UNIVERSITY OF CAPE COAST

DEVELOPING CLIMATE AND WEATHER INFORMATION FOR PLANNING AND DECISION MAKING FOR SMALLHOLDER FARMERS IN NORTHERN GHANA

KOFI ASARE

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BY

KOFI ASARE

Thesis submitted to the Department of Geography and Regional Planning of the Faculty of the Social Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy degree in Geography

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:.. Date: 13th December, 2023

Name: Kofi Asare

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:.................................... Date: 13th December, 2023

Name: Prof. Benjamin Kofi Nyarko

Co-Supervisor's Signature: .... Date: 13th December, 2023

Name: Prof. Nana Ama Browne Klutse

ABSTRACT

The evidence of climate change and variability and its risk to climate-dependent livelihoods is enormous. The sensitivity of rain-fed agriculture to climate demands evidence-based climate risk management by smallholder farmers. The production and access to useful climate information are imperative in building smallholder farmers' resilience and adaptive capacity. This research established the evidence of climate change, the relationship between ENSO and the climate over the North of Ghana, and produced relevant agricultural climate information useful for smallholder farmers' planning and decision-making. The study was framed on the theory of planned behaviour as its theoretical lens in guiding the presentation of the study's outcome. The climate data used spans from 1960 to 2018. This study has revealed that rainfall in the north of Ghana and the rainfall-dependent relevant agricultural information have not changed over the years but remains variable. The southern part of the study area has a spatial and temporal advantage over the northern part of the studied agriculturally relevant information. The day and night temperatures have all changed with spatial and temporal dynamics in the study area. Evaporation is increasing in the entire study area, and for some parts of the north, there is a significant increasing trend in evapotranspiration. There is a weak teleconnection between the climate of the study area and ENSO, although the correlation is relatively stronger with temperature compared to rainfall. The spatial and temporal dynamics require location-specific information for climate risk management decisions for any climate information services delivery.

KEY WORDS

Climate change

Climate variability

Climate information services

Teleconnection

Evapotranspiration

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DEDICATION

I dedicate this work to the almighty God, my Wife, my Children, and my Parents

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LIST OF ABBREVIATION

AMM	Atlantic meridional mode
CTP	Central Tropical Pacific (Nino 3.4)
ENSO	El Niño-Southern Oscillation
NOAA	National Oceanic and Atmospheric Administration
SST	Sea Surface Temperature
TSA	Tropical South Atlantic
WMO	World Meteorological Organization

CHAPTER ONE

INTRODUCTION

Background to the study

The world's climate is changing and it is no longer a future event and it will continue to change (WMO, 2016; Howden et al., 2007). The worth of evidence as depicted in the various IPCC reports (Pachauri et al., 2014; Pachauri & IPCC, 2008; Pachauri & IPCC, 2007) cannot be ignored if we are determined to achieve the sustainable development goals (SDGs). Climate change has taken centre stage in the development agenda of both developed and developing countries (Owusu et al., 2016). Climate change has taken center stage because of the implications and the risk it poses to humanity.

The 4th Assessment Report of the IPCC confirms that African countries are likely to suffer most from the negative impacts of climate change since African countries have the least capacity to adapt to the impacts of climate change (Pachauri et al., 2014; Pachauri & IPCC, 2008). Africa's vulnerability is heightened because most of the economies in this region rely mainly on natural resources and rain-fed agriculture, which are very sensitive to climate change and variability (Pereira, 2017; Olayide et al., 2018). The adverse effect of climate change is particularly devastating in Sub-Saharan Africa (Barrett et al., 2021; Owusu et al., 2020; Sultan & Gaetani, 2016; Codjoe et al., 2020). This is in part attributed to declining precipitation levels, increasing temperatures, low adaptive capacity, high dependence on natural resources, inability to detect the occurrence of extreme hydrological and meteorological events due to low technology adoption (Kurukulasuriya & Mendelsohn, 2006), limited infrastructure, illiteracy, lack of skills, low management capabilities, weak institutions, and information (UNFCCC, 2007). Without taking actions to adapt to climate change, it is imminently going to be a good recipe for failing to achieve the SDGs.

Climate Change has very great significance for sustainable development plans, life, and livelihoods in Ghana. Climate Change is regarded generally in Ghana as a development issue. However, diversity in agro-climatic regions across the country from savannah grassland to tropical rainforest with varying degrees of temporal variability makes climate change discussions challenging. It underscores the necessity for placing a premium on climate concerns in development planning for the long-term achievement of Ghana's development goals as set out in the Growth and Poverty Reduction Strategy (GPRS) and the Sustainable Development Goals (SDGs).

Climate Change adversely affects poor Ghanaians, affecting their health and livelihoods and thereby undermining the growth opportunities that are key to poverty reduction (Leichenko et al., 2014). Climate Change will further aggravate water stress, endanger food security, increase impacts from extreme weather events, and displace many. Floods, droughts, and sea level rise will significantly increase the transmission of vector and water-borne diseases in the country (Pachauri et al., 2014). Impacts of Climate Change appear to be geographically specific, based on local climate and natural resource base of ecological zones, yet they engender pervasive and increased vulnerability due to their linkages with many of the activities that sustain the livelihoods of the people especially poor people. Climate change and variability have threatened the basic elements of life such as food production and security. Ghana is vulnerable to the adverse effects of climate change because Ghana lacks the adaptive capacity to address socio economic and environmental costs emanating from climate change (Asante & Amuakwa-Mensah, 2014).

Agriculture is very sensitive to climate change and variability (Barrett et al., 2021; Nyadzi et al., 2019; Howden et al., 2007). Climatic factors influence greatly crop yields (Nyadzi et al., 2019; Yengoh et al., 2010; Garrett et al., 2013). Farmers are faced with a varied changing context which makes decision making a difficult task (Barrett et al., 2021; Bowler, 2014). An improvement in the agriculture sector will lead to an improvement in the livelihood of the people (Irz et al., 2001). A threat to the agricultural sector is a threat to the people, their livelihood and sustenance, and the achievement of the sustainable development goals (Bessah et al., 2021).

The contribution of the agricultural sector to the Ghanaian economy cannot be over emphasised. Agriculture contributes 30.2% of export earnings to Ghana's GDP (MOFA, 2010), the biggest contributor to GDP (Owusu, 2016) and it’s a backbone to the Ghanaian economy (World Bank, 2018). Farmers form 44.7% of the working population in Ghana (MOFA, 2016). About 39% of the farm labour force are women. Farming in Ghana is basically rain-fed, smallholding, and mostly traditional (Bessah et al., 2021; Abbam et al., 2018; Owusu, 2016) with only 3.44% of cultivated land under irrigation (MOFA, 2016). At the same time, it provides about 80% of the food needs of the country (MOFA, 2016). Climate change has introduced uncertainties over the livelihood of communities engaged in farming who practice rain-fed agriculture in Ghana (Asante & Amuakwa-Mensah, 2014). A threat to the agricultural sector is a threat to the people, their livelihood, and sustenance (Owusu, 2016). It is therefore prudent to consider coping and adaptation strategies that will make agriculture and other activities less vulnerable to the effects of climate change and variability.

Climate and weather information tailored to meet the needs of farmers for planning and decision making is critical in building the adaptive capacity (Perez-Teran et al., 2015) of farmers towards food production, security, improved livelihoods, and development. Access to climate information can help farmers to manage their climate risk based on evidence, improve decision-making, and adapt to climate change (Hansen et al., 2019; Nyadzi et al., 2019; Vaughan et al., 2019). Farmers can no longer ignore climate and weather information in their farming activities. The need for climate and weather information before, during, and at the end of the season is now compelling for climate risk management (Barrett et al., 2021). Agriculture in our current dispensation where climate change and variability are eminent, requires the combination of simultaneous and staged decisions about several issues regarding crop and seed selection, nutrient inputs, planting and harvesting timing, crop insurance, and land management practices (Prokopy et al., 2013; Hollinger 2009; Stone and Meinke, 2006). Farmers make agronomic decisions through planting (including choice of crop type, planting density and date, and planting scale), growing season decisions (irrigation, application of pesticides and fertilizers), harvest decisions (including harvest date), and economic decisions (crop insurance, optimizing costs) which are all dependent on climate and weatherinformation (Sharifzadeh et al., 2012; Hussain et al., 2010).

Promoting sustainable development, productivity, and efficiency in the agricultural sector will require the utilization of appropriate climate information (Sharifzadeh et al., 2012). Relevant climate information for agriculture is considered a major production variable affecting crop yields (Harrison & Williams, 2007). For example, drought is a major limiting factor to crop production worldwide (Pasban, 2009). Farmers depend on climate information, like the onset of the season, seasonal rainfall total, the length of the growing season, etc, (Troccoli et al., 2008) for planning and decision making. This makes the provision of this information very important for planning and decision making. The weather and climate information will have implications on the farmers' decision making. The use of climate information in agriculture has the potential to increase profitability and sustainability if farmers match farm management decisions to expected climatic conditions. This will reduce losses and maximize production (Barrett et al., 2021; Stern & Easterling 1999).

Rainfall, Temperature, and other climatic variables will only be useful unless they have been transformed into useful information relevant to farmers. A comprehensive analysis of rainfall data is of great importance in agricultural planning and decision making. Rainfall is the only non-cash input responsible for maximum crop yield (Hussain et al., 2010). Analyzing historical climate data and production of climate and weather information may have absolutely no value unless they can change key management decisions (Stone & Meinke, 2006). The acute sensitivity of agriculture to climate will demand timely, location-specific, accurate, accessible, and understandable climate information for evidence-based decision making by smallholder farmers in their farm management decision (Owusu et al., 2020; Singh et al., 2018; Niang et al., 2014).

Statement Of The Problem

Across the tropics, smallholder farmers were already facing numerous risks to agricultural production before climate change became a critical issue. Climate change is expected to affect smallholder farmers and make their livelihoods even more unstable (Harvey et al., 2014). Smallholder farmers constitute a significant portion of the world's population, with an estimated 450–500 million smallholder farmers worldwide, representing 85% of the world's farms (Nagayets, 2005). Smallholder farmers are also estimated to represent half of the hungry worldwide and probably three-quarters of the hungry in Africa (Harvey et al., 2014).

Climate-related risks pose serious threats to our social and ecological systems (Lemos et al., 2012). Climate change and variability is a threat to food production and security and ending hunger. It is a threat to achieving the Sustainable Development Goals (Sanfo et al., 2014). Agriculture in Ghana is being threatened by climate change (Naab et al., 2019). A lower agricultural production in Northern Ghana as a result of climate change will have repercussions on food prices which has a linked effect on the livelihood of the farmers. (Chijioke et. al., 2011).

Northern Ghana is very sensitive and vulnerable to climate change and variability. This region has been affected by exceptionally long dry spells and the farmers in this region practice rain-fed agriculture (FAO, 2016; Yengoh et al., 2010). Northern Ghana is the poorest of all the regions with poverty levels lingering between 52-88% (Yengoh et al., 2010; FAO, 2007). Most studies in Northern Ghana have focused on seasonal rainfall total, vulnerability assessment (Acheampong et al., 2014), perceptions on climate change (Nyadzi, 2016) etc. Unfortunately, studies of users of relevant agricultural climate information have revealed that the information of most interest to the farmers is not annual rainfall totals but the start and end dates of the wet season, length of the season, and other relevant agricultural information (Ingram et al., 2002; Ziervogel & Calder, 2003; Kniveton, et al., 2009). In spite of the high variability in rainfall distribution in this region, farmers are not able to access quality climate and weather information (Bessah et al., 2021). Again, farmers are unable to relate rainfall patterns to their local environment and also make informed decisions, especially on the choice of crops and varieties, when to plant, and detailed management within seasons. Historical information on rainfall amounts and distribution, start, end, and length of the season, number of rainy days, drought, etc. have not been available to farmers but are needed by farmers (Nyadzi et al., 2019) and prevent them from making informed decisions before the commencement of the farming season. The lack of access to relevant climate information will impair smallholder farmers' resilience and adaptive capacity (Bessah et al., 2021).

There is a gap this study seeks to fill as identified in the existing literature and that is:

1. To affirm or deny the evidence of climate change (rainfall – annual totals, seasonal cycle, climatological comparison, rainy days, heavy rainfall events, temperature – annual mean, seasonal cycle, climatological comparism) over the North of Ghana based on data (Nyatuame et al., 2014).
2. To provide evidence of the need for location-specific agriculturally relevant climate information and assess their characteristics under climate change
3. To examine the relationship between remote climate indices and the climate of the study area.
4. There is a lack of research on evapotranspiration in the study area although evapotranspiration is an important component of agriculture.

Mase & Prokopy (2014) have reported that most research has focused on the seasonal forecast at the expense of other sources of climate information and recommended that this gap should be filled. The problem of studying climate information at the regional level and using data sets other than gauge data is good but does not offer the very best results. The various sources of climate data for the provision of climate information do not stand the accuracy that gauge data sets offer because of inherent biases (Fitzpatrick et al., 2015). Again, climate change is a global phenomenon, and that, what may be experienced at the local level may not be the same as the global picture (Nyatuame et al., 2014). This indeed forms the basis of this work by transforming gauge data into useful information for decision making by smallholder farmers. Using the local conditions and gauge datasets allows for customization of the climatology of the area of interest (Marteau et al., 2011). In addition, using gauge data from one to five stations (Mensah et al., 2016 ; Amekudzi et al., 2015; Yengoh et al., 2010) to represent a vast area will lead to missing a lot of details which will be good sources for informed decision making and policy formulation and implementation at the local level. Few studies have considered the rainfall and temperature pattern in the north of Ghana (Nyatuame et al., 2014; Kabo-Bah et al., 2016; Boansi et al., 2017; Nkrumah et al., 2014). The majority of these studies above concentrated on specific areas of interest (Asare-Nuamah & Botchway, 2019) without any study on trends and characteristics of evapotranspiration an important component of agriculture and the hydrological cycle. The need to possibly capture more details will require using more data sets. Further, the use of historical climate information for most approaches offering climate information to farmers has been neglected and such approaches mostly start with the seasonal forecast. However, the past can guide farmers into the future. Focusing only on seasonal forecasting is not enough since historical climate data is rich with useful information for decision making.

Limited studies exist in literature over the study area using data from 11 stations that have considered together the state of the climate of Northern Ghana in relation to the trend of relevant agricultural climate information and have used geospatial techniques to interpolate for spatial temporal display. There is a dearth of literature on evapotranspiration over the study area, an important variable for agriculture and the hydrological cycle. Further, there are scanty records of studies assessing the climatological cycle of rainfall, temperature, and evapotranspiration of the study area. Again, there is a lack of studies examining the teleconnection between the climate of the north of Ghana and remote climate indices.

The climate of the North of Ghana will be assessed to confirm whether there is climate change using relevant statistical tests. Gauge data sets will be transformed into useful climate information for use by smallholder farmers. A comprehensive analysis of useful climate information for decision making by farmers in the context of the climatology of the North of Ghana will be conducted. The study will not only consider the onset, cessation, and length of the season but also seasonal rainfall totals, evapotranspiration, rainy days, heavy rainfall totals, seasonal cycles, and longest dry spells. etc. Statistical significance test will be conducted to affirm trends and also determine their significance for the purposes of informing decision making and policy.

This study was conceived based on the challenges the Ghanaian smallholder farmer faces in the era of climate change and variability where climate and weather information is most critical but are not available and accessible to these farmers for planning and decision making. This study seeks to fill the gaps indicated above. In addition, it will seek to increase the number of stations (at least ten) that will be used in the study, with the main aim of capturing more details. Also, the climatology of the North of Ghana will be factored in the definition of the various climate information that will be derived from the rainfall and temperature data. Also, the datasets that will be used in the analysis will be subjected to rigorous quality control checks to avoid any influence besides climatic factors.

Addressing the identified gaps is essential in managing climate risks based on evidence and building the resilience and adaptive capacity of smallholder farmers. Again, it will provide scientific information for evidence-based policy formulation and decision making toward the achievement of the Sustainable Development Goals.

Purpose of the study

Main Objective

The main objective of this research is to establish the evidence of climate change and produce agriculturally relevant climate information useful for planning and decision making by smallholder farmers of Northern Ghana.

Specific objectives

The specific objectives of the study are to:

- Assess the state of the climate of the north of Ghana to ascertain long term changes
- Produce agriculturally relevant climate information and assess their trends
- Assess the relationship between remote climate indices and climate variables
- Examine the state and trends of evapotranspiration in the study area

Research Questions

The research will seek to answer these questions:

1. Has the climate of the north of Ghana changed and in what ways has it changed?
2. In what ways is the changing climate expressed in the agriculturally relevant climate information?
3. What relationship exists between ENSO and the climate of the north of Ghana?

Significance of study

Providing relevant climate and weather information to farmers will enable farmers to make well-informed, targeted, and sustainable strategies for climate change adaptation. Farmers must be provided with credible scientific evidence-based information to manage their climate-related risk. Climate change evidence of Northern Ghana is quite general. There is the likelihood to miss certain details that may be specific to a particular location.

Provision of climate and weather information is what has been prescribed by scientists but not based on farmer needs. There is not enough detailed analysis of relevant agricultural information useful by farmers for planning and decision making for the study area. In addition, you will hardly find any information on evapotranspiration a critical variable for agriculture and hydrology over the north of Ghana. Studies that have been conducted on the perception of climate change in the study area have been general and not specific to relevant agricultural analysis.

No spatial assessment has been conducted on climate and weather information for planning and decision making. There is currently not enough comprehensive study on relevant agricultural information for planning and decision making, and climate projection. Studies like (Giesen et al., 2010) based their analysis of the onset and cessation of the season on farmers' perception but not on historical rainfall data. Again (Yengoh et al., 2010) used data from two stations and their study was limited to the Tamale municipality. This study however seeks to use data from at least 11 gauge stations spread across the entire North of Ghana and conduct analysis on about eight different variables. Studies on evapotranspiration over the north of Ghana are limited. Authors usually assume that there is climate change in Northern Ghana but this study seeks to use historical climate information to determine climate change and variability or otherwise, not only for rainfall and temperature but also for the agriculturally relevant climate information and evapotranspiration.

The current study seeks to fill the gaps enumerated above by producing research outcomes that will provide evidence-basedinformation that will help smallholder farmers and other stakeholders to manage their climate risk. The outcome of this study will help Ghana in achieving the Sustainable Development Goals to end hunger, eradicate poverty, gender equality, achieve food security, improve nutrition, and promote sustainable agriculture. The findings from this research will be useful to farmers, relevant governmental agencies, development and non-governmental agencies, policymakers, and international organizations for policy, planning, and decision making. The study will provide relevant information to build the adaptive capacity and resilience of farmers. Policymakers will use the outcome of this study to develop short-term, medium-term, and long-term adaptation strategies for smallholder farmers. The results will contribute to the existing empirical knowledge and intellectual discourse on relevant agricultural climate information useful for farmers and also provide useful information for drought management by policymakers and researchers.

Delimitation of the study

The focus of this study is on establishing the current state of the climate of north of Ghana using historical data, transforming the data into agriculturally relevant information for climate risk management for the smallholder farmer, and further assessing the teleconnection between remote climate indices and the climate of the north of Ghana. This study evaluated these climate variables in the context of the changing and variable climate without considering the causes of climate change and variability being experienced in the study area.

Limitation of the study

The study used the positivist approach and did not engage farmers directly on the kind of relevant agricultural climate information that may be useful to them. However, there was an extensive review of literature in arriving at the selected relevant information presented by this study. A direct interaction with farmers may have enriched the outcome of this work. In addition, the study relied on IDW interpolation method in presenting the spatial and temporal pattern of the selected relevant agricultural information. This was necessitated by the limited number of weather stations in the study area with quality data meeting the criteria used in selecting weather stations for this study. The interpolation method used may not have given the true reflection of the actual spatial and temporal patterns because of the inherent assumptions of these interpolation techniques.

Organization of the study

This study is organized into eight chapters. Chapter one provides background to the study, defines the problem being addressed, highlights the study's objectives, and indicates the critical research questions the study answered. Further, the chapter provided the significance of the study, ethical consideration, delimitation, limitation, and organization. Chapter two of this research presents an empirical review of the literature and conceptual debates on the perception and the use of climate information. The review focused on the concept of climate change and variability, climate change and variability impacts on food production, farmers' perception of climate change, relevant climate information useful for agriculture, ENSO cycle, and rainfall patterns. The chapter also reviewed empirical studies related to the major themes of the study. The review was beneficial in identifying gaps this study filled. The research approach and methodology are presented in chapter three of this study. Chapter three focused on detailing the research philosophy, approach and design, and the study area. This was followed by the description of the data and source of data used for the study. The statistical techniques used in this research and methods used for data formatting and analysis are presented in this chapter. Chapters four, five, and six were dedicated to presenting the results according to the objectives of this thesis. The fourth chapter focused on establishing the state of the climate of the north of Ghana, while the fifth chapter focused on the agriculturally relevant climate information for climate risk management. The sixth chapter assessed the teleconnection between the remote climate indices and the climate of the north of Ghana. Chapter seven of the thesis presents and discusses the study results and relates the results to empirical findings available in the literature to affirm the findings or otherwise. The eighth and last chapter of this thesis presented the summary of the findings, their implications for policy formulation, the recommendation for further research, and how this thesis contributes to knowledge.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter presents relevant information and existing knowledge of the subject under study. While presenting what currently exists, it identifies existing gaps to situate this study in a useful context.

Climate change and variability

Risk related to climate change and variability poses daunting threats to the management of a broad range of social, economic, and ecological systems (Lemos et al., 2012). The focus of climate change in recent years has shifted from querying whether the climate has changed to an important issue of how society can manage the unavoidable to avoid the unmanageable (Bierbaum et al., 2013). Overcoming the threats posed by the changing climate requires policy-making and management decisions actively informed by scientific knowledge (Lemos et al., 2012).

Climate change has taken center stage of topical issues across the globe. The cause of the change in climate has been attributed to the emission of Greenhouse gases (Asante & Amuakwa-Mensah, 2014). There is also consensus from various scientific evidence that the changes are as a results of human activities (Pachauri et al., 2014; Van de Giesen et al., 2010). The change and variability will continue (WMO, 2016) and that is the more reason why measures have to be taken to avert impacts that may emanate as a result of climate change and variability. The worth of evidence as depicted in the various IPCC reports is compelling to be ignored. The IPCC fifth assessment report has suggested an increase in extreme weather and climate phenomenon such as drought, flood etc. in the world (Pachauri et al., 2014). Imbedded in the changing and variable climate is a wide range of uncertainties that sometimes obscures the direction and magnitude of change (Vermeulen et al., 2012). Climate change will amplify existing risks and beyond that new risks will also emerge (Pachauri et al., 2014). The impacts of climate change and variability will mostly affect developing countries, particularly, countries in Africa (IPCC, 2005). Access to food in some certain African countries is compromised because of climate change and variability (Chijioke et. al., 2011).

The adverse effect of climate change is particularly devastating in Sub-Saharan Africa (Codjoe et al., 2020). Climate change is not only a global concern but it is affecting the people in West Africa (Chijioke et. al., 2011). The majority of the population in West Africa are engaged in rain-fed agriculture (Tambo, 2016; Stern & Cooper, 2011). Climate change is posing a great threat to food production and security in Sub-Saharan Africa. The impacts of climate change with the associated extreme events have the potential to affect adversely agricultural production (Garrett et al., 2013; Tambo, 2016).

Climate change is evident in Ghana and its effects have been demonstrated in major sectors of our environment (Asante & Amuakwa-Mensah, 2014). This has been demonstrated in the changing rainfall pattern in Ghana (Owusu et al., 2008). The changes being observed is disrupting the agricultural system, and energy supply, and also the emergence of flood during the rainfall season. Making the situation more critical is Ghana's lack of capacity to check relevant and timely adaptive measures (Asante & Amuakwa-Mensah, 2014). This has become compelling because of the strong evidence, and the likelihood of possible changes occurring and the rising scale of its impacts (Howden et al., 2007).

The key to avoiding the unmanageable is climate change adaptation (Bierbaum et al., 2013). Managing the risk posed by the changing climate demands knowledge-intensive adaptive management and policymaking actively informed by scientific knowledge (Lemos et al., 2012). Smallholder farming has become a notable coping strategy for the population. The upsurge of climate change and its accompanying impacts have made smallholder farmers in Northern Ghana vulnerable (Frimpong et al., 2015).

Climate change and variability impacts on crop production and food accessibility

Food security and production are part of the global challenges of this century (Slingo et al., 2005; Knox et al., 2011). The world will need to increase its food production to feed its projected 9 billion people by 2050 (Knox et al., 2011). Agriculture is a worldwide livelihood activity and a major land use all over the world (Howden et al., 2007). Agriculture will continue to serve as a bedrock for many economies in the developing world particularly in Africa serving as a major livelihood for its population. Deserving to note is the high vulnerability of the agriculture sector to climate change (Sultan & Gaetani, 2016; Knox et al., 2011). The plethora of climate change evidence which is not static but keeps on changing will also increase the scale of impacts. This gives a compelling reason to address agricultural adaptation with urgency (Howden et al., 2007). The assessment of many studies in different regions across the world has revealed more negative impacts of climate change than positive (Pachauri et al., 2014).

Agricultural production is very sensitive to climate variability and change (Vermeulen et al., 2012; Pereira. 2017; Yengoh et al., 2010; Rao et al., 2011). Climate change with accompanying extreme events such as floods, drought etc. is a threat to the agricultural sector, food security, and economic growth (Zuma-Netshiukhwi et al., 2016; Mutunga et al., 2017). Achieving food production and security is already a challenge (Vermeulen et al., 2012) and climate change and variability has the potential to worsen the situation and undermine food security (Pachauri et al., 2014).

Agricultural production in Africa is thought to be one of the most vulnerable sectors to be affected by climate change and variability (Hirons et al., 2018; Naab et al., 2019; Challinor et al., 2007; Slingo et al., 2005; World Meteorological Organization & Global Framework for Climate Services, 2016). Most economies in Africa are agricultural dependent (Benhin, 2008) with most of the farmers being smallholding rainfall-dependent (Naab et al., 2019) and with the majority not up to current in terms of modern farming techniques and support to rural livelihoods (Challinor et al., 2007). Climate change and variability may have impacts on the viability of existing dry (Challinor et al., 2007) and irrigated lands (Knox et al., 2011). Changes in rainfall and temperature patterns may also bring about changes or perhaps shifts in ecological zones (Kurukulasuriya & Mendelsohn, 2008). Though Africa is the likeliest to be hit by the effects of climate change, the continent knowledge of use of climate information is the most undeveloped (Slingo et al., 2005) with most of its farmers practicing rainfed agriculture (Sultan & Gaetani, 2016).

Changes in rainfall and temperature patterns have the possibility of impacting the viability and yields in crop production (Mutunga et al., 2017; Knox et al., 2011; Stern & Cooper, 2011). Recent studies have indicated that the impact of climate change and variability on crop yields will be severe (Slingo et al., 2005). About 20% - 80% of interannual variability in yields emanates from climate variability (Gommes et al., 2010).

Farmers' perception of climate change

Farmers are not independent of their environment and are usually aware of their climate and perhaps have a general understanding of the climate of their area and its impacts on their activities (Rao et al., 2011). The perception of climate change and variability by people whose livelihood is climate-dependent is important in understanding how society interacts with climate as climate change adaptation is being explored (Meze-Hausken, 2004; Ovuka & Lindqvist, 2000). Farmers usually make key decisions before and through to the end of the season based on their perceptions and experiences (Rao et al., 2011). There have been several studies on farmers' perception of climate change (Fosu-Mensah et al., 2012; Yaro, 2013; Codjoe & Owusu, 2011) but very few studies have tried to assess the accuracy of farmers' perceptions with observed data on rainfall and temperature (Meze-Hausken, 2004; Rao et al., 2011; West et al., 2008).

There is evidence of inconsistencies regarding farmers' perceptions and the reality which is based on scientific evidence. According to Yengoh et al. (2010), farmers perceived that the onset of the season had changed but that was contrary to scientific evidence based on the data analyzed for Tamale in the Northern Region of Ghana. In a similar study, farmers in Tolon and Kumbungu districts have observed that the climate was getting warmer in their area with rainfall decreasing. Interestingly, their perception of temperature was consistent with scientific evidence whereas that of rainfall was otherwise (Nyadzi, 2016). A study conducted by Sanfo et al. (2014) in Burkina Faso also revealed contrasting perceptions where in some parts farmers' perception was consistent with scientific evidence but it was also inconsistent at some point. On the contrary, a study in Kenya also affirmed smallholder farmers' perception with scientific evidence (Mutunga et al., 2017).

Climate change adaptation is considered an important step to reduce the impacts of climate change and it is therefore a critical component for policymakers (Nyadzi, 2016). It is therefore important to also ascertain the perception of climate and useful climate information of the people of Northern Ghana since effective adaptation is also contingent on the perception of farmers (Yaro, 2013). West et al. (2008) have also highlighted the need for ground truthing scientific evidence with farmers' perceptions. Some authors have found perceptions of farmers to be consistent with scientific evidence (West et al., 2008; Ovuka & Lindqvist, 2000) whereas others have found inconsistencies (Meze-Hausken, 2004; Rao et al., 2011). For the avoidance of doubt and uncertainties, it will be expedient to ascertain the situation in Northern Ghana.

Climate information in adaptive decision making

The least developed countries in the world lack the capacity to mitigate and adapt to the risk posed by climate change and variability. In the same vein, the socially and economically marginalized in the society are vulnerable to adaptation and mitigation response to climate change and variability (Pachauri et al., 2014). Farm-level management decisions are mostly determined by knowledge of the interaction of the environment, crop characteristics, technology, and socio economic factors. Among these factors, weather remains the main source of variability of farm inputs (Gommes et al., 2010). Close to 70% of the population of sub-Saharan Africa depends on rain-fed agriculture as a principal source of livelihood (Stern & Cooper, 2011).

The agriculture sector in Ghana largely depends on rainfall for farming activities. This makes the sector vulnerable to climate variability and change (Asante & Amuakwa-Mensah, 2014). Northern Ghana is affected by frequent climate extreme events like drought and flood, which affects the farming activities in the area which is the main livelihood activity of the people (Tambo, 2016). The rate of poverty in Northern Ghana is very high and climate variability poses risks to smallholder farmers in Northern Ghana (Yengoh et al., 2010). This is a threat to achieving the Sustainable Development Goals.

Farmers are vulnerable to the impacts of climate change. There remain challenges regarding food availability and access in Ghana (Al-hassan, 2015). The need to build the adaptive capacity and resilience of smallholder farmers through the production and dissemination of useful climate information for planning and decision making is critical. A changing climate requires responses that will help people to strategically adapt to expected changes to avert or reduce negative impacts (Ingwersen et al., 2014). Climate and weather information have impacts on agricultural decisions at different time scales. Farmers make short-term, operational decisions impacting field work in part based on current weather and meteorological forecasts, while tactical or strategic decisions may have a longer lead time and depend upon climatological information of the area (Hollinger 2009; Stone and Meinke 2006). Agriculture today has become very intensive and combines simultaneous farm management decisions, each season, about several issues which include crop and seed selection, nutrient inputs, planting and harvesting dates, crop insurance, and other land management practices (Prokopy et al., 2013) which all depend on relevant weather and climate information. Tambo (2016), in his study, recommended that farmers increasing knowledge of climate information and the capacity of Agricultural extension agents (AEA) to deliver climate information will be key to successful adaptation. Advanced climate information informs farmers' choices regarding land assignation, production schedule, sowing date, crop density, and time of fertilization (Marx et al., 2007; Bert et al., 2006). The climate information provided for use should enlighten and influence the farmers' decision to confirm or adjust a previous decision (Troccoli et al., 2008). This affirms the importance of transforming historical climate data into useful information. This helps farmers to understand the climate of their area and plan long before the season, during, and after the season. The provision of the climate information is not a panacea for farmers to use the information. Climate information will be used by farmers when it is accurate and presented in context, with lead times and concern with nonweather risks (Mase & Prokopy, 2014).

Because of the potential impacts of climate change and variability on agriculture, the need for adaptation is non-negotiable in meeting the Sustainable Development Goals. Other authors have asserted that without adaptation, climate change is generally detrimental to the agriculture sector. However, the adaptive capacities of farmers could reduce their vulnerability (Reilly & Schimmelpfennig, 1999; Smit & Skinner, 2002). The degree to which an agricultural system is affected by climate change depends on its adaptive capacity (Nyadzi, 2016). The creation of enabling environment by governments by providing institutional and macroeconomic conditions that favour adaptation and resilience to climate change and variability at all levels, particularly at the local level (Challinor et al., 2007). The provision of climate information to farmers for decision making will make them resilient (Zuma-Netshiukhwi et al., 2016). Agriculturally relevant climate information is not only useful to farmers but also to agricultural extension agents, agrochemical dealers, policymakers among others (Gommes et al., 2010).

Relevant climate information for agriculture

The greatest challenge faced by rain-fed agriculture is seasonal and intra-seasonal variation of rainfall (Gadgil et al., 2002). Farming in the tropics has always been a risky endeavour to undertake especially for smallholder farmers because of season to season variability in rainfall (Rao et al., 2011). There has been great evolution and emerging complexity in models in efforts to get the best results but the use of such scientific knowledge in decision making, particularly that of climate variability and change leaves more room for improvement (Kirchhoff et al., 2013).

Rainfall is a non-cash input in agricultural planning. Rainfall records can provide a wealth of guiding information for farmers, particularly sowing dates (Hussain et al., 2010). Farmers are keen on receiving climate information that is relevant to their decision making. Such information includes the commencement and cessation of the season and dry spells during the season (Stone & Meinke, 2006). Because of the variations from season to season particularly in the tropics, farmers have to make several decisions such as crop type, variety to grow, whether to invest in fertilizer, pesticides, planting date, how much land, water, and crop management (Gadgil et al., 2002; Rao et al., 2011; Zuma-Netshiukhwi et al., 2016). Yengoh et al. (2010) have asserted that farmers have an interest in knowing the onset of the season, seasonal rainfall total, and length of dry spells among others for decision making. Zuma-Netshiukhwi et al. (2016) have opined that farmers will make well-informed decisions when they receive climate information regarding when to plant, land preparation, what to plant, pest and insect management, fertilizer application, breed tolerance, grazing camp management among others. The authors further affirmed that farmers need science based climate information. The production of climate information is important and hence this study.

Communication of climate information and barriers to usage

Climate-related risks pose serious threats to our social and ecological systems. As we prioritize issues relating to climate change in the development process, we can reasonably expect that the need and demand for climate information will grow (Lemos et al., 2012). Climate information will be required in many regions to support agricultural decision-makers because of climate change and variability (Garrett et al., 2013).

End users of climate information such as smallholder farmers have long sought for climate information to inform their decisions (Giorgi et al., 2009). Sometimes, existing or available climate information does not get to users (Hirons et al., 2018). This is partly due to the challenge of moving from production of climate information to its use in decision making (Bierbaum et al., 2013). Lack of effective communication impedes farmers' or users' access to climate information. In some cases, farmers may think they know what they want and scientists may feel they know what farmers want (Gommes et al., 2010). Farmers make relevant decisions long before the start of the season based on climate information (Bert et al., 2006).

Channels of communicating climate information can be broadly grouped into three. That is individual contacts, group methods, and mass and electronic media (Gommes et al., 2010). The most reliable means of communicating climate information is through television and radio (WMO, 2012). Cherotich et al. (2012) asserted in their study that most of the respondents preferred receiving climate information through radio stations. Other sources of climate information as indicated by the authors were through extension officers and indigenous knowledge. Radio and ICT mediums of communication also presents an opportunity in communicating climate information to users. They affirmed that mutual interaction and face-to-face interaction are the ideal methods (Hansen et al., 2007).

The development of climate information should be approached using participatory techniques in sharing climate information (Patt et al., 2005; Garrett et al., 2013). The use of a participatory approach to the dissemination of climate information will help farmers to make appropriate decisions on whether or not to apply insecticides (Garrett et al., 2013). The participatory approach will help farmers to combine experiential and analytical learning in the decision making process (Marx et al., 2007). Conscious efforts should be made by scientists to provide relevant climate and weather information for planning and decision making. The design and delivery of climate information should be done in a way that promotes farmers' willingness and ability to use the information in agricultural decision making (Mase & Prokopy, 2014).

Beyond the design and delivery of climate information, Furman et al. (2011) have asserted that a disconnect between the timing of the delivery and decision making could lead to the nonusage of climate information by farmers. Another impediment in the usage of forecasts by farmers has to do with the lack of specificity regarding the location (Crane et al., 2010). The lack of desired information by farmers for decision making has also served as an impediment to farmers (Sonka et al., 1992). The lead time to the issuance of climate information is critical to decisions made by farmers because it gives them ample time to plan and factor the information in their decision making (Keogh et al., 2004; Ingram et al., 2002). Resource constraints also serve as a limitation to the use of climate information by farmers (Crane et al., 2010; Hansen, 2002; Furman et al., 2011). A lack of conviction by farmers that a change in their decision based on climate information will lead to improvement in agricultural outcomes is also a limiting factor (Marshall et al., 2011; Power et al., 2007; Roncoli, 2006). The credibility of the source of climate information also played an essential role for users of climate information in accepting and accessing the information and further making use of it (Ingram et al., 2002). The shift from the old ways of farming and embracing new techniques sometimes serves as a hindrance to the use of climate information (Breuer et al., 2008). The lack of awareness of existing climate information and perhaps understanding of the information contributes to the limitation in the use of climate information for decision making by farmers (Furman et al., 2011; Hansen, 2002).

Trusted sources of climate information as indicated by Mase & Prokopy (2014) are climate scientists, private agronomists and consultants, extension agents, other farmers, and family or business partners. Mase & Prokopy (2014) have reported that most research has focused on the seasonal forecast at the expense of other sources of climate information and recommended that this gap should be filled. The authors further recommended a more participatory approach in communicating climate information to farmers. This study will focus on transforming climate data into useful information that farmers need for planning and decision making as asserted by the authors above. Specifically, information on the onset of the season, end of the season, length of the season, drought index, rainy days, dry spells, risk, and historical probabilistic forecast among others will be provided through this study.

Generating climate information

The onset of the season is critical for farmers in West Africa since it helps farmers to decide when to plant, and which type of crop and variety to plant (Sultan et al., 2005; Marteau et al., 2011; Yengoh et al., 2010; Dodd & Jolliffe, 2001). This is a result of the high dependence on rainfall for farming activities (Sultan et al., 2005; Vellinga et al., 2013; Mensah et al., 2016; Amekudzi et al., 2015). There have been several definitions of the onset of the season by different authors at regional and local scales (Fitzpatrick et al., 2015). Regional studies on climate information particularly on the onset of the season for West Africa have used different data sets from GPCP/TRMM (Diallo et al., 2014), mean sea level pressure, and zonal winds from GCM (Nguyen et al., 2014), daily MSE daily data from GCM (Vellinga et al., 2013). These authors have used different definitions of onset. There have been few instances where gauge datasets have been used for a regional study (Marteau et al., 2011; Sultan & Janicot, 2003; Le Barbé et al., 2002). Few studies have used gauge data sets because of the sparse nature of gauge stations (Fitzpatrick et al., 2015). Regional studies mostly rely on global or regional datasets for such studies of which certain details are missed in the analysis. In addition, regional onset definitions focus on large-scale movement and modulation of atmospheric dynamics over the region. On the contrary, local analysis of onset focuses exclusively on monsoon onset as a given threshold of local precipitation as its definition (Fitzpatrick et al., 2015). Fitzpatrick et al. (2015) have indicated that regional scale definition of climate information (onset) provides results that is smooth and may not show inherent variability from locality to locality and recommend the use of gauge data at the local level. The various sources of climate data for the provision of climate information do not stand the accuracy that gauge data sets offers because of inherent biases (Fitzpatrick et al., 2015). This indeed forms the basis of this work by transforming gauge data into useful information for decision making by small holder farmers. Again, using the local conditions and gauge datasets allows for customization of the climatology of the area compared to the regional analysis which may be broad (Marteau et al., 2011). This study will provide climate information in the context of the climatology of Northern Ghana.

Besides the studies that focused on the West African sub-region, other studies have been undertaken in other countries within the subregion. Studies in Nigeria (Aweda & Adeyewa, 2010; Adelekan & Adegebo, 2014; Odekunle, 2004), Zimbabwe (Mupangwa et al., 2011b), Kenya (Mugalavai et al., 2008); and Zambia (Stern & Cooper, 2011), among others have mostly centered on onset and cessation of rainfall in these countries with different methodology in defining the onset of the season and cessation.

Similar studies in Ghana have focused on the onset, cessation, and length of the season. Mensah et al. (2016) in their studies compared climate information (onset, length cessation) generated from gauge datasets with GCM (RegCM4). Mensah et al. (2016) used the fuzzy logic approach in defining the onset, cessation, and length season. The same definition was used across Ghana and did not consider the differences in agroecological zones and the bimodal and unimodal rainfall regimes characterized by the country. The study mainly focused on validating how well the RegCM4 can be used as an alternative source of producing climate information. The study used 22 stations covering the entire country. The entire Northern Region was represented by 5 stations which was not quite representative of this vast region. A similar study by (Amekudzi et al., 2015) focused on the variability of the onset, cessation, and length of the season in Ghana. This study also used the same data sets used by Mensah et. al. (2016) but used a different methodology in defining the onset and cessation of the season. Amekudzie et. al., (2015) used percentage mean cumulative rainfall and/or the rainy days method in defining their onset and cessation dates. Both methods as used by Mensah et. al. (2016) and Amekudzie et. al. (2015) did not take into account the climatology of the area. There is the possibility of meeting this requirement before the rainfall season so there should be a caveat to determine the start month where the requirement should be met knowing the climatology of the area. The definition of this relevant climate information should consider the flexibility of the definition, how readily can it be modified, agronomic sufficiency, and the needs of the end users. Their methods lack flexibility in defining the onset of the season because in defining the onset you may also take into account the water requirement of the crop into consideration etc. Again, these studies failed to take into consideration evaporation in determining the cessation of the season. In addition, both studies used five stations to represent the entire Northern Region of Ghana which will certainly hide certain relevant details.

Most studies across the globe on using climate information by farmers have centered on the use of seasonal forecasts (Hansen, 2002; Keogh et al., 2004; Marshall et al., 2011; Ingram et al., 2002; Power et al., 2007; Crane et al., 2010; Roncoli et al., 2009; Zuma-Netshiukhwi et al., 2016). Only few studies have used historical climate information to generate useful climate information. The studies that used historical climate data were also skewed towards the onset, cessation, and length of the season as the only useful climate information generated (Mensah et al., 2016; Yengoh et al., 2010; Amekudzi et al., 2015). The studies usually used between one to five stations to represent the entire Northern Ghana. No study has had a comprehensive look at the relevant climate information for decision making and has been able to conduct relevant statistical tests to affirm or deny changes in all of these relevant climate information in Ghana. The knowledge of change or no change in any of these parameters is critical to inform policy direction. None of these studies has looked at the state of the climate over the study area in relation to the agriculturally relevant climate information. The studies were further silent on the quality control processes the data used in the analysis were subjected to. If the quality control process were not rigorous, it means the outcome of their analysis could be influenced by non climatic factors.

El niño-southern oscillation (enso) cycle and rainfall pattern

The degree of hotness or coldness of the ocean can have a great deal of impact on the weather and climate of a particular place across the globe. ENSO has two phases which are not synonymous with each other (Collins et al., 2010). The cycle of the phases is described by the term ENSO cycle. The ENSO cycle describes the volatility in temperature between the ocean and atmosphere in the east-central Equitorial Pacific Ocean (Collins et al., 2010; Owusu et al., 2019). La Nina is usually used to depict the cold phase of ENSO while El Nino depicts the warm phase of ENSO. Both the La Nina and El Nino phases usually last for nine to twelve months but there are some few cases where either phase had stayed for years. The frequency of their occurrence is irregular however El Nino seems to occur more regularly compared to La Nina.

ENSO is known to be the highest impact factor of climate variability across the globe and it's a naturally occurring phenomenon that is a natural source of variability (Collins et al., 2010). ENSO influences rainfall variability across the world (Owusu et al., 2019) and it affects fresh water supplies, and agriculture, and also influences severe weather events worldwide (Collins et al., 2010). The association of the ENSO phenomenon with the rainfall pattern and variation in West Africa is evident in many studies. It has been estimated that West Africa receives above-normal rainfall during La Nina phase of ENSO and below-normal rainfall during El Nino phase of Enso (Boadi & Owusu, 2019; Owusu et al., 2008)

Studies in Ghana have shown the teleconnection between ENSO and rainfall patterns in Ghana (Waylen & Owusu, 2014; Owusu et al., 2008). Adiku & Stone (1995) asserted in their paper that the ENSO phases have impacts on the onset of rainfall season over Southern Ghana. They argued that La Nina phase of ENSO brings about early onset while El Nino is associated with late onset over southern Ghana. Boadi & Owusu, (2019) have also affirmed in their study that the ENSO phases influence rainfall in the Volta Region of Ghana. They concluded in their paper that annual and monthly rainfall is high during La Nina years while the same is low during El Nino years. ENSO accounts for the variation in the rainfall pattern in Ghana (Boadi & Owusu, 2019). Literature on ENSO in the north of Ghana is almost nonexistent, particularly current studies on the impact of ENSO on the climate variability of the north of Ghana.

Theory of planned behaviour

This study is situated in the context of the theory of planned behaviour. The TPB is an improved version of the theory of reasoned action (TRA) developed in the 1980s by Ajzen and Fishbein. It assumed that there is a linkage between attitude and human behaviour. Ajzen (1991) developed the Theory of Planned Behaviour (TPB) because TRA could not adequately account for behaviours where individuals were not in total control (Sentosa and Mat, 2012). The theory of planned behaviour posits that when a person intends to perform a specific behaviour, they will do so because behavioural intentions are formed based on attitudes, subjective norms, and perceived behavioural control (Gu & Wu, 2019).

This theory as developed by Ajzen (1991) fits well with the study of climate information (Sharifzadeh et al., 2012). Sharifzadeh et al. (2012) underscore this viewpoint and indicate that agricultural climate information use is mainly influenced by environmental factors. Some of these environmental factors are water stress and drought. It is the environmental factors that compel the farmer to use climate and weather information. Tolma et al. (2006), have opined that the theory of planned behavior provides direction that helps one to understand farmers' cultural beliefs which influence their behaviour towards the use of climate information.

The major objective of this study is to generate relevant climate and weather information that will help farmers build their adaptive capacity and resilience towards improved livelihood. Farmers need to adapt to the changing and variable trends in rainfall and temperature patterns to reduce the risk posed by climate change and variability. The study will make more impact when the results help farmers change their behaviour and adopt the use of climate and weather information for planning and decision making.

The theory of planned behaviour has five major components. Each of these components influences one's behaviour. The components are attitude, subjective norms, perceived behavioural control, intention, and one's behaviour (Ajzen, 2005). The theory asserts that human action is guided by three major thoughtful considerations, that is, attitude to behaviour (beliefs about likely consequences of the behaviour), subjective norms (beliefs about the normative expectation of others), and perceived behavioural control (beliefs about the presence of factors that may facilitate or impede the performance of behaviour). These three components lead to the formation of the intention of the person involved. If the person's attitude, subjective norm, and perceived control are all favourable, then the person will have a firm intention to perform the behaviour.

The farmers' attitude towards the use of climate information will greatly impact their behaviour (use of climate information). How easily the farmer can access and use the information is critical and how useful it will be for the farmer (Kraft et al., 2005; Smarkola, 2008). The subjective norm highlights how farmers viewed the belief or confidence of producers/intermediaries in the climate information being disseminated and also how other farmers or people believed the information (Sharifzadeh et al., 2012; Lemos et al., 2012). Perceive control deals with the application of climate information to help the farmer solve a specific decision need. For example planting date. The first three components of the theory as explained will have an impact on the farmers' desire to use climate information. A more favourable attitude, subjective norm, and perceived control resulting in strong intention will lead to a behaviour and that is the use of climate and weather information.

The theory of planned behaviour has been used in several studies in the field of agriculture (Borges et al., 2014; Chin et al., 2016; Borges and Lansink, 2016; Senger et al., 2017) assessing farmers' intentions in making relevant decisions. The evidence of these studies using the theory of planned behavior provides empirical underpinnings and support for this theory hence its use in the context of this study.

The study uses the theory of planned behaviour to underscore the need to produce agricultural-relevant climate and weather information for use by farmers for planning and decision making. The erratic nature of rainfall, drought, and increasing temperatures are compelling farmers to find answers to relevant climate and weather information knowledge that could be useful for their adaptation, planning, and decision making.

A conceptual model

The conceptual model presented below depicts the linkage between the production and use of climate and weather information and livelihood outcomes. The production, availability, and access to and the use of agriculturally relevant climate and weather information as an adaptation strategy will hugely impact the livelihood outcome of smallholder farmers. Existing institutions mandated to produce climate and weather information can worsen climate change impacts on farmers by not producing relevant information to farmers and also inaccurate information for planning and decision making. Farmers alike can worsen their plight should they decide not to use climate and weather information for their farm management decisions. Most importantly, potential barriers to access and use after the production of climate information should be broken to ensure the usage of climate and weather information for planning and decision making.

The model reinforces the need for possible co-production of climate and weather information. Co-production is critical to the production of climate information since there exists dynamism in the interaction and usability of climate information by users. The involvement of users at the production level will ensure that what will be supplied will be what users demand but not what producers feel users will demand. This will ensure effective communication between users and producers of climate information (Gommes et al., 2010). This is important because the adoption and use of climate information hugely depend on the accuracy, level, and quality of interaction between the producers of the information and its users (Lemos et al., 2012; Mase & Prokopy, 2014). Users of climate information will find the information useful only when it addresses a need that is both real and perceived (Hansen, 2002). The production of the information will not serve its purpose unless it reaches its users for planning and decision making. The timely production with an effective communication system using different platforms will enable users to access the information through the most convenient means. The expected impacts will be made when users have found the information useful and it has influenced their decision making.

The medium through which users receive and participate in the process of production of useful climate information will affect their willingness to use the information (Lemos et al., 2012). As asserted in the theory of planned behaviour, cognitive, emotional, and behavioural influences shape both public and private decisions of users (Ajzen, 1991; Lemos et al., 2012). Farmers' confidence and acceptance in using the information will help them make decisions based on scientific evidence and reduce any impact of the risk posed by climate change and variability.

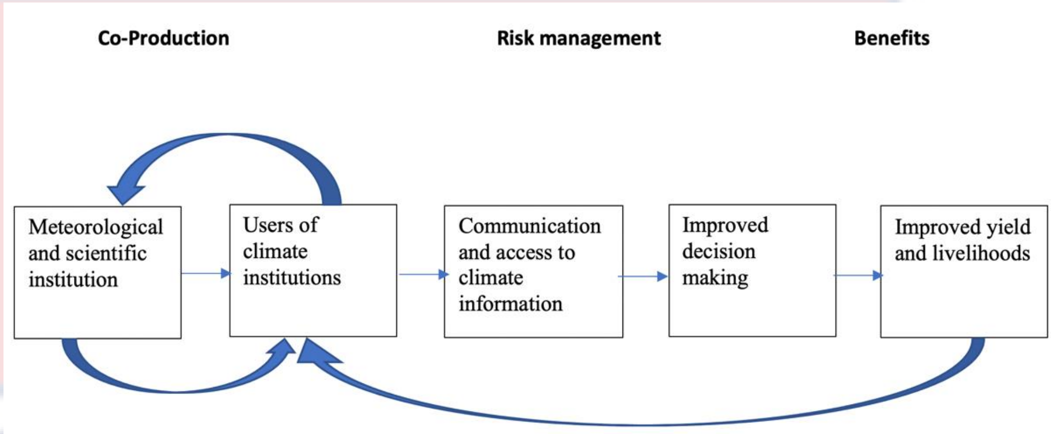


Figure 1: Conceptual model

Source: Asare, 2021

One of the adaptation strategies for climate change and variability is the production of climate information for planning and decision making by smallholder farmers. Pilifosova (2001) defined adaptation as the ability of a system or an entity to adjust to suit the impacts of climate change. This also involves reducing risk to the minimum level if it cannot be eliminated. The adaptive capacity of the farmer will help the farmer to be resilient to the impacts of climate change. The access of the farmer to useful and usable climate and weather information will help the farmer build his adaptive capacity to make informed decisions regarding climate risk management decisions on their farm. This research will be focused on the above framework. That is from producers of climate and weather information to the users leading to improved livelihood. Users will have the opportunity to give feedback to the relevant institutions producing climate information for dicision making at the end of the season. This feedback will complete the communication cycle and also provide useful input in improving the climate information shared with farmers.

Conclusion

This chapter has placed the study in a more specific context of climate change adaptation by building the resilience and adaptive capacity of smallholder farmers through the production and use of climate information for decision making. The existing literature indeed affirms the presence of climate change and variability. The implication of climate and variability on agriculture, particularly food production and security is enormous. Most at risk among farmers are smallholder farmers. The need to build the resilience and adaptive capacity of farmers is crucial. The production of useful climate information from historical climate data is very useful for decision making before, during, and at the end of the season.

The study uses the theory of planned behaviour and the conceptual model to underscore the need to produce agriculturally relevant climate and weather information for use by farmers for planning and decision making. The impacts of climate change and variability are compelling farmers to find answers from relevant climate and weather information that could be useful for planning and decision making. The climate information produced should be relevant to the needs of users, accessible, and accurate. These will help farmers adopt and use the information.

Not enough work has been done on agriculturally relevant climate information for decision making in Northern Ghana. It is this gap in the existing literature that informed the objectives of this study as indicated in section 1.8.

CHAPTER THREE

RESEARCH APPROACH AND METHODOLOGY

Introduction

This chapter describes the study area, approach to the research and the methods used for the research and the data analyzed

Research philosophy

Every scholarly research is guided by philosophical underpinnings (Held, 2019; Mertins, 2015) and although the various research paradigms have conflicting philosophical underpinnings, every researcher is required to carefully evaluate each paradigm before employing it in the research activities (Aliyu et al., 2014). Upon reflecting carefully on the different philosophical world views and their assumptions as posited by Creswell (2014) in the planning of this research, this study adopted the positivist philosophical stance. This is because the scope of work does not fit well with the philosophical underpinnings of the constructive, pragmatic, and transformative schools of thought. While the constructive focuses on developing a theory from observations which is inductive, the Positivist rather, focuses on scientific methods and begins from theory and validates or refutes the theory which is deductive.

Research approach and design

Epistemologically, this study uses the positivist approach. This approach thrives on the assumption that objective reality is independent of human behaviour. It avers further that reality can be measured and objectively studied (Mertens, 2010). The Positivist approach uses methods that obtain the truth by using data and coming out with precise, unbiased, and verifiable (Evely et al., 2008) output. The work is purely quantitative research and is best situated with the positivist school of thought. The study used this approach because verified data was used for the analysis to provide empirical evidence based on which informed decisions can be taken by all users. This approach offers no scope for the biasing of results. The results achieved are numerical and are thus, fair in most cases.

This study employs the descriptive and correlational research method under quantitative research as opined by Carrie (2007). It examines the situation of a phenomenon as it exists in its current state, which also involves the exploration of the correlation between two or more phenomena. This study examined the current state of climate over the north of Ghana, transformed rainfall and temperature data into useful agriculturally relevant information, and assessed their trends. Further, the study examined the correlation between the teleconnection between remote climate indices and the climate of the north of Ghana.

Study area

The research focuses on the five regions of the north of Ghana located above latitude 7.9^0. The five northern regions that constitute the study area experience a unimodal rainfall regime. The study area is bordered to the north, east, and west by Burkina Faso, Togo, and Cote d'Ivoire respectively. These countries are our international neighbours. Northern Ghana shares boundaries to the south with the Bono East and Oti regions of Ghana.

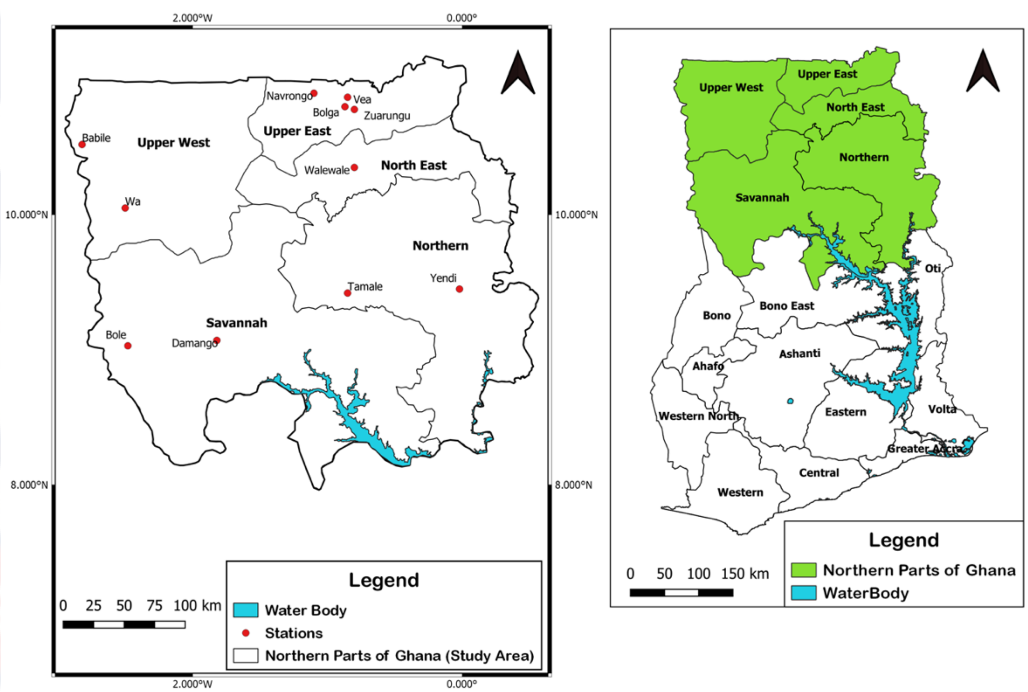


Figure 2: Study area

Northern Ghana as shown by Figure 2 includes the North East, Northern, Savannah, Upper East, and Upper West Regions which cover close to about fifty percent (50%) of the total land area of Ghana (290000 square kilometres), and located between latitudes 8^{0} 30$^{'}$ 000$^{''}$ N and 11^{0} 150$^{'}$ 2900$^{''}$ N and longitudes 4^{0} 00$^{'}$ W and 2^{0} 00$^{'}$ E. The area lies mainly in the Guinea savannah eco-region of Sub-Saharan Africa, the remaining portion, which is just about a third of the Upper East Region lies in the Sudan Savannah eco-region.

The north of Ghana was chosen for this study because agriculture is a dominant livelihood activity in the area and it is climate dependent. About 88% of the people depend on agriculture as a major economic activity (WFP, 2013). Most of the farmers who are smallholders practice rain-fed agriculture. In addition, the region is considered the poorest compared to the southern part of Ghana. The region continues to record high incidents of poverty (WFP, 2013). The emerging changing climate and possible risk, demands that the climate of the region should be well understood and produce agriculturally relevant climate information to manage their climate risk and further enable relevant policy formulations that will augur well for the wellbeing of the people.

Data analysis

Source of data

This study used data from secondary sources. Daily rainfall and temperature data from the North of Ghana covering a period of 57 years was collected from the Ghana Meteorological Agency for the analysis conducted in this study. The stations selected for this study were based on data availability and quality. Data from stations with data availability of at least 80 percent of the selected period was used for the purposes of understanding the climate of the area and agriculturally relevant climate information. Stations meeting this criteria qualified and were selected for the analysis. The El Niño-Southern Oscillation (ENSO) indices selected for this analysis are Tropical South Atlantic (TSA), Central Tropical Pacific (Nino 3.4), and Atlantic meridional mode (AMM) SST. The ENSO indices data was downloaded from the NOAA website.

Quantitative data analysis

The research used a secondary source of data collected from the Ghana Meteorological Agency and ENSO indices data downloaded from the NOAA website. Rainfall, temperature, and evapotranspiration data were analyzed and transformed into useful climate information. Tables and graphs were generated. Spatial plots were produced for the onset, end, and length of the season, and longest dry spell, etc. Trend analysis with a significance test was performed to show the pattern of all the relevant weather and climate information for planning and decision making. Specifically, trend analysis was produced for annual rainfall total, rainy days, heavy rainfall events, annual mean temperature for both minimum and maximum temperature, and evapotranspiration. Further analysis was performed to assess the correlation between the climate of the study area and ENSO indices. These analyses were conducted to understand the patterns of the past to the present climate of the study area and provide evidence of variability or change, its nature, and the impact of ENSO in the study area. The R statistical, Climate Data Tool, and Instat+ software were used in the data analysis. These tools were used to conduct quality control analysis of the data sets, transform the datasets into useful information, generate spatial maps of the agricultural relevant analysis, trend analysis, and their significant test, tables, and graphs among others.

Data formatting and quality control

The rainfall and temperature data for the selected stations were subjected to a rigorous quality control process. Quality Control (QC) measures were taken to detect and identify the errors made during data collection, recording, transmission, and archiving data (WMO, 2002). Raw daily rainfall, maximum and minimum temperatures were subjected to different quality control tests, in order to identify and flag major errors of digitization, remove outliers, negative rainfall and temperature values, and check internal consistency, temporal and spatial coherency. Periods without data for all the climatological variables were set to a missing value.

Gross error checks (aberrant values, problems with the decimal point, in calendar dates etc.), Tmax < Tmin values, consecutive values repeating 4 times, temperature values greater than ± 4 standard deviations threshold for the candidate record and its group of reference stations, and values exceeding the expected amount of change between consecutive observations were assessed in the raw data (Toreti et al., 2011). Besides the routine quality control checks, a homogeneity test was performed to evaluate the climate data before the analysis was performed (Toumenvirta & Alexandersson, 1997). A homogeneous climate time series is defined as one where variations are caused only by variations in climate. The aim of homogenization is the removal of non-climatic factors, whereas the climatic signal must be preserved (Conrad & Pollack, 1950; Toreti et al., 2011). For long-term climate analyses, particularly climate change analyses to be accurate, the climate data used must be as homogeneous as possible. This was done using the standard normal homogeneity test (SNHT) which was developed by Alexandersson and Moberg (1997). The analysis was conducted by using data from the last fifty-seven years.

Estimating evapotranspiration

There are several methods of estimating evapotranspiration (PET). PET can be estimated by using an empirically determined method or the land-atmosphere energy balance aerodynamics principles (Li et al., 2018; GaviláN et al., 2008). The most widely accepted PET method is the FAO-56 PM and is considered as the best and most accurate compared to Thornthwaite, Hargreaves etc (Allen et al., 1998). The FAO method requires lots of variables and makes it difficult to adopt this method. The most widely used approach is the empirical method with Hagreaves (HS) method being the most widely used in the agricultural field (Li et al., 2018) which uses only temperature data (Raziei & Pereira, 2013). This method is recommended by the FAO in places where all the needed weather variables are not available (Allen et al., 1998). This is because the HS model is efficient in estimating PET (Raziei & Pereira, 2013; Tukimat, 2012). It captures the atmospheric mean status through the mean air temperature and partly captures the land surface property information, such as soil moisture and land surface albedo with the introduction of a diurnal temperature range. HS provides a most accurate global performance in arid, and semiarid regions (Li et al., 2018; Almorox et al., 2015). This study adopts the Hargreaves method as used by Tukimat (2012 and Raziei & Pereira (2013) as shown below.

The HS method estimates PET as follows:

$ET_O = k_{RS} (Tmax - Tmin)^{HE} (Tm + HT) Ra$

where ET_o is daily PET in mm·day^{1}

Ra is extraterrestrial radiation in mm·day^{1}

$Tmax$ and T_{min} are daily maximum and minimum air temperature in ^{o}C,

k_{RS} is the empirical radiation adjustment coefficient and the value is set to 0.0023

HE is the empirical Hargreaves exponent and the value is set to 0.5

HT is the empirical temperature coefficient and the value is set to 17.8

Mann kendall trend analysis

After completing all the quality control and homogeneity processes, rainfall and temperature data was ready for the various analyses to meet the objectives of this research work.

Mean annual rainfall totals and annual averages for temperature were generated. Trend analysis was produced to determine whether a trend was established and further determine the direction of change if any. This was calculated and plotted for rainfall and temperature for the study area and also for the agricultural relevant analysis (onset of the season, cessation, length, and longest dry spell). A significant test using the Mann -Kendall was conducted.

Mann–Kendall (Mann, 1945; Kendall, 1975) is a nonparametric trend test that basically involves the ranks obtained by each data in the data series and is a statistical yes/no type hypothesis testing procedure for the existence of trends. The Mann–Kendall nonparametric test, as described by Sneyer (1990), was applied in order to detect trends. The Mann–Kendal test has been widely used by several researchers to detect trends in hydrological time series data (Wilks, 1995; Serrano et al., 1999; Brunetti et al., 2000a,b; Onoz and Bayazit, 2003; Luo et al., 2008; Pal & Abir Al- Tabbaa, 2010).

The magnitude of the trends will be estimated using Sen slope (Sen 1968), and according to Hirsch et al. (1982), Sen's method is robust against extreme outliers. The procedures and equations for Mann–Kendall test statistic and Sen's methodology were described by Bandyopadhyay et al. (2009) and Subash et al. (2011).

The MK test can be expressed mathematically as;

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_i)$$

Note that whenever $S > 0$, then later observations in the time series tend to be larger than those that appeared earlier in the time series, while the reverse is true if $S < 0$. The variance of S is given by

$$\sigma^2 = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5) \right\} / 18$$

σ^2 is the variance, t_j are the sets of data points in j j th term. The Statistic S is approximately normally distributed with

$$z = \frac{S}{\sigma} = \left\{ \begin{matrix} (S-1)/\sigma, S>0 \\ 0, S=0 \\ (S+1)/\sigma, S<0 \end{matrix} \right\}$$

S is also related to Kendall's τ in the expression;

$$\tau = \frac{S}{D}$$

Where D is given as;

$$D = \left[\frac{1}{2} n(n-1) - \frac{1}{2} \sum_{j=1}^{p} t_j(t_j-1) \right]^{\frac{1}{2}} \left[\frac{1}{2} n(n-1) \right]^{\frac{1}{2}}$$

The MK test was used to ascertain trends and their statistically significant test to affirm change or otherwise. The trend and statistical analysis were performed for both rainfall and temperature data that were analysed. The trends established in the study were evaluated at a 95% significant level. This means that the null hypothesis is rejected by positing that trend exists as the alternate hypothesis (Okafor et al., 2017).

The main advantages of using Kendall's tau are as follows:

- The distribution of Kendall's tau has better statistical properties.
- The interpretation of Kendall's tau in terms of the probabilities of observing the agreeable (concordant) and non-agreeable (discordant) pairs is very direct.
- In most situations, the interpretations of Kendall's tau and Spearman's rank correlation coefficient are very similar and thus invariably lead to the same inferences.

Based on the above-mentioned benefits of Mann Kendall, this study used this statistical approach for the trend analysis. The trend analyses were performed for annual rainfall total, annual mean for minimum and maximum temperature, evapotranspiration, the onset of the season, length of the season, cessation, and longest dry spell using R statistical software.

The deviations of the annual rainfall from the annual mean rainfall for each station were computed and subsequently, the annual rainfall departures for each station over the period of study as used by Nkruman et al. (2014).

Spatial analysis

The spatial analysis of this study was conducted to underscore the spatial and temporal variation of the various climate variables and agriculturally relevant climate information. This gave evidence-based knowledge and provided clarity on whether climate and agriculturally relevant information in the study area are homogenous or vary in space and time. In addition, climate data in most cases are incomplete in some parts of the world with missing gaps and sparse station networks. The spatial interpolation provides finer resolution data for decision making (Yang et al., 2015). The study used the Inverse Distance Weighting (IDW) approach considering the landscape of the study area which is generally flat and the variable nature of the climate data used. It is one of the commonly used models in spatial interpolation with easy interpretation (Lu and Wong, 2008). This approach estimates values for unsampled locations using the weighted average of observed data at surrounding points (Ly et al., 2011). The IDW method is based on the functions of the inverse distances in which the weights are defined by the opposite of the length and normalized so that their sum equals one. The weights decrease as the distance increases (Ly et al., 2013).

This formula posits that the unknown value of a point is influenced by a point closer than a position far away. The weight can be computed by:

$$\lambda_i = \frac{\frac{1}{|D_i|^d}}{\sum_{i=1}^{ns} \frac{1}{|D_i|^d}}, \quad d > 0$$

D_i--is the distance between known and unknown points. The *d* parameter is specified as a geometric form for the weight while other specifications are possible. Thus, small power *d* tends to give estimated values as averages of Zs_i in the neighbourhood, while large power *d* tends to give larger weights to points closer and increasingly down-weights points located farther apart (Ly et al., 2011; Lu et al., 2008).

Spatial plots were generated for the onset of the season, end of the season, length of the season, longest dry spell, and evapotranspiration using the R statistical software.

Multiple regression

The multiple regression analysis was used to assess the relationship between ENSO and climate in the north of Ghana. The assessment helped to underscore which of the climate variables have an association with ENSO over the North of Ghana. Multiple regression analysis is a linear statistical technique that allows us to find the relationship between climate variables and multiple climate indices (Mekanik et al., 2013; Gao et al., 2014). In the regression model, the climate variables were expressed as a function of the climate indices (predictors). The regression model is represented mathematically as;

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots + \beta_i x_i + \varepsilon$$

Where y is the climate variable (dependent variable),

$x_1, x_2 \ldots x_i$ = climate indices (independent variables),

β_0 = intercept of regression model,

$\beta_1, \beta_2, \ldots \beta_i$ = coefficients of predictors,

ε = error margin.

The regression analyses were performed to ascertain the relationship if any between the selected ENSO indices and various climate variables using the R statistical software.

Agriculturally relevant information

Five agriculturally relevant analyses (onset, cessation, length of the season, longest dry spell, evapotranspiration), were produced and plotted in a time series format for the purposes of planning and decision making by smallholder farmers. Dry spells were calculated for each of the stations. Both minimum and maximum temperatures were similarly analyzed to determine their pattern over the years.

The R statistical software and the Instat+ software were used for the analysis of the climate data. The Instat+ software (Stern et al., 2003) was used to generate the agriculturally relevant climate information (onset, length, cessation, dry spell). The remainder of the analyses were generated using the R statistical software.

Selected relevant agricultural climate information and definitions

This study focused on relevant climate information for decision making. The emphasis is on the Start of the rain (onset), End of the season (cessation), Length of the season, and Dry spells. Although this study is situated in the positivist school of thought, it also affirms the need for co-design and co-production as asserted in the conceptual framework. To generate information that meets the needs of farmers, an extensive literature review (Gadgil et al., 2002; Rao et al., 2011;

Zuma-Netshiukhwi et al., 2016; Yengoh et al., 2010; Sultan et al., 2005; Marteau et al., 2011; Yengoh et al., 2010; Dodd & Jolliffe, 2001) was conducted over the study area and across the globe to ensure that the selected relevant agricultural climate information that will be generated meets the needs of farmers. The study considered the agronomic sufficiency, flexibility, the climatology, and the needs of users before adopting the definitions used in this study.

Table 1:Definition of terms

Term	Definition
Seasonal rainfall total	Total rainfall received from April 1st to October 30th
Start of the rain/onset	A day or two consecutive days after 1st April with rainfall greater than 20mm without a dry spell exceeding 10 days within 30.
End of the rains/cessation	the first day after October 1st when the crop water index is less than 0.5
Length of the season	the difference between the End and Start of the rains
Meteorological Drought	meteorological drought reflects on lack of precipitation
Dry spell	Continuous days without rain during the rainfall season

Source: Asare, 2021

The definitions of the relevant agricultural climate information were tailored to meet the needs of Users. The onset of the season definition as shown by Table 1 above was adopted from (Stern et al., 2003; Mupangwa et al., 2011). The definitions for the onset and cessation of the season were used during the implementation of PICSA in the north of Ghana (Clarkson et al., 2019). The study adopted the water balance model as used by Brown (2008) and Mupangwa et al. (2011) to determine the cessation of the season. This has been used widely in sub-Saharan Africa (Stern & Cooper, 2011). A rainy day is defined as a day with rainfall amount equaling 0.85mm and above. This definition is appropriate for the West African region (Odekunle, 2004). A heavy rainfall event is defined as a day with a rainfall amount of 20mm or above. This same approach is used by the Ghana Meteorological Agency in estimating both the start of the rain (onset) and cessation of the season.

Ethical considerations

Ethical clearance was sought from the Institutional Review Board (IRB) of the University of Cape Coast (UCC). Permission was also sought from the Department of Geography and Regional Planning, UCC. The researcher followed standards in collecting the secondary data used for the analysis of this research.

Conclusion

This chapter discussed the study area for this research and justified why it was chosen for this study. The research approach adopted as a guide for this study was discussed and methods used. The chapter further discussed data sources for this research, data formatting, quality control, and the analysis of the dataset. Finally, this chapter highlighted the ethical procedures that were followed in undertaking this research.

CHAPTER FOUR

STATE OF CLIMATE IN THE NORTH OF GHANA

Introduction

This section seeks to present results to ascertain or deny any change in the climate over the northern part of Ghana. The focus of this analysis is on two main variables critical to climate and very relevant to agriculture.

Rainfall

Farmers in the north of Ghana practice rain-fed agriculture. The understanding of the current state of rainfall in the study area is important towards climate risk management decisions. The analysis sought to understand the state of annual rainfall totals, rainy days, heavy rainfall events, and seasonal rainfall cycle and compared two different climatologies for the eleven (11) different stations in the north of Ghana.

Annual rainfall

The north of Ghana experiences a unimodal rainfall regime as shown in Figure 3. The onset of the rainfall for rain-fed livelihood activities usually begins in April.

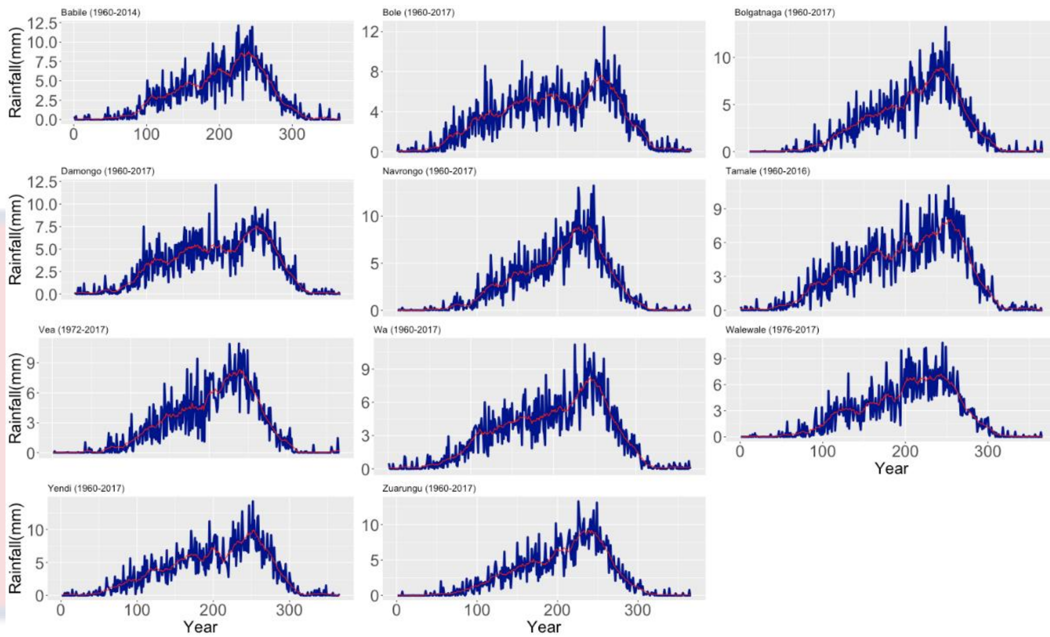


Figure 3: Rainfall climatology of the study area
Source: Asare, 2021

Although the rainfall season usually begins in April and ends in October for all the stations, the peak rainfall month for the season differs from station to station. Rainfall peaks in August for Vea, Zuarungu, Wa, Babile, Navrongo, and Bolgatanga. On the contrary, Walewale. Tamale, Yendi, Damango, and Bole rainfall peaks in September. After the peak in either August or September, the rains decline and end in October. The months from November to March are classified as the harmattan. This period is dry and does not receive much rain. The annual rainfall total was computed for all the stations in the study area. Other summary statistics were also calculated to ascertain the dynamics and differences in the study area. This is of great importance for understanding the annual rainfall situation in the study area.

Table 2:Summary statistics for annual rainfall

Station	Max Year	Max Rainfall	Min Year	Min Rainfall	Mean	SD	Range
Babile	1973	1416.5	1983	563.5	1032.0	157.3	853.0
Bole	1968	1819.6	2014	742.1	1094.4	196.4	1077.5
Bolgatanga	1996	1306.8	1977	633.7	952.8	148.8	673.1
Damongo	1963	1527.4	1998	716.3	1086.8	176.0	811.1
Navrongo	1999	1365.3	2015	338.4	962.4	184.7	1026.9
Tamale	1963	1666.4	2015	654.7	1089.2	192.4	1011.7
Vea	1999	1275.9	1984	594.5	906.9	147.6	681.4
Wa	1963	1543	1986	522.9	1040.5	191.7	1020.1
Walewale	1979	1804.9	1986	469.3	909.7	217.4	1335.6
Yendi	1989	1712.1	1983	832.7	1239.9	206.0	879.4
Zuarungu	2007	1463.9	1977	605.0	1001.5	189.0	858.9

Source: Asare, 2021

The highest annual rainfall received within the study area from 1960 to 2017 was 1819mm. This was recorded in 1968 at Bole. The highest annual rainfall recorded in the study area for all the eleven stations ranged between 1275.9mm recorded at Vea in 1999 and 1819.3mm recorded at Bole in 1968.

The lowest annual rainfall recorded during the same period totaled 469 mm. This was recorded at Walewale in 1986. The smallest yearly rainfall total ranges between 469 mm recorded at Walewale in 1986 with the highest of the lowest being 832.7mm recorded at Yendi in 1983. Mean rainfall recorded in the study area spans between 1239.9mm and 906.7mm. The highest mean was recorded at Yendi with the lowest mean recorded at Vea. Walewale has the highest standard deviation from the mean with Bolgatanga recording the least (148.8mm) deviation from the mean. Walewale recorded the highest (1335.6mm) range with Vea recording the lowest range of 681.4mm.

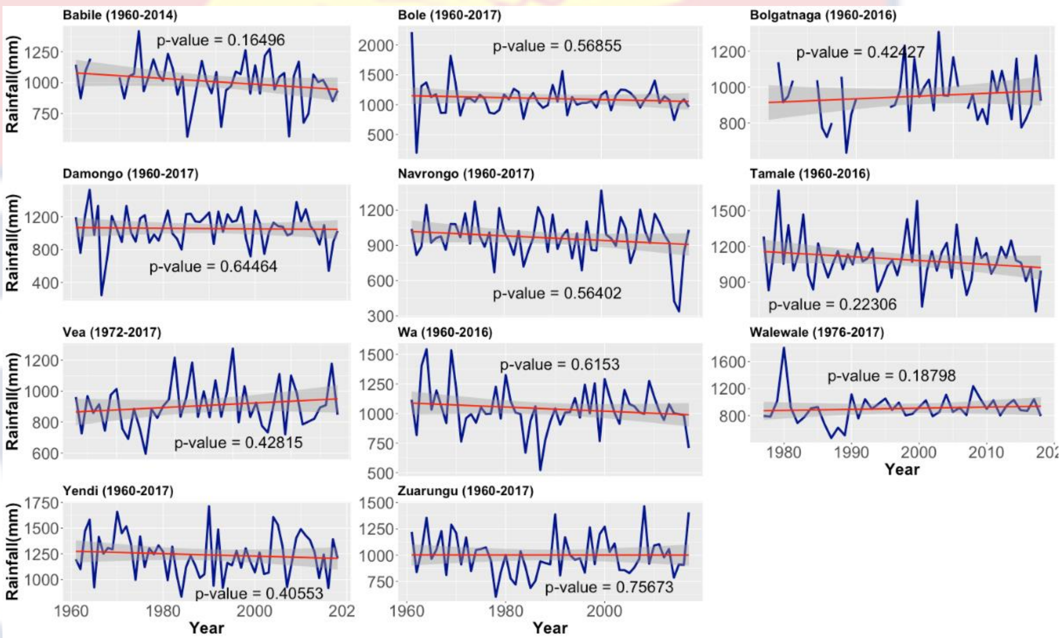


Figure 4: Annual rainfall total
Source: Asare, 2021

Annual rainfall totals have shown different trends by the stations, as shown in Figure 4. All the stations, except for Walewale, Vea, and Bolgatanga, are showing a decreasing trend. Vea and Bolgatanga are showing increasing trends. None of the trends, however, is statistically significant from the mean.

Annual rainfall anomaly plot

Figure 3 presents how each year's rainfall over the period for each station differs from the long-term mean. The behaviour and pattern for each station differ in addition to the extent of the deviation.

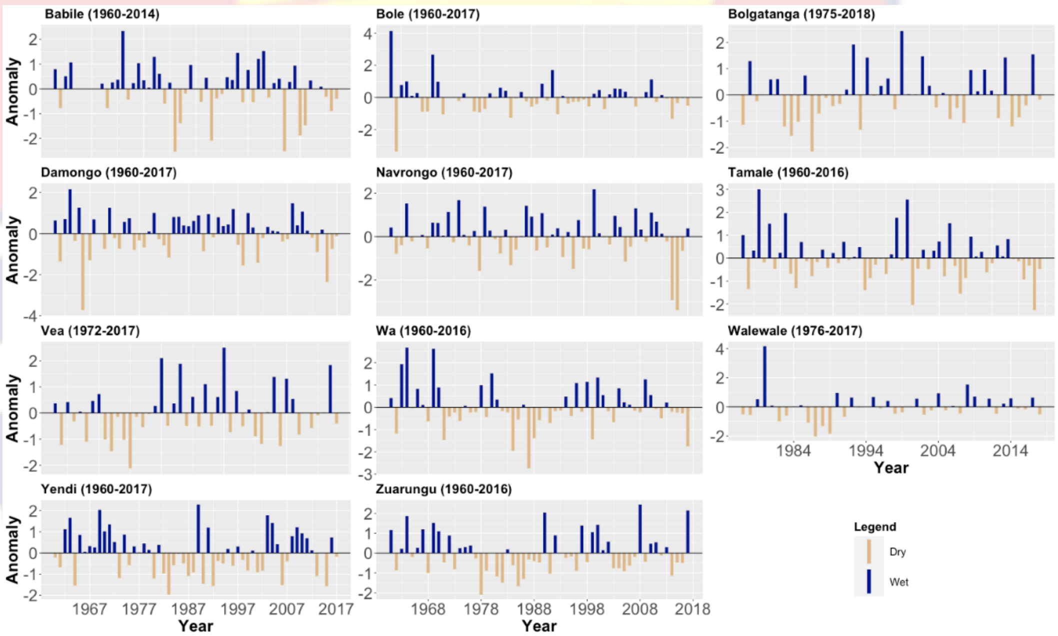


Figure 5: Rainfall anomaly plot
Source: Asare, 2021

All the stations are showing deviations from the long-term mean. The deviation from the long-term mean is positive for some years and negative for some other years. With the exception of Walewale and Bole, the remaining stations have a wide deviation from their respective long-term means. Consistent with all the stations in the study area is a negative anomaly being depicted in the last five years (2012 - 2017).

Heavy rainfall events

To understand the characteristic nature of the changing climate in the study area, there was the need to understand the nature of the rainfall events experienced since they may increase, decrease, or remain stable. The study aims to underscore whether heavy rainfall events are on the increase in the study area and if that could also underpin any evidence of climate change in the north of Ghana.

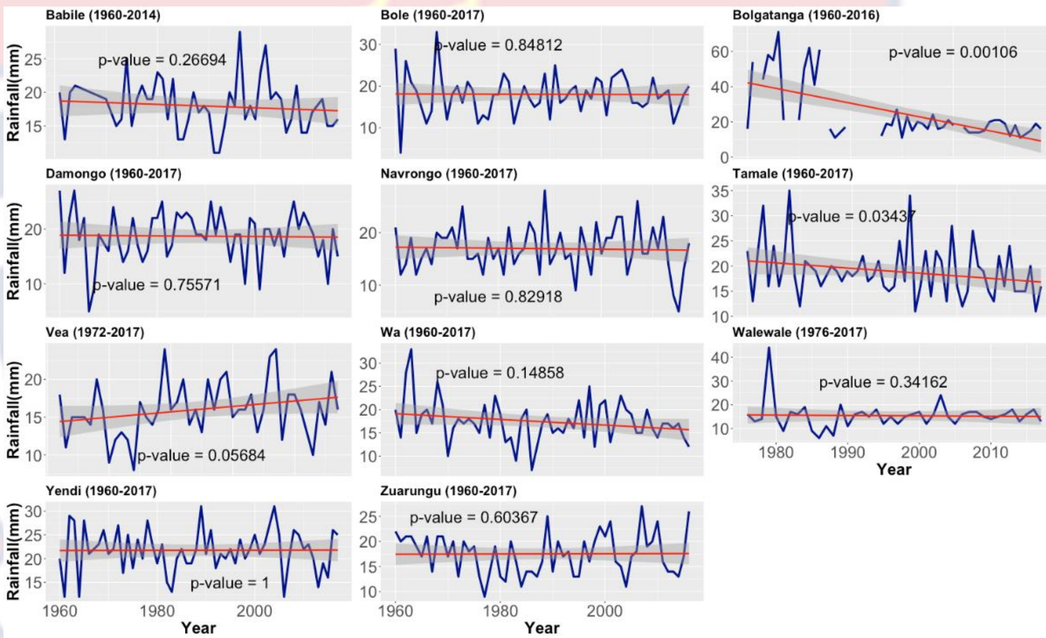


Figure 6:Heavy rainfall events occurrence
Source: Asare, 2021

As shown by Figure 6, heavy rainfall events in the study area have generally not shown any change except for Bolgatanga and Tamale for the entire north of Ghana. For all the stations in the study area, there is inter-annual variation in heavy rainfall events. It is only Vea that is showing an increasing trend in heavy rainfall, but it is not significant. The rest of the stations are mostly and contrastingly showing a decreasing trend but not significant. The decreasing trend at Bolgatanga and Tamale is statistically significant with P values of 0.001 and 0.03, respectively.

Annual rainy days

The number of rainy days for each year for the last fifty-seven years (57) was analyzed to assess whether there has been any change over the years. The results are shown in Figure 7 for all the stations in the study area.

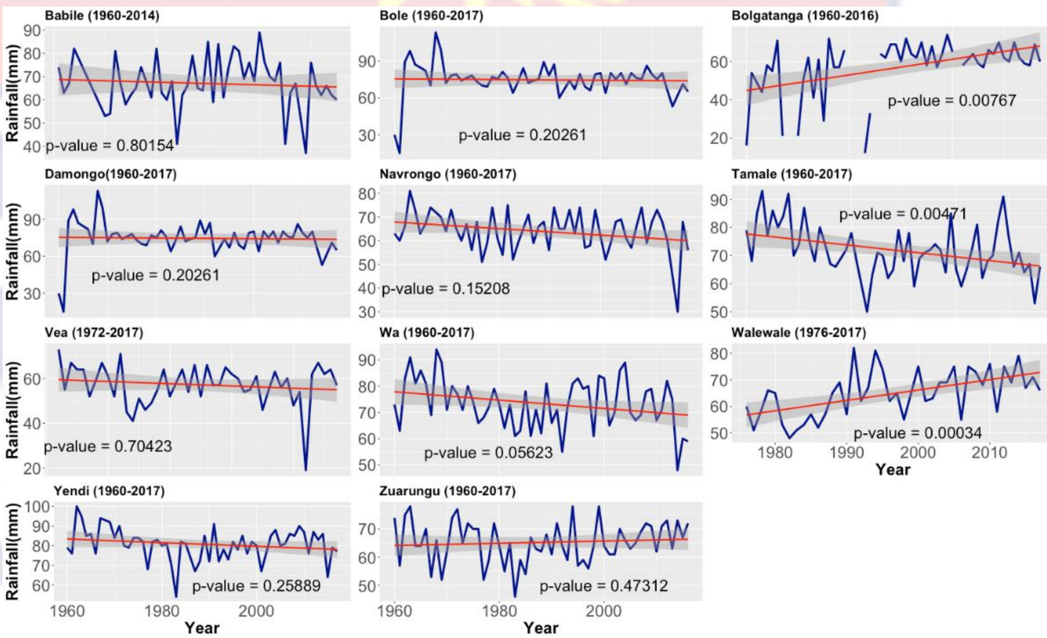


Figure 7: Annual rainy days
Source: Asare, 2021

The behavior and nature of rainy days in the study area are not uniform for the stations. Rainy days for all the stations are decreasing in the study area, except Bolgatanga and Walewale. For all the stations showing a decreasing trend in rainy days, it is only Tamale, which is statistically significant, with a p-value of 0.005. Bolgatanga and Walewale, on the other hand, are showing an increasing trend in rainy days. The rising trend in rainy days for Bolgatanga and Walewale is statistically significant, with P values of 0.01 and 0.00, respectively. However, the difference in the trajectory of trends, consistent with all the stations, is the annual variations in the number of rainy days for each year for each station.

Table 3 presents the highest rainy days ever recorded in the study area for each of the stations and the entire north of Ghana. The highest number of rainy days per month ever recorded in the north of Ghana is 16 days of rainfall events within a month. This was recorded at Yendi in September, which is its peak month for the rainy season. This means that it rained over a half period of the month. The maximum rainy day at Bolgatanga, which is 11 days of rain within a month, is the lowest in the north of Ghana. The rest of the stations' highest rainy days ever recorded range between 11 and 16. The highest rainy days always occur in the peak month of the rainy season, that is either August or September.

Table 3:Highest rainy days for each station

Station	Month	Max RainDays
Babile	August	12
Bole	September	13
Bolga	August	11
Damongo	September	13
Navrongo	August	15
Tamale	September	15
Vea	August	13
Wa	September	14
Walewale	August	13
Yendi	September	16
Zuarungu	August	15

Source: Asare, 2021

It is only at Walewale that the highest rainy day recorded differed from the peak month of the rainy season.

Rainfall climatology

The monthly rainfall totals depict a single peak in the rainfall season for the study area. From Figure 8 below, the peak month differs from station to station.

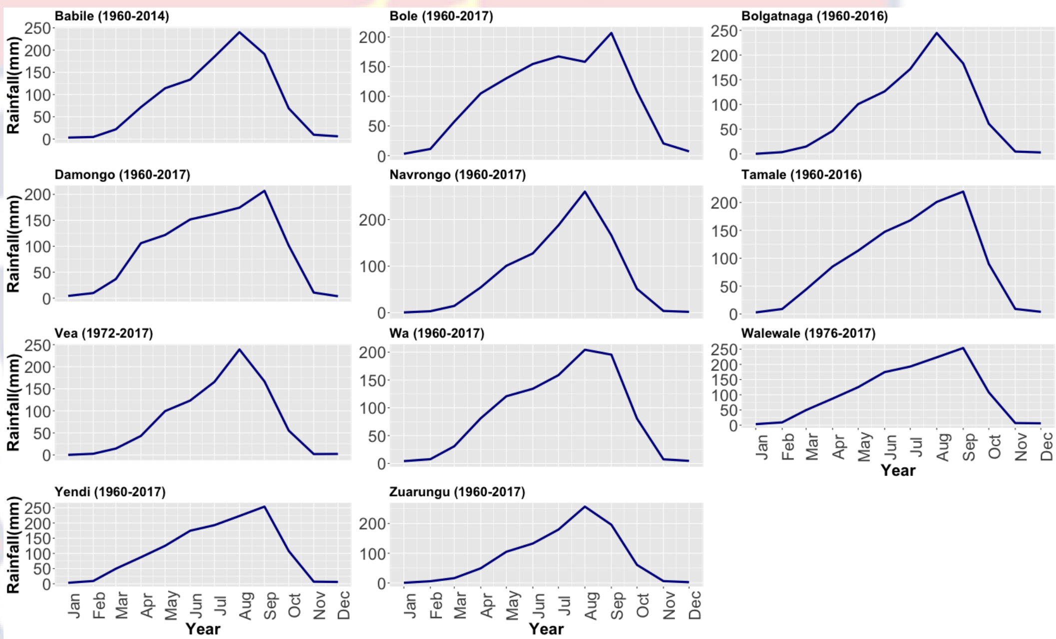


Figure 8: Rainfall climatology of the study area
Source: Asare, 2021

Rainfall peaks in August for Vea, Zuarungu, Wa, Babile, Navrongo, and Bolgatanga. On the contrary, Walewale, Tamale, Yendi, Damango, and Bole rainfall peaks in September. Consistent with all the stations in the study area is the lack or low amount of rainfall received in the study area from November to March each year. The period from November to December is described as the dry season or harmattan. Both rainfall totals and events build up gradually, particularly from the month of April, peaks in August or September, and then declines.

Comparing two climatologies

Two climatologies were compared for this study to assess any change in the study area's rainfall pattern. Also, to uncover any change in the climatology of the study area.

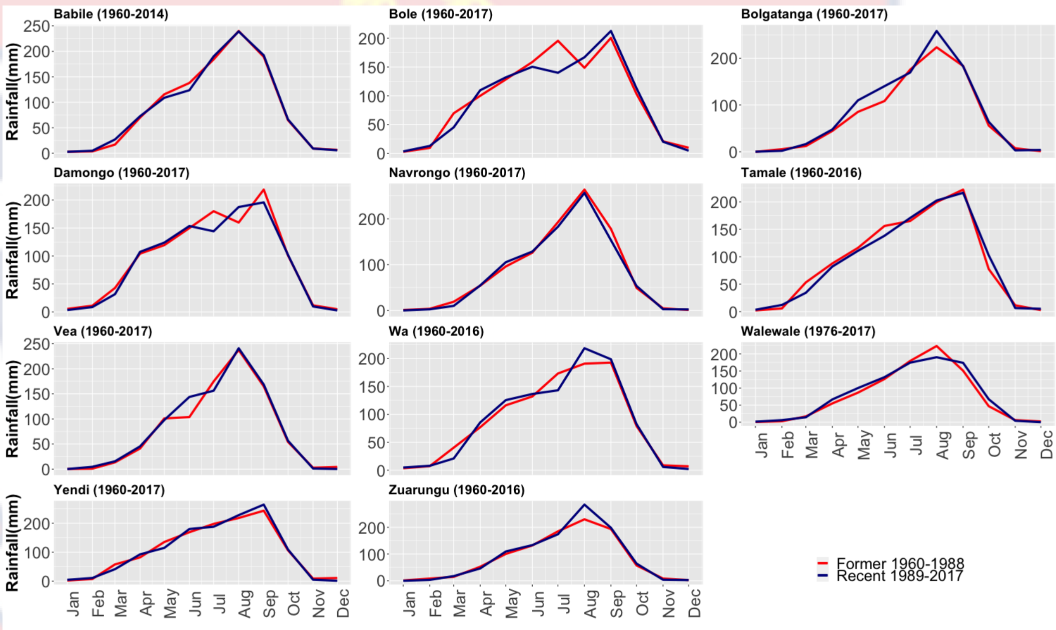


Figure 9: Comparism of two climatologies
Source: Asare, 2021

The results after comparing the two periods for each station, as shown in Figure 9 reveal that none of the stations has seen a complete change in the rainfall climatology in the study area. However, there are changes in some of the months, and the margins differ from station to station. The rainfall pattern of stations in terms of the beginning of the season, peak, and cessation remain unchanged.

However, the situation is different for Wa, where the peak month has retreated from September to August. Despite the general consistency of the old (1960-1988) climatology with the new (1989-2017), there are variations. While Zuarungu, Bolgatanga, Yendi, and Wa have seen an increase in rainfall at their peak, Walewale and Damango have seen a decline at their peak in recent years. But Tamale, Babile, Navrongo, Bole, and Vea have not seen any shift at their peak.

Temperature

Temperature is an essential component of the climate of an area. This study analyzed both minimum and maximum temperatures to ascertain the state of this critical climate variable. Changes in temperature over a while have a lot of implications for the livelihoods of the people and sustainable development. This section presents the analysis conducted on the minimum and maximum temperatures. The study focused on the time series plot of annual average temperature, anomaly plot, and seasonal cycle, and compares two climatological periods for minimum and maximum temperature.

Maximum temperature

The maximum temperature indicates the degree of hotness during the day in the study area. To understand the state of the climate in the study area, maximum temperature data were analyzed. The analysis focused on the annual average temperature, anomaly plot, and seasonal cycle, and compares two climatological periods for minimum and maximum temperature.

The seasonal cycle of maximum temperature

The seasonal cycle presents temperature from the first day of the year to the last day of the year.

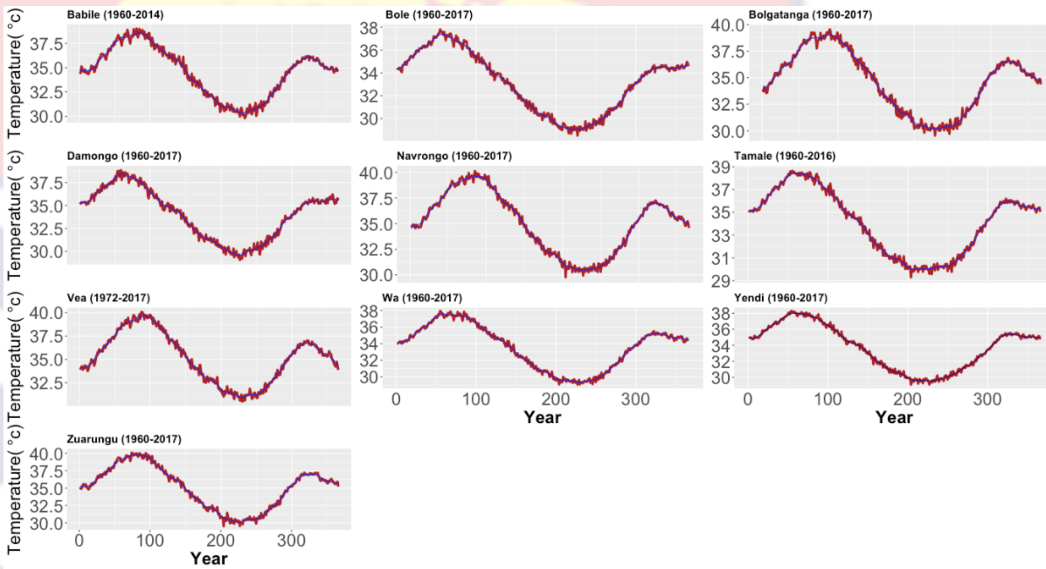


Figure 10: Maximum temperature cycle
Source: Asare, 2021

The maximum temperature over the north of Ghana reaches its peak in March. After the peak in March, it declines until it reaches the minimum in August. The cycle of maximum temperature is consistent with all the stations in the north of Ghana. The period where the maximum temperature is seen to rise until it reaches its peak in March is noted for its dryness.

Table 4 presents the daily statistics of maximum temperature for the stations in the north of Ghana. The hottest day temperature recorded in the north of Ghana is 45℃, and it was recorded in 1991 at Zuarungu. This was repeated in 2005 at Vea.

The lowest hottest day temperature of 42℃ was recorded in 2010 and repeated in 2016, all at Wa. The difference in the hottest day temperature for the north of Ghana over the analysis period is 30℃. The mean hottest day temperature for the north of Ghana is 43.4℃. Seven out of the ten stations recorded their highest-ever day temperature in March, which is consistent with the seasonal cycle plot, as shown in Figure 10. Again, the hottest day temperature for all the stations except for Damango was recorded after 1980.

Table 4:Summary statistics of daily maximum temperature

Station	Max.day	Max.tmax	Min.day	Min.tmax	Sd	Mean	Range
Babile	25/03/1983	44.4	17/07/2003	23.6	3.2	34.6	20.8
Babile	25/03/1983	44.4	11/08/2010	23.6	3.2	34.6	20.8
Bole	06/03/2013	43.5	08/06/1962	21.7	3.3	33.1	21.8
Bolgatanga	06/03/2013	43.5	01/07/1989	23	3.5	34.6	20.5
Damongo	12/03/1973	42.8	19/08/1961	22.2	3.3	34.0	20.6
Damongo	13/03/1973	42.8	19/08/1961	22.2	3.3	34.0	20.6
Damongo	15/03/1973	42.8	19/08/1961	22.2	3.3	34.0	20.6
Navrongo	19/04/2010	44.2	01/07/1989	22.8	3.6	35.1	21.4
Tamale	08/04/1983	42.8	09/09/1967	22.9	3.4	34.1	19.9
Tamale	08/02/1998	42.8	09/09/1967	22.9	3.4	34.1	19.9
Vea	12/10/2005	45	20/07/2016	23.2	3.4	35.2	21.8
Wa	21/02/2010	42	11/08/2010	22.1	3.3	33.6	19.9
Wa	02/03/2016	42	11/08/2010	22.1	3.3	33.6	19.9
Yendi	31/03/2017	42.3	22/07/1975	22.2	3.3	33.7	20.1
Zuarungu	22/03/1991	45	22/07/1975	22.2	3.6	35.0	22.8

Source: Asare, 2021

The coldest day temperature ever recorded in the study area was 22.1℃. This was recorded in August 2010 at Wa. The coldest day temperature recorded in the study area ranges from 22.1℃ at Wa to 23.6℃ at Babile. All the stations recorded their coldest day temperature either in July, August or September, which is a month before or after August, the coldest month of the year. The mean coldest day temperature for the north of Ghana is 22.6℃. The mean daily maximum temperature ranges between 35.2℃ and 33.1℃, with a difference of 2.1℃. The highest daily mean temperature was recorded at Vea in the Upper East region. The lowest was recorded at Bole in the Savannah region, indicating a spatial variation. The standard deviation from the daily mean ranges between 3.2℃ at Babile to 3.6℃ at Navrongo with a mean of 3.3℃. The daily maximum temperature has a considerable variation spatially and temporally. The range in daily maximum temperature spans between 19.9℃ at Tamale and Wa in the Northern and Upper West Region to 22.8℃ at Zuarungu in the Upper East Region. The mean range is about 20.8℃.

Annual average maximum temperature

The annual average maximum temperature, which describes the degree of hotness during the day varies from station to station. Consistent with all the stations is the continuous increase in temperature and interannual variations in temperature across the years.

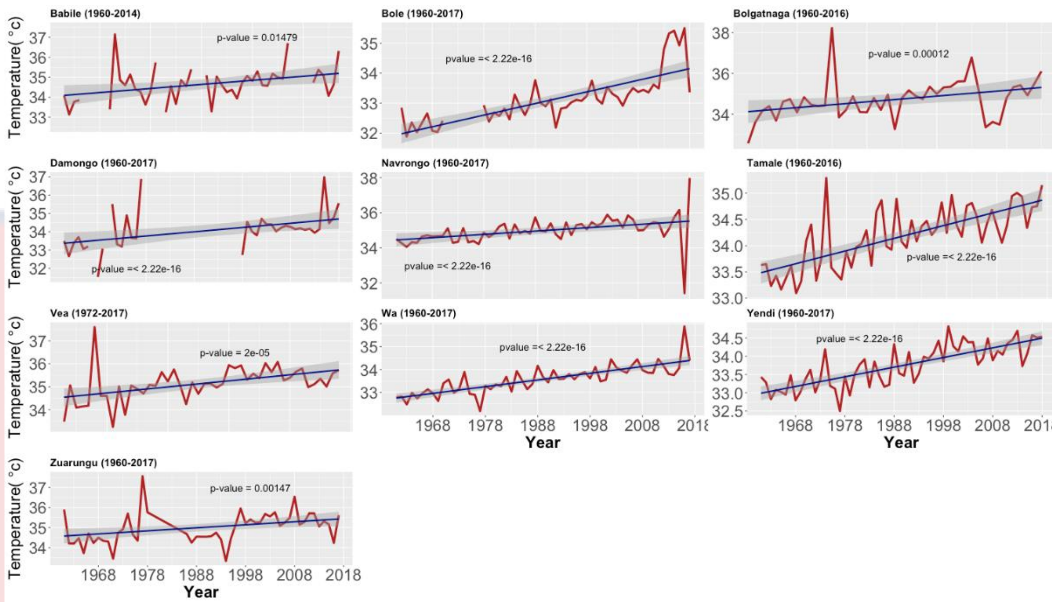


Figure 11: Annual Maximum temperature
Source: Asare, 2021

Trend analysis of maximum temperature has shown an increasing trend throughout the study area. The rising trend in maximum temperature is statistically significant for the stations in the north of Ghana. This means that there has been a considerable deviation from the long-term mean. This indicates that maximum temperature may be changing in the study area, and it is consistent with global warming. Interestingly, the differences in the extent of variation and the gradient of the slope in maximum temperature differ across the stations.

Anomaly plot for maximum temperature

The study further assessed how each year's average maximum temperature deviated from the long-term mean as the time series plot above (figure) has proved a statistically significant increasing trend in maximum temperature.

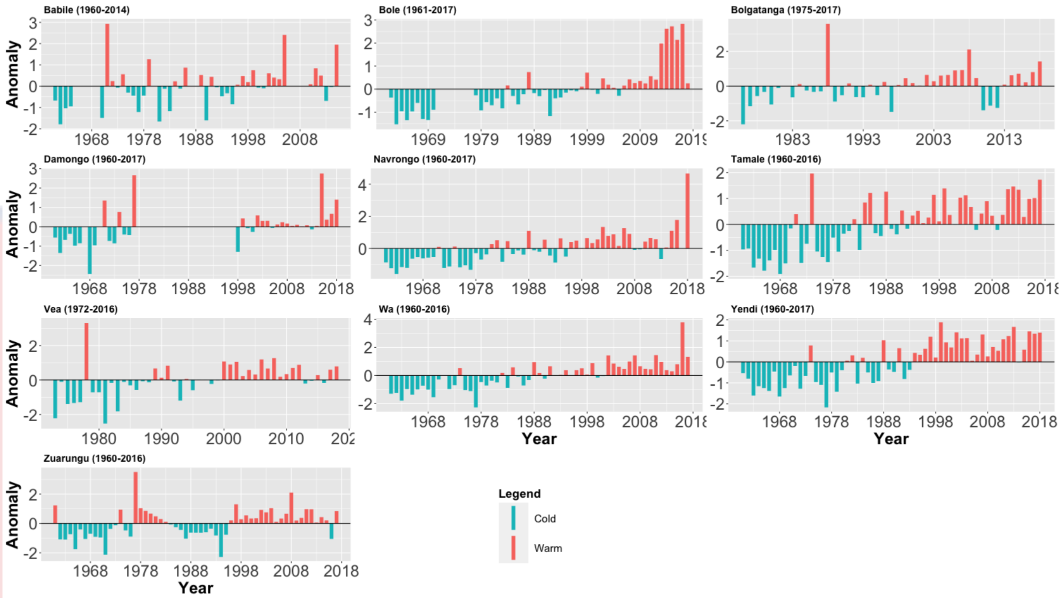


Figure 12: Anomaly plot for Maximum temperature
Source: Asare, 2021

Most parts of the sixty's up to the late 1990s had maximum temperatures below the long-term mean. Beyond the late 1990s, the temperature has consistently been increasing for all the stations, as evidenced by positive anomaly to the recent. Embedded in the positive anomaly is a variation from station to station. This result also affirms the time series analysis, which was statistically significant for all the stations in the north of Ghana. Interesting to note again is the consistent positive anomaly for all the stations for the past decade or more. This is an affirmation of climate change.

Table 5:Summary statistics for temperature

Station	Max Year	Max.Tmax	Min Year	Min.Tmax	Sd	Mean	Range
Babile	1973	35.1	2007	28.3	1.3	34.5	8.9
Bole	2016	35.5	1962	31.9	0.8	33.2	3.6
Bolgatanga	1987	38.2	1975	32.6	1.0	34.7	5.7
Damongo	2014	37.0	1967	31.5	1.1	34.1	5.5
Navrongo	2017	38.0	2016	31.4	0.8	35.0	6.6
Tamale	1973	35.3	1967	33.1	0.6	34.2	2.2
Vea	1977	37.6	1980	33.3	0.7	35.1	4.4
Wa	2015	35.9	1976	32.2	0.6	33.6	3.7
Yendi	1998	34.8	1976	32.5	0.6	33.7	2.3
Zuarungu	1976	37.6	1993	33.3	0.7	35.0	4.2

Source: Asare, 2021

It is evident from Figure 12 that the maximum temperature for the entire north of Ghana has been increasing in recent years, which is an affirmation of global warming. When it comes to the hottest year during the day (maximum temperature) for the north of Ghana, it varies from station to station, and for some stations, the hottest year has not been recent, as shown in Table 5. The highest annual mean maximum temperature of 38.2℃ was recorded in 1987 at Bolgatanga, followed by 38.0℃ recorded in 2017 at Navrongo, all in the Upper East Region of Ghana. Most of the highest mean maximum temperature was recorded in the 1970s (Tamale, Zuarungu, Vea, and Babile) and after the year 2010 (Bole, Damango, Navrongo, and Wa). The highest annual mean maximum temperature ranges between 38.2℃ and 34.8℃. The lowest annual mean maximum temperature of 28.3℃ was recorded in 2007 at Babile. This was followed by 31.40℃ in 2016 at Bole. The lowest annual mean maximum temperature ranges between 28.3℃ and 33.3℃. The mean maximum temperature for the entire north of Ghana for the period of analysis (1960-2017) is 34.3℃ with a mean, standard deviation of 0.8℃. The mean, however, varies from station to station. The highest annual mean maximum temperature recorded is 35.0℃ at Navrongo and Zuarungu, all in the Upper East Region of Ghana with the lowest 33.2℃ recorded at Bole in the Savannah region of Ghana. Babile has the highest variability in mean annual maximum temperature of 8.9℃, with Tamale having the least variability of 2.2℃.

Annual average maximum temperature

This study further conducted analyses to ascertain the state of temperature climatology of the study area. This is important since the study seeks to uncover any change concerning the north of Ghana's climate. The pattern, as known, remains the same as shown in Figure 13. The significant rise in maximum temperature from November, which peaks in March and begins to decline until it reaches its minimum in August, has not changed. The maximum temperature pattern remains the same for all the stations in the study area, except for Bole. Bole's maximum temperature peak month has shifted from February to March, as shown in Figure 13. The peak maximum temperature ranges between 38℃ to 40℃. The stations in the Upper East of the north of Ghana recorded the highest temperature in the study area. The monthly maximum temperature recorded in August hovers around 30℃ for all the stations in the study area.

Figure 13: Monthly maximum temperature
Source: Asare, 2021

The temperature difference between the peak months of March and August is about 10℃.

Comparing two climatologies

There are dynamics in the changing pattern of maximum temperature in the study area. After assessing the maximum temperature pattern in the study, which has remained unchanged, the study went further to ascertain any shift in the maximum temperature climatology in the study. This was done by comparing two periods for each station to discover any change. This revealed an unusual pattern spatially and temporally. The red colour on the map represents the recent (1989-2017) period, and the blue colour represents the past (1960-1988). The analysis revealed a shift in climatology with the current shifting upwards for all the stations, although they differ in time and space. The maximum temperature change is more pronounced during the dry season of the year compared to the rainy season. This means that the hottest period of the year is becoming warmer, and the coldest period is becoming more heated. There is an average shift in maximum temperature, ranging between 1℃ to 2℃ depending on the time of the year.

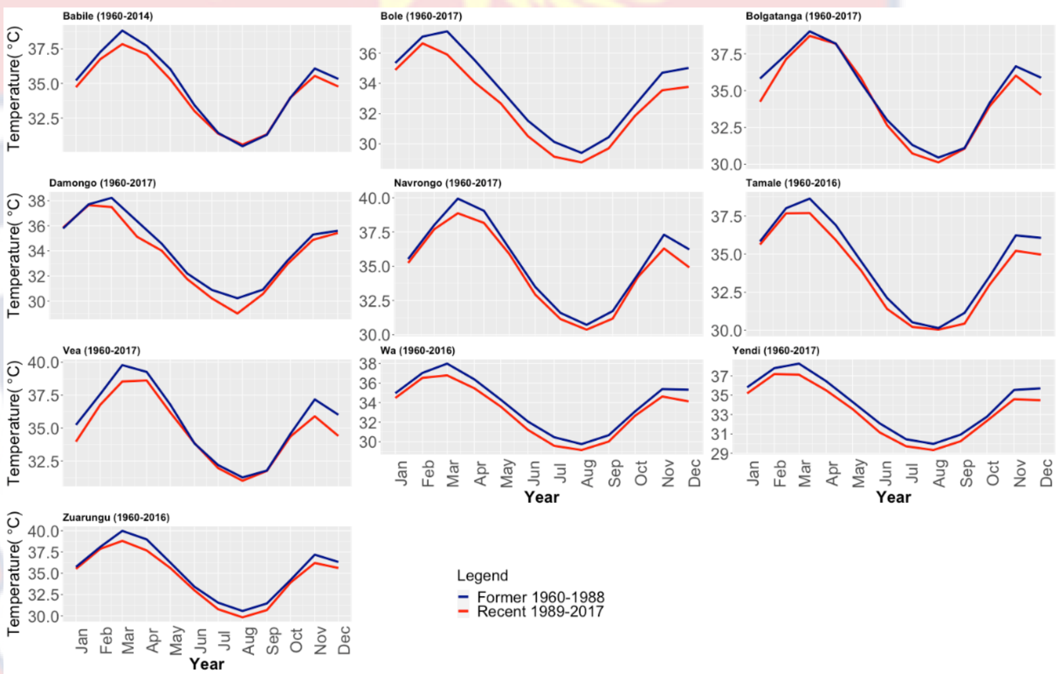


Figure 14: Comparing two periods of maximum temperature
Source: Asare, 2021

Vea, Babile, and Tamale have not seen many changes during the coldest period of the day in August as the rest have seen significant changes. Damongo has seen about 2℃ change in temperature for the month of August.

Minimum temperature

The minimum temperature indicates the degree of hotness during the night. It provides us with information on the night temperature. Our understanding of the pattern and trends in temperature will help us to underscore changes being experienced during the night. To achieve these, analyses were performed on a seasonal cycle, trend analysis, anomaly plot, monthly plot, and comparison of two periods.

Seasonal cycle of minimum temperature

The seasonal temperature cycle reflects the daily temperature from day one of the year to the last day of the year. Night temperature has two peaks during the year. The first peak is in April, and the second peak is in October each year. The minimum temperature reaches its minimum in August, which is the month when the maximum temperature also reaches its minimum. The seasonal cycle is consistent with all the stations in the north of Ghana.

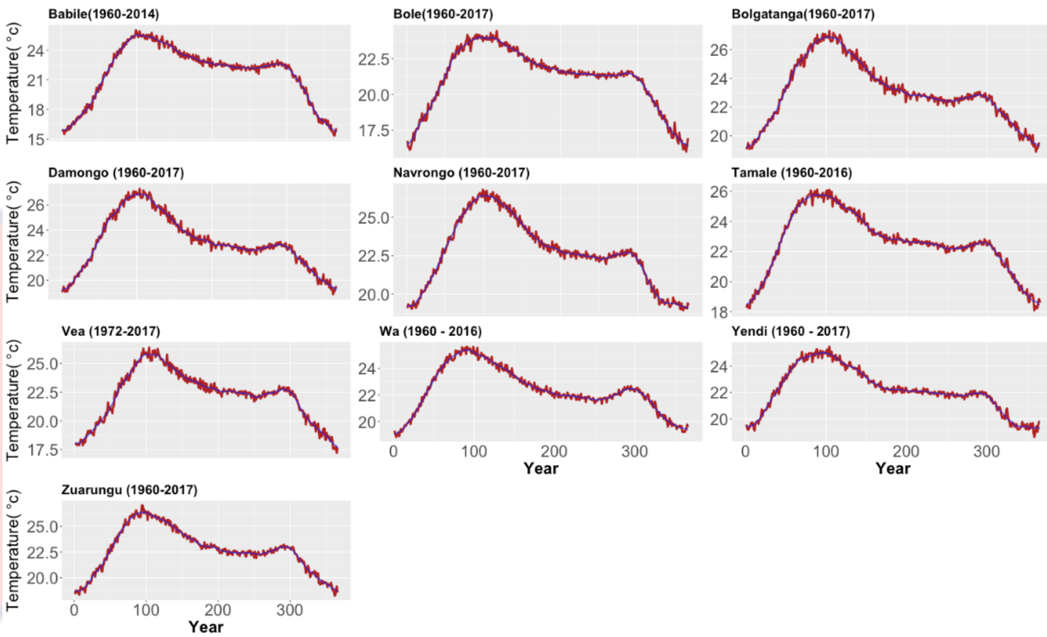


Figure 15: Seasonal cycle of minimum temperature
Source: Asare, 2021

The minimum temperature reaches its first peak in April, and after that, it gradually declines until it reaches its lowest in August. After reaching its minimum in August, it begins to rise until it reaches another peak in October, after which it declines again.

Table 6:Summary statistics of minimum temperature

Station	Max.day	Max.tmin	Min.day	Min.tmin	Sd	Mean	Range
Babile	30/03/2012	30.7	29/12/1960	7.2	3.5	21.7	23.5
Bole	26/04/2016	30.5	04/12/1982	9	2.9	21.1	21.5
Bole	02/05/2016	30.5	04/12/1982	9	2.9	21.1	21.5
Bolgatanga	23/04/1983	31.1	05/12/1977	13.3	2.8	23.0	17.8
Bolgatanga	27/04/1987	31.1	28/12/1977	13.3	2.8	23.0	17.8
Bolgatanga	28/04/1987	31.1	29/12/1977	13.3	2.8	23.0	17.8
Bolgatanga	NA	NA	20/12/1980	13.3	2.8	23.0	17.8
Damongo	04/03/2005	29	26/12/2002	10	2.9	21.2	19
Damongo	05/03/2005	29	29/11/2006	10	2.9	21.2	19
Navrongo	22/03/1979	31.6	19/12/1980	12.7	2.8	22.7	18.9
Tamale	29/03/2004	30.3	08/01/2012	10.5	3.4	22.6	19.8
Tamale	29/03/2004	30.3	17/01/2012	10.5	3.4	22.6	19.8
Vea	18/04/1998	31	25/01/1975	6.7	3.3	22.2	24.3
Vea	06/03/2005	31	25/01/1975	6.7	3.3	22.2	24.3
Wa	31/03/1988	31.7	20/12/1980	12.2	2.4	22.4	19.5
Yendi	26/04/2017	29.5	05/12/1969	12.8	2.3	22.2	16.7
Yendi	26/04/2017	29.5	23/12/1984	12.8	2.3	22.2	16.7
Zuarungu	01/06/2006	31.7	04/02/1967	12.2	2.8	22.7	19.5

Source: Asare, 2021

Table 6 presents daily minimum temperature statistics, which provide information about night temperature for the north of Ghana. The hottest night temperature recorded over the north of Ghana during the period of analysis ranges between 29℃ recorded in 2005 at Damongo and 31.7℃ recorded in 1988 at Wa and Zuarungu in 2006. The mean hottest night temperature in the north of Ghana is 30.6℃. All the hottest night temperature was recorded between 1979 and 2017 with most of the hottest night occurring after the year 2000. Besides Zuarungu, where its hottest night was recorded in June, the rest of the stations were recorded in April and March, the hottest month of the year. Unlike the hottest night, recorded in March and April, the coldest night was recorded in December and January. It is only Zuarungu, whose record is in February. The coldest night temperature recorded during the period of the analysis occurred between 1960 and 1980, except for Tamale, which was recorded in 2012. The coldest night temperature ranges between 6.7℃ recorded in 1975 at Vea and 13.3℃ recorded in 1977 in Bolgatanga. The mean coldest night for north Ghana is 10.9℃. The mean daily night temperature ranges between 21.1℃ and 23.0$^{℃}$ with a standard deviation range of 2.3℃ to 3.5℃. The mean daily temperature is 22.2℃, with a mean, standard deviation of 2.9℃. There is also a high variability in the night temperature. The range spans from 16.7℃ recorded at Zuarungu to 24.3℃ recorded at Vea. The mean of the range is 19.7℃.

Annual average minimum temperature

The trend analysis of minimum temperature for the north of Ghana revealed an increasing trend for all the stations in the study area. Imbedded also in the upward trend in minimum temperature is interannual variability.

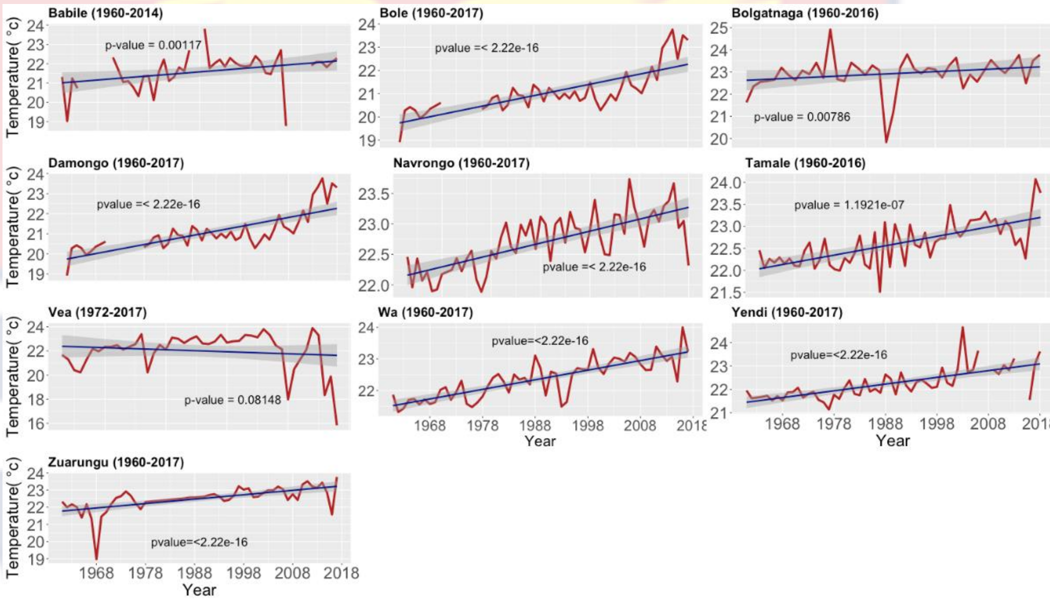


Figure 16: Annual Minimum temperature
Source: Asare, 2021

The gradient of the slope of the trend line for minimum temperature is relatively steeper than that for maximum temperature. There has been a consistent rise in night temperature in the study area since the 1990s and this trend is still ongoing for most of the stations. Except for Vea, all the remaining stations' increasing trend is statistically significant. This means that there has been a deviation from the long-term mean which is evidence for climate change.

Anomaly plot for minimum temperature

The anomaly plots were produced to appreciate and understand the nature of the increasing trends from year to year. The past 15 to 20 years have been mostly dominated by positive anomaly for all the stations in the north of Ghana. For most of the stations, the night temperature was below the long-term mean for the 1960s and 1970s, but this began to change in the 1980s. For both periods where negative and positive anomaly were experienced, you will notice that the extent of variation differs from station to station, confirming spatial and temporal variations. This result is also affirming the time series analysis, which was statistically significant for all the stations in the north of Ghana. Interesting to note again is the consistent positive anomaly for all the stations for the past decade or more. This is an affirmation of climate change in the study area.

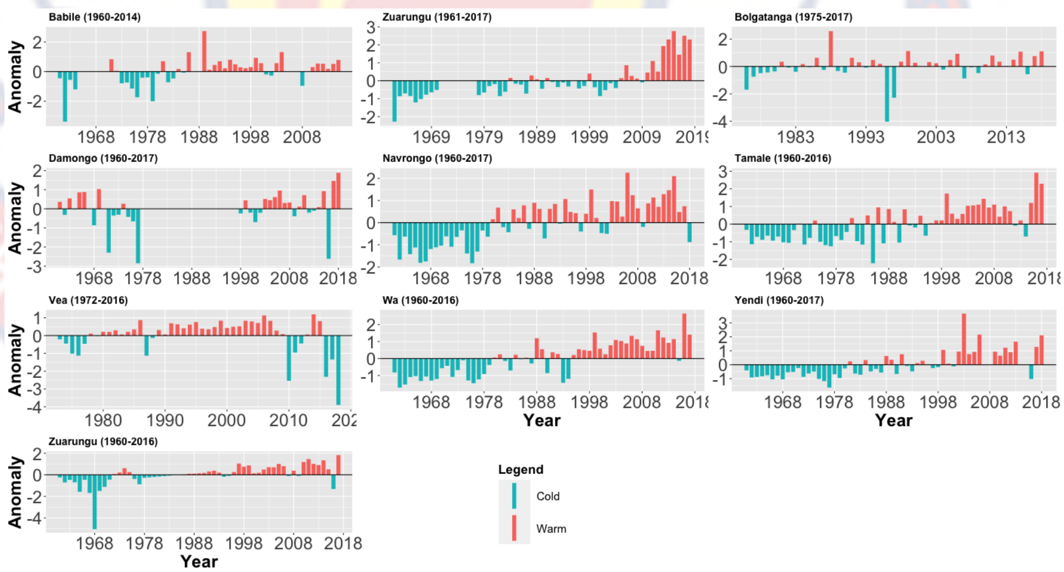


Figure 17: Minimum temperature anomaly
Source: Asare, 2021

Table 7 provides summary statistics for minimum temperature, which also gives further details and affirms the previous analysis. The highest annual night temperature recorded for the north of Ghana ranges between 23.8℃ to 24.9℃. The mean annual hottest night temperature for the north of Ghana is 24℃. The hottest annual night temperature of 24.9℃ was recorded in 1987 at Bolgatanga with a minimum of 23.8℃ recorded in 1988, 2014, and 2016 at Babile, Bole, and Zuarungu respectively. Except for Bolgatanga and Babile, whose highest annual night temperature was recorded in the late 1980s, the rest of the stations were recorded after the year 2000. The hottest annual temperature for six of the stations was recorded in the last five years. This also confirms the consistent positive anomaly dominating all the stations. The coldest annual night temperature for the north of Ghana ranges between 18.8℃ to 21.9℃. The lowest annual night temperature of 18.8℃ was recorded in 2004 at Babile, with the highest of 21.9℃ recorded in Navrongo in 1975. Contrastingly, while the hottest annual night temperature was recorded for most of the stations after the year, 2000 that of the coldest was recorded before the year 2000.

Table 7:Summary statistics of annual minimum temperature

Station	Max.Year	Max.Tmin	Min Year	Min.Tmin	Sd	Mean	Range
Babile	1988	23.8	2004	18.8	0.9	21.6	5.0
Bole	2014	23.8	1961	18.9	1.0	21.1	4.8
Bolgatanga	1987	24.9	1995	19.8	0.8	22.9	5.1
Damongo	2014	23.8	1961	18.9	1.0	21.1	4.8
Navrongo	2005	23.7	1975	21.9	0.5	22.7	1.8
Tamale	2015	24.1	1984	21.5	0.5	22.6	2.6
Vea	2013	23.9	2017	15.8	1.6	22.0	8.1
Wa	2015	24.0	1961	21.3	0.6	22.4	2.7
Yendi	2002	24.7	1976	21.1	0.7	22.2	3.5
Zuarungu	2016	23.8	1967	19.0	0.7	22.5	4.8

Source: Asare, 2021

The average annual night temperature for the north of Ghana is 22.1℃, with a mean, standard deviation of 0.8℃. The mean annual night temperature for all the stations ranges between 21.1℃ to 22.9℃, with the standard deviation ranging between 0.5℃ to 1.6℃. Vea has the highest variability of annual night temperature of 8 ℃, with Navrongo having the lowest of 1.8℃.

Climatology of minimum temperature

To ascertain the change in minimum temperature, the study sought to assess the climatology of minimum temperature to uncover any change or shift in the study area, as shown in Figure 18. The minimum temperature pattern in the study area has not seen any change over the period of analysis. The minimum temperature rises from January, peaks in April, and further declines until it reaches its lowest in August. After August it rises again and peaks in October and then declines again. This pattern remains the same for all the stations analyzed. The peak night temperature in April ranges from 24℃ to 27℃. The second peak night temperature in October ranges between 22℃ to 23℃. The stations in the Upper East of the north of Ghana recorded the highest temperature in the study area. The minimum monthly temperature recorded in August hovers around 22℃ for all the stations in the study area. The temperature difference between the peak months of April and October is 4℃. Important to note is the differences in the peaks for both minimum and maximum temperatures. While maximum temperature peaks in March and November, Minimum temperature peaks in April and October.

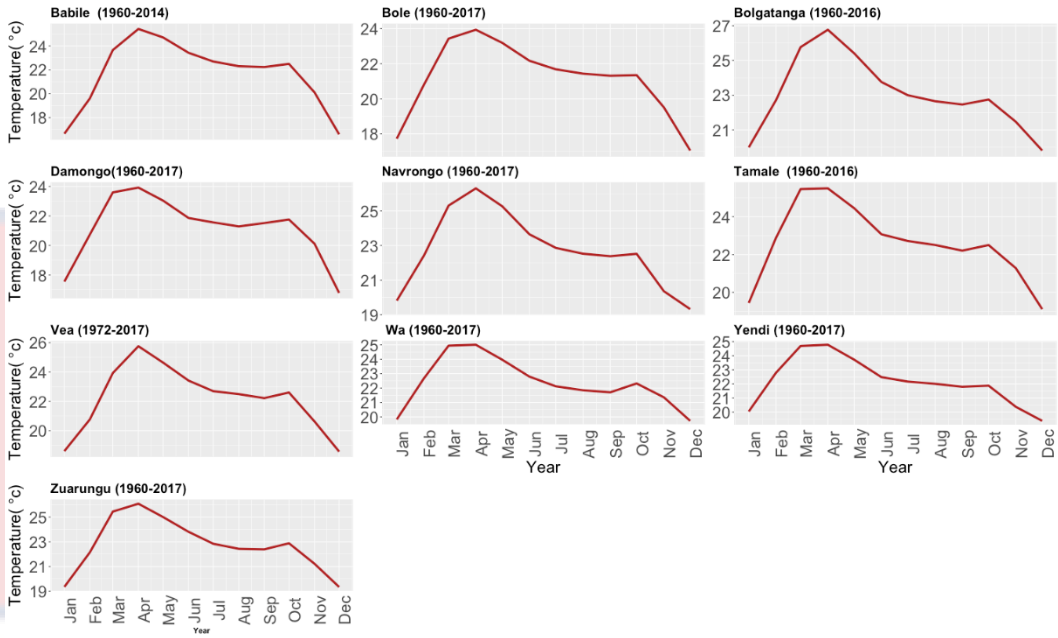


Figure 18: Monthly climatology of minimum temperature
Source: Asare, 2021

Comparing two climatology

After assessing possible changes in the minimum temperature climatology, further analysis was conducted to check if there has been an upward or downward shift.

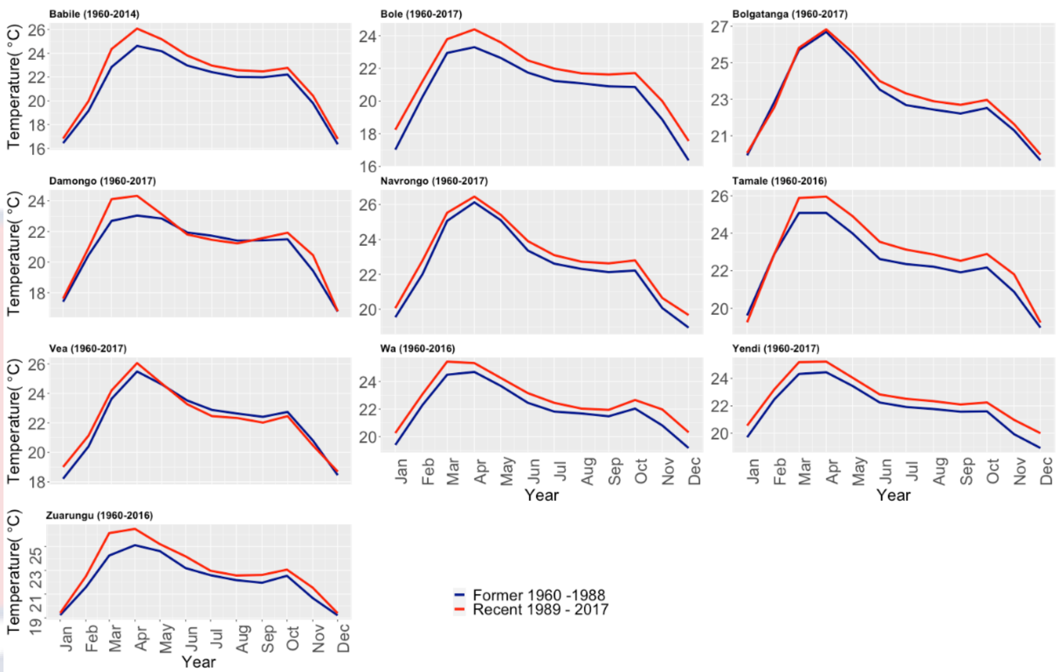


Figure 19: Comparing two periods of maximum temperature
Source: Asare, 2021

The result is presented in Figure 18, except for Vea and Damongo, the remainder of the stations have seen a complete upward shift. The recent period lies above the past period. This means that for all these stations, the night has become warmer throughout the year. Beyond April, night temperature seems to have slightly declined. Whereas the night temperature barely remains the same between May and October. The hottest period of the year is becoming hotter compared to the rest of the year. The temperature change per the upward shift of the recent period above the former ranges between 1℃ and 2℃.

Evapotranspiration

Evaporation is a crucial component of the climate of an area and it is also essential for agriculture. This is because it helps us to know the amount of water that is transferred from the soil, plants, and other surfaces into the atmosphere through evaporation and transpiration. The understanding of the current state of evapotranspiration is relevant for agriculture. The analysis focused on the time series plot of annual average evapotranspiration, anomaly plot, and seasonal cycle, and compared two climatological periods of evapotranspiration.

Seasonal cycle of evapotranspiration

The seasonal cycle for evapotranspiration presents the daily evapotranspiration from the beginning to the end of the year. The annual cycle of evapotranspiration follows a similar pattern, like the maximum temperature.

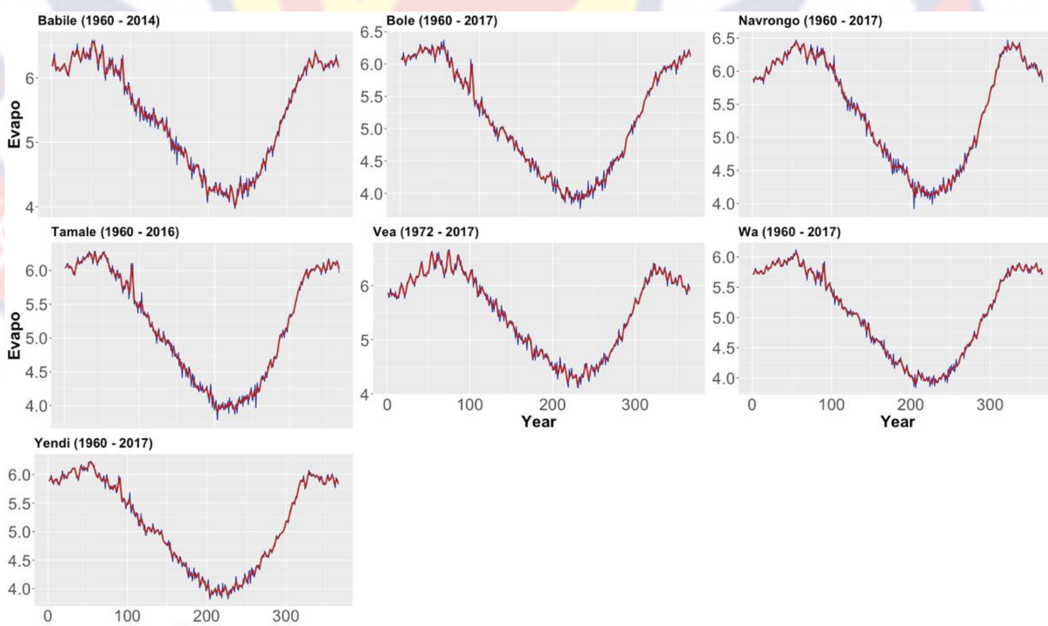


Figure 20**:**Seasonal cycle of evapotranspiration
Source: Asare, 2021

Evapotranspiration has two peaks during the year that is March and November while it reaches its minimum in August. Beyond each of the peak periods is a decline in evapotranspiration in the study area. Evapotranspiration reaches its minimum in August but that is the peak month for rainfall in the study area. The seasonal cycle of evapotranspiration is consistent with all the stations in the study area.

Table 8 presents the summary statistics of daily evapotranspiration for the period of analysis over the north of Ghana.

Table 8:Summary statistics of daily evapotranspiration

Station	Max.Day	Max.ETP	Min.Day	Min.ETP	Sd	Mean	Range
Babile	05/02/1998	8.6	16/07/2010	0.7	1.1	5.4	7.9
Bole	20/03/1983	8.2	02/08/2006	1.3	1.1	5.1	7.0
Navrongo	13/04/2017	8.7	11/08/1995	0.4	1.1	5.4	8.3
Tamale	22/02/1992	8.3	29/03/2009	1.0	1.1	5.2	7.2
Vea	14/04/2017	8.9	08/07/1994	0.9	1.1	5.5	8.0
Wa	02/03/2016	8.0	26/03/1980	0.4	1.0	5.1	7.6
Yendi	04/03/1990	8.1	06/08/1985	0.5	1.0	5.1	7.6

Source: Asare, 2021

The highest evapotranspiration recorded in the study area is 8.9mm. This was recorded in 2017 at Navrongo. The lowest of the highest evapotranspiration of 8.0mm was recorded at Wa in 2016. None of the highest evapotranspiration was recorded before the 1980s. Three of the highest figures were recorded in 2016 and 2017. The highest evapotranspiration is usually recorded between February and

April, as shown in Table 8. The minimum evapotranspiration of 0.4mm was recorded first in 1980 and repeated in 1995 at Wa and Navrongo, respectively. Interestingly, all the minimum evapotranspiration was recorded in the 1980s, and they were mostly recorded in July and August. The mean evapotranspiration in the north of Ghana ranges between 5.1mm recorded at Yendi, Bole, and Wa to 5.5mm recorded at Navrongo. The mean evapotranspiration for the north of Ghana is 5.3mm, with a mean, standard deviation of 1.1mm. Evapotranspiration has also shown variability at the daily time step. The range spans between 7.6mm recorded at Yendi and Wa to 8.3mm recorded at Navrongo. The mean variation in daily evapotranspiration is about 7.7mm.

Annual average evapotranspiration

The annual time series analysis was conducted to understand the pattern of evapotranspiration in the north of Ghana. Tamale and Wa show a decreasing trend while the remainder of the stations (Yendi, Babile, Vea, Bole, Navrongo) are showing increasing trends.

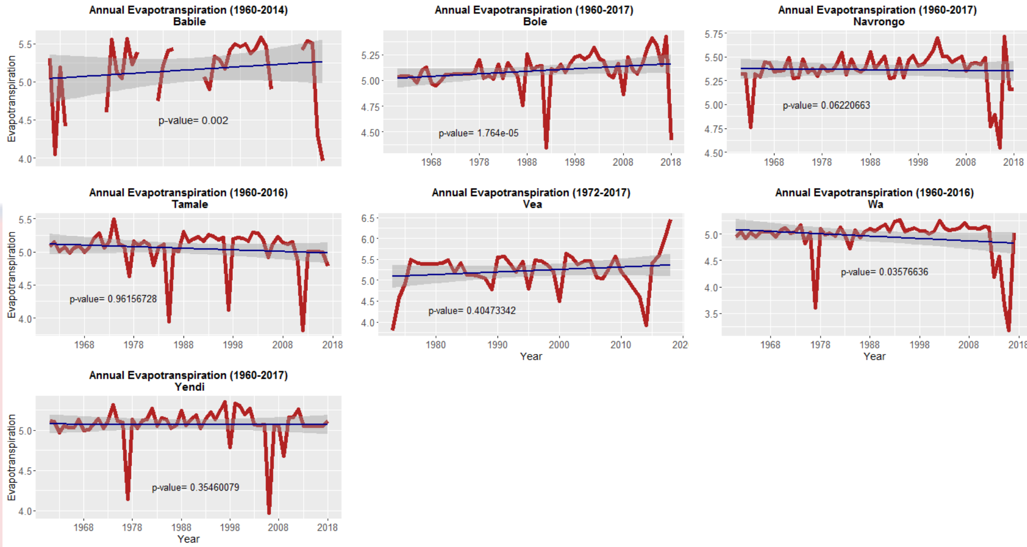


Figure 21: Annual mean evapotranspiration
Source: Asare, 2021

The increasing trends being experienced at Babile, Bole, are statistically significant. In contrast, the decreasing trend at Wa is statistically significant, but the other stations' patterns are not statistically meaningful. The annual evapotranspiration measurements differ from station to station, and there's an interannual variability. This affirms the existence of spatial and temporal variation.

Anomaly plot for evapotranspiration

The anomaly graph presents the interannual deviation of evapotranspiration from the long-term mean, as shown in Figure 22. The plots depict spatial and temporal variation in evapotranspiration across the north of Ghana. The extent of variation, be it positive or negative, differs from station to station. Years of above-average dominates for all the stations in the study area. Evapotranspiration has been high in the north of Ghana. This could be linked to the increasing temperature for both day and night. Besides Vea and Bole, evapotranspiration has reduced for the past five years for the remainder of the stations. This may be caused by a reduction in rainfall in those areas.

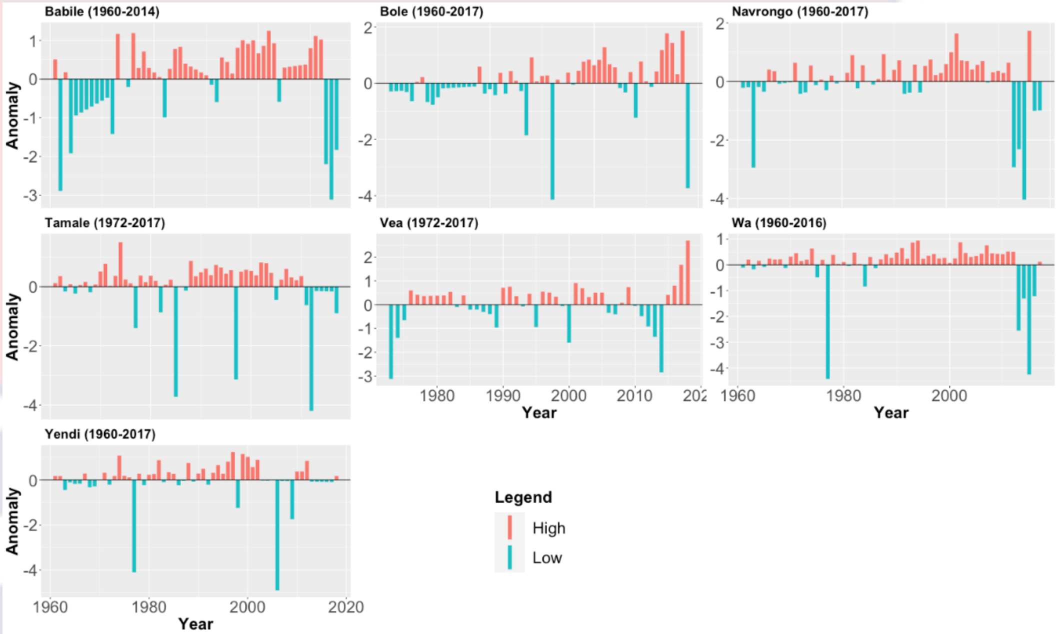


Figure 22: Evapotranspiration anomaly
Source: Asare, 2021

Table 9 presents the summary statistics of annual evapotranspiration over the period of analysis. The highest yearly average of evapotranspiration recorded in north Ghana is 6.5mm. This was recorded in 2017 at Vea. The highest annual evapotranspiration recorded in the study area ranges from 6.5mm to 5.3mm. The highest evapotranspiration recorded for each station was recorded beyond the 1990s with most of them after the year 2000. The mean highest annual average evapotranspiration is 5.6mm.

Table 9:Summary statistics of annual evapotranspiration

Station	Max.date	Max.Evap	Min.date	Min.Evap	Sd	Mean	Range
Babile	31/12/2001	5.6	31/12/1980	0.5	1.5	4.5	5.1
Bole	31/12/2016	5.4	31/12/1991	4.3	0.2	5.1	1.1
Navrongo	31/12/2015	5.7	31/12/2014	4.5	0.2	5.4	1.2
Tamale	31/12/1973	5.5	31/12/2011	3.8	0.3	5.0	1.7
Vea	31/12/2017	6.5	31/12/1972	3.8	0.5	5.2	2.7
Wa	31/12/1993	5.3	31/12/2015	3.2	0.4	5.0	2.1
Yendi	31/12/1996	5.4	31/12/2005	4.0	0.2	5.1	1.4

Source: Asare, 2021

The lowest annual average of evapotranspiration recorded in the study area is 0.5mm. This was recorded in 1980 at Babile. The lowest evapotranspiration recorded in the north of Ghana ranges from 0.5mm to 4.0mm. The mean of the lowest evapotranspiration recorded in the study area is 3.4mm. The minimum annual mean evapotranspiration was recorded in 1972. More than half of the stations recorded their minimum annual mean of evapotranspiration from 2005. The mean evapotranspiration for the study area is 5.0mm, with a standard deviation of 0.5mm. The mean for the stations ranges between 4.5mm at Babile to 5.4mm at Navrongo. There is evidence of variability. The station with the highest range is Babile, and it has a range of 5.1mm. The variation from the stations spans from 1.1mm to 5.1mm.

Monthly average evapotranspiration

Changes in monthly temperature will affect the populace's livelihood activities depending on the activities being undertaken and the limitation that will be presented based on the extent of the evapotranspiration. The study sought to assess the climatology of evapotranspiration in the study area. Figure 23 displays the monthly evapotranspiration for the different stations in the north of Ghana.

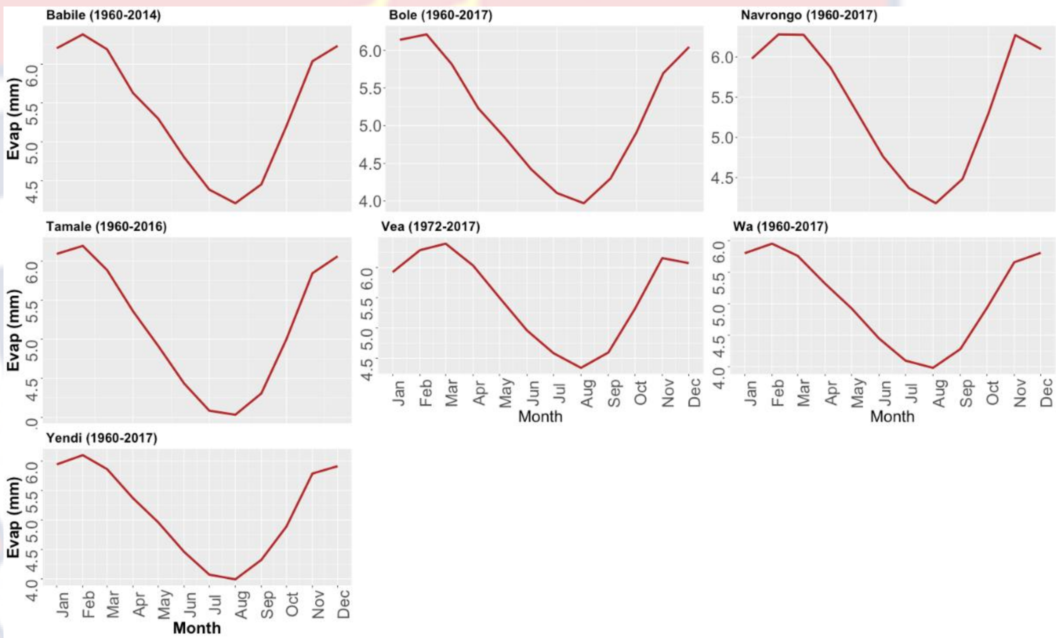


Figure 23: Monthly climatology of evapotranspiration
Source: Asare, 2021

Evapotranspiration peaks in February for most of the stations in the study area except for Vea and Navrongo, where it peaks in March. Beyond the peak in March or February, it declines and reaches its minimum in August for all the stations. After reaching its minimum in August, evapotranspiration begins to rise again until it peaks again in November. The evapotranspiration recorded at the summit in February and March ranges from 6mm to 7mm.

Comparing two climatology

The study divided the period of analysis into two to compare if there has been a change by comparing the latest to the former. Figure 24 presents these two periods for each of the stations in the north of Ghana. The differences between the stations differ from station to station.

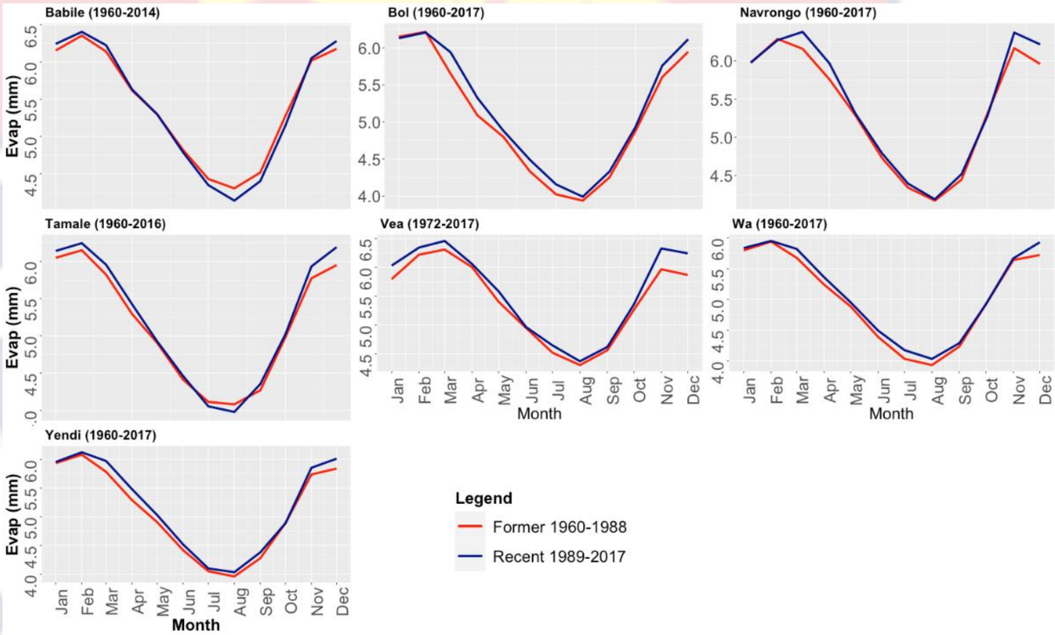


Figure 24: Comparing two periods of evapotranspiration
Source: Asare, 2021

There has not been a complete shift of the latest from the former but a strong increasing signal in evapotranspiration. In comparison, some months of the year have experienced a decrease while others have an increase in evapotranspiration. A noticeable difference in Babile is a decrease in evapotranspiration in August. Most of the stations are seeing increasing evapotranspiration from February to August. All the stations are experiencing an increase in evapotranspiration in November and

December but by different margins with stations in the Upper East having the highest margins.

CHAPTER FIVE

AGRICULTURALLY RELEVANT CLIMATE INFORMATION FOR NORTHERN GHANA

Introduction

This chapter presents results on the agriculturally relevant information for planning and decision making. The critical information needed by farmers according to the literature is seasonal rainfall total, the onset of the season, length of the season, end of the season, and information on drought.

Spatial analysis of agriculturally relevant climate information

This section presents the spatial overview of the agriculturally relevant climate information to understand spatial and temporal differences in this agriculturally pertinent information in the study area. This will help to underscore the need for location-specific climate information for planning and decision making

Seasonal rainfall total

Seasonal rainfall total distribution, as shown in Figure 25, is uneven spatially across the region.

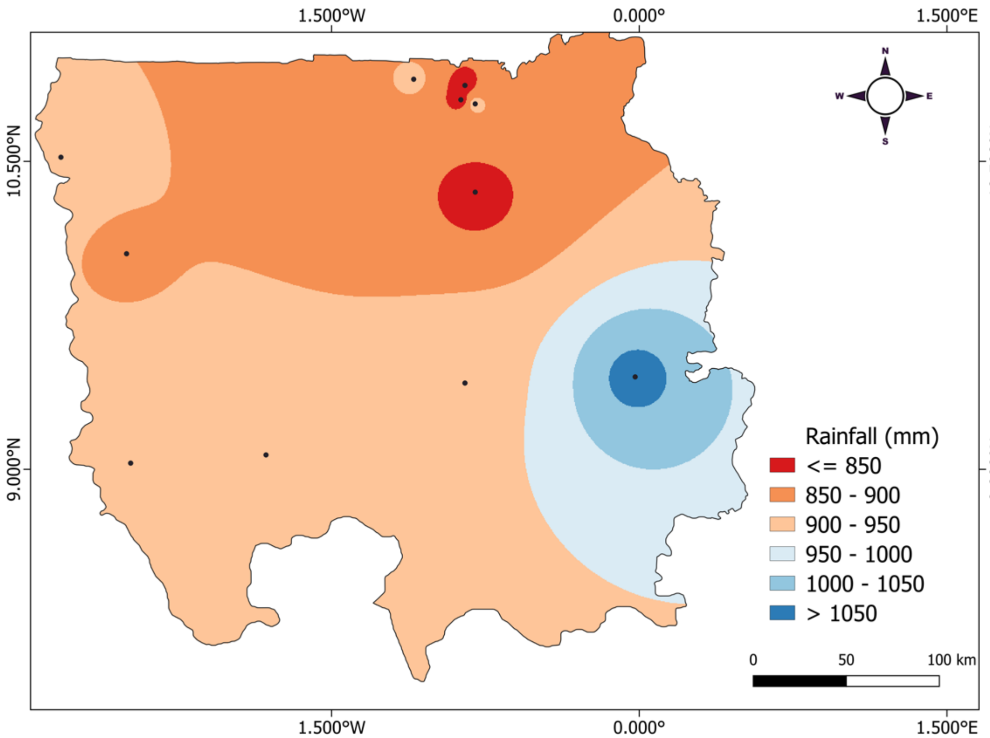


Figure 25: Seasonal rainfall total
Source: Asare, 2021

Seasonal rainfall totals range from 800mm to 1150mm, with the southeastern part of the north of Ghana receiving more rain than the north and northwest parts. Generally, locations in the south of the north of Ghana receive more rainfall than the northern part of the region.

Start of the season

The onset of the season over the north of Ghana is not uniform spatially and temporally across the region. Some areas in the study area have an early start whereas other areas have a late onset. Generally, the southern part of the north of Ghana has an early onset of the season compared to the northern part of the study area.

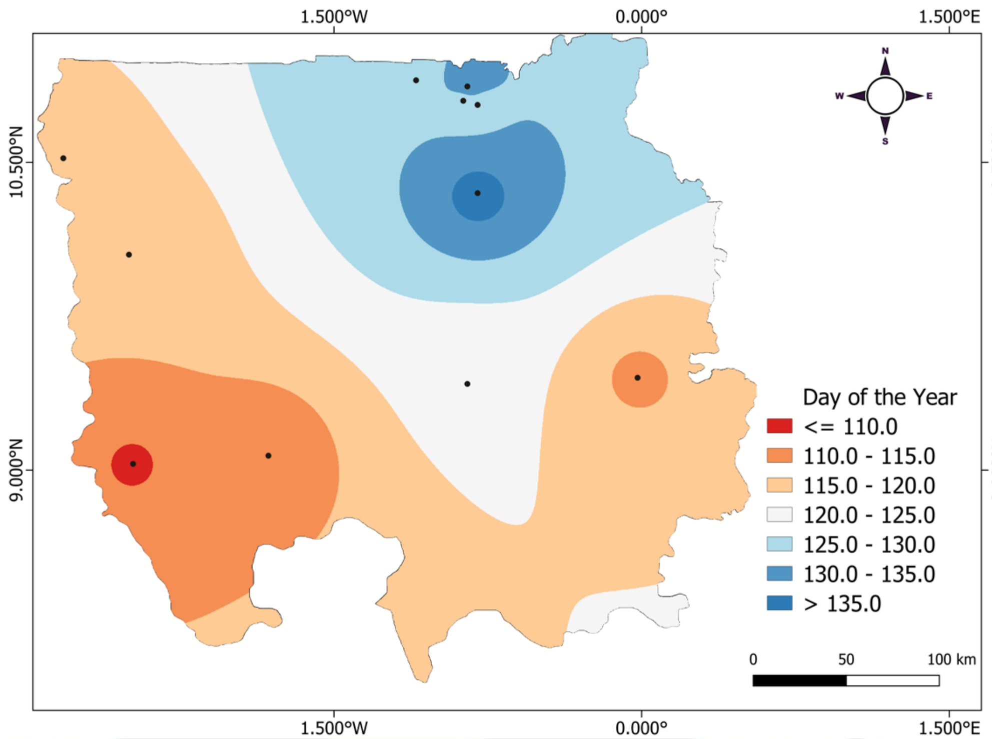


Figure 26: Start of the season
Source: Asare, 2021

The earliest onset date for the study area is the 100th day of the year (April 9) and the most delayed onset 140th day of the year (May 19), as shown in Figure 26. Communities in the southern part of the north of Ghana have an early onset of the season, and as you move farther north the onset delays. Communities located in the northeastern corner of the study area have the most delayed start of the season.

End of the season

Communities in the north of Ghana have different end of the season dates. Some parts of the region have relatively early cessation dates compared to other parts of the study area. The season ends early in the northern part of the study area and later in the southern part. The northeastern part experiences early cessation around the 280th day of the year (October 6), and the late has been day 305 of the year (October 31). The cessation of the season regresses as you move farther north of the study area, as shown in Figure 27.

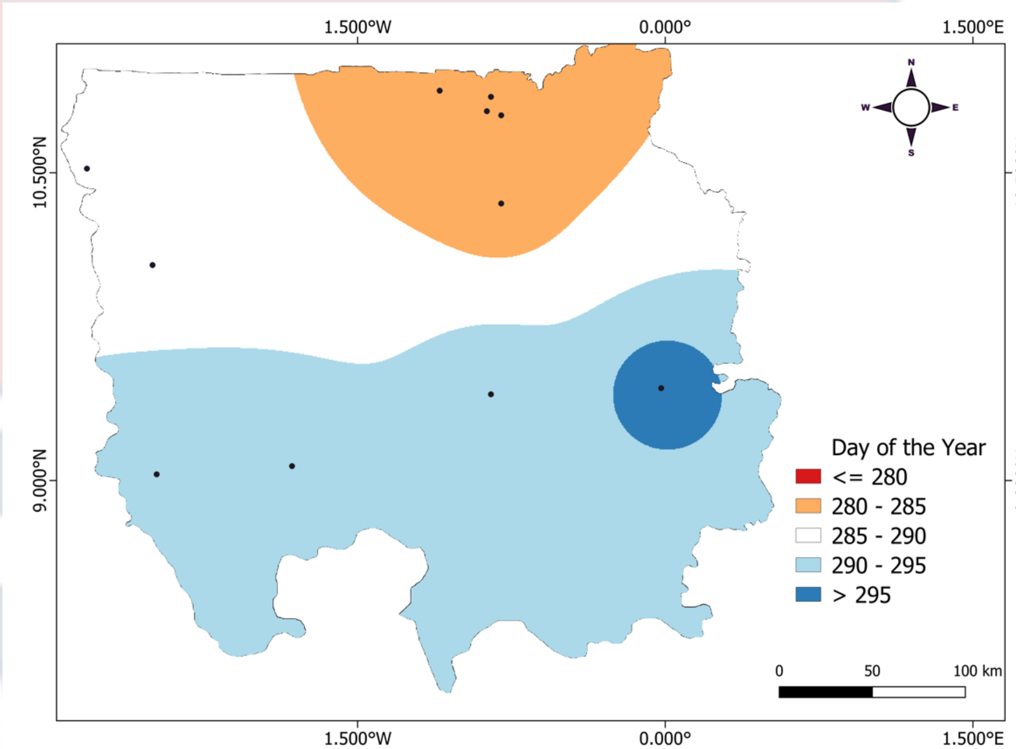


Figure 27: End of the season
Source: Asare, 2021

Length of the season

The length of the season is critical for farmers in deciding the crops to plant and the variety. This is important because some crops mature early, whereas others may require more days to mature. Figure 28 displays spatial variations in the length of the season in the study area. The southern part of the north of Ghana has a relatively longer season compared to the northern part. The length of the season regresses as you move from the south to the north of the study area.

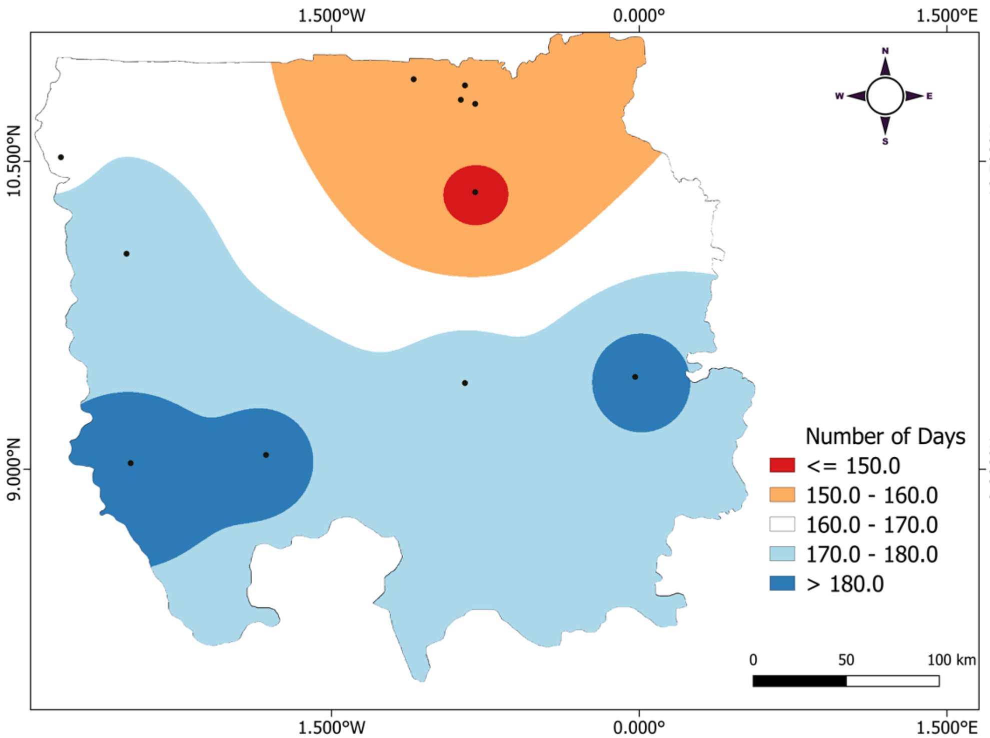


Figure 28: Length of the season
Source: Asare, 2021

The northeastern part of the study area experiences a relatively shorter season than the rest of the study area. The length of the shortest season of the study area is about 140 days, an equivalent of four months and twenty days (19 weeks), and the most extended length of the season is about 210 days equaling seven months (28 weeks). This culminates into a difference of nine weeks significant for crop development and an indication of high variation as you move up north.

Longest dry spell

Consecutive days without rainfall during the farming season can be detrimental to plant growth and development and may have an eventual negative impact on yield. Consistent with the other agriculturally relevant climate information, there is a spatial variation with the most prolonged dry spell within the rainfall season.

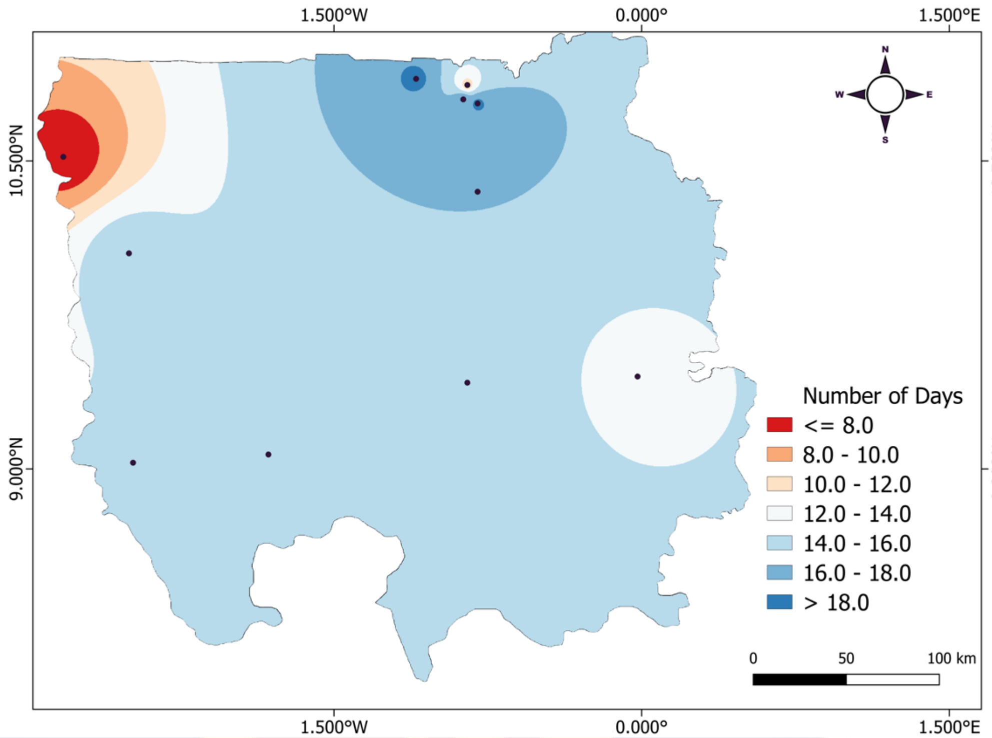


Figure 29: Longest dry spell
Source: Asare, 2021

The central part of the north of the study area has the longest dry spell of about 20 days, an equivalent of about three weeks, whereas the northwestern corner has the least dry spell of 6 days which is almost a week.

Evapotranspiration

Evapotranspiration is an important variable that affects agriculture. It is an important variable to access its spatial patterns and behavior, which will help farmers make an informed decision. Figure 30 presents the spatial profile of evapotranspiration in the north of Ghana. The map suggests the East-West contrast at its northernmost parts. Evapotranspiration is generally uniform in most parts of the study area.

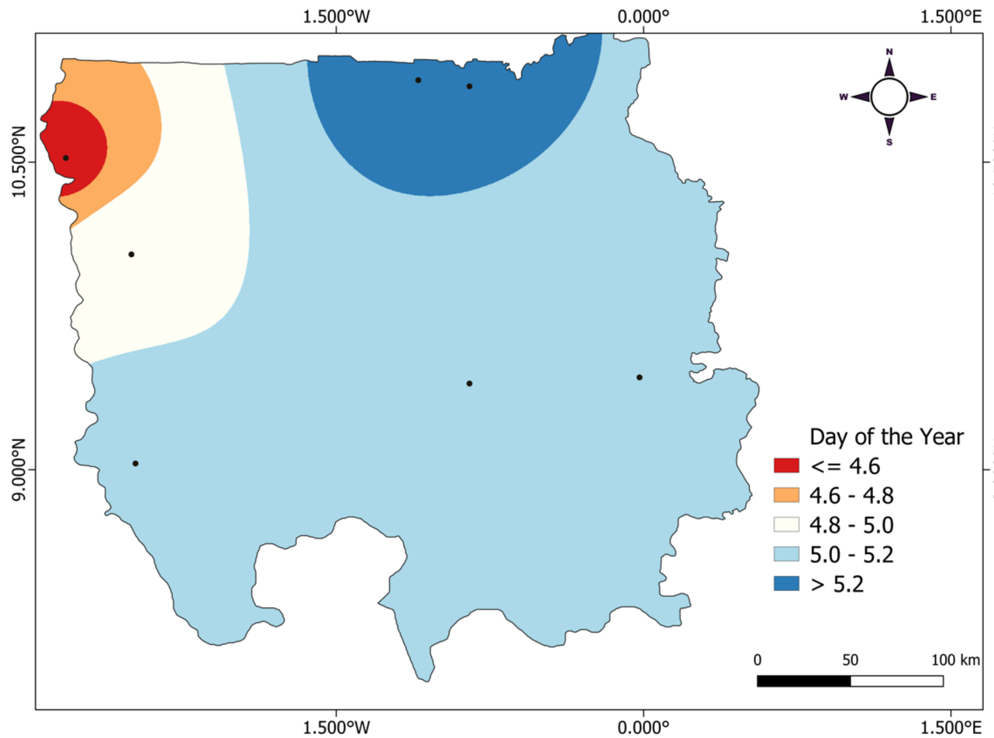


Figure 30: Evapotranspiration
Source: Asare, 2021

Evapotranspiration is highest along the North of Ghana's central and eastern corners, while the Upper West part experiences the least evapotranspiration. Evapotranspiration over the north of Ghana does not vary much since most of the study area has the same mean evapotranspiration.

Trend analysis of agriculturally relevant climate information

This section presents the interannual behaviour and pattern of the agriculturally relevant climate information. The understanding of this information and behaviour will influence decisions by relevant stakeholders

Seasonal rainfall total

Annual rainfall total is essential, but what matters most to the rain-fed farmer is the amount of rainfall during the season. This study, besides assessing the annual rainfall over the north of Ghana, further analyzed the seasonal rainfall totals, which are presented below, as shown in Figure 31. Seasonal rainfall total for Babile, Damongo, Navrongo, Tamale, Wa, and Yendi show a decreasing trend. In contrast, Bolgatanga and Vea, show an increasing trend, with the remainder of the stations not showing any visible trend. None of the patterns being experienced is statistically significant. This means that there has not been a change in seasonal rainfall total for all the stations in the north of Ghana.

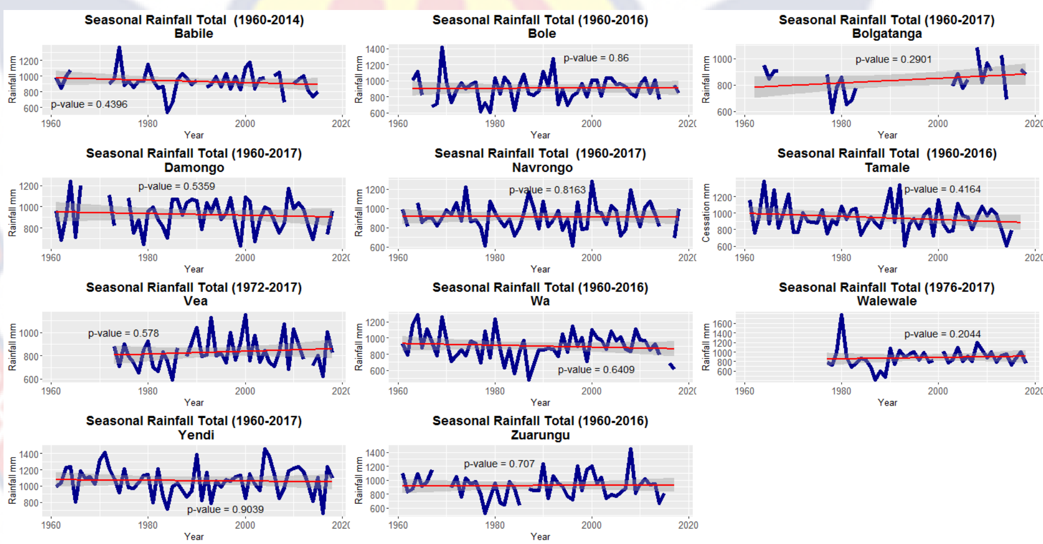


Figure 31: Season rainfall total
Source: Asare, 2021

Most of the stations had high rainfall totals in the 1960s but lower seasonal totals in the 1970s and 1980s. Similar to the variation in the seasonal rainfall total trends over the north of Ghana is interannual variation in seasonal rainfall total for the stations in the north of Ghana. The difference is not uniform across stations but differs from location to location.

Table 10 presents the seasonal rainfall total statistics over the north of Ghana. The highest seasonal rainfall total recorded among the stations over the north of Ghana for a particular year was 1770.6mm in 1979 at Walewale. The lowest seasonal rainfall total recorded among the highest season total recorded among the eleven stations over the north of Ghana was 1083.8mm in 2007 at Bolgatanga. The highest seasonal rainfall total recorded for each of the stations spans between 1083.8mm and 1770.6mm. The highest seasonal total for each of the stations has occurred just once over the last 57 years. The mean of the highest rainfall recorded across the north of Ghana is 1353.2mm. Most of the highest records occurred in the 1960s, 1970s, 1990s, and 2000s, with none occurring in the 1980s. The lowest seasonal rainfall total recorded over the north of Ghana was 423.7mm in 1986 at Walewale, and the highest among the lowest is 662.7mm, which was recorded in 2015 at Yendi. Except for Damango, which recorded its lowest seasonal rainfall in 1998, and Yendi which recorded the same in 2015, the remaining stations recorded their lowest seasonal rainfall total between 1977 and 1986.

Station	Max.Date	Max.total	Min.Date	Min.total	Mean	Sd	Range
Babile	1973	1365.6	1983	542.6	931.2	138.3	823.0
Bole	1968	1416.2	1978	608.3	906.0	155.6	807.9
Bolgatanga	2007	1083.8	1977	595.0	832.5	115.5	488.8
Damongo	1963	1240.3	1998	632.1	925.1	151.0	608.2
Navrongo	1999	1282.4	1973	609.9	912.7	140.8	672.5
Tamale	1963	1384.3	1992	602.7	940.1	168.0	781.6
Vea	1999	1149.7	1984	594.5	831.1	130.7	555.2
Wa	1963	1282.4	1986	485.4	897.6	169.3	797.0
Walewale	1979	1770.6	1986	423.7	879.1	211.0	1346.9
Yendi	2003	1459.4	2015	662.7	1063.7	174.7	796.7
Zuarungu	2007	1450.7	1977	522.4	920.6	180.4	928.3

Table 10:Summary statistics on seasonal rainfall total
Source: Asare, 2021

The mean lowest rainfall recorded among the stations in the north of Ghana is 626.1mm. The lowest seasonal rainfall total recorded for each of these stations has occurred just once over the past 57 years. The mean rainfall for each of the stations ranges between 831.1mm at Vea to 1067.7mm at Yendi. Yendi has the highest seasonal rainfall total mean among all the stations in the north of Ghana. The mean seasonal rainfall total over the north of Ghana is 912.7mm, with a mean standard deviation of 157.8mm. The departure from the mean for each of the stations ranges between a minimum of 115.5mm at Bolgatanga and a maximum of

211mm at Walewale. The highest rate of variations from one station to the other is manifested in the high amount of differences between the maximum and minimum seasonal rainfall totals for each station. The variations span between 555.2mm at Vea and 1346.9mm at Walewale.

Start of the season

Farmers consider the start of the season critical information to begin farming activities in their respective locality. This study analyzed to understand the trends and characteristics of the start of the season in the north of Ghana. Figure 32 presents the annual pattern of the start of the season for the period of analysis. Conspicuously revealed in all the stations is interannual variation at the start of the season. Again, the period within the 1960s had an early onset among the stations, but there was a contrast in the 1980s when the start of the season was delayed for the stations. This relatively changed in the 1990s and 2000s, when the start of the season was a bit earlier.

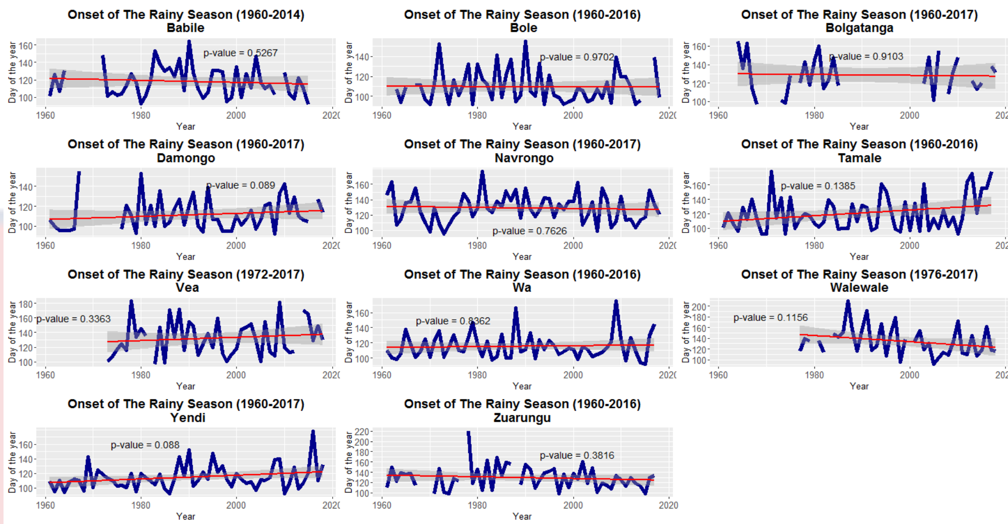


Figure 32: Onset of the season
Source: Asare, 2021

Tamale, Damongo, Vea, and Yendi are all showing an increasing trend at the start of the rain. This means that the start of the rainfall season is delaying for these stations. At the same time, Zuarungu and Walewale show a decreasing trend, which depicts an early start of the season. The remainder of the stations Wa, Navrongo, Bole, and Bolgatanga do not show any visible trend. For all the locations with either decreasing or increasing trends, they are not statistically significant. This means that the start of the season over the study area has not changed, but we can affirm interannual variability in the study area.

Table 11 presents the summary statistics for the start of the season. The study analyzed the worst years of the beginning of the season for all the stations in the north of Ghana. The worst start of the season date for each station spans between day 220, which is equivalent to August 7 in 1977 at Zuarungu, to day 155 of the year, which is equal to June 3 in 1989 at Bole. The worst or most delayed start of the season has occurred only once for each of the stations, except for Tamale, whose most delayed onset has repeated twice. The most delayed start of the season for Tamale is day 179 of the year, which is equivalent to June 27, which first occurred in 1970 and repeated itself in 2016. Most (7 stations) of the late start of the season over the study area happened in the 1970s, and 1980s with two recorded in the 1960s and the remainder (3) recorded between 2008 and 2016.

Table 11:Summary statistics of the onset of the season

Station	Max Year	Max Year	Min Year	Min.start	Mean	Sd	Range
Babile	1989	164	2014	92	117.8	17.3	72
Bole	1989	155	1960	92	109.4	16.5	63
Bole	1989	155	1969	92	109.4	16.5	63
Bole	1989	155	1973	92	109.4	16.5	63
Bole	1989	155	1978	92	109.4	16.5	63
Bole	1989	155	1993	92	109.4	16.5	63
Bole	1989	155	1997	92	109.4	16.5	63
Bole	1989	155	2012	92	109.4	16.5	63
Bolgatanga	1963	165	1967	97	128.5	19.8	68
Damongo	1966	155	2007	92	111.3	16.1	63
Navrongo	1980	177	1972	95	128.8	18.3	82
Tamale	1970	179	1968	92	120.7	24.3	87
Tamale	2016	179	1969	92	120.7	24.3	87
Tamale	1970	179	1973	92	120.7	24.3	87
Tamale	2016	179	2009	92	120.7	24.3	87
Vea	1977	183	1982	97	132.2	23.9	86
Wa	2008	175	2014	92	115.2	16.8	83
Walewale	1986	209	2004	92	134.1	26.4	117
Yendi	2015	178	1985	92	114.5	16.4	86
Yendi	2015	178	2009	92	114.5	16.4	86
Zuarungu	1977	220	1973	98	129.1	22.7	122
Zuarungu	1977	220	2014	98	129.1	22.7	122

Source: Asare, 2021

The earliest onset date was analyzed for all the stations. The earliest onset dates range between day 92 of the year, which is equivalent to April 1 for all the stations except for Navrongo, Vea, Bolgatanga, and Zuarungu, all located in the Upper East Region of Ghana. The earliest onset date for Navrongo is day 95 of the year, which is equivalent to April 4, Bolgatanga, and Vea is day 97 of the year, which is equivalent to April 6, Zuarungu is day 98 of the year which is equivalent to April 7. The earliest onset date repeated itself for two of the stations. The earliest onset date repeated itself seven (7) times (1960, 1969, 1973,1978,1993, 1997, 2012) for Bole and four (4) times for Tamale (1968, 1969, 1973, 2009). Eight out of the earliest onset dates occurred after the year 2000, with the remaining 14 occurring between 1960 and 1999. The mean start of the season date for all the stations ranges between day 109 of the year, which is equivalent to April 18 at Bole to day 132 of the year equivalent to May 11 at Walewale. The mean start of the season date over the north of Ghana is day 118 of the year, which is equivalent to April 27 with a mean standard deviation of 20 days. There is high variability concerning the start of the season over the north of Ghana. The variations for each of the stations span between 63 days at Bole to 122 days at Zuarungu. The mean variation to the start of the season over the north of Ghana is 81 days.

Length of the season

The length of the season is a vital variable considered by farmers in their planning of the season. The possible length of the season usually influences a lot of decisions made by farmers at the beginning of the season. This study analyzed the length of the season to understand the north of Ghana's trend and characteristics. This was achieved by analyzing the length of the season for each of the eleven stations.

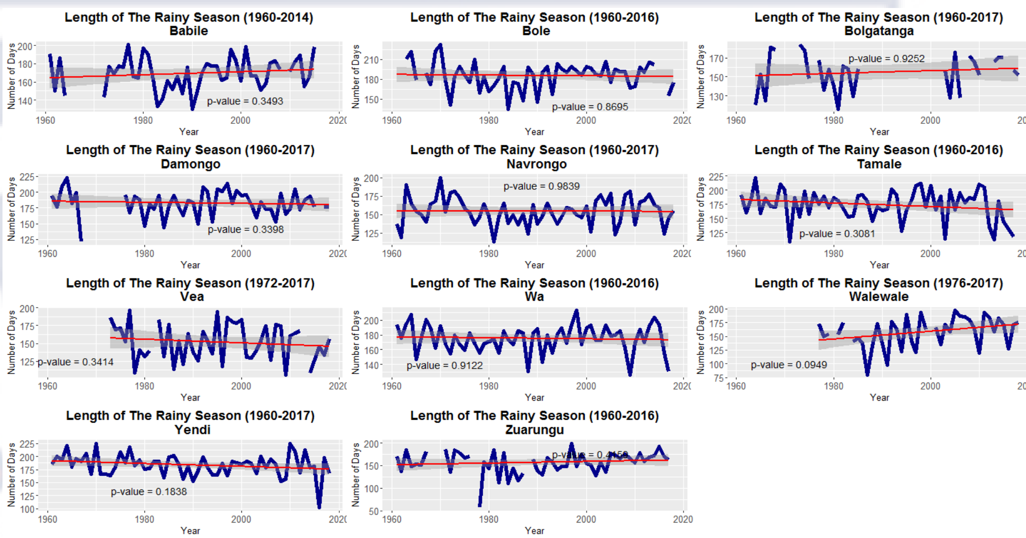


Figure 33: Length of the season
Source: Asare, 2021

The analysis results revealed interannual variability for the length of the season for all the stations in the study area, as shown in Figure 33. Babile, Walewale, and Bolgatanga are showing increasing trends in the length of the season, while Vea, Tamale, and Yendi are depicting a decreasing trend. The rest of the stations are not showing a visible pattern. None of the trends being experienced is statistically significant. The length of the season has not changed over the period of analysis over the north of Ghana.

Table 12:Summary statistics for the length of the season

Station	Year	Max.length	MinYear	Min.length	Mean	Sd	Range
Babile	1976	201	1989	130	169.4	17.8	71
Bole	1969	232	1983	135	185.4	20.1	97
Bolgatanga	1972	184	1980	116	154.9	19.6	68
Damongo	1963	223	1966	121	182.5	20.1	102
Navrongo	1969	200	1980	113	154.5	18.4	87
Tamale	1963	222	1970	109	174.2	26.8	113
Vea	1976	196	2008	106	151.6	25.2	90
Wa	1997	213	2008	126	175.2	18.5	87
Walewale	2004	197	1986	80	157.8	27.1	117
Yendi	2009	225	2015	102	183.6	20.9	123
Zuarungu	1996	199	1977	57	156.8	24.6	142

Source: Asare, 2021

The variability in the length of the season being experienced in the north of Ghana is reflected in the summary statistics shown in Table 12. The mean longest season over the north of Ghana is 208 days, an equivalent of 30 weeks (7 months and two weeks). The longest season experienced in the north of Ghana was 232 days, which is the equivalent of 33 weeks (8 months). This occurred at Bole in 1969. The longest season for all the stations spans between 184 days, an equivalent of 26 weeks (6 months and two weeks) at Bolgatanga and 232 days at Bole, which is equivalent to 33 weeks. The longest season recorded for each of the north of Ghana's stations has only occurred once in the last 57 years. Most of the longest length of the season occurred between 1960 and 1970, with the remainder occurring between 1996 and 2009. The mean shortest season over the north of Ghana is 108 days equaling 15 weeks (3 months and 3 weeks). The shortest season recorded over the study area is 57 days representing about eight weeks (2 months). This was experienced at Zuarungu in 1977. The shortest season for all the stations ranges between 57 days an equivalent of 8 weeks (2 months) at Zuarungu in 1977 and 135 days equaling 19 weeks (4 months) at Bole in 1983. This means that the longest length of the season that you may expect over the north of Ghana is 208 days, and the shortest duration of the season is 108 days. The shortest length of the season for each of these stations has occurred only once in the last 57 years. Most of the shortest length of the season occurred between 1960 and 1980, with the majority occurring in the 1980s.

The remainder occurred in 2008 for Vea and Wa and in 2015 for Yendi. The average length of the season of the mean of all the individual stations is 168 days representing 24 weeks (6 months). The mean length of the season for all the stations spans between 151 days representing 22 weeks (5 months and two weeks) and 185 days representing 26 weeks (6 months and two weeks). The deviation from the mean ranges between 19 days at Wa to 27 days at Walewale. The mean standard deviation over the north of Ghana is 22 days. The station with the highest variability in the length of the season is Zuarungu with 142 days, which is equivalent to 20 weeks (5 months). The station with the least variability for the length of the season is Babile with 71 days. The variations in the length of the season over the north of Ghana span between 71 and 142 days. The average variability for the length of the season is 100 days.

End of the season

The end of the season is an essential parameter for a farmer and relevant stakeholders to plan for the season, keeping in mind when the season will end. Thus, the study extracted the cessation date from the daily rainfall data to understand the trends and characteristics. Figure 34 presents the annual variations and trend analysis of the cessation of rainfall over the north of Ghana.

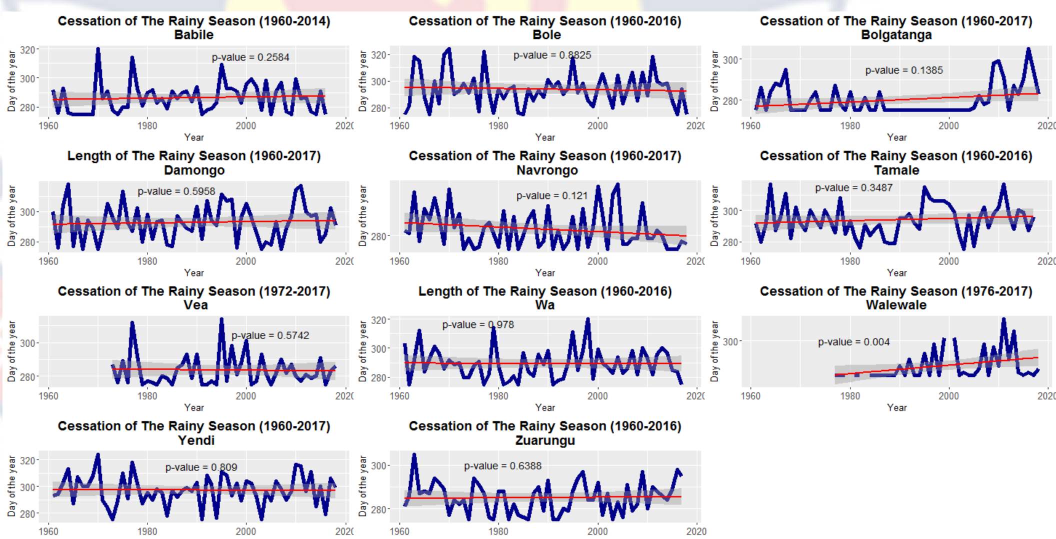


Figure 34: Cessation of the season
Source: Asare, 2021

Prominent among all the stations are the interannual variations in the cessation of rainfall from year to year. While Bolgatanga, Tamale, and Walewale are showing increasing trends in the cessation date, Navrongo shows a decreasing trend, which means that the rainfall season is extending for the former and retreating for the latter. The remainder of the stations in the north of Ghana are not showing any visible trend. The cessation of rainfall at Walewale is extending, and it is statistically significant, but the cessation date for the remainder of the stations remains only variable.

Table 13 provides further details on the cessation of rainfall over the north of Ghana. The study compared the most delayed cessation among the 11 stations. Yendi and Bole recorded the most delayed cessation in 1969. The cessation occurred on day 324, which was November 19. Navrongo recorded the earliest cessation among the most delayed cessation for all the stations in the north of Ghana. This occurred at Navrongo in 1992, and the season ended on day 299, which was October 25. The mean of the most delayed end of the season over the north of Ghana is day 304, which is October 30. Six out of the 11 stations had their most delayed end-of-the-season date in the 1960s, two of the stations in the 1990s, and the remainder between 2003 and 2015. The most delayed end-of-the-season date had occurred just once for each station except Tamale, which had recorded the same date (day 317 – November 12) twice in 1963 and 2010 over the past 57 years.

Table 13:Summary statistics on cessation of the season

Station	Max Year	Max.end	Min Year	Min.end	Mean	Sd	Range
Bolgatanga	2015	305	1960	275	280	7	30
Bolgatanga	2015	305	1962	275	280	7	30
Bolgatanga	2015	305	1967	275	280	7	30
Bolgatanga	2015	305	1968	275	280	7	30
Bolgatanga	2015	305	1969	275	280	7	30
Bolgatanga	2015	305	1970	275	280	7	30
Bolgatanga	2015	305	1973	275	280	7	30
Bolgatanga	2015	305	1974	275	280	7	30
Bolgatanga	2015	305	1975	275	280	7	30
Bolgatanga	2015	305	1978	275	280	7	30
Bolgatanga	2015	305	1980	275	280	7	30
Bolgatanga	2015	305	1981	275	280	7	30
Bolgatanga	2015	305	1983	275	280	7	30
Bolgatanga	2015	305	1984	275	280	7	30
Bolgatanga	2015	305	1986	275	280	7	30
Bolgatanga	2015	305	1987	275	280	7	30
Bolgatanga	2015	305	1988	275	280	7	30
Bolgatanga	2015	305	1989	275	280	7	30
Bolgatanga	2015	305	1990	275	280	7	30
Bolgatanga	2015	305	1991	275	280	7	30
Bolgatanga	2015	305	1992	275	280	7	30
Bolgatanga	2015	305	1993	275	280	7	30
Bolgatanga	2015	305	1994	275	280	7	30
Bolgatanga	2015	305	1995	275	280	7	30
Bolgatanga	2015	305	1996	275	280	7	30
Bolgatanga	2015	305	1997	275	280	7	30
Bolgatanga	2015	305	1998	275	280	7	30
Bolgatanga	2015	305	1999	275	280	7	30
Bolgatanga	2015	305	2000	275	280	7	30
Bolgatanga	2015	305	2001	275	280	7	30
Bolgatanga	2015	305	2002	275	280	7	30
Bolgatanga	2015	305	2003	275	280	7	30
Bolgatanga	2015	305	2011	275	280	7	30

Source: Asare, 2021

Table 14:Summary statistics on cessation of the season continued

Station	Max Year	Max.end	Min Year	Min.end	Mean	Sd	Range
Navrongo	2003	299	1981	275	282	7	24
Navrongo	2003	299	1983	275	282	7	24
Navrongo	2003	299	1990	275	282	7	24
Navrongo	2003	299	1992	275	282	7	24
Navrongo	2003	299	1995	275	282	7	24
Navrongo	2003	299	2001	275	282	7	24
Navrongo	2003	299	2013	275	282	7	24
Navrongo	2003	299	2014	275	282	7	24
Navrongo	2003	299	2015	275	282	7	24
Tamale	1963	317	2002	275	294	10	42
Tamale	2010	317	2002	275	294	10	42
Vea	1994	314	1978	275	284	9	39
Vea	1994	314	1981	275	284	9	39
Vea	1994	314	1984	275	284	9	39
Vea	1994	314	1990	275	284	9	39
Vea	1994	314	1991	275	284	9	39
Vea	1994	314	1993	275	284	9	39
Vea	1994	314	2000	275	284	9	39
Vea	1994	314	2004	275	284	9	39
Vea	1994	314	2015	275	284	9	39
Wa	1997	320	1961	275	289	10	45
Wa	1997	320	1976	275	289	10	45
Wa	1997	320	1980	275	289	10	45
Wa	1997	320	1983	275	289	10	45
Wa	1997	320	1990	275	289	10	45
Wa	1997	320	2016	275	289	10	45
Damongo	1963	318	1966	275	293	12	43
Damongo	1963	318	1969	275	293	12	43
Damongo	1963	318	2002	275	293	12	43
Damongo	1963	318	2006	275	293	12	43
Navrongo	2003	299	1972	275	282	7	24
Navrongo	2003	299	1974	275	282	7	24

Source: Asare, 2021

Table 15: Summary statistics on cessation of the season continued

Station	Max Year	Max.end	Min Year	Min.end	Mean	Sd	Range
Babile	1969	320	1964	275	286	10	45
Babile	1969	320	1965	275	286	10	45
Babile	1969	320	1966	275	286	10	45
Babile	1969	320	1967	275	286	10	45
Babile	1969	320	1968	275	286	10	45
Babile	1969	320	1973	275	286	10	45
Babile	1969	320	1990	275	286	10	45
Babile	1969	320	2004	275	286	10	45
Babile	1969	320	2008	275	286	10	45
Babile	1969	320	2013	275	286	10	45
Babile	1969	320	2015	275	286	10	45
Bole	1969	324	1960	275	294	13	49
Bole	1969	324	1965	275	294	13	49
Bole	1969	324	1984	275	294	13	49
Bole	1969	324	2015	275	294	13	49
Bole	1969	324	2017	275	294	13	49
Walewale	2010	307	1976	289	292	5	18
Walewale	2010	307	1977	289	292	5	18
Walewale	2010	307	1978	289	292	5	18
Walewale	2010	307	1980	289	292	5	18
Walewale	2010	307	1981	289	292	5	18
Walewale	2010	307	1983	289	292	5	18
Walewale	2010	307	1984	289	292	5	18
Walewale	2010	307	1985	289	292	5	18
Walewale	2010	307	1986	289	292	5	18
Walewale	2010	307	1987	289	292	5	18
Walewale	2010	307	1988	289	292	5	18
Walewale	2010	307	1990	289	292	5	18
Walewale	2010	307	1992	289	292	5	18
Walewale	2010	307	1993	289	292	5	18
Walewale	2010	307	1995	289	292	5	18
Walewale	2010	307	1997	289	292	5	18
Walewale	2010	307	2001	289	292	5	18
Walewale	2010	307	2003	289	292	5	18
Walewale	2010	307	2004	289	292	5	18
Walewale	2010	307	2007	289	292	5	18
Walewale	2010	307	2014	289	292	5	18
Walewale	2010	307	2016	289	292	5	18

Source: Asare, 2021

The earliest end-of-the-season date for all the stations in the north of Ghana except for Walewale is day 275, which is October 1. This has occurred more than once for each of the stations except Tamale, which had occurred just once. It has repeated itself 11 times (1964, 1965, 1966, 1967, 1968, 1973, 1990, 2004, 2008, 2013, 2015) at Babile, 5 times (1960, 1965,1984, 2015, 2017) at Bole, 33 times (1960, 1962, 1967,1968, 1969, 1970, 1973, 1974, 1975, 1978, 1980, 1981, 1983, 1984, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2011) at Bolgatanga, 4 times (1966, 1969, 2002, 2006) at Damongo, 11 times (1972, 1974, 1981, 1983, 1990, 1992, 1995, 2001, 2013, 2014, 2015) at Navrongo, 9 times (1978, 1981,1984, 1990, 1991, 1993, 2000, 2004, 2015) at Vea, 6 times (1961, 1976, 1980, 1983, 1990, 2016) at Wa, 3 times (1972, 1990, 2002) at Yendi and 7 times (1973, 1978, 1981, 1985, 1990, 1991, 2002) at Zuarungu. The earliest cessation date for Walewale is day 289, which is October 15. This has also repeated itself 22 times (1976, 1977, 1978, 1980, 1981, 1983, 1984, 1985, 1986, 1987, 1988, 1990, 1992, 1993, 1995, 1997, 2001, 2003, 2004, 2007, 2014, 2016) at Walewale over the last 57 years. The mean end-of-the-season date ranges between day 280 of the year, which is October 6 at Bolgatanga, and day 297 of the year, which is October 23 at Yendi. The mean end of the season date over the north of Ghana is day 286 of the year, which is October 12 with a standard deviation of 8 days. The standard deviation for the stations ranges between 5 days at Bole and 13 days at Walewale. The extent of variation from year to year spans between 18 days at Walewale and 49 days at Bole.

Longest dry spell

The study analyzed the most prolonged dry spell over the north of Ghana for all eleven stations. This analysis was conducted to understand the state of continuous days without rainfall within the rainfall season. The trend analysis undertaken for all the stations revealed a high level of variability for all the stations in the study area, as shown in Figure 55.

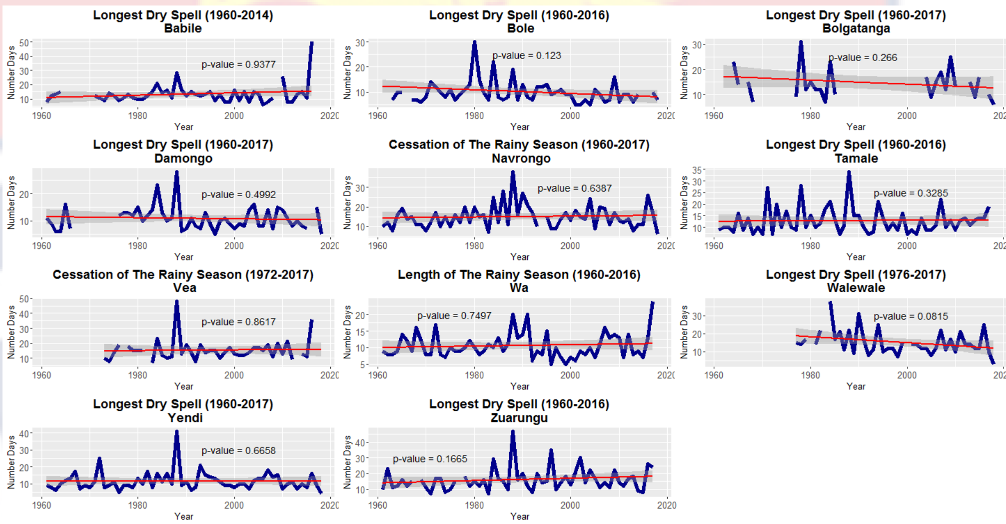


Figure 35: Longest dry spell over north of Ghana
Source: Asare, 2021

Consistent with all the stations is the high level of dry spell incidents during the 1980s. Besides Bole, Bolgatanga, and Walewale, which showed a reduction in the most prolonged spell, the rest of the stations are not showing any visible trend. The statistically significant test conducted on the stations also revealed that none of the station's trend is statistically significant. This means that the longest consecutive days without rainfall during the rainy season have not changed, but what is in existence is a high interannual variation.

Table 14 presents the summary statistics for the longest dry spell over the north of Ghana. The most prolonged dry spell recorded over the north of Ghana for a particular location is 50 days and equivalent of a month and three weeks. This was recorded at Babile in 2015. The maximum longest dry spell recorded across the north of Ghana spans between 24 days at Wa in 2016 and 50 days at Babile in 2015. The mean maximum longest spell over the north of Ghana is 35 days representing a month and five days. The longest dry spell for each of the stations has occurred just once over the past 57 years. The majority of the maximum longest dry spell for the stations happened in the 1970s and 1980s, with only Wa and Babile occurring in 2016 and 2015, respectively.

Table 16: Summary statistics for longest dry spell

Station	Max Year	Max.spell	Min Year	Min.spell	Mean	Sd	Range
Babile	2015	50	2005	6	13	7	44
Bole	1979	30	2000	5	10	5	25
Bole	1979	30	2001	5	10	5	25
Bole	1979	30	2003	5	10	5	25
Bolgatanga	1977	31	2017	6	15	7	25
Damongo	1987	28	1995	5	11	4	23
Damongo	1987	28	2017	5	11	4	23
Navrongo	1987	38	2017	6	15	6	32
Tamale	1987	34	1967	7	13	6	27
Tamale	1987	34	1969	7	13	6	27
Tamale	1987	34	1971	7	13	6	27
Tamale	1987	34	1985	7	13	6	27
Tamale	1987	34	1991	7	13	6	27
Tamale	1987	34	1999	7	13	6	27
Tamale	1987	34	2001	7	13	6	27
Vea	1987	48	2017	6	15	7	42
Wa	2016	24	1995	5	11	4	19
Wa	2016	24	1998	5	11	4	19
Walewale	1983	38	2017	3	15	7	35
Yendi	1987	41	2017	4	11	6	37
Zuarungu	1987	47	1970	7	16	7	40
Zuarungu	1987	47	1982	7	16	7	40

Source: Asare, 2021

The shortest consecutive days without rain recorded over the period of the analysis is four days which is less than a week during the rainy season. This occurred at Yendi in 2017. The shortest spell for all the stations in the study area spans between 4 days at Yendi in 2017 and 7 days at Tamale in 1967, 1969, 1971, 1985, 1991, 1999, and 2001. The shortest dry spell has repeated itself at least once and at seven times for Bole, Damango, Tamale, Wa, and Zuarungu. It remains just onec for Babile, Bolgatanga, Navrongo, Vea, Walewale, and Yendi. The mean shortest dry spell for all the stations in the study area is six days, less than a week. This means that the worst case of dry spell you may expect over the north of Ghana is 35 days, and the least you may expect is six days. The mean longest dry spell over the north of Ghana is 13 days, which is one week and five days. However, the mean for each of the stations ranges between 15 days at Navrongo and 10 days at Bole. The mean, standard deviation from the mean longest dry spell is six days. The standard deviation from the mean for each station spans between 4 days and seven days. As depicted by Figure 35, there is high interannual variability in the most prolonged dry spell in the study area. The variations span between 19 days at Wa and 44 days at Babile. The variation concerning the longest dry spell is 29 days, which is almost a month.

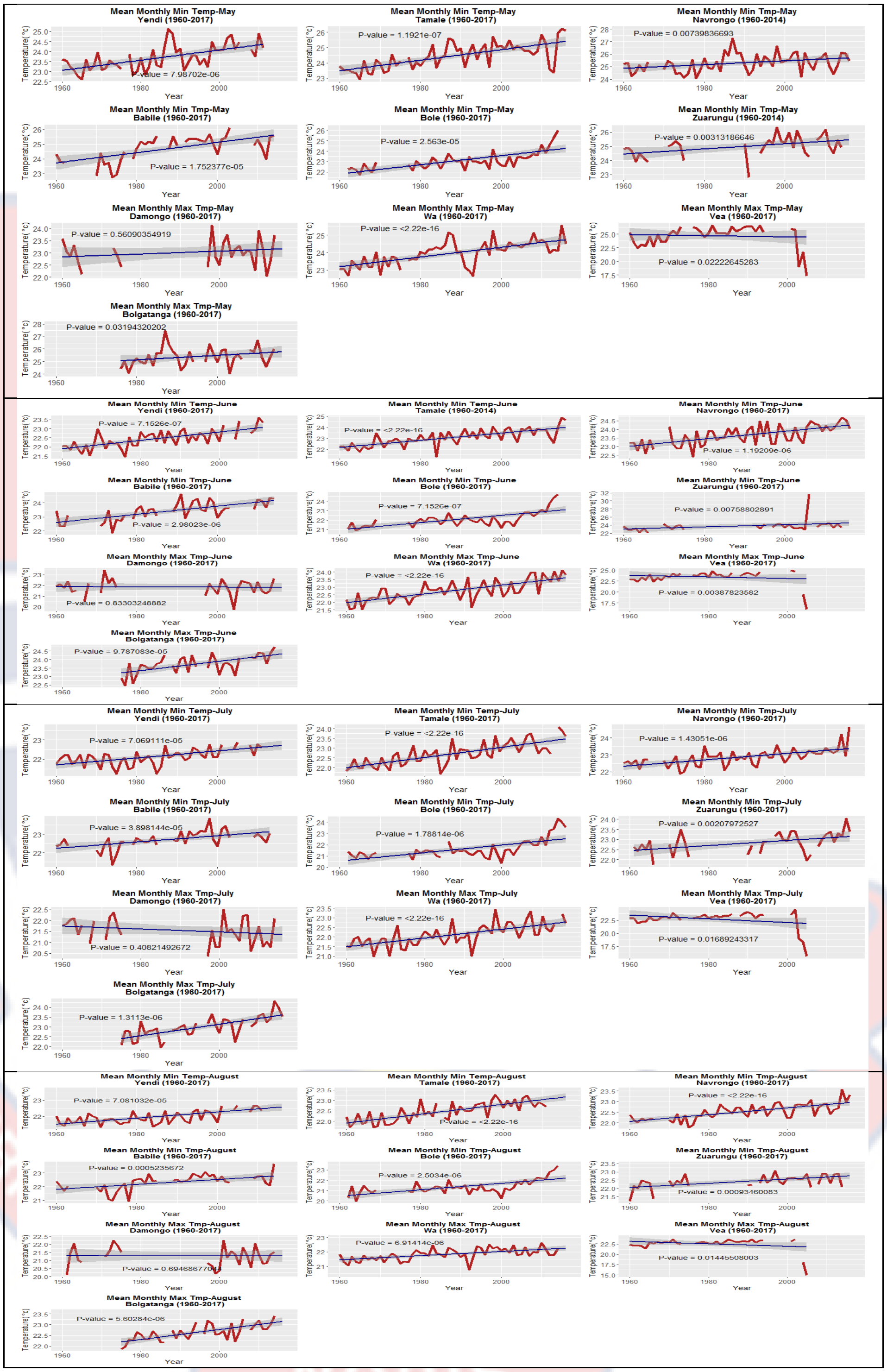
Seasonal temperature

Temperature plays an essential role in agriculture and has an impact on plant growth and development. Historical analysis of minimum and maximum temperature is presented at monthly intervals. The focus is the temperature during the farming season because that is what affects farmers. The analysis under this section focused on temperature from May to October when the season ends. This is important because different plants will be at various stages of development with varying temperature requirements. Some plants are planted early and harvested early or later, depending on the days required to mature and their water requirement.

Their temperature requirement will, therefore, differ from month to month, thus, there is a need to understand monthly trends of temperature during the day and night.

Minimum temperature

Notably, for all the stations, there is a consistent increase in minimum temperature and interannual variation, as shown in Figure 36. For May, except for Damongo, the increasing trends for all the stations are statistically significant.



Source: Asare, 2021

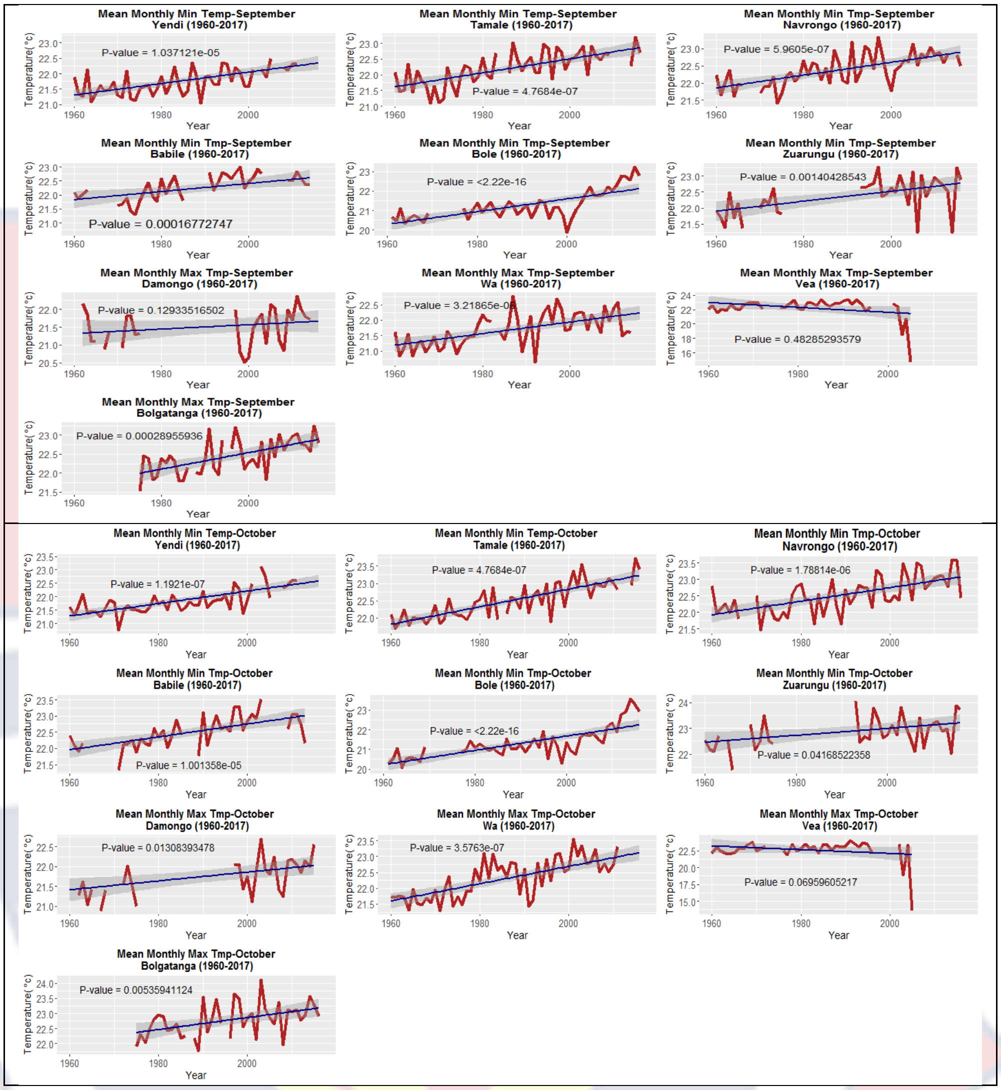
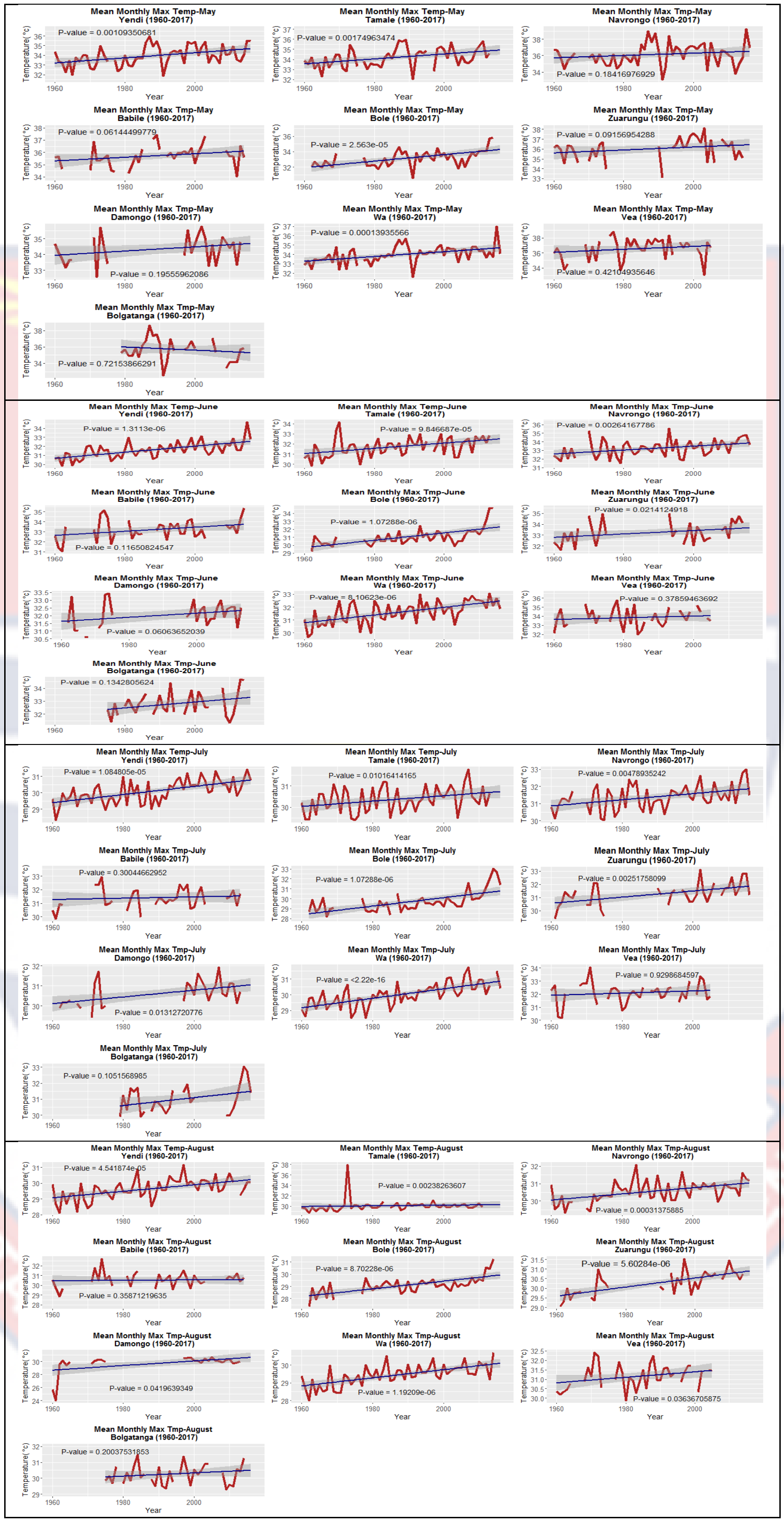


Figure 36: Monthly minimum temperature trends
Source: Asare, 2021

Similarly, comparing the night temperature for all the stations from June to September revealed increasing trends and the trends are statistically significant, except for Damongo. This trend changes in October, where all the months show increasing trends that are also statistically significant.

Maximum temperature

The maximum temperature for the study area has generally shown consistent increasing trends for all the stations over the north of Ghana during the farming season. But critical to agriculture from sowing to harvesting is the dynamics of temperature trends at monthly intervals. For May, all the stations except for Bolgatanga have shown increasing trends in maximum temperature.



Source: Asare, 2021

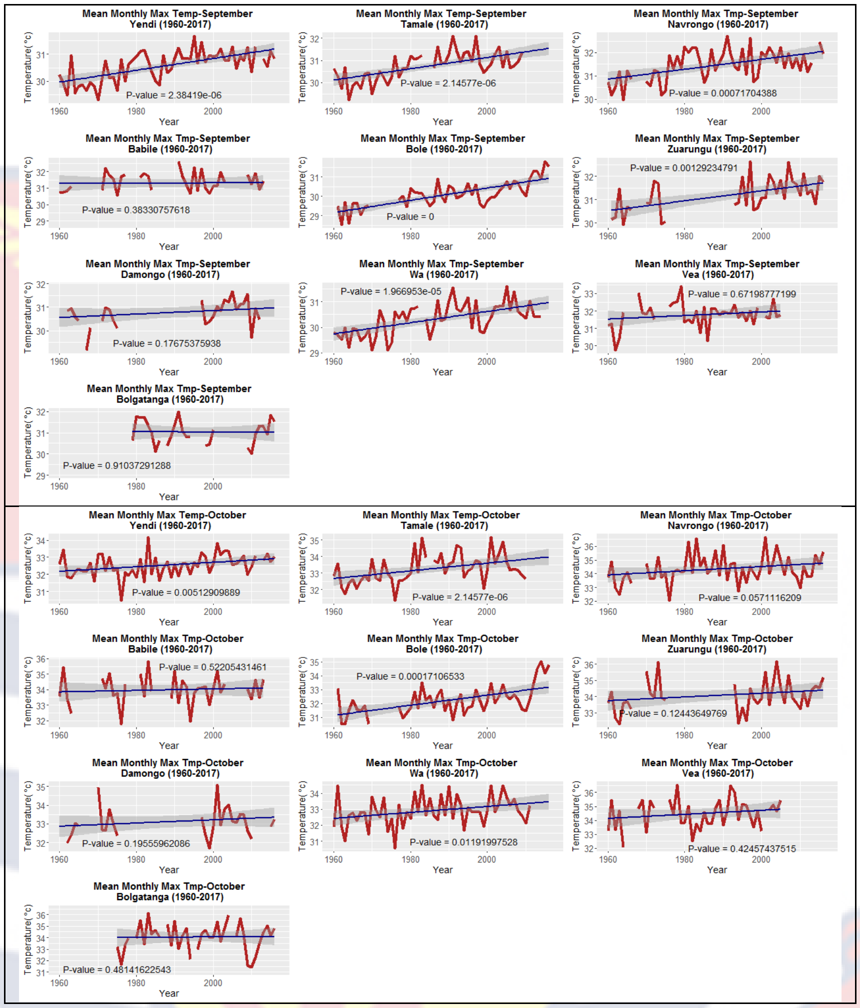
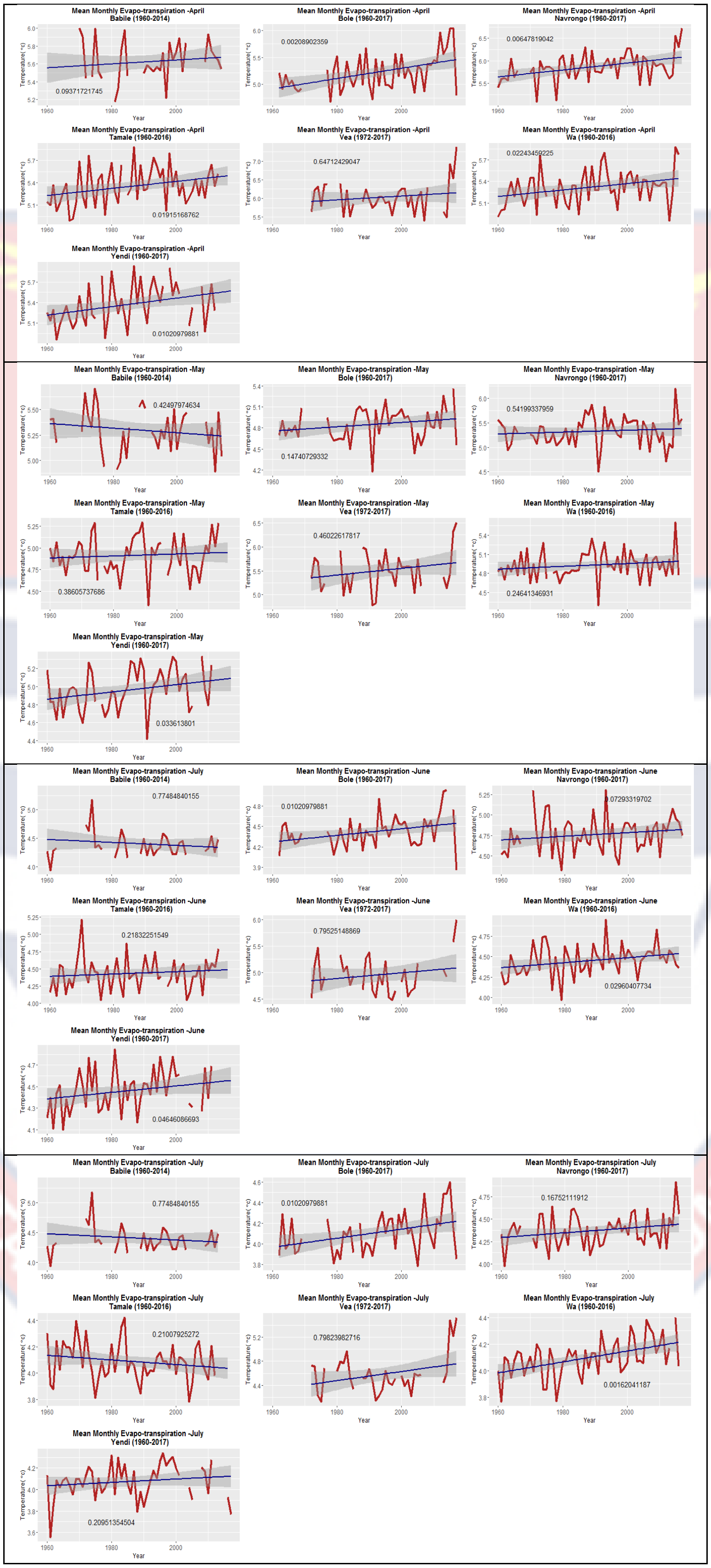


Figure 37: Monthly maximum temperature trends
Source: Asare, 2021

But it is interesting to note that few of the stations have shown significant deviation from the long-term mean. Except for Yendi, Tamale, Bole, and Wa, which show statistically significant increasing trends in temperature, the remainder of the stations, although showing rising trends, were not statistically significant. The maximum temperature for June has also demonstrated an increasing trend for all the stations. Six of the stations have shown statistically significant trends, with the remaining stations not being significant.

Seasonal evapotranspiration

Much emphasis is given to rainfall and temperature when discussing climate change and variability and agriculture-related issues. This study sought to explore the seasonal characteristics and trends of evapotranspiration in the north of Ghana. This is important to the farmer because what happens within the season is what impacts farming activities. Evapotranspiration was analyzed from April to September for each of the stations in the north of Ghana.


Mean Monthly Evapo-transpiration -April Babile (1960-2014)
0.09371721745
Mean Monthly Evapo-transpiration -April Bole (1960-2017)
0.00208902359
Mean Monthly Evapo-transpiration -April Navrongo (1960-2017)
0.00647819042
Mean Monthly Evapo-transpiration -April Tamale (1960-2016)
0.01915168762
Mean Monthly Evapo-transpiration -April Vea (1972-2017)
0.64712429047
Mean Monthly Evapo-transpiration -April Wa (1960-2016)
0.02243459225
Mean Monthly Evapo-transpiration -April Yendi (1960-2017)
0.01020979881
Mean Monthly Evapo-transpiration -May Babile (1960-2014)
0.42497974634
Mean Monthly Evapo-transpiration -May Bole (1960-2017)
0.14740729332
Mean Monthly Evapo-transpiration -May Navrongo (1960-2017)
0.54199337959
Mean Monthly Evapo-transpiration -May Tamale (1960-2016)
0.38605737686
Mean Monthly Evapo-transpiration -May Vea (1972-2017)
0.46022617817
Mean Monthly Evapo-transpiration -May Wa (1960-2016)
0.24641346931
Mean Monthly Evapo-transpiration -May Yendi (1960-2017)
0.033613801
Mean Monthly Evapo-transpiration -July Babile (1960-2014)
0.77484840155
Mean Monthly Evapo-transpiration -June Bole (1960-2017)
0.01020979881
Mean Monthly Evapo-transpiration -June Navrongo (1960-2017)
0.07293319702
Mean Monthly Evapo-transpiration -June Tamale (1960-2016)
0.21832251549
Mean Monthly Evapo-transpiration -June Vea (1972-2017)
0.79525148869
Mean Monthly Evapo-transpiration -June Wa (1960-2016)
0.02960407734
Mean Monthly Evapo-transpiration -June Yendi (1960-2017)
0.04646086693
Mean Monthly Evapo-transpiration -July Babile (1960-2014)
0.77484840155
Mean Monthly Evapo-transpiration -July Bole (1960-2017)
0.01020979881
Mean Monthly Evapo-transpiration -July Navrongo (1960-2017)
0.16752111912
Mean Monthly Evapo-transpiration -July Tamale (1960-2016)
0.21007925272
Mean Monthly Evapo-transpiration -July Vea (1972-2017)
0.79823982716
Mean Monthly Evapo-transpiration -July Wa (1960-2016)
0.00162041187
Mean Monthly Evapo-transpiration -July Yendi (1960-2017)
0.20951354504
Temperature(°c)
Year

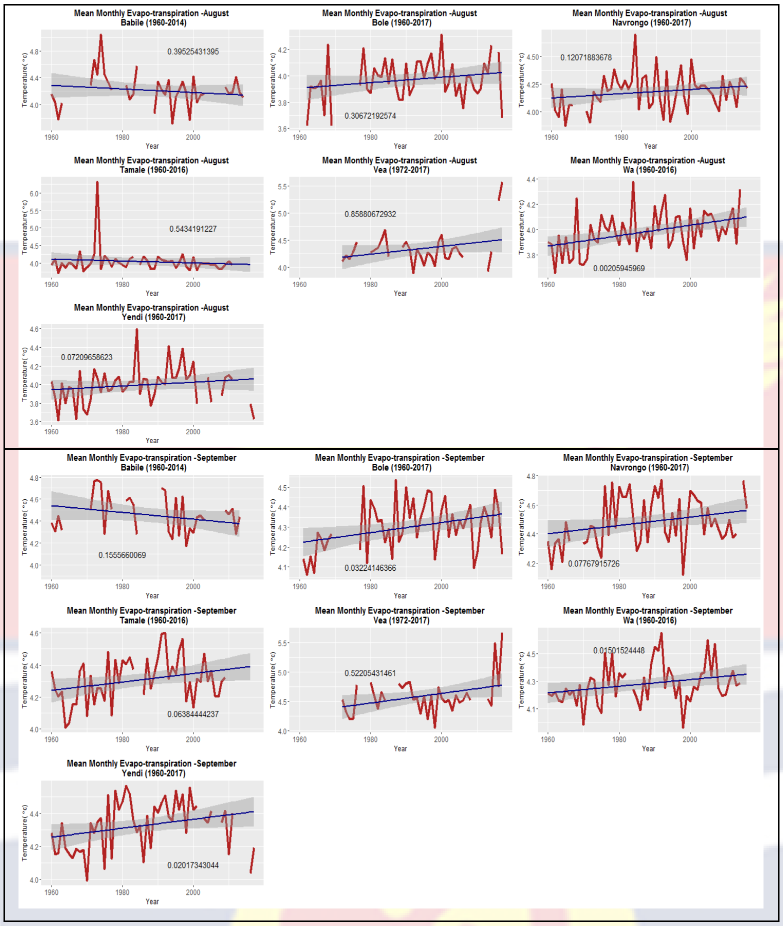


Figure 38: Monthly evapotranspiration trends
Source: Asare, 2021

Evapotranspiration for the growing season has shown variability from year to year for increasing trends in many cases for all the stations and decreasing trends in a few instances for some stations in the north of Ghana. Evapotranspiration in April is rising for all the stations in the study area. The increasing trend in evapotranspiration in April is not statistically significant for Babile and Vea but significant for the remainder of the stations. This means that there is a change in the pattern of evapotranspiration for most parts of the north of Ghana in April. Evapotranspiration in April ranges between 4mm to 7mm. All the stations show increasing trends for evapotranspiration in May except for Babile, which is showing a decreasing trend. The decreasing trend at Babile and the rising trends at the remainder of the stations are not statistically significant, except for the increasing trend at Yendi. This means that the pattern of evapotranspiration at Yendi has changed and deserves attention. The range of evapotranspiration for May is between 4mm and 6.5mm.

Similarly, evapotranspiration is increasing for all the stations in the study area except Babile and Tamale for June. It is only Wa, Yendi, and Bole which have increasing trends that are statistically significant, meaning that there has been a considerable deviation from the mean. Evapotranspiration ranges between 3mm and 5.5mm. The situation in July is reminiscent of the previous month. This is because Babile and Tamale are showing decreasing trends but that are not significant. The rest of the stations show increasing trends but are not significant, except for Bole and Wa. This means that there is a change in evapotranspiration for Bole and Wa. While Babile and Tamale continue with their decreasing trend, Navrongo, Yendi, Wa, Vea, and Bole continue to increase in August, but none is statistically significant except Wa. This means that despite the general increase in evapotranspiration in the study area, it is only at Wa, where a substantial change in evapotranspiration occurs. Evapotranspiration ranges from 3.0mm to 6.5mm in August for the study area. Evapotranspiration continues to increase across the study area in September except for Babile. It is only Yendi, Bole, and Wa, that have statistically significant results, depicting a change in evapotranspiration in these areas. Evapotranspiration in September ranges between 4mm and 6mm. Consistent with the previous months, October, which is the last month of the rainy season, has revealed an increasing trend for all the stations. However, it is only Bole that has a statistically significant increase. Evapotranspiration in October ranges between 4.0mm to 7.0mm.

CHAPTER SIX

TELECONNECTION BETWEEN REMOTE CLIMATE INDICES AND CLIMATE OF THE NORTH OF GHANA

Introduction

This section of the study presents an analysis conducted to assess the relationship between rainfall and temperature of the north of Ghana and remote climate indices. Also, the study sought to evaluate the potential of predicting the north of Ghana's climate using the remote climate indices. The El Niño-Southern Oscillation (ENSO) indices selected for this analysis are Tropical South Atlantic (TSA), Central Tropical Pacific (Nino 3.4), and Atlantic meridional mode (AMM) SST.

Rainfall

A correlational and multiple regression analysis was conducted on rainfall to observe any relationship between annual rainfall totals and the collective impact of these indices on rainfall in the study area. Tables 17 and 18 present the correlation and regression analysis results between the dependent variable (Rainfall) and the independent variables (ENSO indices).

Table 17: Correlation between ENSO and rainfall

ENSO	Tamale	Yendi	Bole	Damango	Wa
TSA	0.0657	0.0725	0.1172	0.1883	0.0164
AMM	-0.0746	0.0880	0.0282	-0.1534	0.1166
			-		-
NINO34	-0.0852	0.0390	0.0538	-0.1145	0.2352

Source: Asare, 2021

Table 18: Correlation between ENSO and rainfall continued

ENSO	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
TSA	0.2114	0.0779	0.2083	0.0779	0.0773
AMM	-0.0604	0.0286	0.0367	-0.0286	0.0192
NINO34	-0.0056	0.1341	0.2532	-0.1314	0.0693

Source: Asare, 2021

The results of the correlational analysis between rainfall and selected ENSO indices as presented in Table 17 and Table 18 revealed both negative and positive correlations between rainfall and ENSO over the north of Ghana. There is a positive correlation between rainfall and the Tropical South Atlantic Ocean (TSA) for the stations in the north of Ghana. However, the relationship is not strong. The correlation between rainfall and TSA for all the stations ranges between 0.07 being the lowest at Yendi and the highest of 0.21 recorded at Babile and Zuarungu. The correlation between the Atlantic meridional mode (AMM) and rainfall revealed a negative correlation for Tamale, Damongo, and Babile and a positive correlation for the remainder of the stations, as shown above. The correlation between the places exhibiting negative and positive relationships is all weak for AMM. Similar to the AMM, the NINO 3.4 had both positive and negative correlations with rainfall. Besides Tamale, Bole, Damango, Wa, and Navrongo, the remainder of the stations had a positive relationship with rainfall. Zuarungu had the highest correlation of 0.25 between rainfall and NINO 3.4. Yendi, Zuarungu, Babile, and Bolgatanga showed a positive correlation among the ENSO indices though weak.

The analysis further sought to assess the combined impact of these ENSO indices on the rainfall over the north of Ghana. The result is presented in Tables 19 and 20.

Table 19: Regression analysis between rainfall and ENSO

	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
F-Stats	1.183	0.3399	1.82	0.2824	0.2633
Pvalue	3.28E-01	0.7966	1.55E-01	8.38E-01	8.52E-01
Residual error	0.8829	151	184.9	150.4	188.4
Adj R Squ	0.01262	-0.04713	0.04207	-0.05271	-0.04034
Multiple R Squ	0.08151	0.02427	0.09339	0.02074	0.01442

Source: Asare, 2021

Table 20:Regression analysis between rainfall and ENSO continued

	Tamale	Yendi	Bole	Damango	Wa
F-Stats	0.3385	0.2414	0.3955	1.496	1.416
Pvalue	0.7976	8.67E-01	7.57E-01	0.2262	2.48E-01
Residual error	195.9	210.2	274	216.1	186.4
Adj R Squ	-0.03674		-0.03286	0.02589	0.02179
Multiple R Squ	0.0188		0.0215	0.07808	0.0742

Source: Asare, 2021

The multiple regression analysis conducted with rainfall as the dependent variable and the ENSO indices as the independent variable revealed a weak association between the ENSO indices and rain over the north of Ghana. The association between rainfall and each of the ENSO indices was not statistically significant for each station. The proportion of variation of rain over the north of Ghana attributed to the ENSO indices for each of the stations spanned between 0.01

for Navrongo and 0.09 for Zuarungu. The highest R square was 0.1 recorded at Zuarungu, with the remainder being less than 10%. The P-value for the F-statistic was 0.85 which is also not significant.

Maximum temperature

The temperature during the day is a vital climate parameter that affects the livelihood of the people. Understanding the impact of ENSO on the daily maximum temperature was examined. The north of Ghana's analysis revealed the varied effect of ENSO on maximum temperature over the study area.

Table 21: Correlation between ENSO and maximum temperature

ENSO	Tamale	Yendi	Bole	Damango	Wa
TSA	0.72	0.59	0.41	0.19	0.52
AMM	0.44	0.34	0.34	0.08	0.26
NINO34	0.49	0.28	0.19	0.26	0.24

Source: Asare, 2021

Table 22: Correlation between ENSO and maximum temperature continued

ENSO	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
TSA	0.10	0.38	0.11	0.24	0.23
AMM	0.06	0.32	0.11	0.24	0.24
NINO34	0.03	0.13	0.10	0.28	-0.06

Source: Asare, 2021

The correlational analysis conducted assessed the teleconnection between the Tropical South Atlantic Ocean (TSA), Atlantic meridional mode (AMM), and NINO 3.4 and the maximum temperature in the study area. Tables 21 and 22 present the results of the analysis. The results revealed a positive correlation for all the ENSO indices and maximum temperature in the study area, except for Navrongo, which had a negative correlation with NINO 3.4 ENSO indices. There is a relatively strong correlation between maximum temperature and TSA in the north of Ghana compared to the other ENSO indices (AMM, NINO 3.4). The correlation between TSA and maximum temperature ranges between 0.72 for Tamale to 0.1 at Zuarungu. Stations in the south of the north of Ghana have a strong correlation. The correlation between AMM is relatively stronger in the south of the north of Ghana and the northeastern part, whereas the western part remains very weak. NINO 3.4 has the lowest correlation for most of the stations in the north of Ghana.

The study assessed the combined impact of the ENSO indices on the maximum temperature over the study area. Tables 23 and 24 present the results of the multiple regression analysis with maximum temperature as the dependent variable and the ENSO indices as an independent variable.

Table 23: Regression analysis between maximum temperature and ENSO

	Tamale	Yendi	Bole	Damango	Wa
F-Stats	11.5600	16.2100	5.2040	1.0280	17.1900
Pvalue	0.0000	0.0000	0.0035	0.3932	0.0000
Residual error	0.4554	0.4234	0.7368	1.0550	0.4500
Adj R Squ	0.3612	0.4446	0.2047	0.0024	0.4644
Multiple R Squ	0.3955	0.4739	0.2534	0.0879	0.4931

Source: Asare, 2021

Table 24: Regression analysis between maximum temperature and ENSO

	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
F-Stats	0.2391	4.4490	1.5500	2.2140	2.6840
Pvalue	0.4569	0.0084	0.2125	0.1018	0.2916
Residual error	1.3070	0.6695	0.7327	0.9305	0.7539
Adj R Squ	-0.0561	0.1869	0.0286	0.0798	0.0814
Multiple R Squ	0.0176	0.2411	0.0806	0.1455	0.1297

Source: Asare, 2021

The multiple R square, which indicates the proportion of maximum temperature variation over the north of Ghana attributed to the ENSO indices for each of the stations, ranged between 0.01 at Babile and 0.49 at Wa. The stations in the south of the North of Ghana had a relatively higher R square compared to the other stations, except for Wa located northwestern part of the region. The ENSO indices could explain about 50% of the maximum temperature variation at Wa. The

P-value for the F-statistic was significant for Tamale, Yendi, Bole, Wa, and Vea, with the remainder of the stations not being significant.

Minimum temperature

The impact of ENSO may differ from the temperature during the day and that of the night. The correlational analysis conducted as shown in Tables 25 and 26 reveals different levels of relationship between ENSO at the varied locations over the north of Ghana.

Table 25: Correlation between ENSO and Minimum temperature

ENSO	Tamale	Yendi	Bole	Damongo	Wa
TSA	0.42	0.41	0.37	0.40	0.55
AMM	0.33	0.42	0.27	0.25	0.41
NINO34	0.37	0.35	0.50	0.42	0.23

Source: Asare, 2021

Table 26: Correlation between ENSO and Minimum temperature continued

ENSO	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
TSA	0.27	-0.19	0.44	0.10	0.36
AMM	-0.01	0.10	0.16	0.12	0.25
NINO34	0.03	-0.56	0.26	0.23	0.01

Source: Asare, 2021

The correlational analysis revealed a positive correlation between ENSO and minimum temperature except for Vea, which had a negative correlation of -0.19 for TSA, -0.56 for NINO 3.4, and -0.01 at Babile for AMM. Generally, TSA has a relatively higher correlation with minimum temperature than AMM and NINO 3.4, as shown above. The positive correlation between TSA and minimum temperature ranges between 0.1 at Bolgatanga and 0.55 at Wa. The southern and western part of the North of Ghana has a relatively higher correlation than the northeastern part of the north of Ghana.

ENSO's overall impact on minimum temperature was assessed and the results are shown in Tables 27 and 28.

Table 27: Regression analysis between minimum temperature and ENSO

	Tamale	Yendi	Bole	Damango	Wa
F-Stats	10.71000	10.86000	5.20400	4.65700	17.19000
Pvalue	0.00001	0.00001	0.00353	0.00823	0.00000
Residual error	0.40530		0.73680	0.66240	0.45000
Adj R Squ	0.34220	0.35810	0.20470	0.23860	0.46440
Multiple R Squ	0.37750	0.39440	0.25340	0.30390	0.49310

Source: Asare, 2021

Table 28: Regression analysis between minimum temperature and ENSO continued

	Babile	Vea	Zuarungu	Bolgatanga	Navrongo
F-Stats	1.18300	7.57900	6.11300	0.91490	4.51400
Pvalue	0.32830	0.00037	0.00119	0.44260	0.00675
Residual error	0.88290	1.32500	0.61310	0.76980	0.15610
Adj R Squ	0.01262	0.30490	0.21500	-0.00611	0.15610
Multiple R Squ	0.08151	0.35120	0.25710	0.06575	0.20050

Source: Asare, 2021

The analysis affirmed the impact of ENSO on the minimum temperature over the study area. The multiple R square, which explains the proportion of variation in minimum temperature caused by ENSO over the study area, revealed a weak impact. The R square for each of the stations ranged between a minimum of 0.08 at Babile and a maximum of 0.49 at Wa, all in the northwestern part of the north of Ghana. The impact and the extent to which ENSO explains the variation in minimum temperature in the north of Ghana is significant for all the stations except Babile and Bolgatanga.

CHAPTER SEVEN
DISCUSSION OF RESULTS

Introduction

This section presents the interpretation of the results presented in chapters four and five. The interpretation of the empirical evidence, which is the findings of this study, will be presented given available literature to affirm the results of this study or on the contrary present new findings. The research questions will be addressed to achieve this objective.

Contextualization

This study was undertaken to present useful climate information for decision making in the broader context of climate change and variability through literature and the theory that underpins this research. The chapter summarises the critical findings of this work in filling the gap identified through the review of existing literature.

Climate change over north of Ghana

A general understanding of the past to the present is critical in undertaking any critical decision to manage climate risk, building resilience, and adaptive capacity of farmers. The section discusses important climate variables of rainfall, temperature, and evapotranspiration.

Rainfall

The seasonal cycle of rainfall in the study area has not been impacted by climate change and has remained similar over the period of analysis. The rainfall climatology of the north of Ghana remains unimodal as was expounded by (Asare-Nuamah & Botchway, 2019; Nyadzi, 2016). The rainfall season begins in April and peaks in August/September (Nyadzi, 2016), and ends in October. This trend was affirmed in the analysis conducted over the north of Ghana as was shown by Nkrumah et al. (2014) in their study.

This study has revealed that the north of Ghana's climate has not changed, but another critical finding is the shift in the peak of the rainfall season from September to August for Wa. The stations in the south of the north of Ghana have their peak month in September, while stations from the middle part peak in August. All the stations in the study area are depicting interannual variation in rainfall without showing any consistent trend. The variable nature of rainfall and the decreasing nature although not statistically significant over the study area corroborates with the findings of Nyatuame et al. (2014); Kabo-Bah et al. (2016); Nkrumah et al. (2014); Asare-Nuamah & Botchway, (2019); Lawson et al. (2020). Although findings from Abbam et al. (2018) corroborate this work, they reported a statistically significant decrease in rainfall over the north of Ghana which contradicts this work. The seeming increasing trend of annual total rainfall at Bolgatanga and Vea also affirms the findings of Kwasi. et al. (2014) and Issahaku et al. (2016) that there is increasing rainfall in parts of the Upper East Region of Ghana.

The extent of variation is not uniform spatially and temporally and differs from station to station. While some stations depict a decreasing trend, others show either no trend or an increase, as shown in Figure 3. Still, in all cases, the trends are not statistically significant.

Heavy rainfall events in the study area are decreasing for almost all the stations. Bolgatanga and Tamale have experienced a significant decline in heavy rainfall events, while Vea is the standalone experiencing a substantial increase in heavy rainfall. The number of rainy days in the study area has not changed for most of the stations. However, most of the stations have assumed a decreasing trend but are not significant statistically, with only Tamale being significant with a P-value of 0.005. The significant decline in the number of rainy days at Tamale has reflected the decrease in its annual rainfall total, although that is not statistically significant. Again, the rainy days for Walewale and Bolgatanga have assumed an increasing trend, which is statistically significant, as shown by Figure 7 but this has not reflected in increasing the annual total rainfall for these locations. But while the annual rainfall total has not increased significantly for Bolgatanga and Walewale, heavy rainfall events are also on the decline. This means that Bolgatanga is experiencing high rainfall frequency, which will be suitable for agriculture and must be exploited. The reduction in heavy rainfall events at Bolgatanga and Tamale could mean a potential decrease in rainfall-related hazards, that is if rain is the only variable causing floods in the area. The decreasing trend shown by Tamale in annual total rainfall could also be explained by the reduction in the number of rainy days and heavy rainfall events, which are statistically significant.

Rainfall in the north of Ghana has not changed over the past 57 years, as some authors (Nyadzi, 2016) have concluded. What is evident in the north Ghana annual rainfall variability with some years and months having more rain and vice versa. Consistent with the rainfall variability is variation in the heavy rainfall events and the number of annual rainy days. However, it is essential to note an emerging trend for some specific stations with statistically significant changes in heavy rainfall events and the number of rainy days. This also affirms the lack of uniformity across the study area, which bears differences in the spatial and temporal dynamics in the study area.

Temperature

The maximum temperature climatology for the study area has not changed over the period of analysis, as depicted by the season cycle plot (Figure 10). March remains the hottest month of the year during the day, with August being the coldest during the day. This result affirms the findings of Nkrumah et al. (2014) and Nyadzi (2016). The Upper East part of the north of Ghana is the hottest part of the country. Although the climatology of maximum temperature has not changed, the mean annual maximum temperature has changed with a statistically significant P value for all the stations in the north of Ghana. This finding corroborates the various IPCC reports and findings from other authors (Issahaku et al., 2016; IPCC, 2018, 2013; Kabo-Bah et al., 2016; Asare-Nuamah & Botchway, 2019; Lawson et al., 2020) and affirms the global warming signature.

The spatial dynamics reveal the non-uniform rate of increase, as shown by the slope of each station. The southern part of the north of Ghana has a relatively sharper slope compared to those at the northernmost. The stations in the south of the study area's maximum temperature are increasing at a relatively faster rate than those in the north. The rate of increase in the maximum temperature at the hottest part of the north is comparatively rising at a moderate pace. Consistent warming in the study area began in the 1990s, and this trend has continued to the present. This also resonates with other findings from Nicholsen (2013). The analysis has revealed that the 1960s and 1970s were colder while the 1980s served as a transition, and the continuous warming during the 1990s has continued till the present. The increase in the annual mean of daily temperature is reflected in the monthly cycle. While the monthly cycle has not changed, the mean monthly temperature has rather seen increases ranging between 1℃ to 2℃ depending on the time of the year. Similar studies by Mesti (2020) and Mesti (2015) concluded on about onedegree change in daily temperature. The temperature difference between the hottest and coldest months is about 10℃ over the north of Ghana. The temperature patterns and dynamics can impact rainfall patterns, soil moisture, plant growth, and development. The extent of deviation from the normal differs from station to station for all the months of the year.

The seasonal cycle and its climatology of minimum temperature have remained unchanged over the period of analysis. Minimum temperature peaks in April, unlike maximum temperature, which peaks in March. The minimum temperature reaches its lowest in August. This low point also coincides with maximum temperature. This result is consistent with Nkrumah et al. (2014).

The annual mean temperature for the study area has changed over the period of analysis. The change being experienced is statistically significant and has been consistent for over a decade for all the stations that meet the IPCC definition of climate change. The night temperature has assumed an increasing trend across all the stations in the study area. In a similar study, Asare-Nuamah & Botchway, (2019), Mesti (2020), Mesti (2015), and Lawson et al., (2020) confirmed the increasing trend in temperature over the Sudan and Guinea savannah ecological zones of Ghana.

The gradient of the slopes of each station differs. The night temperature at Damango has remained stable for the entire rainfall season. However, the night temperature in October has begun to show statistically significant increasing trends in October at the end of the season. While the coldest nights over the north of Ghana were recorded before 2000, the warmest nights were recorded after the year 2000, which affirms recent warming trends globally (IPCC, 2018; IPCC, 2014).

While the monthly cycle of minimum temperature has not changed, significant changes are observed over the entire north of Ghana. The southern and western part of the north of Ghana has seen a relatively higher increase in temperature compared to the Upper East part of the north of Ghana. This means that the rate of increase of nighttime temperature is slower in the hottest part of the north of Ghana (Upper East) compared to the other parts of northern Ghana. On the other hand, the nighttime temperature increases at a higher rate in the peak month compared to the additional months of the year.

Evapotranspiration

The seasonal cycle of evapotranspiration for the north of Ghana is high at the beginning of the year, peaks in February, and reaches its minimum in August. Evapotranspiration has a lot in common and in contrast with both rainfall, maximum, and minimum temperature, but they have differences in their peak periods. While maximum temperature peaks in March, minimum temperature peaks in April, rainfall peaks in August/September, and evapotranspiration peaks in February. While rainfall peaks in August/September, both minimum and maximum temperatures reach their lowest ebb in August, which is the same for evapotranspiration. Evapotranspiration reaching its lowest in August can be explained by low temperatures both at night and day.

The mean annual evapotranspiration for the north of Ghana generally remains variable and shows increasing trends across the region; however, Tamale in the south and Wa in the northwestern part of the study area are experiencing a statistically significant decrease in evapotranspiration while Bole and Babile are experiencing a statistically significant increase in evapotranspiration. The rise in evapotranspiration at Bole and Babile and other stations could also be attributed partly to the increasing temperature. The decrease in evapotranspiration over Tamale and Wa could be linked to the decreasing rainfall trends and increasing temperature. The study area has been dominated by a high rate of evapotranspiration, which is above the long-term mean with a few years experiencing below-average annual mean evapotranspiration across the north of Ghana. The increasing evapotranspiration in the study area can be attributed to the rising night and day temperature in the study area (Asare-Nuamah & Botchway, 2019b; Issahaku et al., 2016).

Evapotranspiration is increasing through the year, and comparing the recent climatology to the former has revealed an upward shift of the current from the former. It is only at Babile and Tamale that it has seen a decrease in the monthly mean of evapotranspiration in August.

Agriculturally relevant information

The need to produce and assess climate information is paramount, and it must also be done in the context of the changing and variable climate. This section of the discussion focuses on the agricultural season which is a period designated for farming activities. Also, what affects farmers is what happens during the farming season. The agriculturally relevant climate information was assessed to ascertain any changes and understand their trend for planning and decision making. The rainfall total, temperature, and evapotranspiration during the farming season affect crop development with the onset, cessation, and length of the season for rainfed farmers. Further, this section will underscore the spatial underpinnings of the climate and agriculturally relevant climate variables.

The rainfall amount received in the season affects the livelihood activities of farmers during the farming season. Seasonal rainfall total over the north of

Ghana decreases as you move northwards with the northeastern part of the study area having the least seasonal rainfall total. The seasonal rainfall total for the study area has generally assumed a decreasing trend. This means that the seasonal rainfall total over the north of Ghana is reducing. However, the total seasonal rainfall reduction is not statistically significant, which means there have not been substantial changes in the mean of seasonal rainfall over the north of Ghana. Seasonal rainfall total over the north of Ghana can best be described as variable as Nyadzi (2016) concluded in their study. In the context of climate change, it is important to indicate that the seasonal rainfall total has not changed over the study area. The current state of seasonal rainfall total, which is inconsistent, and oscillating makes planning by farmers, stakeholders, and policymakers more difficult. The variable nature of the seasonal total and the assumed decreasing but not significant trend is consistent with the annual rainfall total for the north of Ghana. This finding also resonates with the work done by Abbam et al. (2018).

The onset of the season is an essential agricultural variable that enables farmers to begin farming for a particular season. The start of the season has not changed over the north of Ghana over the period of analysis. There is interannual variation in the onset of the season, with some years having an early start and other years with late-onset. The start of the season trends are not uniform over the north of Ghana. While some places are experiencing early onset, other locations are also experiencing late onset. Still, none of these is statistically significant, and therefore it cannot be concluded that the start of the season over the north of Ghana has changed. Most of the locations in the north of Ghana are experiencing a statistically non-significant delay in the onset of the season, and this can be linked to the statistically non-significant decreasing and variable rainfall pattern. However, this experience is not consistent with all the stations because Walewale and Babile are showing early onset. At the same time, Vea, which has assumed an increasing trend in annual rainfall total, is showing a late-onset trend. The mean onset date for the north of Ghana is April 27.

The end of the season over the north of Ghana has not changed over the period of analysis except for Walewale, which has shown a statistically significant late or extension of the end of the season. The situation at Walewale is consistent with its increasing trend in annual and seasonal rainfall total, the number of rainy days, and the early onset of the season. Besides Walewale, the end of the season over the north of Ghana can best be described as variable and presents a challenge since some years will experience early cessation, and other years will be longer. This observation of variability with the end of the season conforms with variable annual and seasonal rainfall totals and the onset of the season. The mean end of the season for the north of Ghana is October 12.

The length of the season over the north of Ghana has not changed over the period of study. Most of the stations have assumed a decreasing trend indicating a shortening of the season in the study area, but none of these is statistically significant. Contrary to the general trend in the study area, the length of season for Walewale and Babile has assumed an increasing trend; therefore, farmers in these areas will be experiencing longer seasons compared to the other areas of the north of Ghana. The lengthening of the season for these stations can be attributed to the onset observed at these locations and with Walewale, which has experienced a significant change at the end of the season date with the season ending at a later date compared to the other places. There is interannual variation in the length of the season over the north of Ghana, with years having longer seasons while other years being shorter. The average length of the season for the study area is six months. Most of the shortest seasons recorded for the stations occurred in the 1980s, reflecting the dry conditions experienced during the period.

The most prolonged dry spell is a piece of useful climate information that farmers and relevant stakeholders can use to make an informed decision. This is important because the majority of farmers in the north of Ghana practice rain-fed agriculture. Consecutive days without rainfall can hamper the development of the plants depending on the stage of development. The longest continuous days without rain during the rainfall season in the study area have not changed over the period of analysis. The north of Ghana registered long spells during the 1980s, but beyond that, consecutive days without rainfall have relatively declined but remain variable across the study area. While locations around Bole, Bolgatanga, and Walewale show a statistically non-significant decreasing trend in the most prolonged dry spell, the remainder of the stations do not show any visible trend. The drought situation in the north of Ghana has not changed over the years, but what is evident is interannual variation in the longest spell to be expected during the rainfall season for each year. This presents a challenging situation for farmers to manage their risk, but knowing the worst-case scenario will also help in coming out with relevant adaptation strategies. The worst case of dry spell you may expect over the north of

Ghana is 35 days, and the least you may expect is 6 days. The mean longest dry spell over the north of Ghana is 13 days, which is one week and five days.

The temperature of both day and night during the rainfall season affects farming activities dependent on the climate. Night temperature during the rainfall season for each month has assumed an increasing statistically significant trend except for Damongo and Vea. The general increase in temperature is consistent with the finding of Kwasi. et al. (2014) and Nyadzi (2016). The trend at Damongo is not significant for all the rainy months except September. Vea is also showing a statistically significant decreasing trend for all the rainy months. Like the changes being experienced during the night, day temperature is also increasing but with lots of inconsistencies concerning changes in day temperature at the monthly time step. While some location experiences statistically significant changes for a particular month, the increasing trend may not be significant in the preceding or succeeding month. These dynamics in the day time temperature will require different approaches for a particular location for a specific month. A wholesale solution for all will not work, but a particular solution will be needed for a particular location. There is a change in temperature, particularly for the night for each month of the season, unlike rainfall, which has not changed. The change in temperature at the season level also affirms the changes experienced for the annual mean for the study area. The general increase in temperature during the farming season will impact crop development, which will seamlessly impact crop yield and, by extension, hinder the efforts of alleviating poverty and improving the livelihoods of smallholder farmers. This will worsen the poverty situation in the north of Ghana if appropriate coping and adaptation strategies are not implemented.

Evapotranspiration is an essential agricultural parameter that affects plan phenomenology. The need to understand the state of evapotranspiration during the farming season is vital to building the resilience and adaptive capacity of smallholder farmers. It is essential to understand and appreciate what has been the situation during the crop season. The rate of evapotranspiration is high in April. Evapotranspiration in April has changed over the north of Ghana. Although the remainder of the months from May to September haves mostly assumed an increasing trend, most of the station's evapotranspiration has not changed. It is only a few of the stations that are experiencing a change in evapotranspiration. The general trend of increasing evapotranspiration during the crop season can be attributed to the increasing minimum and maximum temperature. The month and stations where there is no change in evapotranspiration can be described as variable. The variation can be ascribed to rainfall variability during the rainfall season. Babile among all the locations showed a contrasting behavior assuming a decreasing trend in evapotranspiration though not statistically significant for all the months. The pattern can be attributed to the gentle slope of the increasing pattern of both night and day temperatures at Babile for the rainfall season. The rise in the rate of evapotranspiration in the study area has the potential to reduce soil moisture. The reduction in soil moisture and possible dry spells has the possibility of stressing plant development and eventual yield.

The nature of the climate variable over the north of Ghana is not uniform. There are spatial dynamics among the climate and agriculturally relevant climate information. The rainfall amount received at the end of the year differs from places in the north of Ghana. The southern part of the north of Ghana gets the highest rainfall, and it's the wettest part of the north of Ghana, receiving between 1000mm to 1200mm of rain. The southwestern part of the north is wetter relatively compared to the northwestern part of the north. The areas northeast of the north are the driest part of the north of Ghana. The onset of the season over the north of Ghana begins early in the southern part of the north of Ghana and progresses with time to the northernmost part of the region. The early onset grants farmers in the south of the study area the advantage of having a relatively longer season compared to the stations north of the study area. These will determine the kind of crops to be grown in these areas. Farmers in the south of the study area can afford to engage in plants that take a relatively longer period to mature compared to the stations northwards. Locations in the northwestern part stretching towards the east has the earliest cessation of the season over the north of Ghana. This regresses diagonally from the northwest part to the southwestern part of the study area. The areas over the study area with less rainfall and late onset of the season experience early cessation of the season. The length of the season over the study area is relatively longer over the southern part of the study area, but this reduces as you move towards the north of the study area.

The late onset for the northern part of the north and early cessation explain the relatively shorter length of the season compared to the southern part of the north.

Like the length of the season, dry spells are relatively shorter over the southern part of the north of Ghana, and as you progress northwards, dry spells increase. The relatively longer spells experienced in the northern part of the study area can be explained by the low rainfall totals the area experiences with a relatively small number of rainy days. Similarly, the relatively shorter dry spells over the south of the study area are due to relatively higher rainfall and the number of rainy days. Both minimum and maximum temperatures also increase with latitude across the north of Ghana. The hottest part of the north of Ghana is the northern part of the study area, particularly the northeastern part. In terms of evapotranspiration, the more significant part of the study area has a similar rate of evapotranspiration because of the generally high and increasing temperature in the study area. However, the extreme parts of the region that are the northeastern and western part has a horizontal contrast. The northwestern part has the least evapotranspiration, and the northeastern part has the highest rate of evapotranspiration. The horizontal disparity can be explained by the temperature differences, with the eastern part being the hottest part of the study area. The northwestern portion is experiencing a less steep gradient concerning an increasing trend in temperature. The climate and agriculturally relevant information generally have vertical contrast and horizontal similarity. The spatial variation of rainfall, onset, cessation, and length of the season patterns across the region has also informed the types of crops grown in specific areas of the north. These crops will have a specific water requirement, and maturity period, and the particular plant will do well in the north of Ghana's wettest areas while others will do well in the dry areas of the north of Ghana.

Teleconnection between rainfall and temperature

The risk management of a variable rainfall regime and increasing temperature will require an effective early warning system. The understanding of external variables impacting the climate of the study area will help provide lead time information on the expected rainfall and temperature for a particular season. Depending on what is to be expected during the season, farmers and all relevant stakeholders can make an informed decision.

There is a relationship between rainfall over the north of Ghana and ENSO. Still, the link is fragile to make any significant impact on the rainfall regime over the study area. In some stations, there is a negative relationship. The Tropical South Atlantic (TSA) has the strongest association with rainfall compared to AMM and NINO3.4. The correlation between TSA and rain over the study area is very weak to influence rainfall. Also, the effect of ENSO on rainfall in the study area is not statistically significant. ENSO's impact on rainfall in the study area accounts for less than 1%. This means that there are other significant factors influencing rainfall in the study area than the ENSO effect.

There is a relatively stronger relationship between maximum temperature and ENSO over the north of Ghana. This is evidenced by the firm, relatively stronger correlation between maximum temperature and ENSO. Among the ENSO indices assessed, TSA had a very high correlation with maximum temperature, especially with the stations south of the study area. Although there is a correlation between AMM and NINO3.4 and maximum temperature, TSA has the strongest association. The correlation between ENSO and maximum temperature was positive and statistically significant for most stations in the study area. ENSO accounts for about 10% to 50% depending on the location of the day temperature over the north of Ghana. This means that other factors are influencing the maximum temperature in the study area besides ENSO. The ENSO indices used in this study influence minimum temperature over the north of Ghana because of the positive correlation between most stations. The correlation among the various ENSO indices is not biased towards TSA, but AMM and NINO3.4 have shown some association with minimum temperature. ENSO's influence on minimum temperature over the north of Ghana is significant for most of the north of Ghana. ENSO explains about 10% to 50% of minimum temperature depending on your location in the study area.

There is evidence of the impact of ENSO on the general climate of the north of Ghana. Specifically, ENSO does not impact the rainfall over the north of Ghana. The teleconnection between ENSO and rainfall is less than 5%. On the contrary, there is a teleconnection between ENSO and temperature. TSA has the most substantial impact compared to AMM and NINO3.4.

CHAPTER EIGHT

SUMMARY OF FINDINGS

Introduction

This section presents the summary of the findings of this study and provides its implication and the needed policy trajectory that needs to be taken, recommendations for further research, and contribution to knowledge.

Summary of main findings

Rainfall over the north of Ghana has not changed although it has assumed a decreasing trend for most areas. The rain situation over the north of Ghana can best be described as variable. The average rainfall for the north is 1028mm but it ranges between 952mm and 1240mm. The southwestern part gets the highest rainfall whereas the northeastern part gets the least rainfall. Similarly, the rainfall-dependent agriculturally relevant climate information (onset of the season, length of the season, and cessation of the season) has not changed and can be described as variable. The southern part of the study area has a spatial and temporal advantage overs the northern part over the studied agriculturally relevant information. This is expressed in the shortening of the season and the increasing longest dry spell as you progress northward. Similarly, the farther you move northwards in the study area, the later the start of the season and the lesser number of rainy days. The Climate has changed with respect to temperature over the north of Ghana. Both minimum and maximum temperature has changed over the north of Ghana. There are spatial dynamics of climate over the north of Ghana for all the climate variables in terms of the rate of variability and change for temperature. Evapotranspiration for the study area is increasing and for some parts of the north of Ghana, it has changed which will impact the hydraulic cycle, drought, and agriculture. The mean evapotranspiration over the study area does not vary from north to south, unlike rainfall and temperature. There is no teleconnection between rainfall and ENSO over the north of Ghana. Temperature has on the other hand shown a ssignificant connection with ENSO.

Implications of findings

The general variability in annual rainfall, heavy rainfall events, and rainy days makes planning difficult and exposes people whose livelihoods depend on rainfall to a high risk. Again, planning for water resources management for irrigation, hydro energy generation, disaster risk reduction, and management becomes difficult because of the non-uniform and erratic nature of rainfall trends in the study area. The spatial and temporal dynamics require location-specific information for climate risk management decisions. The consistent increasing trends in temperature generally are an indication that our nights and days have become warmer. This has the potential of impacting negatively on agriculture through reduced yield, reduced underground water recharge, and livestock production (IPCC, 2018; Asare-Nuamah & Botchway, 2019). The high rate of evapotranspiration in April will have implications on livelihood activities influenced by evapotranspiration. The increasing pattern in temperature in the study area can be linked to the increasing evapotranspiration in the study as asserted by

IPCC (2018) and Asare-Nuamah & Botchway (2019). The increasing rate of evapotranspiration has the potential to reduce soil moisture. The reduction in soil moisture and potential cases of dry spells could stress crops and impact negatively on yield and farmers' economic and social wellbeing. The inconsistent trend in annual and seasonal rainfall total over the north of Ghana presents a worrying circumstance to smallholder farmers who are vulnerable with weak adaptive capacity. The shortening trend of the season if it continues will impact negatively on farming activities over the north of Ghana. The increasing temperature in the study area will reduce crop yield (Sultan & Gaetani, 2016). The presence of drought in the study area will impede agricultural activities which will lead to a reduction in crop yield and deepened poverty.

Access to water is a big challenge in the north of Ghana. A reduction in rainfall will worsen the already limited access to water in the study area. Most communities in the study area depend on hand-dug wells as a source of water for domestic use and agriculture. The decreasing trend in rainfall will reduce underground water recharge and this will affect the livelihood activities and by extension their wellbeing. In addition, the rising temperature and evapotranspiration will likely reduce surface runoff and underground water levels. It will further contribute to the drying up of water bodies such wells and other similar ones (Issahaku et al., 2016). This will likely worsen water scarcity in the study area and will affect the health of the people and agriculture.

The increasing temperature over the north of Ghana during the day and night will increase the demand for energy. While demand for energy during the day will continue to grow, demand during the night will also increase since households will need power to ventilate and or cool their rooms. Relevant state institutions would have to make provision for enough energy supply for the study area because of the potential increase in demand because of climatic factors. Energy conservation practices should be promoted in the study to manage energy consumption.

The rising temperature could pose health implications for the population, particularly smallholder farmers. Notably, the poor who cannot afford modern ways of cooling their rooms, particularly at night, will be exposed to extreme heat stress. The poor may resort to opening of their windows or sleeping or staying outside for a long period during the night, making them vulnerable to harmful insects like mosquitoes and may end up getting sick. The period during the season when the temperature is high and humidity is also high will lead to heat stress, which will impact the people's health and affect productivity in the city (Kwasi et al., 2014).

The current trends if they continue without deliberate adaptation strategies geared towards building the adaptive capacity and resilience of the smallholder farmers and the population will likely lead to reduced income, deepen the existing poverty levels and food insecurity (Asare-Nuamah & Botchway, 2019)

Recommendations for further research

Research should be conducted to find out what other factors influence the climate variables over the north of Ghana, particularly rainfall. Studies should be conducted to understand the future state of climate in the north of Ghana. Further research should be conducted on the impact of variable rainfall and underground water recharge and trends of groundwater levels. Further research should be conducted to uncover the seemingly uniform spatial nature of evapotranspiration unlike the spatial variation observed in rainfall and temperature.

Implications for policy

The climate of the north of Ghana is characterized by temporal and spatial variations. In addition, while rainfall has assumed a general decreasing trend but not significant, temperature has changed with day and night becoming warmer. Again, evapotranspiration is increasing with reducing the length of the season in the study area. These findings present a challenge to agriculture and can erode gains being made and deepen poverty in the study area if deliberate policy measures are not developed and implemented to reduce these impacts if the trend continues. Climate information and services should be location-specific but not generalized information for the entire region. Early maturing and drought-resistant crop seedlings should be developed for smallholder farmers. Measures should be put in place to exploit underground water for agriculture. Dams should be built for irrigation farming, and they should be made affordable for smallholder farmers to use. Climate information services should be developed to make useful climate information available, accessible, and timely to farmers to enable them to manage their climate risk based on evidence. To reduce poverty in the study area, smallholders farmers should be equipped to explore other livelihood options as an alternative source of income. Social protective systems should be put in place to cater to affected farmers. Robust insurance should be designed for farmers to enable farmers access insurance for their farmers as security for their investment.

Contribution to knowledge

This study has provided scientific evidence-based climate information on a scale covering the whole northern part of Ghana with a relatively higher number and more current observed station data, which was a gap in the literature. This study has opined that though there is global climate change, what affects the people is what they experience in their locality but not what is experienced globally. What has changed in terms of the climate is minimum and maximum temperature, although the seasonal cycle has remained intact in most cases. Rainfall: be it its seasonal cycle, or annual totals, the number of rain days has not changed. The description of climate change should be described and discussed in the context of what is experienced at the local level to inform appropriate, location-specific, and evidence-based policies in addressing the challenges it presents and exploring the opportunities it brings.

Another contribution of this study to knowledge is the evidence provided on the agriculturally relevant climate information. This study has filled a huge gap in the literature by providing an in-depth analysis of evapotranspiration, a critical agricultural parameter. Evapotranspiration is increasing in the study area with a clear upward shift by comparing the recent climatology to the former, which is also backed by the trend analysis conducted. The research on the onset, cessation, most prolonged spells, and length of the season has not changed in the study area. Still, it remains variable, consistent with the rainfall analysis but contrary to the widely held view that there is a change in rainfall and agriculturally relevant information.

Further, this study has filled a gap in the teleconnection between selected climate indices and the north of Ghana's climate. The findings revealed a weaker connection between climate indices and rainfall. On the other hand, there exists a relatively stronger connection between climate indices and temperature.

Conclusion

This work had the objective of providing the present state of the climate of the north of Ghana in relation to the agriculturally relevant information in the context of space and time. The study further examined the characteristics of evapotranspiration and the teleconnection between remote climate indices and the climate of the north of Ghana. The outcome of this study has revealed that the climatology of the north of Ghana has not changed except that the peak of the rainfall season for some places has shifted. Rainfall pattern in the study area can evidently be described as variable although it has assumed a non-significant decreasing trend. The agriculturally relevant climate information continues to be variable with a reducing length of the season. Temperature has changed over the study area with both night and day becoming warmer. The increasing temperature has contributed to the high rate of evapotranspiration in the study area. The emerged outcome of this study calls for policy measures and actions to build the adaptive capacity and resilience of farmers. The combined effect of variable and decreasing rainfall, increasing temperature, increasing evapotranspiration, and variable onset, cessation, drought, and shortening the length of the season would have a negative toll on farmers in the study area. Strategic policies and measures should be put in place to develop appropriate seedlings for farmers. Alternative sources of water for farming should be explored for farming and irrigation systems should developed for agriculture during the rainfall season and the dry season. The policy measure will help build the adaptive capacity and resilience of smallholder farmers and help achieve the Sustainable Development Goals.

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