ASSESSING FLOOD AND DROUGHT EPISODES IN SOME SELECTED SYNOPTIC STATIONS IN GHANA USING RAINFALL ANOMALY INDEX (RAI)

by

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DECLARATION

We hereby declare that this thesis is our original work for the BSC in meteorology and climate science, and to the best of our knowledge, it does not contain any previously published or accepted work for any other University degree, with the exception of instances where appropriate citation has been made in the text.

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Dedication

This study is a tribute to God Almighty for His kindness and fortitude during the research process. We dedicate this work to our families in appreciation of their inspiration and support, as well as to everyone else who contributed to the success of this project.

Abstract

Flood and drought episodes occur when the precipitation values are above or below normal respectively. These anomalies in precipitation may affect socio-economic activities like agriculture and power generation. Using the Rainfall Anomaly Index (RAI), this study assessed historic drought and flood episodes, spatial distribution of mean annual rainfall, zonal distribution of rainfall, yearly precipitation trends and flood and drought events count over selected synoptic stations in Ghana. Rainfall data of spatial resolution $0.25^{\circ} \times 0.25^{\circ}$ and a temporal resolution of monthly spanning from 1981 to 2019 were accessed from the Global precipitation and Climatology Center (GPCC). Rainfall anomaly Index (RAI) method was used to calculate for dry and humid episodes at annual time scales. The results from the study showed that the mean rainfall trend over Ghana is decreasing in the north, transition, forest and the coast agroecological zones with a magnitude of of -0.422, -4.348, -2.455 and -0.874 respectively. Even though precipitation trend over the entire country is , the climate at the forest zone is shifting toward very humid conditions. Meteorologically, there has been more droughts than floods episodes in the last decade. The findings further suggest that between 2014 and 2018, the Ghana experienced very dry episodes. The coast was for the period of the study experienced conditions that were near normal with few extreme wet and dry conditions, however it has been noted to be a flood prone area over the

last decade. This finding proves that, the perennial floods at the coast are not eni=tirely meteorological but could be due to manmade activities such as the predominant utilization of tarred surfaces that prevent infiltration of rain water, construction of structures and facilities in waterlogged areas that disrupts runoffs, poor sewerage and drainage systems and choked gutters, etc. Based on these findings, water resource management is advised to lay out proper guidelines to ensure water availability and sustainability for agricultural and household use.

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God Almighty deserves all the praise for permitting us to attempt this undertaking and for its successful completion. Much thanks to you Lord for this love and kindnesses. We express our gratitude to all the members of the Forecasters' Web, for their contribution to this paper. We are also grateful to our supervisor Dr Jeffrey N. A. Aryee and his assistant, Keren Agyapong-Happuch for their support and patience. We are extremely thankful and indebted to them for sharing their expertise and encouragement.

CHAPTER 1

INTRODUCTION

1.1 Research background

Rainfall plays a vital role in the hydrological cycle and the ecology (Amekudzi et al., 2015). In as much as rainfall is important for socio-economic activities like agriculture and power generation, an increase or decrease in the frequency and intensity can be catastrophic. In the last five decades, there have been variations in the rainfall patterns and this has led to a sequence of flood and drought years. These extreme events create the primary impact of climate change on society since their rate of recurrence has more impact compared to changes in mean climate (Mirza, 2003; Lubchenco and Karl, 2012). The majority of tropical ecosystems are extremely sensitive not only to annual rainfall amounts but also to other aspects of seasonal rainfall, such as the arrival of rain at the start of the wet season, which determines the timing of important crop plant life stages such as leaf flushing and flowering; and the length of the wet season, which influences the timing of leaf fall and thus the total transpiration period (Borchert, 1994; Schwartz and Randall, 2003). The same rainfall seasonality, together with the related drought and flood hazards, provides significant problems to local inhabitants, complicating agricultural activities and soil and water resource management (Wani et al., 2009; Rockström et al., 2003).

The World Health Organization (WHO) suggests that 80 per cent to ninety per cent of the natural disasters globally are droughts and floods. Available statistics show that floods and drought have been two of the costliest natural disaster in the world. Over the last five decades, Flood has affected over three billion people with total deaths of 58,700 and total damages of over USD 115 billion. Further available statistics show that the most devastating flood event in the history of Europe was Germany in 2002 (Panwar and Sen, 2020). This brought a loss of USD 16.48 billion. Drought on the other hand has affected over 2 billion people globally with total deaths of approximately twelve million. Droughts, per statistics from the United Nations Convention to Combat Desertification (Ma and Zhao, 1994; Martínez-Valderrama et al., 2020), between 1998 and 2017, droughts have caused an economic loss of about USD 124 billion globally. Statistics from the Centre for Research on the Epidemiology of Disasters (CRED) Emergency Events Database (EM-DAT) published in (Masih et al., 2014) show that between 1900 and 2015, there have been 624 drought episodes globally. Africa alone has experienced 291 out of the 624 affecting 362,225,799 people with a mortality rate of about 847,143. Flood and drought not only result in economic loss to a country or individual, they have been noted to also affect people's mental well being. Drought as defined by the UNCCD is when a lack of precipitation results in a shortage of water supply. Flood on the other hand occurs when water overflows and submerges normally dry terrain. Floods are usually caused by heavy rainfall in the tropics. Flood and drought are two of the world's most disastrous phenomena destroying human lives, wildlife, agriculture and infrastructure (Mensah and Ahadzie, 2020). Despite their effects, it is difficult to predict their occurrence as well as how intense they are when they occur.

In order to curb the above problem, scientists have formulated mathematical formulas to compute the intensities of floods and droughts into a single numerical value. These indices input climatic parameters like precipitation, temperature, soil moisture etc. Examples of the indices include the Rainfall Anomaly Index (RAI) (Van Rooy, 1965), the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010), Standardized Precipitation Index (SPI) (McKee et al., 1993), Palmer Drought Severity Index (PDSI) (Palmer, 1965), Effective Drought Index (EDI) (Kim et al., 2009), Deciles Index (DI) (Morid et al., 2006), Percent of Normal Index (PN) (Asrari et al., 2011), Palmer Z-Index (Jacobi et al., 2013), Soil Moisture Deficit Index (SMDI) (Narasimhan and Srinivasan, 2005), the Palmer Hydrological drought Index (PHDI) (Karl, 1985), Reconnaissance Drought Index (RDI) (Tsakiris et al., 2007) and many more.

1.2 Literature review

Flood and droughts recently have attracted the attention of researchers all over the globe as they are ranked first and second in terms of people affected respectively (Yang and Liu, 2020).

Moron (1994) computed the rainfall anomalies for the Guinean and Sahelian zones of Africa at both annual and monthly times scales. Since the study area of the research was relatively large with hundreds of point-located stations, Principal Component Analysis (PCA) was used. The study computed RAI for only stations recording rainfall amounts greater than 50 mm per month and the total network for the Atlantic Continental sections was from July to September, the Transitional section was October and the Guinean Coast was from June to October. The study concluded that there is clear coherency between the four regional RAIs over decal periods. Also, the monthly typology suggested that the monthly variability is very close to the annual variabilities. The regions were noted to have experienced “little”, dry and wet seasons which affected rainy and dry seasons. The study has limitations including the fact that spatial resolution is very coarse and some countries in these regions were also neglected by PC analysis. The temporal resolution seems imperfect as regions have different temporal resolutions Also, the data collected for this study were dated as far back as 1933 to 1990. Recent work and data need to be collected due to the change in climatic conditions over areas with time.

A study was conducted by Masih et al. (2014) on the evaluation and analysis of the current drought literature and data to develop a continental, regional, and country-level perspective on drought geographic and temporal variation in Africa. The review and the analysis covered drought events from 1900 to 2013. The data used in the study was drought events published in other studies, events recorded by the Centre for Research on the Epidemiology of Disasters (CRED) Emergency Events Database (EM-DAT) and the global database on the Standardized Precipitation and Evaporation Index (SPEI). The study suggested that the African continent has experienced 50 percent of the global drought events affecting 362,225799 people from 1900 to 2013. The study shows that the African continent has experienced severe and prolonged droughts in the 1970s and 1980s droughts in western Africa (Sahel), 1999–2002 drought in northwest Africa, 2001–2003 drought in southern southeastern Africa and 2010–2011 drought in eastern Africa. The study concluded that Africa is likely to experience another severe drought episode in the future and its impacts are also likely to increase due to the rapid increase in population, land degradation and pollution. Also, the study attributed the difficulty and complexity in forecasting droughts in Africa to El Niño–Southern Oscillation (ENSO) and the highly variant nature of sea surface temperature.

Analysis of drought patterns in the Tano river basin of Ghana was conducted by Narasimhan and Srinivasan (2005). The drought patterns were analyzed using the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI). The drought assessment performed using SPI was validated with RDI at 1,6,12-time scales with a regression coefficient of 0.9789, 0.9689, 0.8799 respectively. The study concluded that the north of the Tano river basin has experienced more dryness than other regions of the basin and that the north is a drought-prone area. Also, the SPI is similar to the RDI at shorter time scales. The study recommended that the water resources managers take action to restrain drought occurrence in the basin and mitigate its impacts to ensure water availability in the basin. The limitation of this study is that three communities were used to represent the entire basin and this was as a result of a sparse gauge network in the study area.

Ansah et al. (2020) did a study on the meteorological analysis on floods in Ghana. The study was carried out using two flood cases in Kumasi and Accra. The study suggested that the rainfall amount in Kumasi over the last three decades has decreased with a negative slope of 0.07 whiles the rainfall amount in Accra over the same period has increased with a positive slope of 0.45. Results from the study concluded that the flood episodes were a result of the development of thunderstorms under weak synoptic features, low Mean Sea Level Pressure (MSLP) with a higher influx of moisture into the developing thunderstorm. The study suggested that human activities like building in waterways and choked gutters were also responsible for these floods. The study recommends that further studies should be done within the country to estimate the 95th percentile of extreme rainfall. The study has limitations, including the fact that only two flood episodes were used from two communities. The rainfall patterns in the study didn't give a clear quantification of floods.

A study was conducted by Antwi-Agyei et al. (2012) to map the vulnerabilities of crop production to drought in Ghana using quantitative, multi-scale and multi-indicator analysis. Results from the study showed that the northern part of Ghana has experienced a low level of drought, and the southern part of Ghana has experienced a high level of drought. The study concluded that even though the northern part of Ghana has experienced a low level of drought, it is more vulnerable to drought than the southern part of Ghana. According to the study crops in the northern part of Ghana has a low degree of adaptive capacity. The limitations of this study are that there was no proper drought index method used to quantify what drought is. The data used in this study were dated as far back as the 20th century (1971 to 2000). New data should be used to provide a drought index for Ghana.

1.3 Problem statement

Various climate variables, such as precipitation and surface temperature, have been used in climate research studies over the years to give a wealth of evidence of climate change and variability at various Spatio-temporal scales. Floods and droughts over the years have been one major disaster affecting many lives. They are very complex and difficult to predict their occurrence. Drought for instance has no definite definition. Most of the nations in Africa are vulnerable to climatic changes since the economies of these countries are reliant on climate-sensitive crop and livestock production (Shittu et al., 2008). Farmers have had concerns about the onset, frequency, intensities and cessation of rains due to changing climatological conditions. Agriculture alone contributes 54 percent to Ghana's GDP but Ghana's Agriculture is purely traditional and mainly rain-fed (Egbadzor et al., 2013). The dependency of agriculture on rainfall has been affected due to the instability of rainfall patterns in Ghana. Water resource management over the years has been uncertain of what to expect ahead of the year whether there is going to be a flood which may cause contamination of dams or a drought which will cause scarcity of water. Natural disaster management always has to deal with crises management instead of risk management since they don't have adequate knowledge about the rainfall anomalies in Ghana. The assessment of the impact of the increase and decrease of rainfall in Ghana will provide adequate information for food security and risk management and ensure the availability of water in the country. The variabilies in rainfall which leads to floods or drought in most cases can also result in low hydroelectric power generation which in the end affects productivity and finally economic crises and food insecurity. Several studies on how rainfall anomalies affect the economy have been conducted, with an emphasis on specific places in Ghana. However, there has been very few research undertaken countrywide assessing the impacts of both floods and drought in Ghana and also how the drought and flood patterns have been over the last five decades. It has been noted that flood especially in the last decade has increased in frequency and intensities in most part of the country. This means that dams will overflow, and crops yields will be greatly affected. This makes it difficult to predict a long-term agricultural policy since rainfall patterns have changed over time. The aim of this study, therefore, is to examine the anomalies and patterns of rainfall and the impacts on the development of Ghana using monthly rainfall data sets from 22 synoptic stations of the Ghana Meteorological Agency (GMet).

1.4 Justification of study

People are far more able to withstand natural disasters if they are well-prepared. It is possible to make sure local residents are as prepared as possible to deal with the worst climate-related disasters that may come their way by understanding the global hotspots of flood and drought risk and assessing the level of risk for specific regions. This study aims to assess flood and drought episodes in some selected synoptic stations in Ghana using the rainfall anomaly index (RAI). Rainfall plays a vital role in the ecology and the hydrological cycle. Changes in the intensity, duration, amounts and frequency can be catastrophic. An increase or decrease in the amount and frequency can result in a flood or drought. Drought causes a reduction in groundwater and soil moisture which do not sustain crop and animal production. Floods also destroy properties and lead to outbreaks of diseases like cholera, diarrhoea and the like. In as much flood and drought are natural disasters, anthropogenic activities like building in waterways, deforestation, and increased emissions of heat-trapping gases can accelerate their occurrence

1.5 Main objectives

The main objective of this study is to assess flood and drought episodes in some selected synoptic stations in Ghana using the rainfall anomaly index (RAI).

1.6 Specific objectives

Specially, the study seeks to:

- Assess precipitation trends in the four agroecological zones of Ghana.
- Asses the zonal distribution of rainfall
- Assess historic droughts and floods in Ghana using RAI.

1.7 Organisation of study

The introduction, which includes the research background, problem statement, justification for the study, objectives, literature review, and thesis organisation, is Chapter 1 of this thesis. The theoretical underpinnings of floods and drought are covered in Chapter 2. A description of the research approach is included in Chapter 3. The description of the analyses and outcomes is covered in Chapter 4. The summary and conclusion of the findings are presented in Chapter 5, which also emphasises the study's contribution to Ghana's climatology.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 General overview of drought

Drought is described as "a shortage of water due to a lack of precipitation over a protracted period of time (typically a season or more)." Drought is evident in Precipitation, temperature, stream flow, ground and reservoir water levels, soil moisture, and snowpack. Drought It's a creeping phenomenon that starts out innocuously and only becomes evident when it has an impact on a region. (Hu et al., 2006). Droughts are natural occurrences, but human action, such as water consumption and management, can exacerbate them. Drought is mostly associated with high temperatures resulting in a high evaporation rate. A high evaporation rate causes a reduction in soil moisture below normal (Helfer et al., 2012). The effects of drought may include the following: low agricultural productivity, starvation, increase in cerebrospinal meningitis outbreak, water deficit and many more.

Figure 2.1: Drought causes cattles to die in Kenya. Source: (Wangai et al., 2013)

The recovery of drought in most areas takes a longer period as the drought make the land difficult to farm on for a certain number of years. Drought causes land slide and also causes the land to loss essential nutrients (Armah et al., 2011)

Figure 2.2: Aftermath effect of drought on farm land in the northern region of Ghana
Source: joynews

2.1.1 Types of drought

Drought is relative. The term “dry” means different in different regions. What is dry to a certain geographical is fair weather to another. Drought has therefore been classified based on the area it affects. Drought has been classified as follows;

2.1.1.1 Meteorological drought

Meteorological drought is when there is a decrease in the amount of rainfall for a stipulated time (day, month, season, year) below normal conditions or rainfall amount. During meteorological drought, evaporation is very high whiles rainfall amounts and frequency are quite low. Meteorological drought occurs in a specific region. This is because the conditions in the atmosphere responsible for rainfall vary from one region to the other.

2.1.1.2 Agricultural drought

Agricultural drought is a type of drought which occurs when there is a decline in soil moisture availability to plants to the point where it negatively affects crop yield and thus agricultural productivity. When available water supplies are insufficient to meet the needs of crops or livestock (Agriculture) at a specific period, agricultural drought is said to have occur. Agricultural drought may emerge from meteorological drought as a result of low precipitation, and high evaporation and as well as poor timing from farmers. This type of drought is considered the most dangerous in developing countries. Drought consequences on agriculture are determined by underlying socioeconomic and environmental vulnerabilities, crop types, and other variables.

2.1.1.3 hydrological drought

Hydrological drought occurs when there is a scarcity of water in the hydrological cycle as a result of a lack of rainfall for a longer period. This is evident in surface water, rivers, streams, reservoirs and groundwater levels. Hydrological drought can be worse in an area of increasing population. This type of drought mostly emerges from meteorological drought.

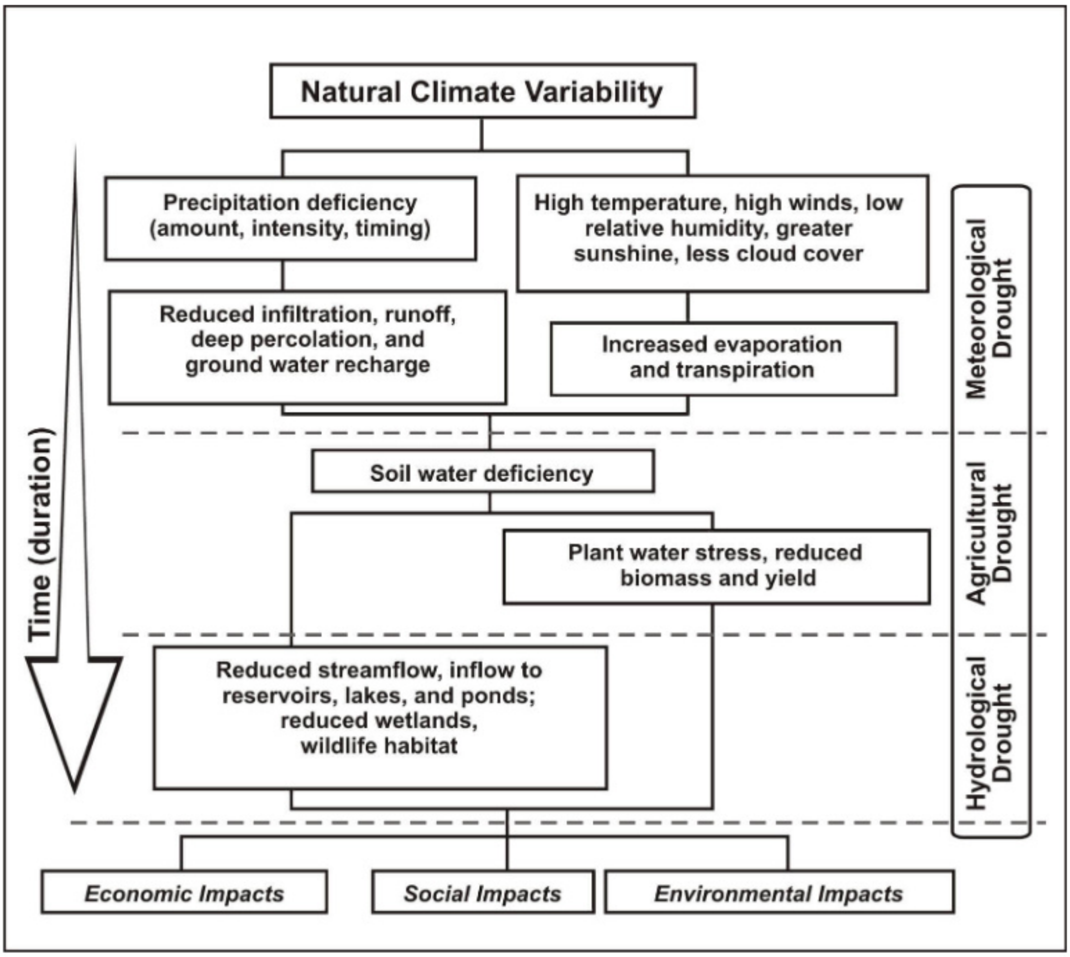

Figure 2.3: sequence of the incidence and effects of the several types of drought that are widely recognised. Every drought starts with a lack of precipitation, or a meteorological drought, but other droughts and effects follow this shortage. (source: NDMC)

2.1.2 Other causes of drought

Drought is mainly caused by a deficit in the amount of rainfall in a geographical area. When the amount of rainfall in an area is below normal or average, drought may occur. What causes the deficit in the amount of rainfall? The amount, frequency, and intensities of rainfall may be a result of the following but are not limited to

1. Land degradation and deforestation

   When trees and vegetation are lost, there is less water available to feed the water cycle, putting entire regions at risk of drought. When plants transpire, water is released into the atmosphere. This water condenses and forms clouds and later comes down as rain. When tress is cut down without replacements, there will be a reduction in the atmosphere's moisture content, which will also affect cloud formation. The same applies to the water in the land (soil). Bad land-use practices, such as intensive farming, and the building of concrete surfaces can affect soil quality and the ability of the land to absorb and retain water. As a result, soil dries out faster (perhaps causing agricultural drought) and groundwater levels drop (which can contribute to hydrological drought).

2.2 General overview of flood

According the World Meteorology Organization (WMO), a flood is the overflow of water on usually dry land. Floods can occur in practically any location. They can cover a large area with a few inches of water or deliver enough water to cover a house's roof. Floods can be detrimental to communities and can linger for days, weeks, or even months. Flooding can be exacerbated by geography. Flooding is a common occurrence around rivers, for example. Rooftops funnel rainwater to the earth below, while concrete surfaces like roads and parking lots hinder the land from absorbing the rain, putting urban regions (areas near cities) at a greater danger of flooding. it is evident how flood can be deterimental to the health of a person and also to the economy of a country. Children and women are the mostly vulnerable these flood events. Figure 2.4 shows rescue operation in hati flood that occurred in February 2022. This flood affectd many people especially children as the water rose feets above their heights.

Figure 2.4: Rescue operation in haiti flood (2022) soruce: United nations)

2.2.1 Types of floods

Unlike drought that is categorized based on the area or sector it affects, flood is categorized based on the cause. Flood is therefore categorized as follows;

2.2.1.1 Flash floods

Flash flood mostly occurs as a result of heavy rainfall. This type of flood occurs when the rate of rainfall (that is water falling from clouds) is higher than the rate at which the surface (ground) absorbs the water falling. This leads to fast rise in water levels. The rise in water levels is also relatively faster than the rate at which the ground absorbs the water. This leads to overflow of water on the ground.

2.2.1.2 River floods

River flood occurs when excessive runoff from prolonged rainfall and/or snow-melt accumulates in rivers. When this becomes consistent, the rivers may exceed their banks and overflow onto the land, leading to flooding. River.

2.2.1.3 coastal floods

As the name implies, this happens on the coastal areas and are influenced by coastal phenomena such as thunderstorms/cyclones and tsunamis. Usually, drylands along the coasts are mostly the victims of these events.

CHAPTER 3

STUDY AREA, DATA AND METHOD

This chapter begins with the description of the study area followed by the data and rainfall indices that are analyzed. It also describes the methods employed to analyze the data collected.

3.1 Study area

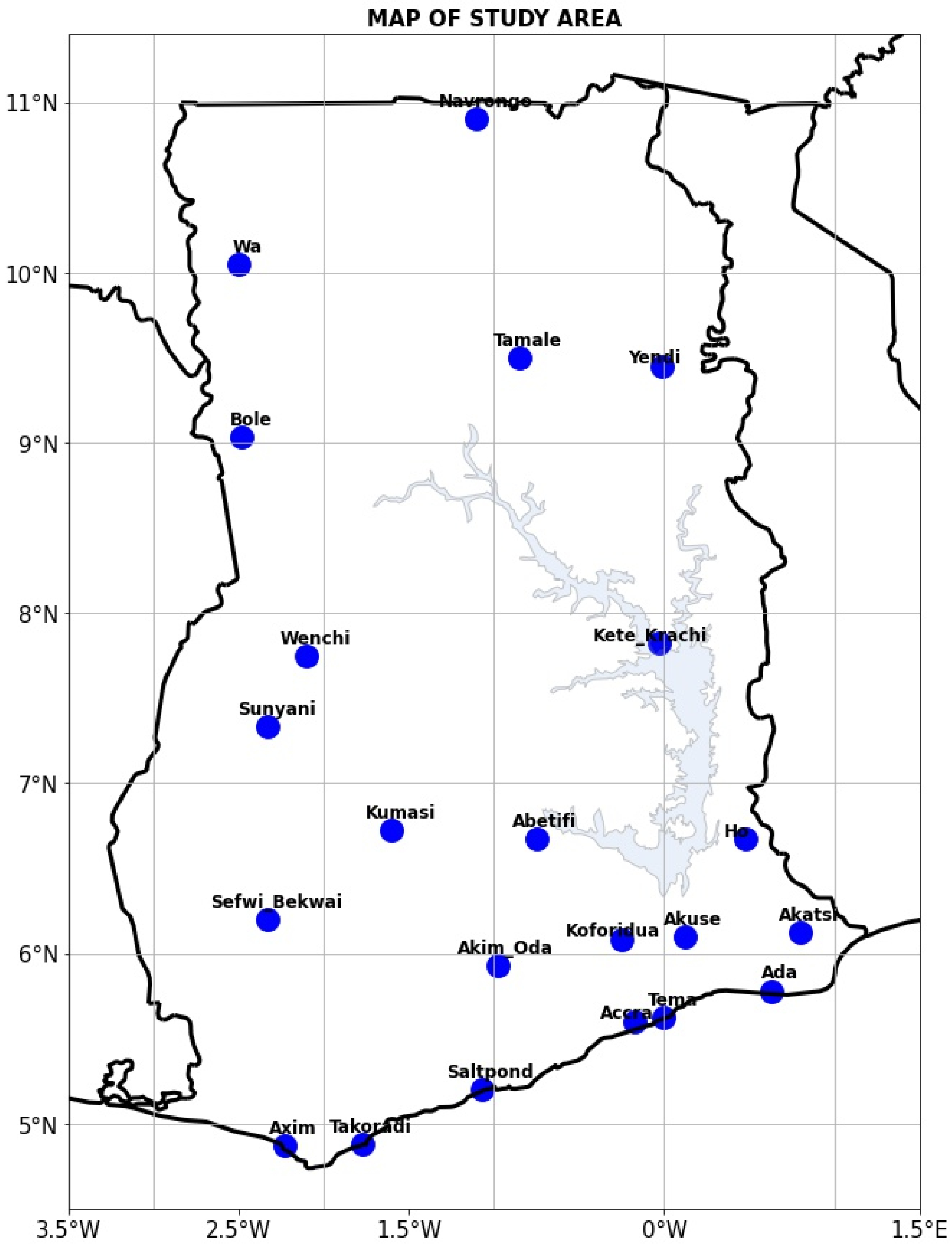

Figure 3.1: Map of the study area (Ghana) showing the locations of the twenty two synoptic stations in Ghana

Ghana is located in southwestern Africa along the Gulf of Guinea. Situated in the tropics, the area is bounded by latitudes 12 degrees north and 4 degrees north and longitudes 3.5 degrees west and 1.5 East. On the west, Ghana shares a border with Ivory Coast and Togo at the east (Ansah et al., 2020). Ghana shares boundary with Burkina Faso at the north and the Gulf of Guinea at the south. The total surface area of Ghana is about 5247845km with a total population of about thirty-one million (Brown et al., 2017). About 52 percent of Ghana's population is into agriculture and with agriculture generating to Gross Domestic Product of about 54 per cent annually. Administratively, Ghana has been divided into 16 regions with 275 districts (Antwi-Agyei et al., 2012). On its southern Atlantic Ocean coast, Ghana is home to lowlands, low hills, rivers, Lake Volta, the biggest man-made lake in the world, Dodi Island, and Bobowasi Island. Four distinct geographic ecoregions may be identified in Ghana. The majority of the coastline is low and sandy, bordered by vegetation and meadows, and it is divided by a number of rivers and streams. The northern part of Ghana has high plains. The wooded plateau region that makes up south-west and south-central Ghana is comprised of the Ashanti uplands and the Kwahu Plateau. Along Ghana's eastern international boundary lie the mountainous Akwapim-Togo ranges. The majority of south-central Ghana is covered by the Volta Basin, and Mount Afadja, which rises to a height of 885 m (2,904 ft) in the Akwapim-Togo mountains, is Ghana's highest peak. The climate is tropical and the eastern coast line is warm and fairly dry, the south-west corner of Ghana is hot and humid, and the north of Ghana is warm and rainy. Lake Volta, the world's biggest manmade lake, stretches over small portions of south-eastern Ghana and various tributary rivers such as the Oti and Afram rivers feed into it (Serra, 2014).

3.1.0.1 Climate of Ghana

Ghana is located in the tropic hence, experiences a tropical climate The country is linked with the development and movement of Mesoscale Convective Systems (MCS) (Kouassi et al., 2020). The climate of Ghana is influenced by the Inter-Tropical Discontinuity (ITD), the South Atlantic (St. Helena) and North Atlantic (Azores high) semi-permanent pressure systems. Climatologically, Ghana has two major seasons; wet and dry seasons. The dry season is the period of total dryness also known as harmattan whiles the wet season is the period of rainfall. Ghana has a further regional climate. The mechanism of the Azores high, St Helena and the ITD brings about the two seasons (Atiah et al., 2020a). The dry season comes as a result of the intensification of the Azores high. The Azores during this period intensifies whiles St. Helena relaxes pushing the ITD southwards. The Azores high pumps dry and dusty winds during this season southwards into Ghana from the Sahara. These winds are called the Northeast Trade Winds (Tropical continental). The northern parts of Ghana experience the dry season from October to mid- May The southern was experiences the dry season from late October to early March (Ansah et al., 2020) .

The wet season emerges upon the intensification of St. Helena high and the relaxation pushing the ITD northwards. During the wet season, the ITD migrates to about 20 degrees north. The intensification of the St. Helena high pumps moisture inland that aid in convective activities. The convective actives lead to cloud formation and provision necessary conditions for rainfall to occur. The country is dominated by warm and moist winds called southwest monsoon winds (Tropical Maritime) during the wet season. The country's rainfall is bimodal in the south and unimodal in the semiarid north. The major rainy season's peak on the coast is in May or June, which is substantially higher than the minor rainy season's peak, which is in late October or early November. The major dry season occurs in the boreal winter in between the minor dry season, which reaches its peak in August. The rainy season is still bi-modal further north, but the minor rainy season's peak is significantly higher and takes place in September and October. Similar to the Sahelian area, the northern section of the nation has a unimodal rainy season that peaks in August (Asante and Amuakwa-Mensah, 2014).

The Ghana Meteorology Agency (GMet), for education and forecasting and reporting purposes has further divided the country into four agro-ecological zones. The four agro-ecological zones are the Savannah, Transition, Forest and the Coastal zones. The climate of the Savannah zone is mostly the driest of the four ecological zones in Ghana and is found in the northern parts of Ghana (Atiah et al., 2020b). Its dryness is practically a result of being in close proximity to the Saharan desert. With a unimodal system of rainfall, the rainy season starts usually from May to mid-September. The Coastal and Forest zones have a very humid climate due to the Atlantic Ocean and receive the majority of rainfall in the country. With a bimodal system, a major (March to July) and a minor (September to mid-October) is experienced. The Transition zone has features and characteristics of the two moist southern zones and the dry northern zone The synoptics stations used in this study are the twenty-two synoptic stations distributed across the four agro-ecological zones in the country (Savannah, Transition, Forest and Coastal) by GMet. These stations are situated in cities/towns as follows, Accra, Wenchi, Sunyani, Kete Krachi, Yendi, Kumasi, Koforidua, Ho, Abetifi, Akatsi, Takoradi, Saltpond, Tema, Big Ada, Akuse, Sefwi-Bekwai, Axim, Akim Oda, Wa, Enchi, Akosombo, Bole.

3.2 Data description

Monthly rainfall data of spatial resolution of 0.25° ×025° spanning from 1983 to 2019 was accessed from the Global Precipitation Climatological Centre (GPCC). The Global Precipitation Climatology Center was established in 1989 and hosted by the German Meteorological Service. A global analysis of monthly precipitation based on in-situ rain gauge data at different spatial resolutions is provided by the Global Precipitation Climatology Centre (GPCC), a gauge-only rainfall product (Atiah et al., 2020a). GPCC incorporates quality-controlled data from nearly 67, 200 stations worldwide. Data from the GPCC may be used for large-scale hydrological applications, research of climatic trends and extremes, drought monitoring, and estimations of the likelihood of precipitation. Gridding gauge-analysis products are produced using the GPCC model using station data that have undergone quality control (Huffman et al., 1997). Two products are available for studying climate: the Full Data Reanalysis Product (1901–2010), which is recommended for studies of global and regional water balances, calibration/validation of remote sensing-based rainfall estimates, and verification of numerical models; and the VASClimO 50–Year Data Set, which is recommended for studies of climate variability and trend (Schneider et al., 2017). In comparison to other datasets, the GPCC is the most ideal due to the gauge-based data sets and reanalysis that provide long-term records of precipitation suitable for climate studies. The short duration of the records in satellite-related data sets is a restriction. The GPCC incorporates the global data collections from the CRU (11,800 stations), FAO (13,500 stations), and GHCN at the National Centers for Environmental Information (34,800 stations from GHCN2 and GHCN daily). It also incorporates data from international regional programmes (Becker et al., 2013).

3.3 Method of the study

3.3.1 Rainfall Anomaly Index

Rainfall Anomaly Index (RAI) was used for this study. RAI was developed by (Van Rooy, 1965). This index includes a categorized course of action to give the severities of the positive and negative anomalies. It is notable for its procedural simplicity because it requires only precipitation data to work with (Costa and Rodrigues, 2017). The RAI was developed for the purpose of monitoring droughts. The computation of the RAI involves, obtaining and standardizing the yearly precipitation departures from a long term average by dividing the standard deviation of the yearly precipitation. Since RAI fluctuates across a greater range, it is more sensitive in identifying extreme drought and wetlands (Katipoğlu et al., 2021)). RAI has been used by many researchers including Moron (1993). Moron used RAI to assess the positive and negative severities of rainfall anomalies in the Guinean and Sahelian regions of Africa. RAI concept was adopted by (Diniz-Filho et al., 2009) to analyse the climatology at the Paraiba river basin in south-east Brazil. The same concept was also employed by Costa and Rodrigues (2017) to assess the variabilities of precipitation in Alegrete for a temporal domain from 1928 to 2009. The findings from these researches, proved that RAI could be an important tool for the assessment and analysing of precipitation patterns from precipitation data. RAI was used to also analyse the climate of the Mamanguape River basin by dos Santos et al. (2015). The study concluded from the results obtained that RAI can be adopted as an alternative tool for the assessment of precipitation patterns of a region.

3.3.2 Calculation of RAI

The Rainfall Anomaly Index is calculated using equations 3.2 and 3.3. To begin with, the rainfall anomaly will have to be calculated first in order to help determine which equation to use. Rainfall anomaly is calculated by subtracting the mean of the rainfall years from the various years of the study. That is

$$Anomaly = N - \overline{N} \tag{3.1}$$

The precipitation data is arranged in either descending or ascending order. The mean of the ten highest values is computed for to form a threshold for positive anomalies and the mean of the ten lowest values is also computed for to form the negative anomalies. The mean of the precipitation for the temporal domain is also calculated. The outcome of the anomalies will be sorted and used in equations 3.2 and 3.3. Equation 3.2 will be used for positive anomalies, whiles equation 3.3 will be used for negative anomalies

$$RAI = 3\left[\frac{N - \overline{N}}{\overline{M} - \overline{N}}\right] \text{ , For positive anomalies} \tag{3.2}$$

$$RAI = -3\left[\frac{N - \overline{N}}{\overline{X} - \overline{N}}\right] \text{ , For negative anomalies} \tag{3.3}$$

Where;

N denotes monthly/yearly rainfall,

$\overline{N}$ represent mean rainfall,

$\overline{M}$ denotes the average of 10 highest rainfall (monthly/yearly) and

$\overline{X}$ is the average of 10 lowest rainfall.

Equation 3.1 represents the positive anomaly and negative anomaly based on positive or negative values ((Aryal et al., 2022). When a certain year value corresponds with the mean average, the RAI value is zero; hence, no anomaly. RAI is usually used to compare the deviation in precipitation in different regions. Table 1 displays the RAI index's level of severity. The level of severity is classified from extremely dry (values $<$ -3) to extremely humid (values $>$ 3). Python programming language was used for all the computations and visualisation in this study.

RAI Range	**Classification**
3.0 or more	Extremely wet
2.00 to 2.99	Very wet
1.0 to 1.99	Moderately wet
0.5 to 0.99	Slightly wet
0.49 to -0.49	Near normal
-0.5 to -0.99	Slightly dry
-1.0 to -1.99	Moderately dry
-2.00 to -2.99	Very dry
-3.0 or less	Extremely dry

Table 3.1: The classification of the rainfall anomaly index (RAI)

CHAPTER 4

RESULTS: ANALYSIS AND DISCUSSION

The results of the study will be shown and discussed in this chapter. The results include the rainfall analysis over Ghana, zonal rainfall patterns in Ghana, and RAI analysis in synoptic stations in Ghana. The assessment is from 1981 to 2019.

4.1 Spatial distribution of rainfall

Figure 4.1 shows the spatial distribution of mean annual rainfall over the 22 synoptic stations in Ghana. Rainfall amount increases latitudinally from north to south. Rainfall amounts also decrease towards the eastern coast. Throughout the entire country, rainfall in Ghana is high on the western- Coast where it is dominated by rain forests. The highest annual rainfall is seen in Axim with an annual rainfall amount of approximately 1600 mm and the lowest is seen at Tema on the eastern coast with an average of 800 mm each year.

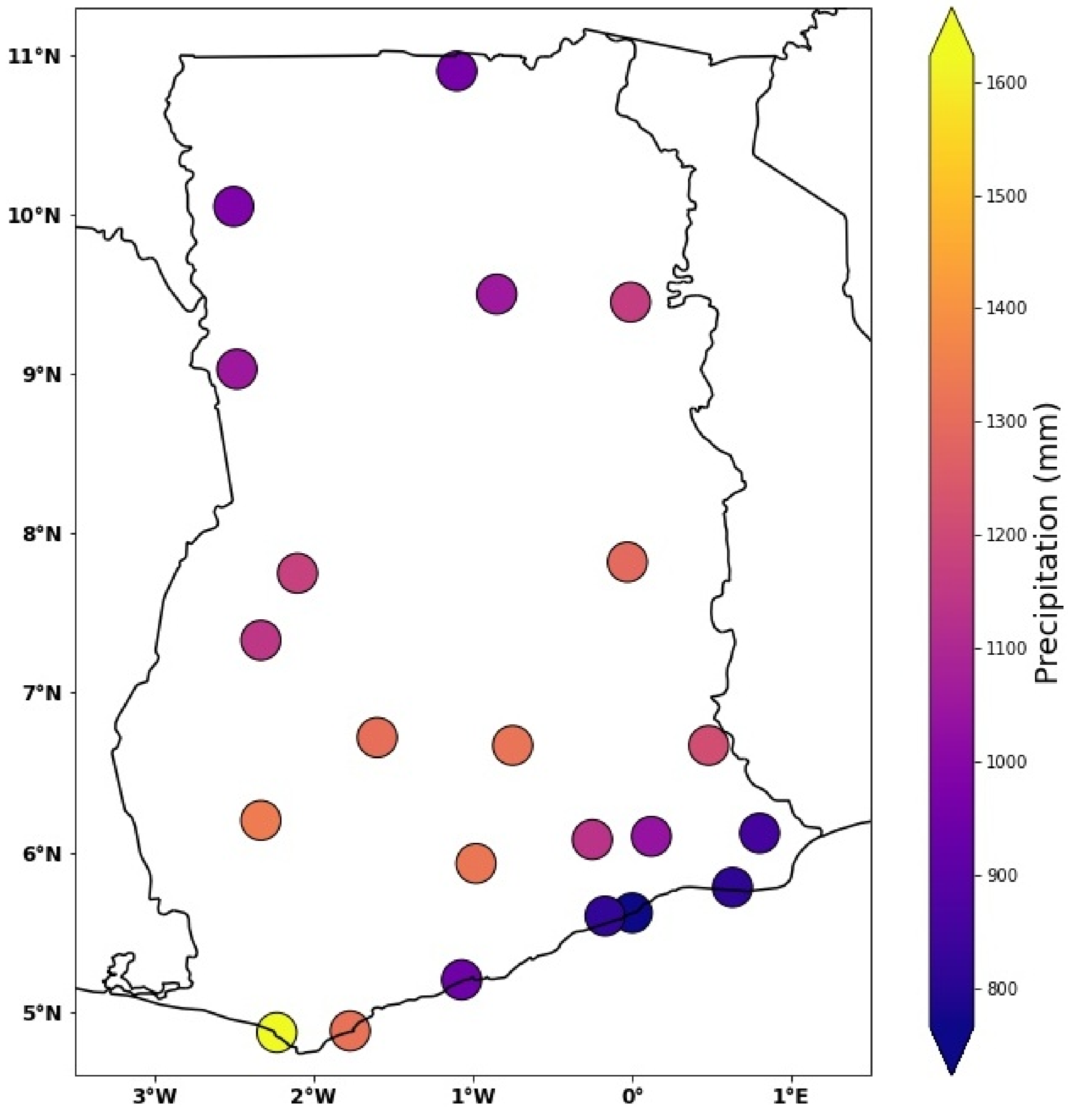

Figure 4.1: Spatial distribution of mean annual rainfall from 1981 to 2019.

4.2 Rainfall trend over the agroecological zones of Ghana

The study analysed the rainfall patterns over the agroecological zones of Ghana. Figure 4.2 shows the rainfall trend over the four agroecological zones of Ghana. Figure 4.2(a) shows the precipitation trend from 1981 to 2019. The yearly total precipitation in the northern zone for the period of study is between 766.74 mm and 1326.23 mm with an average of approximately 1044.71 mm. The lowest amount of rainfall is 766.74 mm in 1983. The region, between 2009 and 2018 received a low amount of rainfall between 800 mm and 936 mm. The highest rainfall amount recorded for the period of study is between 1326.23 mm in 1989. The rainfall trend of the Transition zone is shown in Figure 4.2(b). The transition yearly rainfall is between 888.86 mm and 1635.04 mm with an average of 1025.51 mm. The lowest amount of rainfall is 888.86 mm in 2015 and the highest rainfall amount is 1635.04 mm in 1991. The period between 2010 and 2018 was characterised by drought with precipitation below 1200 mm. Precipitation started recovering in 2018. The annual rainfall pattern of the forest zone is depicted in figure 4.2(c). The annual rainfall is between 882.78 and 1472.50 with a mean of 1194.49 mm. The lowest rainfall amount is 882.78 mm in 1983 and the highest rainfall amount is 1472.58 mm in 1999. Figure 4.2(d) show the rainfall trend in the coastal zone. The coastal zone's annual rainfall is between 592.80 mm and 1347.40 with a mean of approximately 1048.57 mm. The lowest rainfall amount is 592.80 mm in 1983 and the highest amount of rainfall is 1347.40 mm in 1971. The coastal zone just like any other zone has experienced extreme cases of both wet and dry events (episode). These results conform to the findings by Aryee et al. (2018); Baidu et al. (2017); Kyei-Mensah et al. (2019)

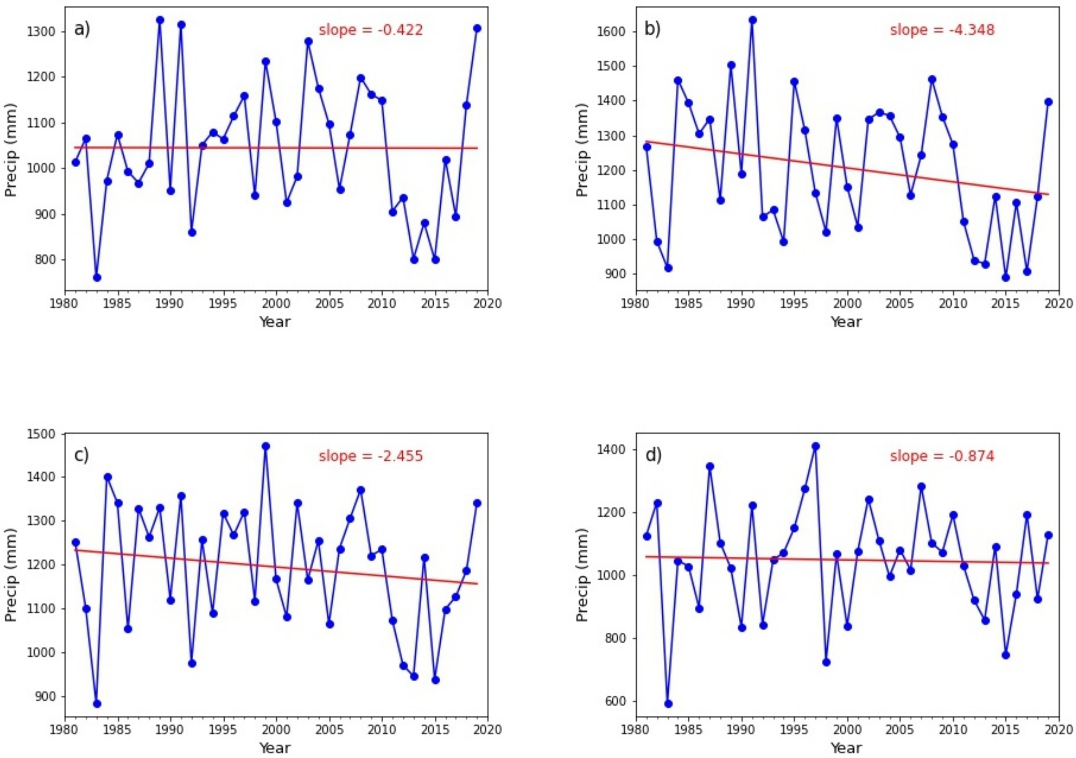

Figure 4.2: Precipitation trend over the agroecological zones of Ghana from 1981 to 2019.

4.3 Latitudinal distribution of rainfall.

Rainfall amounts vary latitudinally with months. Figure 4 shows the monthly latitudinal distribution of rainfall in Ghana. From January (month 1) to the 12th month (December), rainfall increases latitudinally. The onset of rainfall in the south is in March and progresses northward to about latitude 8 degrees and peaks in June. A break in monsoon is seen in August in the south and a peak of rainfall in the north. A minor rainy season is seen in the south in October and cessation of rains in the north. The zonal distribution of the rainfall is a result of Intertropical Discontinuity (ITD). The ITD in January is found in the south of Ghana and migrates north as the months progress. The ITD migrates to about latitude 6 degrees in March and this brings rains during this period (onset of monsoon). The ITD continues to migrate north to about latitude 8 and stays there for some time which produces rainfall southward and the peak of rainfall in June. The ITD moves northward again in July and produces rains as it moves towards the north. Rainfall ceases in the 8th month (August) in the south and peaks in the north. The ITD moves southward from September to October which produces rainfall in the south (minor rainy season). During this period, rainfall ceases in the north. Rainfall ceases in the south as the ITD migrates farther south in early December.

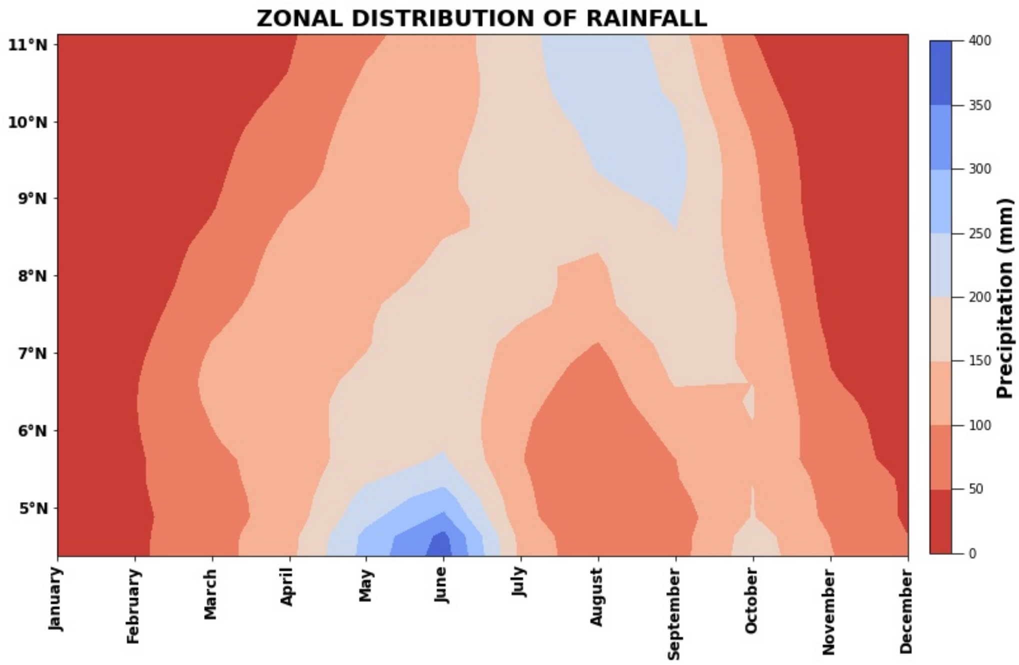

Figure 4.3: Zonal distribution of rainfall in Ghana.

4.4 Rainfall Anomaly Index

The rainfall Anomaly index was calculated for 22 synoptic stations and it's shown in Figure 4.4. The rainfall anomaly index of the northern zone was assessed using data from 5 synoptic stations namely, Navrongo, Wa, Tamale, Yendi, and Bole. Figure 5(a) shows the time series plot for the five stations in the northern zone from 1981 to 2019. The north over the years has experienced both extremely dry and humid conditions. In 1989, 1991, 2000, 2003, 2008, 2009 and 2018 and 2019, the region was characterised by extremely wet to wet conditions. The northern zone was characterised by extremely dry to dry conditions in 1983, 1990, 1992, 1998, 2001, and 2006. These drought events were also reported by (Armah et al., 2011). From 2010 to 2017 the northern zone experienced extremely dry conditions. However, there was a deviation from the mean RAI trend for Wa. Wa in 1986 experienced an extremely dry episode and extremely wet condition in 1994 and 1996. Generally, the KDE plot in figure 4.4(e) shows that most of the events were in -4 to 4 threshhold with the mean shifting slightly towards dryness. Most of the events were near normal. Figure 4.4(b) shows the RAI time series of Kete Krachi, Wenchi, Sunyani, and the mean of the Transition zone. The region in 1982 and 1983 experienced extremely dry conditions. Generally, the transition experienced extremely dry to slightly dry conditions in 1982, 1983, 1992,1993,1994, 1998, and 2001, and from 2011 to 2017, the region was characterised by extremely dry conditions. In the years, 1984, 1985, 1986, 1987, 1989, 1991, 1996, 1999, 2002, 2003, 2008, 2009, the transition experienced extremely to slight humid conditions. Kete Krachi and Wenchi however, deviated from the mean towards extremely humid conditions in 1989 and 1991. Figure 4.4(f) show KDE plot of the Transition zone. The area under the curve bounded by -4 and 4 had most events. The mean curve was observed to have peaked twice; one at -2 and the other at 2. Relatively, the density at 2 was higher than that of -2. Kete Krachi curve however, shifted towards dryness. Antwi-Agyei et al had earlier report that, Kete Krachi is a drought prone region. RAI time series for the forest zone is shown in Figure 4.4(c). The forest zone in 1982, 1983, 1986, 1991, 1992, 1994,2008, 2001, 2005, 2011 – 2013, 2015 – 2017 were characterised by extreme to slightly dry conditions. These dry conditions were reported in Antwi-Agyei et al 2012. In 1984, 1985, 1987,1988, 1991, 1995 – 1997, 1999, 2002, 2004, 2006 – 2008 and 2019, forest zone was characterised by extreme episodes of humid conditions to slightly humid conditions. Ho however in 1999, experienced the most extreme humid condition in the region. Sefwi-Bekwai also in 2011 experienced the most extreme dry conditions after 1983 for all the stations. The KDE plot of RAI in the Forest zone is shown in Figure 4.4(g). The mean of the RAI curve shows a shift towards very wet conditions. However, stations including Sefwi Bekwai and Akuse shifted slightly to dryness. The RAI time series for the coast is shown in Figure 54.4. The coast compared to the other zones has experienced less extreme episodes of dry and wet conditions in the last two decades. The coast in 1983, 1986,1990,1993, 1998, 2000,2013,2015 was characterised by dryness. The coast experienced extreme to slightly wet conditions in 1982, 1987, 1991, 1996, 1997, 2002, 2007 and 2010. From the KDE plot shown in Figure 4.4(h), the coast was observed to take a normal distribution curve pattern but the mean curve shifted slightly towards wet conditions.

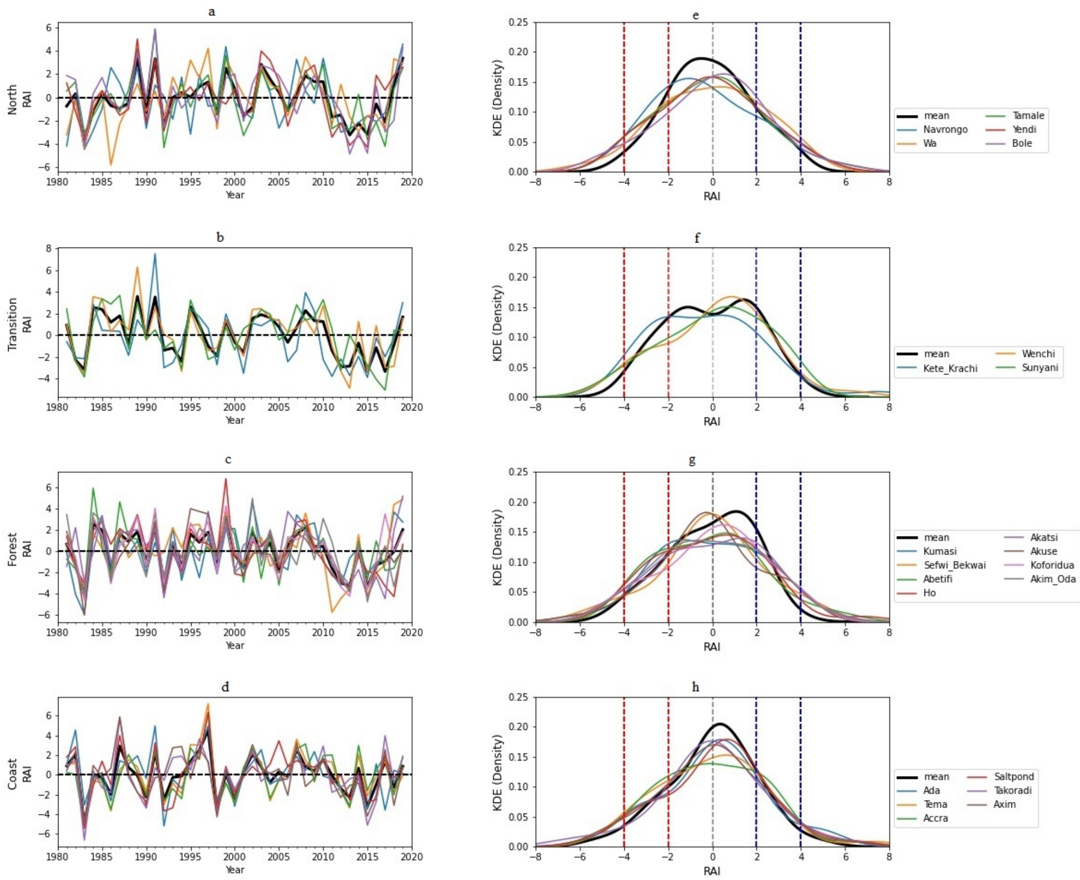

Figure 4.4: Time series (a) and KDE plot (b) over the four agroecological zones of Ghana.

4.5 Event count

According to the RAI classification by Van Rooy (1965) which was also adopted by Sadiq et al. (2020); Tume and Nyuyfoni (2021); Aryal et al. (2022), a year is characterised as a flood with RAI above or equal to 2 and a drought with RAI below or equal to -2. Figures 4.5 shows drought and 4.6 flood count in Ghana from 1981 – 2019. From Figure 4.5, the entire country has experienced at least 10 percent of drought episodes. However, Navrongo, Tamale and Yendi in the northern zone, kete Krachi in the Transition, Kumasi, Akim Oda, Ho and Abetifi in the Forest zone and Accra in the Coast has experienced more than 20 percent of all events. Sekondi synoptic station recorded the least number of drought events whilst Kete Krachi recorded the highest number of drought events. Flood events count from 1981 to 2019 is shown in Figure 4.6. At least 10 percent of the total events recorded at each station was flood. The northern zone has recorded less number of flood events of about 16 percent. The transition zone has recorded about 22 percent of flood events except for Kete Krachi which has recorded the least events of 14 percent in the transition zone. In the forest zone, the number of flood events recorded for the period of the study was between 10 to 30 percent. The highest number of events recodrd was about 24 percent in Kumasi. Ho, Akatsi and Akim Oda recorded about 20 to 22 percent of flood espisodes. The coast looks relatively dry with the highest number of flood events of about 22 percent in Accra and Axim the second higest with about 20 percent. Saltpond had the least flood events with a percentage of less than 14 percent. Generally, there is a higher frequency of drought episodes compared to flood episodes throughout the entire country with few exxecptions including Kumasi, Wechi. Sunyani, Akim Oda, Ho, Akatsi, and Accra which are relataively wetter. However, Accra in the coastal zone has recorded relatively equal drought events as floods.

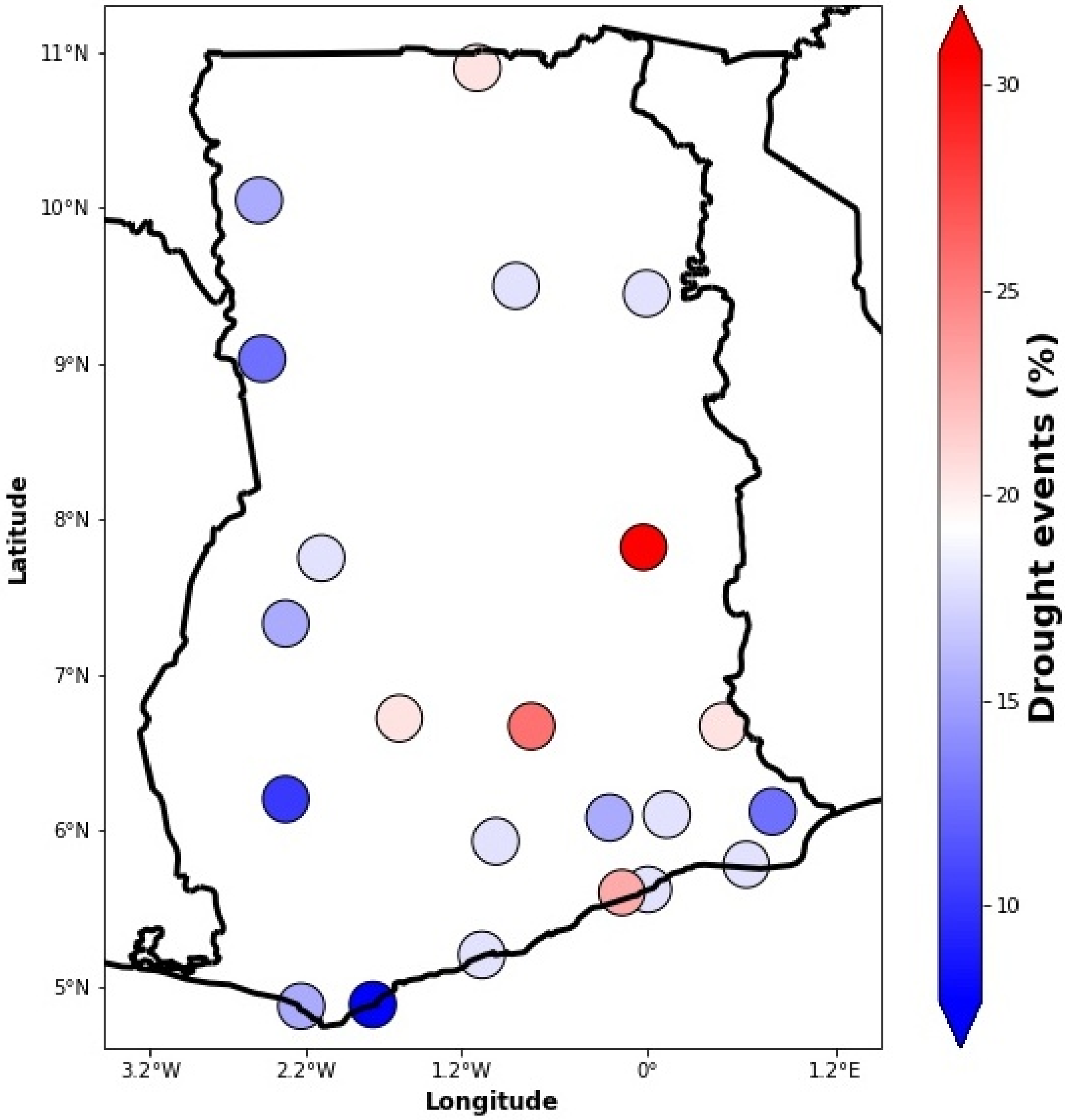

Figure 4.5: Drought event count in the 22 synoptic stations of Ghana from 1981 to 2019

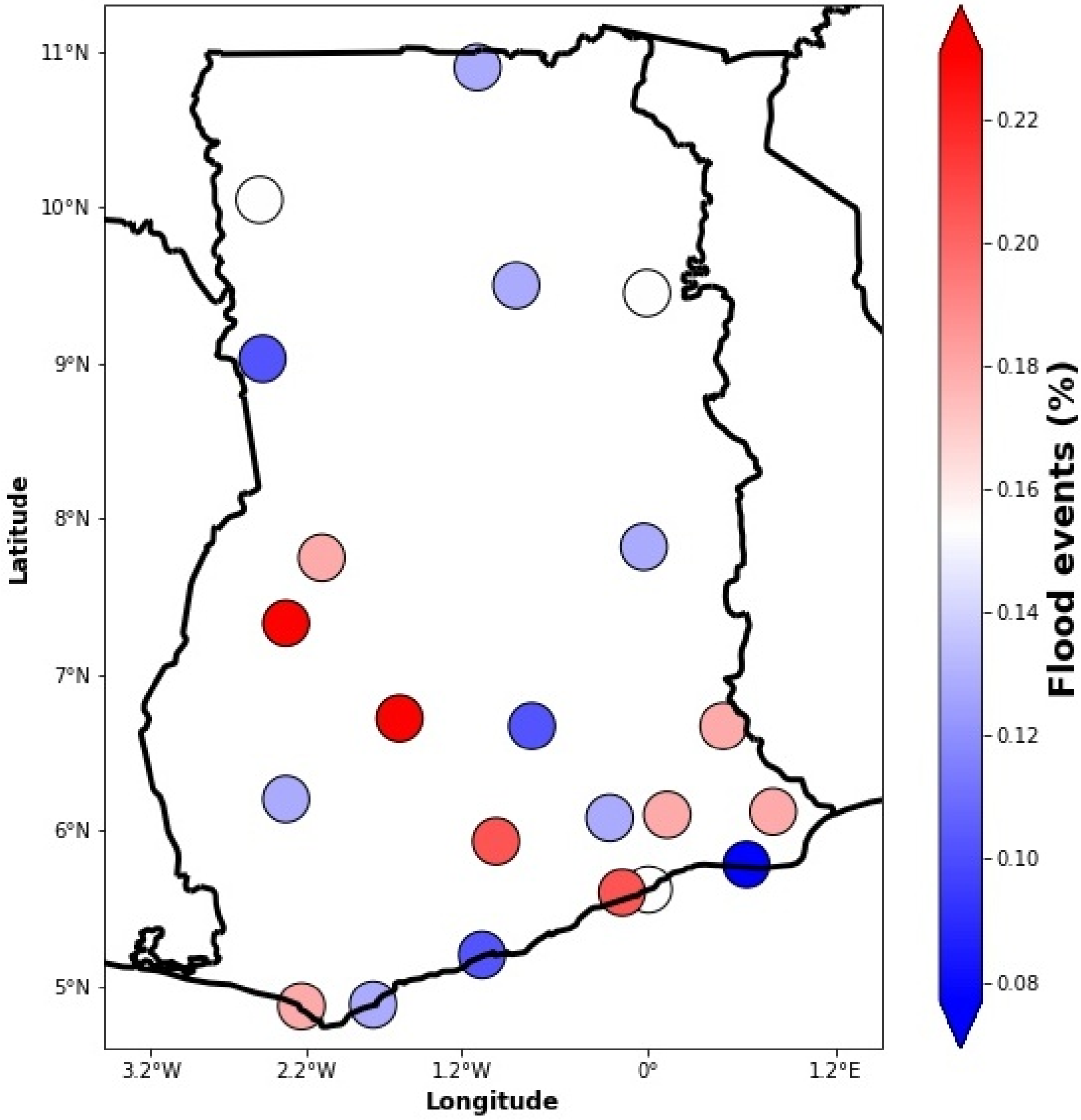

Figure 4.6: Flood event count in the 22 synoptic stations of Ghana from 1981 to 2019

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Floods and droughts from selected synoptic stations in Ghana were assessed using the Rainfall anomaly index (RAI). This study contains information about the spatial distribution of mean annual rainfall, zonal distribution of rainfall, yearly precipitation trends, yearly RAI variabilities from 1981 to 2019, Kernel Density Estimation (KDE) plots of RAI, and flood and drought events count over selected synoptic stations in Ghana. With the help of a python programming tool, and using monthly precipitation data of spatial resolution $0.25° \times 0.25°$ from 1981 to 2019 from GPCC, RAI was calculated for each year. The rainfall patterns over the entire nation was seen to be in regression across the temporal domain of the study (i.e. 1981-2019). The climate of the country shows a paradigm shift results in a negative slope for all four agro-ecological zones, although some zones are observed to be getting relatively wetter in comparison to other zones. The Transition zone has seen the greatest decrease in their total amounts of rainfall relative to their mean precipitations, preceding the Forest zone, Coast and North respectively. The pattern of precipitation in the Transition zone was observed to be deviating from it's average normal with a slope of -4.348, while the Forest, Coast and North saw slopes of -2.455, -0.874 and -0.422 respectively. From the RAI computations, Kete Krachi in the Transition Zone proved to be relatively the driest of all twenty-two (22) synoptic stations in terms of relative precipitation received over the domain of the study. This further points to our result that the Transition zone is having a very sharp negative slope towards its average precipitation. Kumasi in the Forest Zone has the highest number of flood counts nationwide.

The implications of the results obtained in this study points out to the fact that perennial flooding in major cities in Ghana, especially in Accra, are of anthropogenic cause and not entirely meteorological due to decline in the amounts of precipitation across all four zones in the country. Some anthropogenic factors that may be seen as driving forces for these floods are the predominant utilization of tarred surfaces that prevent infiltration of rain water, construction of structures and facilities in waterlogged areas that disrupts runoffs, poor sewerage and drainage systems and choked gutters, among other activities.

The climate of the forest is getting wetter. The results of the study shows frequent occurrence of very humid conditions with the highest occurrence in Kumasi. These occurrences may have been aided my mesoscale systems. The region is dominated by orography and rain forests which creates favourable conditions for the development of thunderstorms.

5.2 Recommendation

From the findings in this study, it is therefore reccomended that water resource managemnt institutions in Ghana should layout proper guidelines and good management practices to ensure water availability and sustainability for agricultural and industrial use especially in the northern Ghana where a sharp decline in precipitation trend was seen. Also with these findings, the natural disaster managements should enconde proper risk managements to mitigate the effects of theses extreme weather events.Floods and droughts are also a driving force in the incidence and distribution of diseases like malaria, cholera, cerebrospinal meningitis (CSM). It is therefore reccomended that the health decison making bodies like the World Health Organisation and the ministry of Health (MoH) should give out proper practices to ensure that there is not a surge in the incidence of these diseases.

CHAPTER 6

Appendix

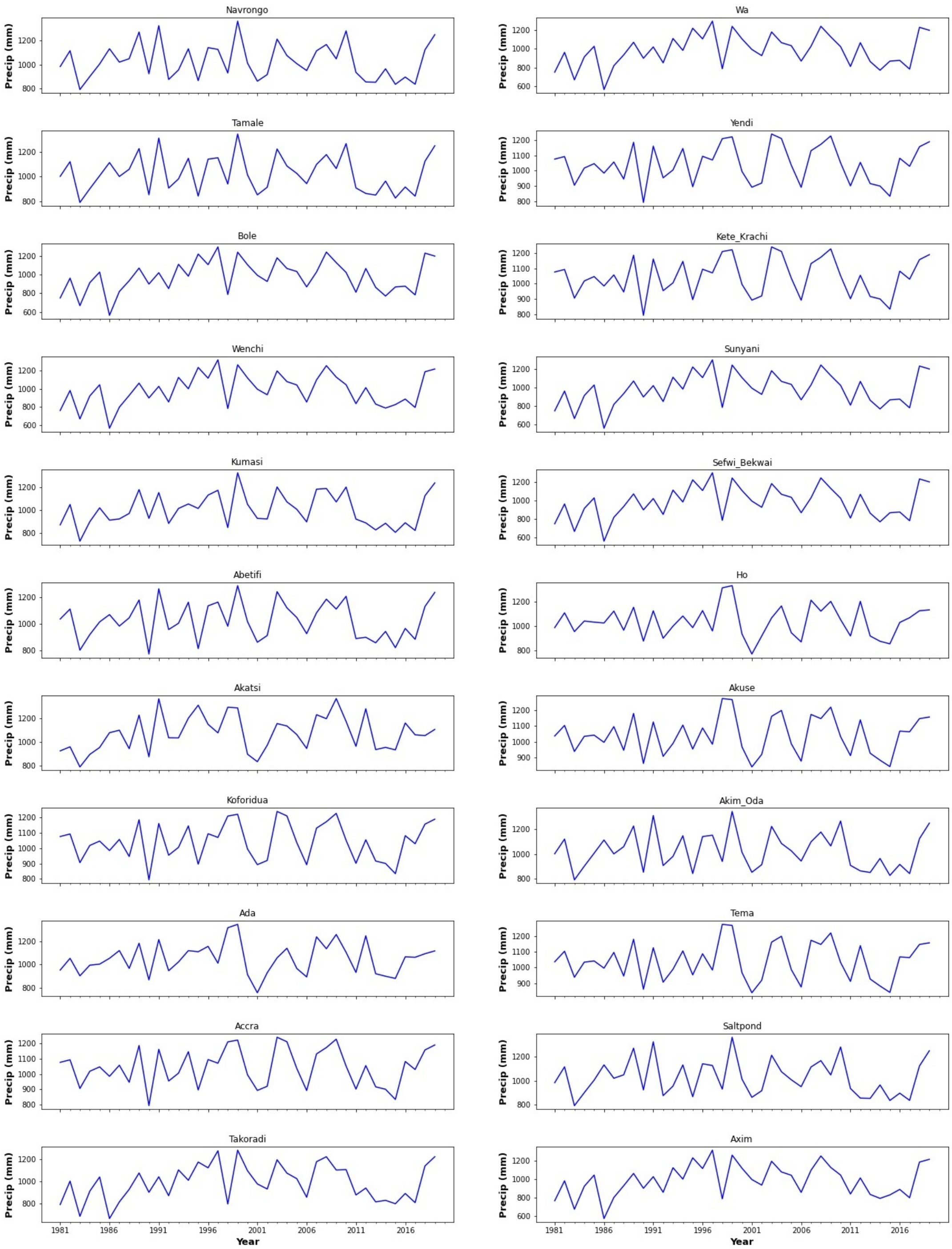

Figure 6.1: Rainfall time series for the 22 synoptic stations in Ghana from 1981 to 2019

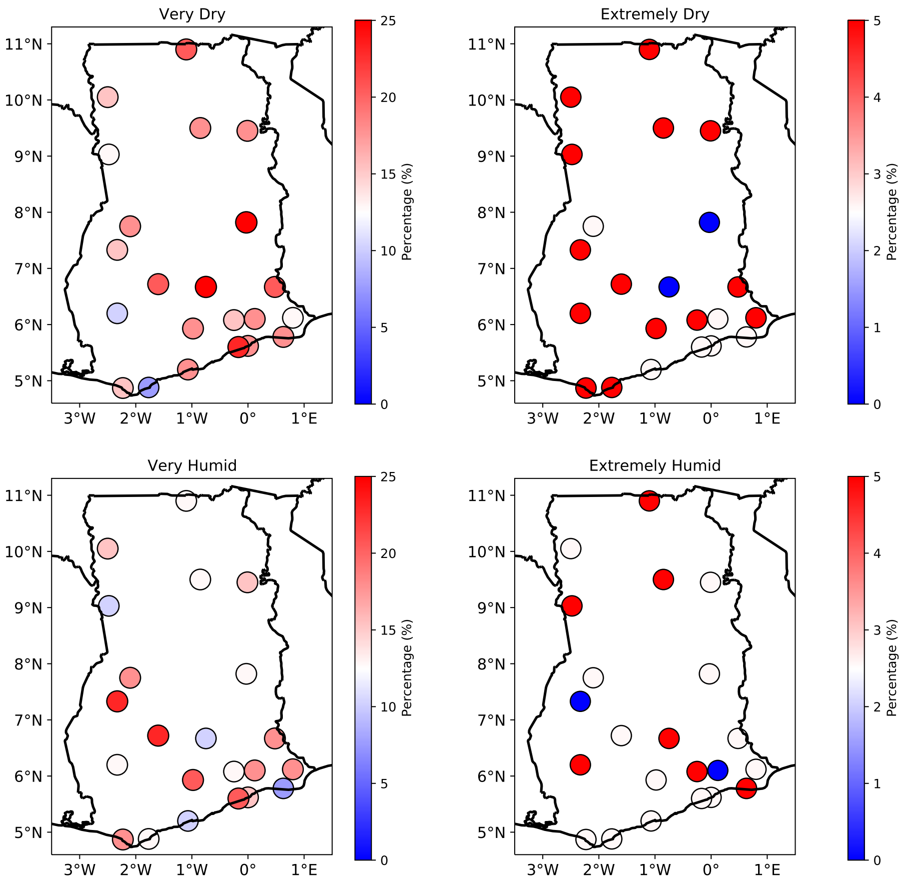

Figure 6.2: RAI event count for the 22 synoptic stations in Ghana from 1981 to 2019

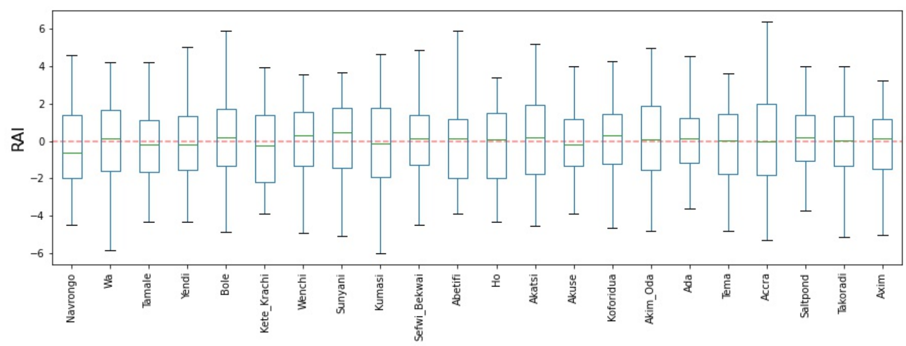

Figure 6.3: Box whisker plot of RAI for the 22 synoptic stations in Ghana from 1981 to 2019

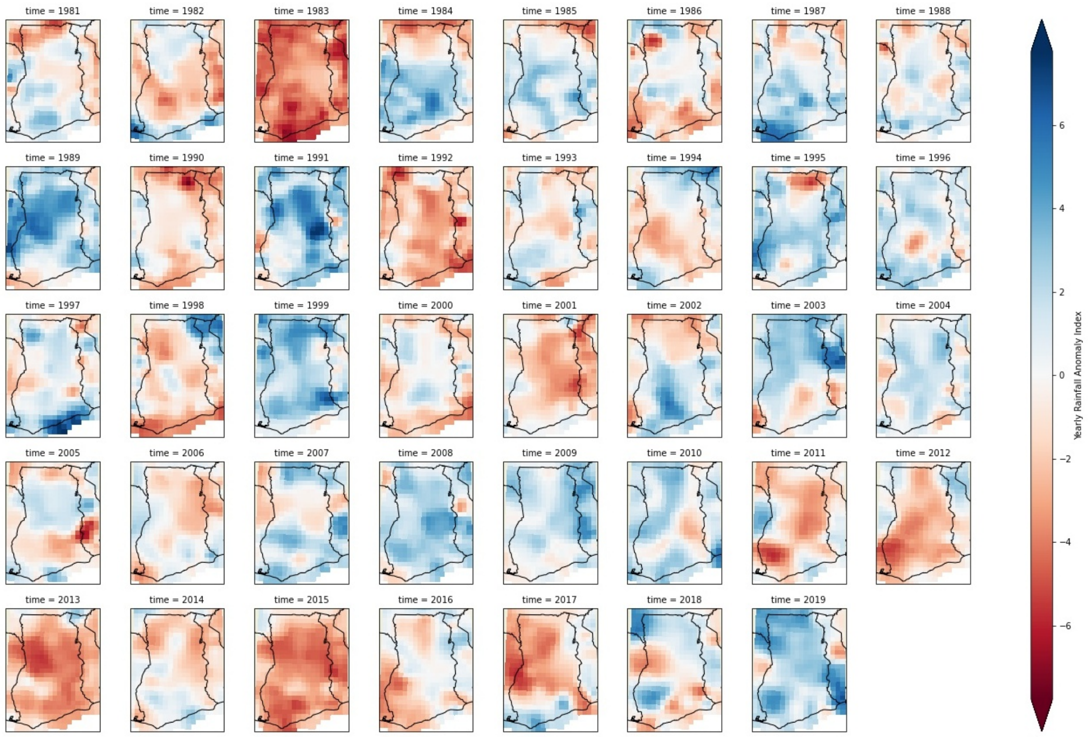

Figure 6.4: Spatiotemporal distribution of RAI in Ghana from 1981 to 2019

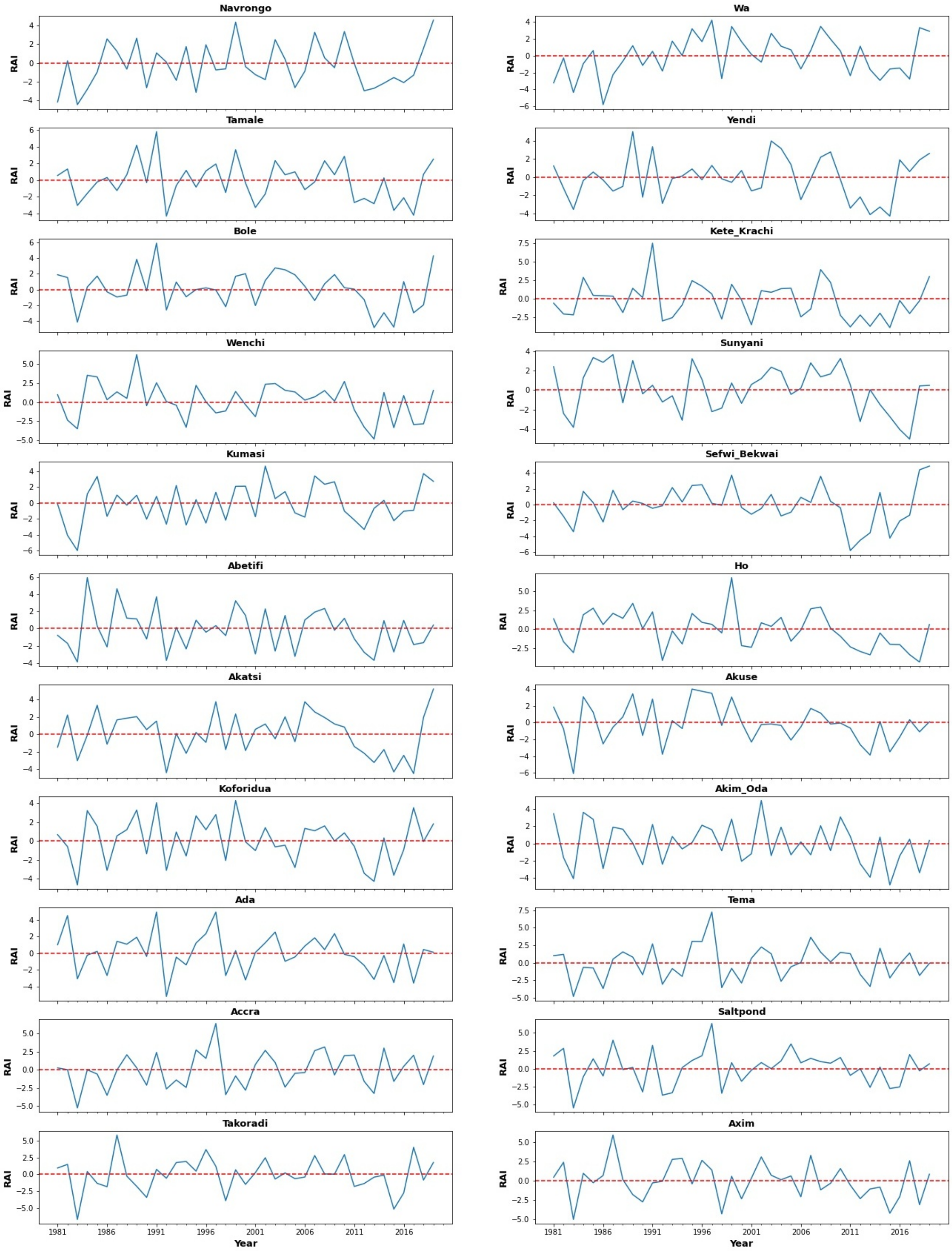

Figure 6.5: RAI time series for the 22 synoptic stations in Ghana from 1981 to 2019

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