenance, produces little or no waste products and also bring economic benefits to the government and the people in general.

It is also disheartening to note that the sporadic nature of rainfall onset has often led to flooding due to blockage of the drainage channels in the city and other urban areas which leads to the contamination dug-out wells, rivers etc. both of which provides the main source of drinking water in the country. This sad event has led to the loss of lives due to cholera, dysentery and other water-borne diseases. The finding of this study will therefore provide vital policy advice that will help minimize the incidence of such catastrophes in Sierra Leone

1.4 Objective of the Study

The main objective of the study was to investigate the variation of intra-seasonal rainfall characteristics over Sierra Leone. The specific objectives addressed in this study were;

i. To determine onset dates, cessation dates, the length of the rainy season and seasonal rainfall totals over sierra Leone
ii. To establish whether there is significant linear relationship between the seasonal rainfall totals and the intra-seasonal rainfall characteristics determined in (i) above
iii. To determine the variability on the onset dates, cessation dates, length of the rainy season and seasonal totals over Sierra Leone.
iv. To determine the trends of onset dates, cessation dates, length of rainy season and seasonal totals over sierra Leone

1.5 Area of Study

The study area is Sierra Leone which is found in the West coast of West Africa at latitude of 7°N and 10°N and longitude 10°W and 14°W. It boarders the Republic of Guinea to the North and North East, Republic of Liberia to the South and South East and the Atlantic Ocean to the West.

1.5.1 Geographical Features and Rainfall Climatology

Sierra Leone has a total area of 71,740 km^2 (27,699sq.miles) of which about 71,620 km^2 is covered by land and 120 km^2 is covered by water. Figure 1 shows the domain of the current study and some of its physical features. The country has a varied terrain consisting of Mountains and zones of low lying coastal features in the West, elevated plateaus with hill and Mountains in the East, Mangroves swamps and Savanna in the North and thick forest in the South. Some of the mountains found in Sierra Leone are the Freetown Peninsula Mountain (723 m) where the Capital city is located, Bintimani Mountain (1945m) which extend to the northeastern part of the country, Neremafondi (1319 m) and Sura Mountains (876m) in the Eastern region and many more among others. The country is very vast with small rivers which are used as means of transport by people to different parts of the country. These rivers, drains the interior upland and empty in to the Atlantic Ocean. Among these rivers are, the Great Scarcies River, Little Scarcies River, River Rokel, River Jong, River Sewa and Moa River.

Because of the influence of the Atlantic Ocean and the close proximity of the country to the equator, the climate is humid with more intense rainfall along the coast but decreases to the inland of the country. The temperatures are fairly constant throughout the year with an average of about 27°C along the coast and decreases as one move further away from the coast. There are two seasons; the rainy season (wet) and the dry season. The rainy season start from April to October peaking between July and September and the dry season is from November to April. During the period of December to February there is the Hamattan wind blowing from the Sahara desert which bring dry dusty wind in to the country with little or no rains.

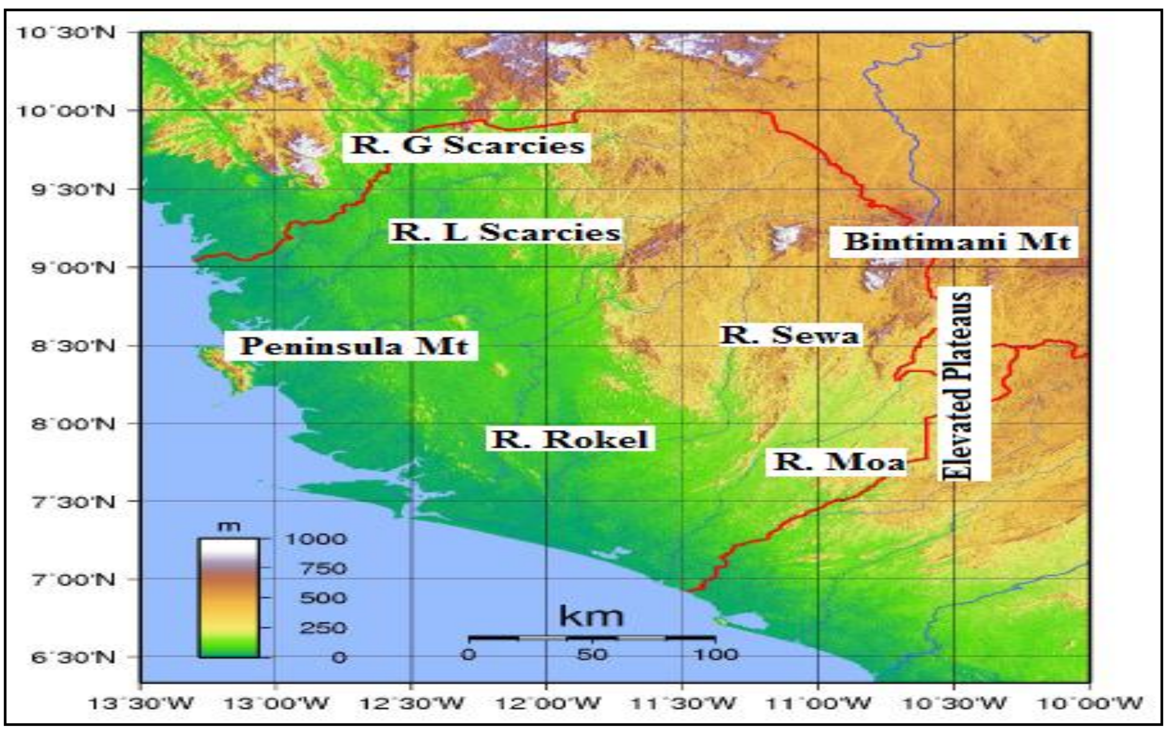

Figure 1: The study region showing altitude, major rivers, mountains and plateaus (source: http://www.google.com/search? q= topography +Sierra Leone +map)

1.5.2 Systems Influencing Rainfall over Sierra Leone

The spatial and temporal variability of rainfall over Sierra Leone like any other West Africa country is controlled by a number of global, regional and local systems. The synoptic scale systems which affect weather and climate over Sierra Leone include the Inter Tropical Discontinuity (ITD), Monsoons, El Niño–Southern Oscillation (ENSO), Jet streams, Squall lines, Mesoscale and more among others. These are briefly discussed in the next subsection.

1.5.2.1 Inter-Tropical Discontinuity

Nicholson *et al* (2013) showed that rainfall in West Africa is associated with a surface feature termed the Inter Tropical convergence Zone (ITCZ) with respect to the movement of the sun; it is marked by the convergence of the northeasterly Harmattan winds that originate in the Sahara and the southwest Monsoon flow that emanates from the Atlantic Ocean. In West Africa, it is called Inter Tropical Discontinuity because of the discontinuity of the temperature and humidity characteristic at the meeting point of the two airstreams. The rain is assumed to result from local thermal instability facilitated by the low level winds convergence with the zone. The northward displacement of the Inter Tropical convergence Zone accounts for the wetter years but that a weakening intensity of the rainy season independent of the ICTZ position is the cause of drought in the Sub-Sahara region (Nicholson 1981). On an inter annual basis, the rainfall maximum and the surface position of the ITCZ are effectively decoupled with the ITCZ keeping a relatively stable location from year to year despite large latitudinal shifts in the rain belt. Wet years in the Sahel are characterized by more intense rainfall Sultan *et al* (2003).

1.5.2.2 Monsoons

Monsoons are seasonal winds that change their direction with persistence and regularity every year in the tropics owing to the thermal contrasts between continents and oceans. These monsoonal winds are caused large-scale differential solar heating and cooling between the land and ocean masses in the low latitudes and the distinction of this during the course of the year (during summer and winter). The differential heating and cooling of large landmasses in turn produces pressure reversals resulting in monsoonal flow patterns. The rainfall in the monsoon months in Sierra Leone decrease with distance from the sea ranging from 3000-5000mm along the coast and 2000-2500mm in the eastern board of the country (Clarke 1996).

West Africa experiences two kinds of monsoons; West Africa Summer Monsoon (South East turning to South West), these monsoon occurs during the months of June-September. It arises due to differential heating of the land including the vast Sahara desert and the Atlantic Ocean. The winds are moist and cool due to the travel over the Atlantic Ocean which is relatively cooler compared to the land temperature and is being heated from the below and become unstable, the water vapor content is very high since it has maritime origin. The West African monsoon intra-seasonal variability has huge socio-economic impact on local population but understanding and predicting it still remains a challenge for weather prediction and climate scientific community.

Poan *et al.*,(2016).The rain band linked with the West African Monsoon Inter Tropical Convergence Zone (ITCZ) is situated along the Guinea coast 5°N from spring to early summer, offering a strong intra-seasonal inconsistency with non-progressive development.

Sultan *et al.,* (2003) investigated the pre-onset and onset of the summer monsoon dynamic part II. The study showed that the onset stage of the summer monsoon over West Africa is linked to an abrupt latitudinal shift of the ITCZ from a quasi-stationary location at 5°N in April-June to another quasi-stationary location at 10°N in July-August.

(Guojun and Adler 2004) studied the seasonal evolution and variability associated with the West Africa monsoon system. The study showed that Surface rainfall and seasonal variability over West Africa seems to be associated with two distinct processes. Near the Gulf of Guinea (about 5°N), intense rainfall begins in April following warm sea surface temperature (SST) in the tropical eastern Atlantic. Also the meridional SST gradients play an essential role in forcing convection and rainfall during the 120-190 periods (May-July).

The West Africa Winter Monsoons commonly known as Northeast (NE) monsoon is dominant during the months of December-February. The Sahara air mass is the source of the winter monsoon, this air mass is hot, dry dusty winds, and stable since it has a continental origin. It does not therefore result in rain.

1.5.2.3 El Niño–Southern Oscillation (ENSO)

Over West Africa, El Nino events tends to result in enhanced north easterlies/ reduced monsoon flow, coupled to weekend upper easterlies, and hence dry condition over West Africa close to the surface position of the ITCZ in July –September, as well as January- March (Camberlin *et al.*,2001).

Nicholson *et al.* (2013) examined the relationship between rainfall variability in West Equatorial Africa and Tropical Ocean and Atmospheric circulation. The result shown that, the intensity of zonal circulation in the global tropics is a crucial control on rainfall over West Africa. La Nina (El Nino) like signal in both SSTs and zonal circulation over the pacific is apparent in association with the wet (dry) condition in the West Equatorial Africa.

1.5.2.4 Jet Streams

A Jet stream is a narrow current of wind concentrated along a quasi-horizontal axis, characterized by strong vertical and lateral wind shears and featuring one or more velocity maxima. As other wind fields that increase with height, jet streams can be explained as an application of the thermal wind relation. In accordance with the thermal wind relation, the zonal wind component is most significant and the meridional temperature gradient increase in magnitude with height since the air temperatures decrease within the troposphere and this effect leads to wind speed attaining maximum value above the surface forming jet streams.

Nicholson and Grist (2003) used Environmental prediction-National Centre for Atmospheric Research (NCEP-NCAR) reanalysis project dataset and two upper air dataset to investigate the dynamic factors influencing the rainfall variability in West Africa Sahel. The study confirms some of the results of earlier studies such as the weaker African easterly jet (AEJ) and stronger tropical easterly jet (TEJ) during the wet years, but suggests different interpretation of the wet-dry contrasts. The important characteristic of the AEJ appears to be its latitudinal location rather than its intensity. This governs the instability mechanisms. The AEJ is displaced northward during the wet years, thereby enhancing both the horizontal and vertical wind shear over the Sahel. Their result further suggests that, the tropical rain belt also has some influence on the tropical easterly jet at 200mb. The Asian branch of the TEJ is forced remotely by the Tibetan high. This may acts as a mechanism of rainfall variability over central Africa, which is the jet's left exit region. Over West Africa, the TEJ seems at least partly a response to the equatorial outflow of convection just the north.

Cook (1999) analyzed the generation of the African Easterly Jet and its role in determining West African precipitation, and shown that while moisture convergence throughout the lower troposphere over East Africa, moisture divergence between 600 and 800mb over lies over West Africa to the south of the African easterly jet (AEJ) and this moisture divergence is important for determining the total column moisture convergence since the moisture divergence is closely tied to the jet dynamics and the jet magnitude and position are sensitive to SST and land surface conditions, a mechanism by which the West African precipitation is sensitive to surface condition.

Okonkwo *et al* (2014) studied the characterization of West Africa Jet Streams and their association to ENSO events and rainfall in ERA- Interim 1979-2011, their results shown that while the low-level African Westerly jet (AWJ) correlates well with rainfall south of the equator in boreal winter month, the Tropical Easterly jet (TEJ) and the African Easterly Jet (AEJ) correlates better with rainfall north of the equator in the boreal summer month. Results of inter-annual to decadal variability in 200mb, 600mb and 800mb of zonal winds revealed that there is enhance variability in the 2-8 years band. Also, the TEJ, AEJ and AWJ fluctuations are coupled with variation in southern oscillation. Further analysis suggested a statistical significant association between TEJ and El Nino events of the 1980s that lead to intense drought in the Sahel region of West Africa, the 2007 moderates La Nina shown a statistical significant coherence with the 500mb, 600mb and 850mb jets.

1.5.2.5 Squall Lines

Squall lines appear has bright white cloud bands oriented in a north-south direction with a convex shaped leading edge and an indistinct shaped area. They are characterized by sudden increase in wind speed with the peak speed remaining for at least two minutes. They are formed by the presence of a deep layer of convective or conditional instability.

Chong and Hauser (1990) studied the kinematic structure of the system, which moved in a moderately unstable atmosphere faster than the environmental air at all levels. They found out that squall lines are large cloud system composed of an organized convective line ahead of an extensive trailing anvil cloud (stratiform rain), fast motion, long lasting structure and a well-marked guest front signature at ground level. Amato and Lebel (1998) studied the characteristics of the rainfall events in the Sahel with a view to the analysis of climate variability and found out that Squall lines are more intense occurrences which caused 85% of the West African Sahel rainfall.

Study by Chong *et al* (1987) showed that the track of a squall line is marked by an immediate shift of the pressure led by a speedy change in the wind direction. Also a decrease of the temperature, an intensification of the wind leads to intense precipitation.

1.5.2.6 Mesoscale Systems

These are motion scales that last for several hours between (1-10) hours covering a horizontal distance of several kilometers between (10-100) km. Example of these system include thunderstorm, land and sea breeze, mountain valley winds, gap winds, convergence zone, orographic lifting and organized convective system among others. Parker *et al*. (2005) studied the diurnal cycle of the West Africa monsoon circulation and found out that in the Jet 2000mb although the overall monsoon layer observations support the continental-scale pattern of diurnal circulation; there is also considerable mesoscale structure within the monsoon circulation. Also, the Local pressure gradient associated with mesoscale variation in planetary boundary layer (PBL) properties may dominates over the continental-scale pressure gradients, so that the diurnal cycle of winds is controlled by the local rather than the continental gradient. They further noted that the system has precipitation characteristics such as rain area and volume which are of the same order of magnitude as systems in the United States.

Laing *et al*. (1999) studied the contribution of mesoscale convective complexes to rainfall in Sahelian Africa and found out that although mesoscales complexes occur throughout the Sahel they are clustered around a few longitudinal bands and rainfall contribution becomes even more important in those locations. Also, mesoscale convective complexes contribute significantly to the rainfall in Sahelian Africa.

CHAPTER TWO

2.0 LITERATURE REVIEW

This chapter deals with the review of materials related to the study. It is broadly divided in to four sections. These sections are tailored in line with the outlined objectives of the study. The first objective deals with the definitions of onset, cessation and associated variables of rainfall given by various researchers. The second section deals with literature on various methods that are used to determine variability in the rainfall parameters (onset, cessation and the associated variables). The third section focuses on the determination of trends on the rainfall parameters. Finally, the fourth section deals with the determination of the relationship between seasonal rainfall totals and the intra-seasonal rainfall characteristics.

2.1 Definitions of onset and cessation dates and the associated variables

Mojisola (2010), Sawa *et al* (2014).These researchers used the percentage cumulative methods. In this method, the mean annual rainfall that occurs at each 5/10 day interval of the year was developed. This is followed by calculating the percentage of the mean annual rainfall that occurs at each of the 5/10 day interval throughout the year and the percentages of these 5/10 day periods are cumulated. The cumulative percentage of the 5/10 day period are plotted against the years, the first point of maximum positive curvature of the graph corresponds to the rainfall onset while the last point of maximum point of curvature corresponds to the rainfall retreat. The differences between onset of the rains and the cessation of the rains define the length of the rainy season and the sum of the onset starting month to the end point of the cessation month defined the seasonal totals.

Mojisola (2010) examined the risk of some major food crop of the guinea savanna ecological zone in Nigeria to vagaries in rainfall features using monthly rainfall data obtained from the Nigeria Meteorological Agency, Ilorin International Airport Kwara state for the period 1956-2005 and the production data on maize, rice, Sorghum and yam are obtained from the Kwara state Agricultural Development project (KADP) for the same period. The onset, cessation and length of growing season were based on pentad method to provide a quantitative summary of variations observed.

Sawa *et al* (2014) examined the impact of climate change on the hydrological growing season at Kano in Nigeria using daily rainfall records from 1976-2011 obtained from the Nigeria Meteorological Agency, Lagos. The onset, cessation and the hydrological growing season were determined using the pentad method.

Camberlin and Mbaye (2003), Camberlin and Okoola (2003) used the principal component analysis to determine the onset and cessation dates. This method was based on the use of cumulative rainfall anomalies to obtain onset and cessation dates. The daily rainfall data in all the given stations were first subjected to a Principal component analysis (PCA), using the correlation matrix (which initially gives the same weight to all the stations in the input matrix). Each principal component then summarized daily rainfall fluctuations for a group of stations, giving to each station a weight which depended upon the variability it shared with the other stations of the group. PCA was applied in the 'S-mode' (spatial) sense, i.e., taking the stations as variables and the days as observations. Prior to the analysis, and in order to reduce the skewness of the data, each time-series was square-root transformed. The times-series of the leading principal component (PC1), corresponding to the dominant mode of variability in the region under study, was then divided into subsets, one for each year. Cumulative series are then computed. The minimum and maximum values of the cumulative scores of principal component 1, (PC1) for each year are used to locate the onset and cessation dates, respectively.

Aweda and Adeyewa (2010) determined the onset, cessation and growing seasons in six stations within the Guinea Savannah Zone of Nigeria for the period 1981-2001. The rainfall data used in the study was obtained from the Nigeria Meteorological Agency (NIMETA) and the Normalized Difference Vegetation Index (NDVI) data was extracted from the PAL Global 8km, 10-day composite Normalized Difference Vegetation Index product archived at Goddard Earth Sciences, Distribution Active Centre (GES-DAAC). The onset, cessation of the rainfall and the growing season were determined from the mean decadal analysis of the NDVI using the percentages of the cumulative rainfall and the NDVI equation as shown in equation1. The NDVI ranges from 0 to 1.

$$NDVI\ ratio = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

In Equation 1: NDVI: is the daily NDVI, NDVI $_{max}$ is the annual maximum NDVI; NDVI $_{min}$ is the annual minimum NDVI.

The results obtained were able to establish the fact that growth of crop does not commence immediately after rainfall. The lag difference for the onsets of rainfall and growing season was between the ranges of 1-4 decades within a month while their cessation was between the ranges of 2-5 decades which enables the determination of the length of the growing season.

Edoga (2007) determine the length of growing season in Samaru Nigeria using related rainfall/ Potential Evapotranspiration Model and daily rainfall, temperature (minimum and maximum), relative humidity, vapor pressure, sunshine hours, wind speed and radiation from 1981-2000. The onset dates were determined using rainfall data and evaporation models. The onset was defined as the date when the accumulated rainfall exceeded and remained greater than 0.5 the potential evapotranspiration (PET) for the remainder of the growing season provided that no dry spell longer than five days occurred immediately after this date. The cessation date was determined when the soil is assumed to be at field capacity of 100mm on the last day of rain that is greater than 0.5 PET provided that the date is not proceeded by a dry spell (less than 1mm average daily rainfall) of more than five days. The result showed that, the onset of the growing season is commonly in the month of April but the amount is small for planting of crops. From the different model used in the comparison, the effective start of rains is in the month of May and the latest is in June and the effective termination date is in the month of October.

Mugalavai *et al* (2008) analysis of rainfall onset cessation and length of growing season for Western Kenya using historical daily climate data of a 15-34 years period and soil data from 26 stations, spatially distributed in the study area for both long and short rainy season. Onset was determined using the cumulative rainfall depth that will bring the top 25mm of the soil profile to field capacity during a maximum of 4 days and the Cessation was quantified by considering the time on which the stress in the root zoon of a crop exceeds the threshold value. The length of growing season for a particular year is obtained from the difference between cessation dates and onset dates of that year. The results indicate that there exist organized progressions of rainfall onset within western Kenya region with the long rains showing a southerly progression while the short rains show a south-westerly progression. Cessation of rainfall for both seasons show strong localized influences, mainly surrounding Lake Victoria and forested areas, including orographic features. For stations with long duration of growing season, the length varies more than the onset date.

Omotosho *et al* (2000) used the soil water balance method in determining the onset dates and cessation dates of the rainy season and the associated variables. In this method, a criterion was set for a number of days that received a certain amount of rainfall. From the starting day at least any other day within that period should not receive rainfall less than a certain threshold and there should be no dry spell of seven or more days in the next 30 days defines the onset of the rainy season. On the other hand, the cessation date of the rainy season was defined by the criterion that, for a certain period of observed rainfall that received rainfall less than a set threshold and the period should be followed by a dry spell of seven or more days. The length of the season is defined as the difference between the cessation dates and the onset dates. The seasonal total was defined by summing the rainfall totals from the first day of the month of onset to the last day of the cessation of rainfall.

Odekunle (2006) assessed the relative efficiency of the use of rainfall amount and rainy days in the determination of rainfall onset and retreat dates in Nigeria based on daily rainfall data for the period 1961-2000 sourced from the Nigeria Meteorological Service at Oshodi, Lagos. The onset and retreats dates were determined using the five day period (pentad). The results obtained showed that both rainfall amount and rainy days are effective in the determination of the mean onset and retreats dates in Nigeria. However, he concluded that the method based on the rainy days is more effective than that based on rainfall amount.

However, this study is based on the use of the soil water balance method. The strength of this method over other methods lies in the fact that it has the ability of giving the exact date of onset and cessation of the rainy season while the other methods are based on estimates which are sometimes unreliable and misleading. Also, it provides a way to determine the onset and cessation dates according to the amount of rainfall for a particular region.

2.2 Association between the onset and cessation dates and the associated variables

Camberlin and Mbaye (2003) analyzed the inter-annual variability of the onset and cessation of the rainy season in Senegal over the 43 years period, using the cumulative rainfall anomalies method from (1950-1992), Their results shown that, over 1950-1992, the time series for the cessation shown that though there was a coincidence with a strong decrease in seasonal rainfall amounts, the correlation between amounts and onset/cessation dates on a year-to- year basis is not as high as expected. Also the total duration of the rains depends more on the onset than cessation and this provides evidence that yield may be as much affected by variation in the timing of the rains as by changes in the total rainfall amount.

Sivakumar (1988) carried out an analysis of long term daily rainfall for 58 locations in the southern Sahelian and Sudanian climatic zones of West Africa. The study showed that a significant relationship exists between the onsets of the rains and the length of the growing season.

Oladipo and Kyari (1993) investigated the fluctuation in the onset, cessation and length of the growing season in Northern Nigeria and reported also that the length of the growing season is more sensitive to the onset of the rains than to the cessation.

Mugo *et al.,* (2016) examined the spatial and temporal variability of the onset and cessation of long rains (MAM) in Kenya. The daily rainfall data used in the study was from 1961 to 2001. They also determined the relationship between onset, cessation and rainfall performance. Their results showed that rainfall over most stations was significantly negatively correlated with the onset.

2.3 The variability and trends on the onset and cessation dates, and the associated variables

Omotosho *et al* (2000) examined monthly and seasonal rainfall, onset and cessation of the rainy season for Kano in West Africa Sahel using only surface data which are based on variation in equivalent potential temperature that occurs as a result of the seasonal, monthly and daily variation of moisture in the summer monsoon flow over West Africa using daily mean values of surface pressure, temperature, relative humidity for the months: March, April and May from 1966-1996. The onset and cessation of the rainy season was determined using a two day period and the 10mm threshold. The results shows that, the annual variations in the dates of onset, cessation and rainfall amounts are accounted for through the variability of the potential temperature resulting from either seasonal or the monthly variations of moisture.

(Camberlin and Okoola 2003) characterized the intra-annual variability of the onset and cessation dates of East African using daily rainfall data for Kenya and north eastern Tanzania from 1958-1987 using the cumulative rainfall anomalies method. The result showed that the average onset occurs on March 25th and cessation on May 21st. Also, the inter-annual variability of the onset (SD 14.5 days) is larger than that of the withdrawal (10.3 days).

Sawa *et al* (2014) examined the impact of climate change on the hydrological growing season at Kano in Nigeria using daily rainfall records from 1976-2011 obtained from the Nigeria Meteorological Agency, Lagos. The onset, cessation and the hydrological growing season were determined using the pentad method. The results showed that, the rainy season has progressively been starting late and the rains ceased earlier in recent decades. The results also showed that, the implications of late onset and early cessation is progressively shortening the hydrological growing season.

Amekudzi *et al* (2015) investigated the variability in rainfall onset, cessation and length of rainy season for various Agro-Ecological Zones of Ghana using gauge data from 1970-2012 and the wavelet analysis spectrum. The onset and cessation were determined from the percentage cumulative rainfall and the rainy days method(s) and assessed the mode of variability using the Bias and the Root mean square method. Their findings showed that, the onset and cessation dates derived from the cumulative rainfall amount and rainy days are in consistent agreement with the various zones while the wavelet power spectrum, its significant peaks and variances showed evidence of variability in the rainfall onset and cessation dates across the country. The coastal and forest zones showed 2-8 and 2-4 year band variability in the onsets and cessations. Similarly, the transition and the savannah zones showed 2-4 and 4-8 year onset and cessation variability respectively.

Kisaka *et al* (2015) studied the extent of seasonal rainfall variability, drought occurrence, and the efficiency of interpolation techniques in eastern Kenya using daily rainfall data for the period 2001-2013. The analyses of rainfall variability utilized rainfall anomaly index, coefficient of variance and probability analysis. Spline, Kriging, and Inverse distance weighting interpolation techniques were assessed using daily rainfall data and digital elevation model using ArcGIS. The validation was done using Root mean square error and Mean absolute error statistics. Results showed that 90% chances of below cropping threshold rainfall (500mm) exceeding 258.1mm during the short rains in Embu for one year return period. The rainfall variability was found to be high in seasonal and number of rainy days in Machang'a, Kiritirib and Kindaruma, respectively.

Monthly rainfall variability was found to be equally high during April and November with high probabilities of drought exceeding 15 days in Machang'a and Kindaruma. Also, dry-spell probabilities within growing months were high (91%, 93%, 81%, and 60%) in Kiambere, Kindaruma, Machang'a and Embu, respectively. Also, dry-spell probabilities within growing months were high, (91%, 93%, 81%, and 60%) in Kiambere, Kindaruma, Machang'a, and Embu, respectively.

Adelekan and Adegebo (2014) examines annual variations and patterns in the onset and cessation dates as well the length of the rainy season in Ibadan Nigeria for the period 1981-2010 used the water balance method. The coefficient of variation (CV) was used to examine the annual variation and pattern in the onset dates, cessation dates and the length of the rainy season. The results shown that, the variation in the length of the rainy season corresponds with the annual variation in the onset and cessation of the rains. The coefficient of variation between the lengths of the rainy season shows a weak relationship ($r = 0.26$) and the overall trend observed in the length of the rainy season also not significant ($p = 0.174$, $p > 0.05$).

Oguntunde *et al*. (2014) determined the spatial and temporal changes on the onset and cessation and examines the relationships among these rainfall attributes in addition to possible synoptic connectivity amongst measurement stations in Nigeria using daily rainfall data from 1971-2005. The change in the average monthly and annual rainfall trends were determined using probability density function and non- parametric test such as the Pettit test, Wilcoxon-rank test and paired sample test The results showed that, the mean rainy season onset dates (ROD), rainy season cessation dates (ROC) and length of rainy season (LGS) have zonal distribution over Nigeria. Onset dates are delayed from the coast northward leading to shorter length of growing season in those stations. Variability is generally high below 8°N with coefficient of variation (CV) ranging from 13-36% for rainfall onset dates, 3-12% for rainfall cessation dates and 8-17% for the length of growing season. In the middle belt (8-11°N), spatially CV showed values ranging from 10-20% for ROD, 3-8% for RCD, 8-21% for LGS. In the Sahel (above 11°N), the rains comes later in the year and coefficient of variation showed values ranging from 2-9% for rainfall onset dates; 2-3% for RCD and 12-13% for LGS.

Lemma *et al (*2016) analyzed the impact of onset, length of growing period a dry spell length on Chickpea production in Adaa District of Ethiopia for the period 1980-2010 using daily climatic data such as temperature, rainfall and sunshine hours obtained from the National Meteorological Agency (NMA) of Ethiopia and yield data from Debrezeit Agricultural Research Center (DARC). The analysis of the results showed that the variability in the start of the season for the stations was relatively high as compared to the end of the season. The mean total rainfall was about 830mm with the growing period ranging from 99-215 days.

Bibi *et al* (2014) analyzed 27 years (1980-2006) of gridded daily rainfall data obtained from a merged data set by the National Centre for Environmental Prediction and Climate Research Unit reanalysis data (NCEP-CRU) for Northeastern Nigeria. The temporal variability was assessed using the percentage coefficient of variation; the temporal trends in rainfall were assessed using maps of linear regression slope for the months of May and October which covers the onset and cessation of the wet season throughout the region and predicting the monthly rainfall amount using the Auto Regression Integrated Moving Average Model (ARIMA). The temporal variability in rainfall showed latitudinal gradient increasing northwards and generally decreasing as the wet season progresses. The temporal trends in monthly rainfall over the 27 years period suggested a decreasing trend in the month after the onset of rainfall. There is an increasing trend in rainfall amounts and frequency towards the middle of the wet season especially towards the northern region

Deshmukh and Lunge (2013) examined trends in rainfall and temperature in Vidarbha district, India using monthly averages of total month rainfall, rainy days and mean of maximum temperature data from 1975-2005 obtained from the India Meteorological Department. The long term changes in temperature, rainfall and rainy days were analyzed by correlation analysis and linear trend analysis. The significance of the trend was tested by the Mann-Kendall trend test and the slope of the regression line by the least square method. The result indicated that, the monthly mean of maximum temperature shown statistically significant decreasing trend, number of rainy days (RD), and number of rainy days (RD J-S) during June to September shows statistically insignificant decreasing trend during 1975-2005 which was confirmed by the Mann-Kendall test at 5% level of significance. The annual mean maximum temperature decreased at a rate of 0.0440°C in Vidarbha district. The mean of total month of rainfall (TMRF) showed a statistically insignificant increasing trend, mean of total month rainfall (TMRF J-S) showed a statistically insignificant increasing trend during the study period and this was confirmed by Mann-Kendall trend test at 5% level of significance.

CHAPTER THREE

3.0 DATA AND METHODOLOGY

This chapter gives a description of the data used, the source and the method employed to analyze the data in order to achieve the specific objectives of the study in section 1.4

3.1 Data Types and Sources

Daily rainfall data for a 25 years period ranging from 1990-2014 was used in this study. The data was obtained from the Sierra Leone Meteorological Department for four synoptic stations (Freetown, Lungi, BO and Daru). Due to the 11 years (1991-2001) civil war in the country, most of the meteorological records and stations were destroyed, therefore, the study is only limited to four synoptic stations.

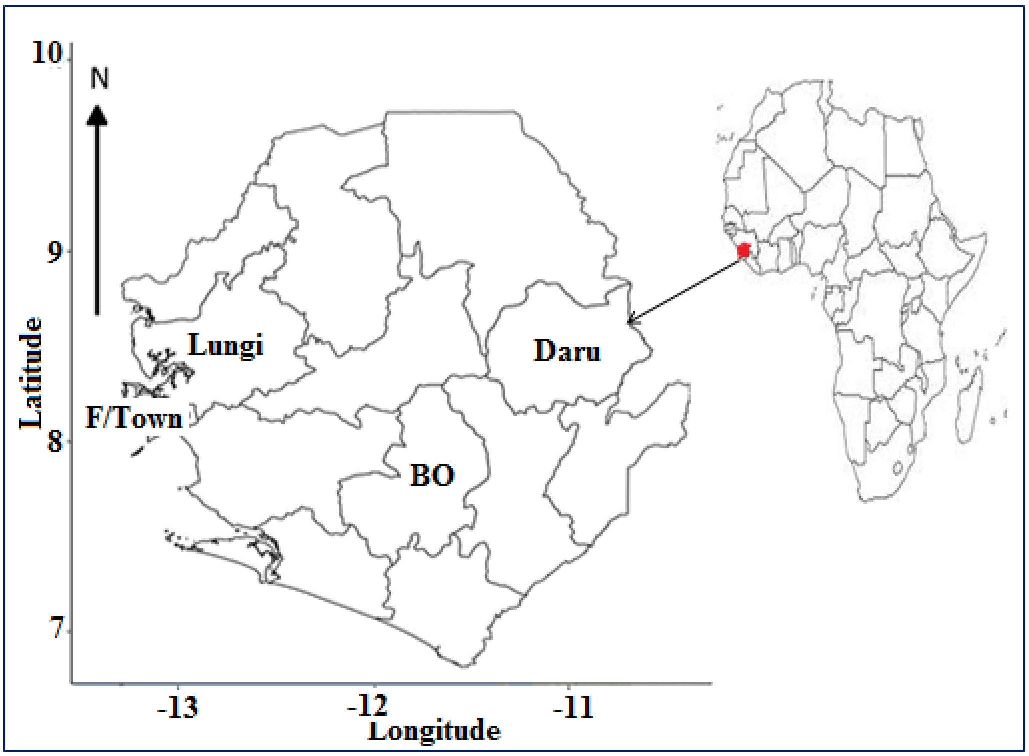

Figure 2: A map of Sierra Leone show location of Meteorological Stations used in the study

3.2 Methodology

3.2.1 Estimation of Missing Rainfall Records

The data quality and quantity is very essential for meteorological analysis. Therefore, before embarking on any data analysis, it is important to ensure that the data has no missing gaps. The missing records were estimated using the Arithmetic Mean Method. In this method, the missing records were replaced with the average value of the data for each station using Equation 2

$$X_m = \frac{1}{N}\sum_{i=1}^{n} X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 2$$

In Equation 2; X_m is the missing data being estimated, X_i is the available data point and N is the number of data points.

3.2.2 Homogeneity Test

Good quality meteorological data is a requirement for data analysis. The homogeneity of the data was tested using the single mass curve. In this method, a time series of accumulated totals of the rainfall is constructed. If the data is from the same population, there will be no change in gradient (slope) and a straight line will be obtained. However, if there is a change in the records; a change of gradient will be detected on the time series.

3.2.3 Determination of onset and cessation dates and the associated variables

In different parts of West Africa, several approaches have been used in determining the onset dates, cessation dates, length of the rainy season and seasonal totals; Ilesanmi (1972), Kowal and Knabe (1972 Rao (1976), Stern (1981), Banney-Morin Nigeria (1984), Adejuwon (1988) and Adejuwon et al (1990), Kogan (1995), Sarria-Dodd and Jolliffe (2001), and many among others.

However, this study is going to narrow on the modified definition of Stern (1981) by Sarria-Dodd and Jolliffe (2001) since it has the advantage of indicating the exact day of the onset and cessation date of the rainy season while the other methods are based on estimate.

The following criteria were used in determining the onset of individual years:

i. For a five consecutive days period of observed rainfall with at least 25mm of rainfall is recorded.

ii. The starting day and at least two other days in this five day period receive rainfall not less than 0.25mm
iii. There should be no dry spell of seven or more days occurring in the next 30 days.

The opposite was used to define the cessation dates of the rainy season.

i. For a five consecutive days of observed rainfall with less than 25mm of rainfall recorded
ii. Three days within this five day period are dry receiving rainfall less than 0.25mm.
iii. And a dry spell of seven or more days.

The length of the rainy season was defined as the difference between the cessation dates and the onset dates.

Following their approach, the area of study being a humid climate and the raining season starts from April to October; the onset of the raining season for the area of study is define as the day after the first April that received at least 25mm of rainfall accumulated over three consecutive days with no dry spell exceeding seven days in the next 30 days.

The cessation dates of the rainy season was defined from the water balance approach, as the day after the first of October when the rainfall become less than 0.25mm, the rate of evaporation is taken to be 5mm per day on average and the soil water holding capacity is fixed at 100mm (average soil moisture during dry days).

Moreover seasonal rainfall total was obtained by summing daily rainfall from 1st April to 31st October for each of the stations for all the years.

3.2.4 Determination of the relationship between the onset, cessation, duration and the seasonal rainfall totals

To determine the relationship between onset and cessation dates and seasonal totals, there are several methods or techniques which can be used but this study adopted the correlation method and tested the significance of the relationship using the student-t-test.

Correlation Analysis was used to establish the degree of relationship between onset, cessation and duration to seasonal totals amount. The Pearson correlation coefficient r is a measure of the linear relationship between variables. The value of r ranges from -1 to +1 and is independent of the unit of measurement. For the values r close to zero indicates little correlation and for it being from -1 to +1 indicates high level of correlation (Deshmukh and Lunge 2013) . The correlation equation used in this study is given in equation 3.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 (y_i - \bar{y})^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where r is the correlation coefficient, x_i is the independent variable and represents onset and cessation dates, y_i is the dependent variable and represent seasonal totals, $\bar{y}$ and $\bar{x}$ are the mean of the dependent and independent variable, respectively.

The computed correlation values was tested for statistical significance using the student t- test as shown in equation 4

$$t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{4}$$

Where; t- is the value of the student-t-test, n- is the number of observations; r- is the correlation coefficient being tested, n-2 is the degree of freedom.

3.2.5 Variability on the onset, cessation dates and associated variables

To determine the intra-seasonal and seasonal rainfall variability of rainfall the coefficient of variation was computed. The coefficient of variation was computed from the mean and standard deviation of the individual stations using the relation described by (Bibi *et al*. 2014) as shown in equation 5.

Coefficient of Variation $CV(\%) = \frac{\sigma}{\mu} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$

In Equation 5; $V\%$: is the coefficient of variation in percentage, σ is the standard deviation and μ is the mean.

According to Hare (1983), the percentage of coefficient of variation is classified as follows, less than 20% as less variable, 20-30% as moderately variable and greater than 30% as highly variable.

3.2.6 Trend analysis on the onset, cessation dates and associated variables

Trend analysis often refers to techniques for extracting an underlying pattern of behavior in a time series which would otherwise be partly or nearly completely hidden by noise. To analyze the trends the linear regression equation and the Mann-Kendall statistics was used. The linear regression was used to visualize the trends.

3.2.6.1 Linear regression

Regression analysis is one of the most important statistical techniques used in trend analysis; it's a statistical methodology that helps estimate the strength and the direction of the relationship between two or more variables using the value of the slope (m). A positive value of the slope indicates an increasing trend while a negative value indicates a decreasing trend. The linear regression equation is shown in equation 6 described by (Deshmukh and Lunge 2013).

$$Y = mX + c \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 6$$

In equation 4; Y is the dependent variable, m is the slope of the regression line,X is the independent variable and c is the intercept of the regression line.

3.2.6.2 The Mann-Kendall Test

The purpose of the Mann-Kendall (MK) test (Mann 1945, Kendall 1975, Gilbert 1987) is to statistically asses if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear. The test can also be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero (Mann, H.B 1945).The significance of the trend was identified using the Mann-Kendall statistics test. The Mann-Kendall test was proposed by Mann (1945) and it has been environmentally used widely in time series analysis (Hipel and McLeod 2005) because it does not require the data to be normally distributed and that the method is less sensitive to abrupt breaks caused by inhomogeneity of the data (Jaagus, 2006). The statistical significance of the trends is indicated by the p-value at 95% confidence level.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the results obtained from the various methods that were used to achieve the specific objectives of the study. The results include single mass curves, onset and cessation dates, seasonal rainfall characteristics, variability and trend of the seasonal rainfall characteristics.

4.1 Data Quality Control

The data used in the study was checked for missing records, few data was found missing (1%) in Freetown station and the missing values was estimated using the arithmetic mean method. The homogeneity of the data was tested using the single mass curves in Figure 3. All the data used in the study showed a straight line.

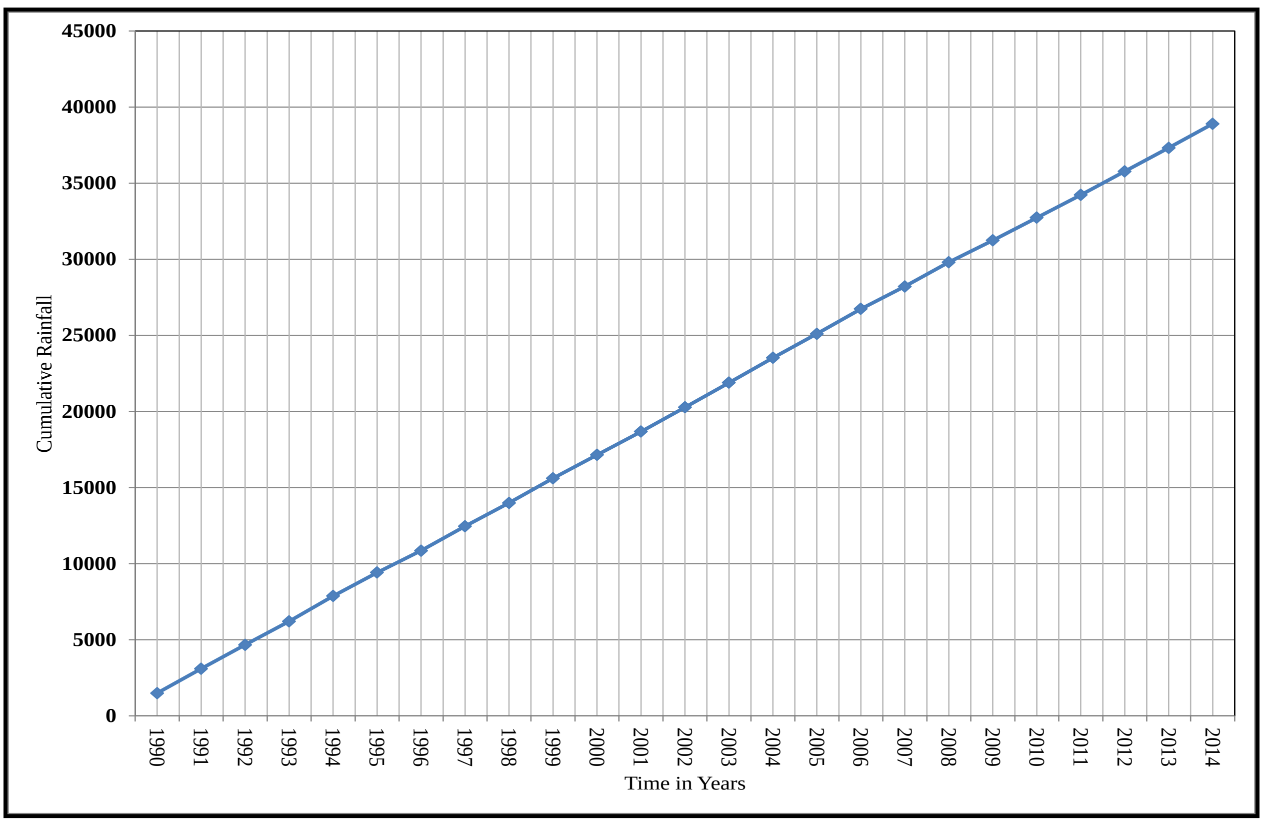

Figure 3: Single Mass Curve of Daru Station in Sierra Leone (1990-2014)

4.2 Determination of the onset dates, cessation dates, duration and seasonal totals.

The onset and cessation dates and the associated variables of the rainy season were determined using the modified definition of Stern (1981) by Sarria-Dodd and Jolliffe (2001) for humid climate. The results obtained are illustrated in Figure 4 and 5.

Over Freetown and Lungi stations, the onset of the rains occurs mostly during the months of late April and early May, while Bo and Daru stations, the onset dates fluctuates between late April, May and early June. These findings agree with Sultan *et al .(*2003) where the onset stage of the summer monsoon over West Africa is linked to an abrupt latitudinal shift of the ITD from a quasi-stationary location at 5°N in April-June.

The cessation dates of Freetown, BO and Lungi stations occur in late November and mid-December and the cessation dates for Daru occur late October (Figure 4).

The duration of the rains is much longer for Freetown, Lungi and BO with an average duration of 231, 231 and 221 days, respectively. At Daru the duration of the seasonal rainfall was slightly shorter (177 days) (Table 1).

The seasonal totals of the rainfall for Freetown and Lungi are between 2650-3500 mm and that of Bo and Daru are between 1500- 2500 mm (Figure 5). These results are similar to Clarke (1996) where the rainfall in the monsoon months in Sierra Leone decrease with distance from the sea ranging from 3000-5000mm along the coast and 2000-2500mm in the eastern board of the country. This could be attributed to the fact that Daru and BO are further inland hence little moisture from the oceans, whereas Freetown and Lungi are close to the Atlantic ocean therefore there is enough moisture to bring more rain.

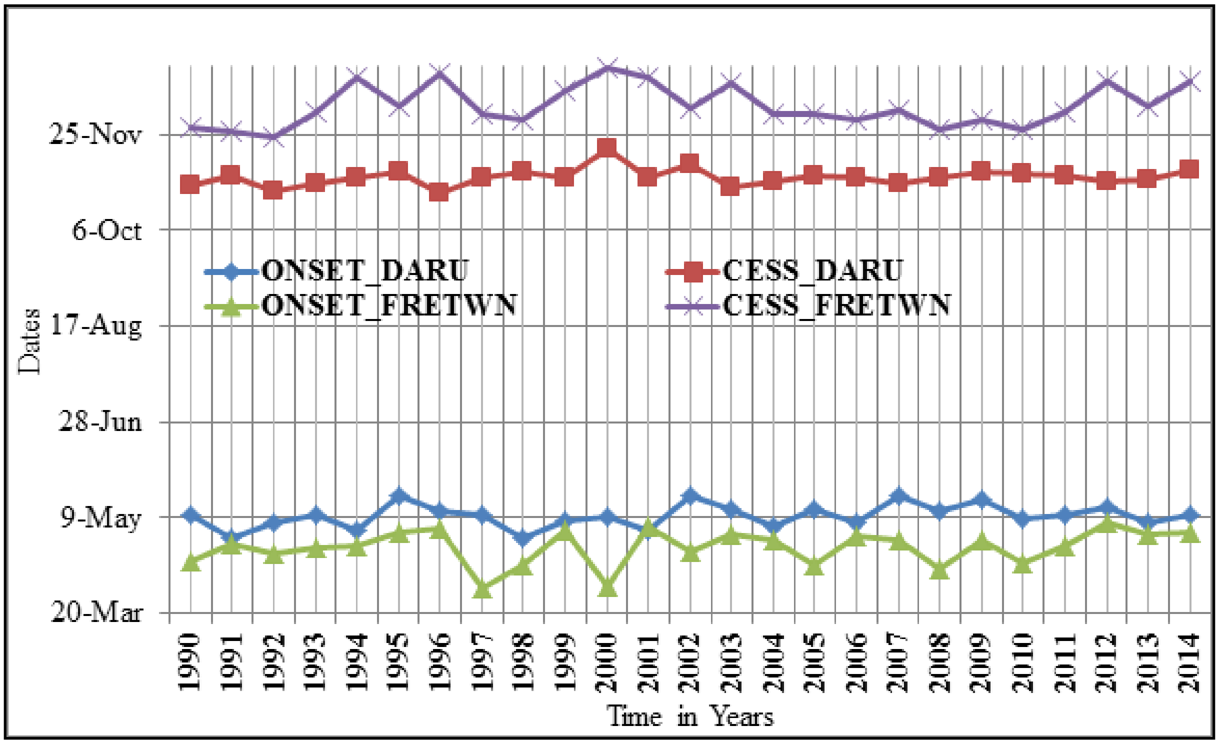

Figure 4: Rainfall Onset and Cessation Dates for Daru and Freetown meteorological stations in Sierra Leone from 1990-2014

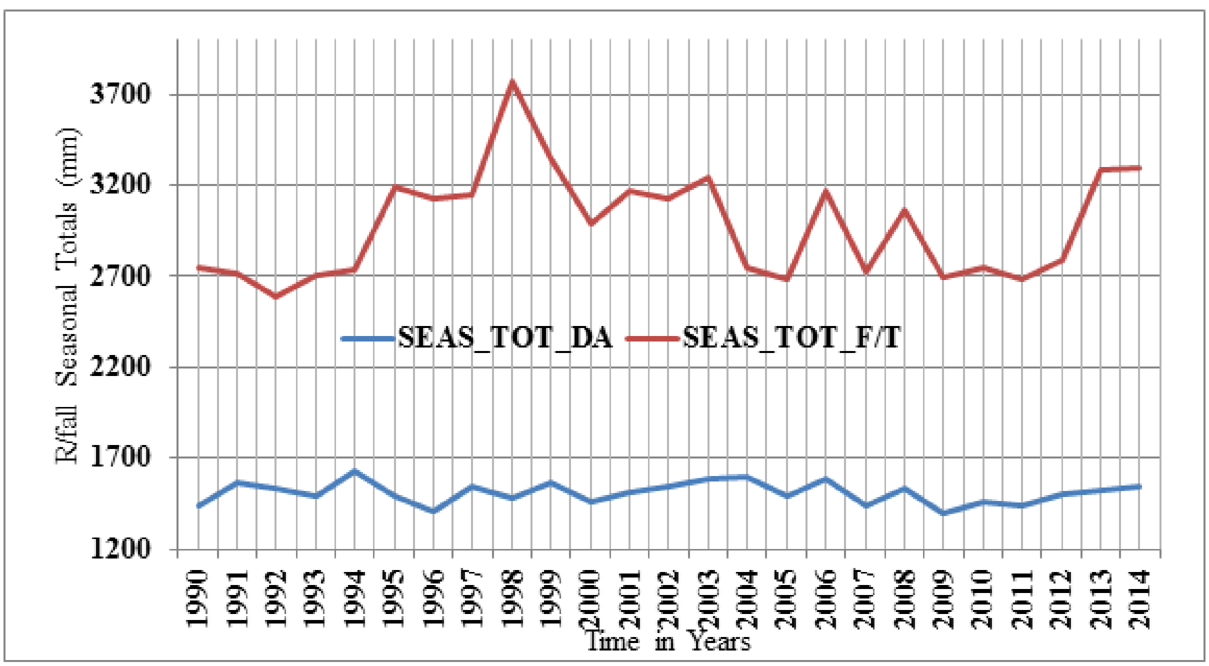

Figure 5: Seasonal Rainfall Totals for Daru and Freetown in Sierra Leone from 1990-2014

Table 1: Mean duration of the seasonal rainfall at the four synoptic stations for the period 1990-2014

Parameter	**BO**	**Daru**	**Freetown**	**Lungi**
Mean Duration	221 days	117 days	231 days	231 days

4.3 Relationship between onset, cessation, duration and seasonal rainfall totals

Table 2 shows the correlation coefficients between onsets, cessation, duration and the seasonal rainfall totals. The significant correlation coefficient at 95% confidence level was estimated using student t–test and the value was ± 1.714 . Any values less than ± 1.714 were thus insiginificant.

From Table 2, it is evident that the correlation between onsets at Daru station with seasonal rainfall totals was negative and significant, implying that early onsets results to higher amounts of seasonal rainfall and late onsets results to lower amounts of seasonal rainfall. For the other three stations insignificant correlation coefficients was observed between the onsets and seasonal rainfall totals. All of the stations except Daru showed positive correlation coefficients between the cessation and seasonal rainfall totals. However, none of the coefficients were significant. Both BO and Daru stations depicted positive and significant correlation coefficients between duration of the rains and seasonal rainfall totals (Table 2). This implies that the longer the duration the higher the seasonal totals and the lower the duration the lower the seasonal totals of rainfall.

Table 2: Correlation between inter-annual variations between onset, cessation, duration and seasonal totals

Parameters	Station Name	Correlation	t-computed	t-tabulated	significance
Onset	BO	-0.15	-0.73	±1.714	insignificant
	Daru	**-0.44**	-2.35	±1.714	*significant*
	Freetown	0.07	0.34	±1.714	insignificant
	Lungi	-0.01	-0.05	±1.714	insignificant
Cessation	BO	0.30	1.51	±1.714	insignificant
	Daru	-0.02	-0.10	±1.714	insignificant
	Freetown	0.30	1.51	±1.714	insignificant
	Lungi	0.18	0.88	±1.714	insignificant
Duration	BO	**0.35**	1.79	±1.714	*significant*
	Daru	**0.35**	1.79	±1.714	*significant*
	Freetown	0.22	1.08	±1.714	insignificant
	Lungi	0.09	0.43	±1.714	insignificant

4.4 The Variability on the Onset Dates, Cessation Dates, Duration and Seasonal Totals

The Box and whisker plots were used to examine the location, the spread and the skweness of the onsets, cessation, duration and the seasonal rainfall totals. The box covers the interquartile range (50% of the data) and its length gives an indication of the variability. The line across the centre of the box marks the median (central observation). The whiskers attached to the box show the range of the data from minimum to maximum.

Over BO station the median of the onset dates was 28th April, 50% of the onset dates lie between 22nd April and 7th May, the minimum and the maximum onset dates are 13th April and 27th May, respectively. The spread of onset dates at BO is considerably larger compared to the other three stations hence it is highly variable compared to the three other stations. The onsets are skewed to the right that is most of the onsets occurs much later (Figure 6). At Lungi the median of the onset dates was 28th April, 50% of the onset dates lie between 25th April and 30th April, the minimum and the maximum onset dates are 23rd April and 7th May, respectively. The spread of onset dates at Lungi is considerably lower compared to the other three stations hence it is less variable compared to the three other stations. However several outliers were noted for Lungi (Figure 6).

At Freetown the median cessation dates was 7th December, 50% of the cessation dates lie between 3rd December and 22nd December, the minimum and the maximum cessation dates are 24th November and 30th December, respectively. The spread of cessation dates at Freetown is considerably larger compared to the other three stations hence it is highly variable compared to the three other stations. The cessation dates are skewed to the right that is most of the cessation dates occur much later (Figure 6). At Daru the median of the cessation dates was 3rd November, 50% of the cessation dates lie between 1st and 5th November, the minimum and the maximum cessation dates are 26th October and 10th November, respectively. The spread of cessation dates at Daru is considerably lower compared to the other three stations hence it is less variable compared to the three other stations (Figure 6).

Over BO the median duration was 222 days, 50% of the length of duration lie between 207 and 234 days. The spread of duration at BO is considerably larger compared to the other three stations hence it is highly variable compared to the three other stations. The duration are somehow symmetrical (Figure 6). At Daru the median of the duration was 176 days, 50% of the length of duration lie between 172 and 181 day. The spread of duartaion at Daru is considerably lower compared to the other three stations hence it is less variable compared to the three other stations (Figure 6).

Over Freetown station the median of the seasonal totals was 2991mm, 50% of the seasonal totals lie between 2278mm and 3172mm, the minimum and maximum seasonal rainfall totals are between 2593mm and 3767mm respectively. The spread of the seasonal totals at Freetown station is considerably larger compared to the other three stations hence it is highly variable compared to the three other stations. The seasonal totals are skewed to the right that is most of the rainfall amounts are above 2991mm (Figure 7). At Daru the median seasonal totals was 1514mm, 50% of the seasonal totals lie between 1462mm and 1545mm, the minimum and the maximum seasonal totals are1398 mm and 1625mm respectively (Figure 7). The spread of seasonal totals in Daru station is considerably lower compared to the other three stations hence it is less variable compared to the three other stations.

Generally the variability of the onsets dates are larger compared to the other variables (Table 3). On the other hand the BO station depicted much variability in most of the variables considered making it not be a good area of practicing rain-fed agriculture. Daru station showed less variability in all the variables considered (Table 3) hence having the advantage of being a good area for practicing rain-fed agriculture.

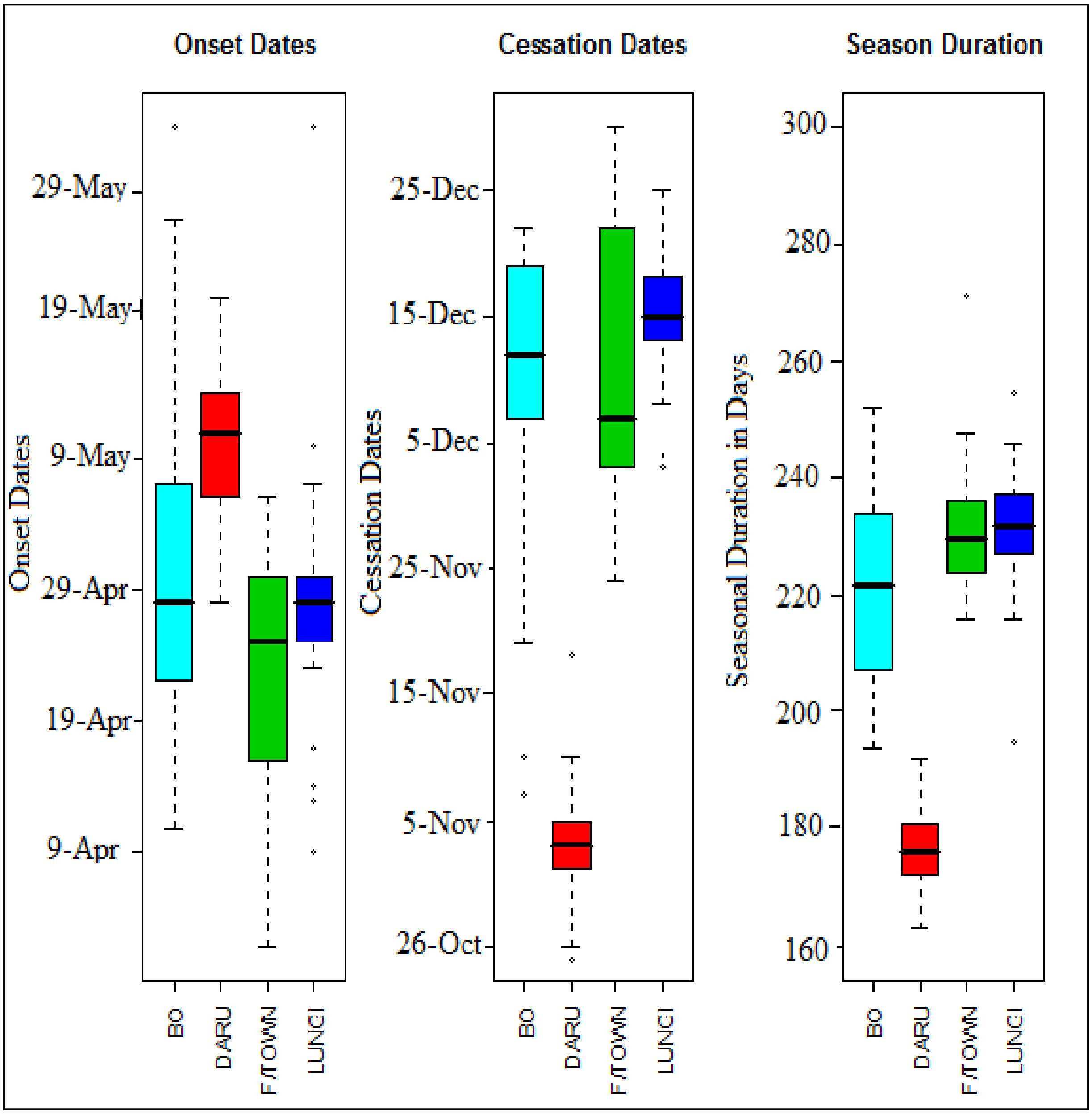

Figure 6: Distribution of onset dates (Right panel), Cessation (Centered panel) and Duration dates (Left Panel) for the period between 1990 to 2014

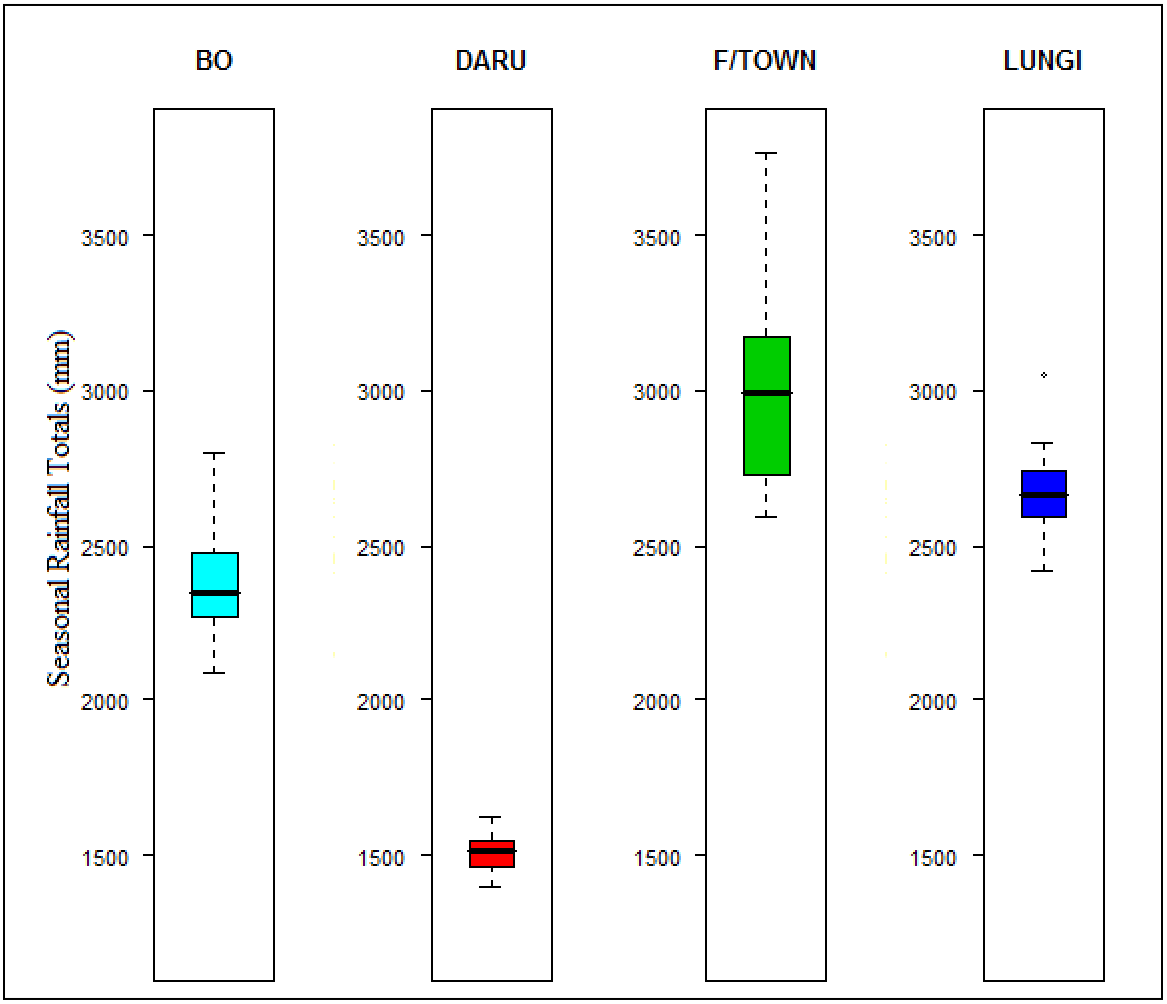

Figure 7 : Distribution of the Seasonal Rainfall Totals in Sierra Leone (1990-2014)

Table 3: Descriptive Statistics of the intra-seasonal rainfall characteristics in the four Meteorological stations for the period 1990 to 2014

Rainfall	Statistical Parameters	Bo	Daru	Freetown	Lungi
Onset	Mean (dates)	28th April	10th May	23rd April	28th April
	Standard Deviation (days)	15	7	9	10
	CV%	12.4	5	8.1	8.6
Cessation	Mean (dates)	9th December	3rd November	10th December	15th December
	Standard Deviation (days)	13	5	11	6
	CV%	3.7	1.5	3.1	1.6
Duration	Mean (days)	221	177	231	231
	Standard Deviation (days)	17	8	12	12
	CV%	7.8	4.4	5	5.1
Seasonal Totals	Mean (mm)	2363	1510	2980	2667
	Standard Deviation (mm)	156	61.1	294.2	134.9
	CV%	6.6	4	9.9	5.1

4.5 Trend results on the Onset, Cessation Dates and the associated variables

During the study period (1990-2014), both increasing and decreasing trends in the intra-seasonal rainfall characteristics were observed in the study area (Table 4). The trends on the onset dates in all the stations showed an increasing trend except BO station that depicted a decreasing trend (Figure 8). However, none of the trends were statistically significant (Table 4). A decreasing (increasing) trend of onsets depicts early (late) onsets.

At Daru and Freetown stations, the cessation dates showed increasing trends which were not significant (Table 4). On the other hand, the trend for cessation at BO showed decreasing significant trend (Figure 9).

All the four stations depicted decreasing trends in the duration, which were not statistically significant (Table 4). All the stations except Freetown displayed insignificant increasing trends on the seasonal totals.

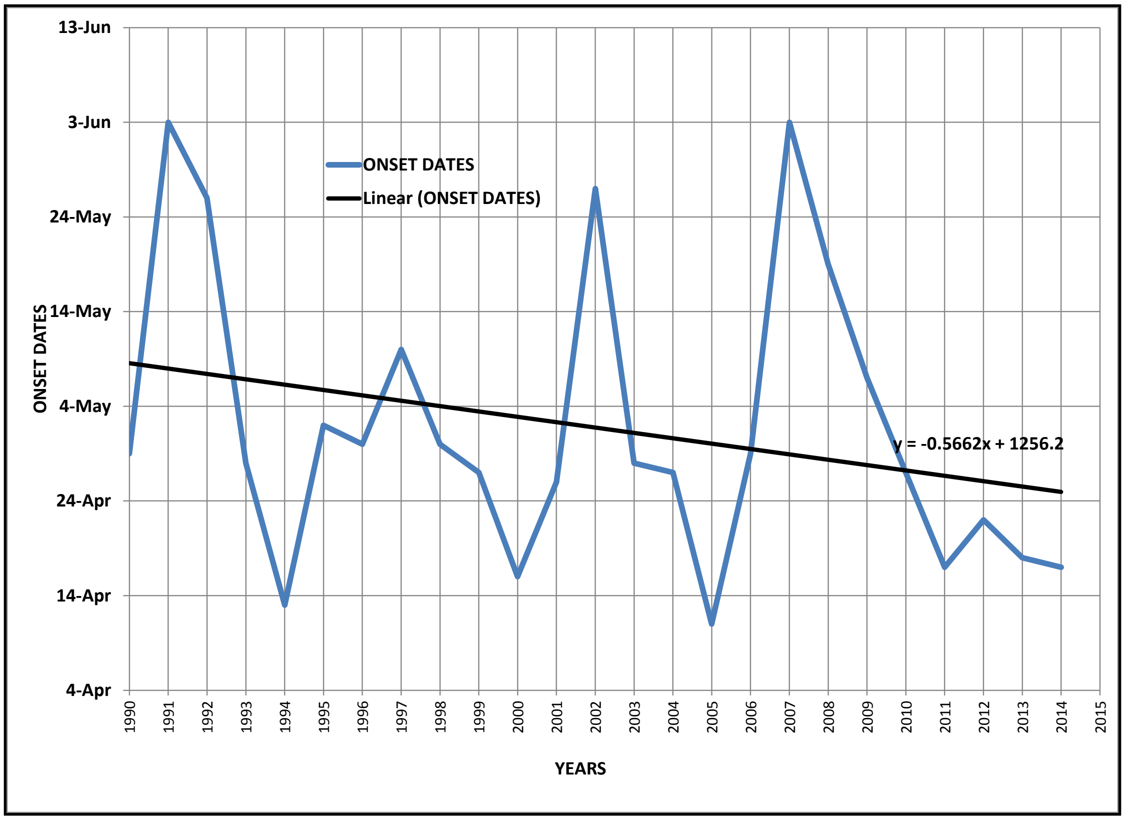

Figure 8: Trend on the Onset of the Rainy Season BO Station the period 1990-2014

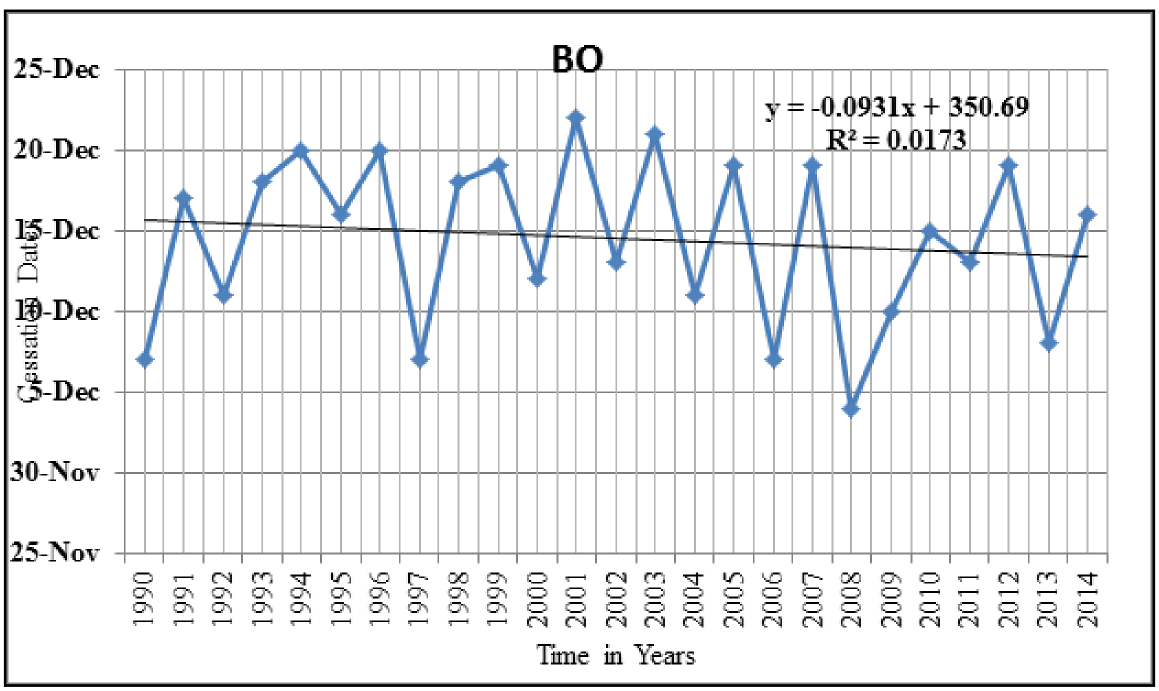

Figure 9: Trend on the cessation dates for BO station for the period 1990-2014

Table 4: The statistical significant of the Trends on the Onset Date, Cessation Dates, Duration and Seasonal Totals

Parameter	Station Name	Mann-Kendall		a	
		tau	p-value		
Onset	BO	-0.264	0.071451	-0.5662	Insignificant
	Daru	0.179	0.23002	0.2423	Insignificant
	Freetown	0.165	0.26127	0.3570	Insignificant
	Lungi	0.0992	0.5108	0.2308	Insignificant
Cessation	BO	**-0.349**	0.016897	-0.0938	Significant
	Daru	0.177	0.23803	0.1362	Insignificant
	Freetown	0.0645	0.67316	0.1577	Insignificant
	Lungi	-0.0172	0.92502	-0.0077	Insignificant
Duration	BO	-0.128	0.38639	-0.5254	Insignificant
	Daru	-0.0272	0.86964	-0.1062	Insignificant
	Freetown	-0.0102	0.96264	-0.1138	Insignificant
	Lungi	-0.0303	0.85159	-0.2385	Insignificant
Seasonal Totals	BO	-0.08	0.59115	-3.7697	Insignificant
	Daru	-0.0267	0.87014	-0.8166	Insignificant
	Freetown	0.06	0.69134	3.0374	Insignificant
	Lungi	-0.113	0.44088	-4.4977	Insignificant

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter offers the major conclusion of the results and discussions from the study. It also provides recommendations and suggestions for further studies.

5.1 Conclusion

The overall objective of the study was to investigate the variation of the intra-seasonal rainfall characteristics in Sierra Leone. These were achieved through the following specific objectives: to determine onset dates and cessation dates of the rainy season and the associated variables, to determine the relationship between onsets, cessation and duration to the seasonal totals, to determine the variability on the onset dates, cessation dates, and the associated variables and to determine the trends of onset and cessation dates, the associated variables.

From the first objective, the result obtained showed that Freetown and Lungi (which are closer to the Atlantic Ocean coastline) have early onsets while BO and Daru (which are both interior), have late onsets. There is early cessation at Daru and late cessations at the other three stations. The results further showed that the duration of the rainy season is much longer for Freetown, Lungi and Bo stations while the duration of the rainy season at Daru station is shorter. The seasonal rainfall totals were lower and higher at Daru and Freetown stations, with values of 1510mm and 2980 mm, respectively.

From the second specific objective, it was also evident that the correlation between the onset, cessation and duration to seasonal totals was generally insignificant in most of the stations except for BO and Daru stations which depicted positive and significant correlation coefficients between duration of the rains and seasonal rainfall totals. On the other hand, there was negative and significant correlation coefficient between Onsets at Daru and seasonal totals.

The variability of the intra-seasonal rainfall characteristics were slightly higher at BO compared to the other three stations though not significance.

Increasing and decreasing trends were evident for all the seasonal rainfall characteristics. However the trends were statistically insignificant except for cessation at BO station which depicted statistically significant decreasing trend.

The results obtained from this could be used by many sectors that depend on rain over the country for planning purposes before the onset of April-June and after the Cessation of October-December.

5.2 Recommendations

Based on the findings of this study, the information obtained can be used in many sectors of the national economy that relies on rainfall either directly or indirectly, the following recommendations are presented:

i. The development of the country relies on the information received from the Meteorological Services, it is therefore recommended to the Meteorological Department to increase the number of the synoptic stations to capture the entire country to provide an accurate forecast on the weather elements.
ii. It's recommended to grow early maturing cereal crops especially when the seasonal rainfall starts too late and ends too early so as to avoid crop failures and allow higher yield in order to improve the food security of the country.
iii. In order to avoid dry spell at the initial stage of crop development, it is recommended that farmers in and BO and Daru stations start their farming activities around mid-May while those in Freetown and Lungi starts mid-April.
iv. Past and present climate data is vital for agricultural production therefore analysis of the trends seasonal rainfall characteristics should be encouraged to provide changes an associated risks and opportunities.
v. The study also considered few elements of intra-seasonal rainfall characteristics. Subsequent studies should incorporate other rainfall derived parameters such as dry spell, wet spell among others

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