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Rainfall Spatio - Temporal Variability in Kano Region, Nigeria

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A DISSERTATION

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DECLARATION

I hereby declare that this work is the product of my own research effort, undertaken under the supervision of Professor Salvatore Fava, and has not been presented and will not be presented elsewhere for the award of academic certificate.

All sources have been duly acknowledged

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USMAN ADAMU AHMAD

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Words cannot express my gratitude to my supervisor Professor Salvatore Fava and Dr. Adriana Nifosi for her invaluable patience and feedback. Additionally, this endeavor would not have been possible without the support from the Selinus University of Sciences and Literature. I am also grateful to my cohort members, especially my office mates (ANAS BALARABE) for his editing help and late night feedback sessions. Thanks should also go to research assistant from Bayero University, Kano. (DR. MOHAMMED AHMED). Who impacted and inspired me. Lastly, I would be remiss in not mentioning my family: Khadijah Ahmad Umar (Spouse), Salim Usman Adam (Son), Adam Usman Adam (Son), Ahmad Usman Adam (Son) and Ruqayya Usman Adam (Daughter). Their belief in me has kept my spirits and motivation high during this process. I would also like to thank my dear brother Umar Adamu Ahmad.

ABSTRACT

One of the Climates variable was examined, the study focused on rainfall and its monthly distribution, monthly variability, Annual distribution, inter annual variation and inter annual trends. Data for daily rainfall was adopted to analyze the decade trend (2010 – 2022). Time series for each station as regionally averaged values for the respective stations were plotted in order to present the Inter annual characteristics of rainfall in the study areas. Rainfall series shows a positive trend in the study area. The values in the study area indicates a relative high range from 70% to 100% in most years, the percentage of rainfall in the high class dominant, suggesting that a significant portion of the dry land areas experienced high levels of rainfall.

DEDICATION

I dedicate this work to my beloved late Parents Adamu Ahmad, Ruqayya Umar. And my late brother Mubarak Musa. May their gentle soul rest in perfect peace, Amen.

CERTIFICATION

This is to certify that the research work for this thesis and subsequent preparation of this thesis titled: Rainfall Spatio – Temporal Variability in Kano Region, Nigeria. By Usman Adamu Ahmad UNISE2514IT has been read and approved for the award of Doctor of Philosophy (PhD) In Environmental Science, Selinus University.

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CHAPTER ONE

BACKGROUND OF THE STUDY

1.1 Introduction

The climate of the planet changes seasonally, decadal, centennially, and over longer durations. Conditions that are warmer, wetter, colder, drier, windier, or quieter can result from each up and down fluctuation (Loua et al 2019). Oceanic and Atmospheric Administration (NOAA, 2007). The causes of these climate shifts could be internal natural processes, external pressures, or enduring anthropogenic changes in the atmosphere's composition or in land use (Bates et al., 2008). El Nio-Southern Oscillation (ENSO), a phenomenon that occurs naturally that affects the ocean and the atmosphere over the tropical Pacific Ocean and has significant effects on weather around the world, is perhaps the most well-known example of climate variability (National Oceanic and Atmospheric Agency (NOAA), 2007; Young and Young, 2021).

In several locations, there have been noticeable long-term changes in the amount of precipitation (Djaman et al 2020). Northeast, South, and Central America have had much more precipitation than have the Sahel, southern Africa, the Mediterranean, and southern Asia (Loua et al 2019; Djaman et al 2020). Even in areas where total amounts have dropped, widespread increases in heavy precipitation episodes have been seen. The warming of the world's oceans, particularly at lower latitudes, is linked to these changes in the atmosphere's water vapour content (Trenberth et al., 2007).

Since the late 1960s, the cons istent decrease in rainfall has been one of the most important climate variations in the African Sahel. According to Fox and Rock storm (2003) and Kanji et al. (2006), the Sahel is characterized by significant climate changes and erratic rainfall with a coefficient of variation ranging from 15% to 30%.

The Sahel region has had a 29–49% decline in rainfall between 1968 and 1997 compared to the 1931–1960 baseline period, according to the Inter-Governmental Panel on Climate Change (IPCC) (McCarthy, et al., 2001). According to the area, rainfall in the West African region has decreased noticeably by 15% to 30% (Niasse, 2 2005). When suitable rainfall conditions returned in 1994, the trend was reversed. This year was thought to be the wettest in the previous 30 years and may have heralded the end of the drought. Sadly, dry weather returned after 1994 (McCarthy et al., 2001).

Large inter-annual variation in rainfall frequently leads to climate hazards, particularly floods and severe widespread droughts, which have catastrophic consequences on food production and are connected with disasters and sufferings (Oladipo, 1993; Okorie, 2003; Adejuwon, 2004). The major climate variable that affects agricultural activity is the rainfall regime. Even a few kilometers apart and over a variety of time scales, rainfall can vary significantly. Accordingly, crop production is thought to be extremely changeable in both place and time, and it primarily influences the crops that can be grown as well as the farming system, the order, and the timing of agricultural operations (Adejuwon, 2005).

1.2 Statement of Research Problem

A precise characterization and identification of the problem's components forms the cornerstone of any scientific study analysis. Studies on the same issue of rainfall patterns have shown that the amount of precipitation is highly varied. With an inter-annual range of between 15% and 20%, the rainfall pattern in Northern Nigeria is very variable in both spatial and temporal dimensions (Oladipo, 1993; FRN, 2000).

Rainfall is highly unpredictable, and trends have shown that depending on the ITD's north-south movement, the rainy season may begin earlier than usual, conclude earlier than usual, or both. There were years during the recovery phase after 1988 when floods were reported, and there were other years when droughts were reported (Ahmed, 1987). According to Muhammad (1993), the pattern of rainfall varies according to the length of the rainy season on various time scales as well as on an annual basis.

The research was driven by the issue of variance, particularly in light of the issue of climate change that is wreaking havoc around the world. This study aims to close the gap left by earlier research that focused only on the vast region of northern Nigeria, without taking into account the study's target location, the Kano region. Additionally, this study aims to comprehend the issue of rainfall variability, specifically to identify any recent changes.

1.3 Aim and Objectives

Analysis of the trend of rainfall variance in the Kano Region is the aim of this study. The investigation was guided by the following objectives:

1) To compile and present numerical data on the temporal and spatial patterns of rainfall in the research area from 2010 to 2022.
2) To identify trends in the spatio-temporal distribution and variability of rainfall in the study area between 2010 and 2022.
3) On the basis of the study's results, make recommendations.

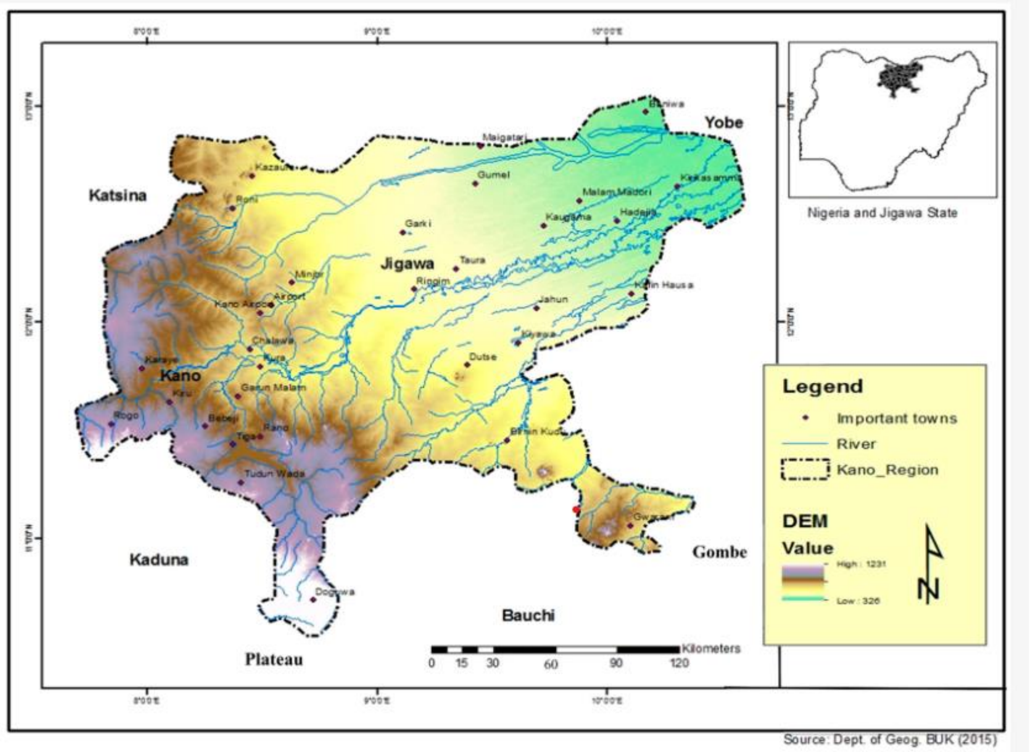
1.4 Hypothesis of the Research

The null hypothesis (HO) for the study is the following formulation of the research hypothesis. Rainfall in the studied area does not vary seasonally or spatially.

1.5 The Study Area: Kano Region

Kano Region is located between the latitudes of 10°3’N and 13°0’N and the longitudes of 7°3’E and 10°33’E, the Kano region is bordered on the east by

Bauchi state and on the north and west by Katsina state. Kaduna and Bauchi State border the region to the south (Fig. 1). The Sub-Sahelian region, where the majority of the region is located, rarely receives enough rainfall. The state is divided into two geological formations: to the north are sedimentary rocks, where rainwater always runs off quickly during the comparatively short rainy season, and to the south are basement complex rocks, which are of Precambrian origin and are less likely to contain underground water because of their impervious nature. The majority of the area is made up of gently undulating plains, particularly where sedimentary rocks (the Chad formation) are present. However, the Kano city is home to several lateritic-capped hills that rise above the plains, including Dala and Goron Dutse. With a height of roughly 1200 meters above sea level, the highest elevation is in the south (Olofin, 1987).



Source: Dept. of Geog. BUK (2015)

Figure 1: Study Area (Tukur et al 2018)

1.6 Climatic Characteristics

According to Olofin's (1987), the Kano Region is marked by noticeable and rapid fluctuations in temperature and humidity. This climatic zone is generally categorized as AW, following the Köppen classification, despite historical evidence suggesting past climate shifts. The delineation between the rainy and dry seasons is well-defined, with sporadic rainfall occurring between June and September and a protracted dry season spanning from October to May.

1.6.1 Rainfall

The rainfall pattern within the study area exhibits a significant and largely consistent South-North gradient. Annual precipitation levels hover around 1000mm in the southern reaches, decrease to approximately 800mm near Metropolitan Kano, and drop further to about 500mm in the north and northeastern sectors. Three distinct rainfall regimes are discerned: Wet, Normal, and Dry. The duration of the rainy season fluctuates from approximately six months in the south to four months in the north. The length of the wet season varies, spanning from 80 days at latitude 13°N to around 200 days at latitude 9°N, aligning with the gradual Northward gradient, as noted by Kowal and Knabe in 1972.

Kowal and Knabe (1972) observed that the duration of the rainy season increases by approximately 21 days for every degree of latitude. The rainy season typically experiences a single peak, with August being the month that receives the most precipitation. The progression of the rainy season moves at a rate of 13 days per degree latitude, while its retreat is nearly twice as swift, at 77 days per degree latitude.

1.6.2 Temperature

Throughout the year, the region maintains warm to hot weather conditions, with only a brief milder period from November to February. The monthly average temperatures vary from 21°C during the coldest months (December to January) to 31°C in the hottest months (April to May). The annual mean temperature remains around 26°C, with typical temperatures falling within the range of 22°C to 28°C.

1.6.3 Humidity

Relative humidity exhibits significant spatial and temporal variations within the region. There is a gradual 2% increase in relative humidity as one moves southward, with minimal regional disparities. During typical harmattan periods, when the dry and dusty northeast trade winds blow in from the Sahara under clear and dusty conditions, diurnal humidity levels can drop from 30% at dawn to as low as 10% in the afternoon. Conversely, the southwest monsoon breeze during the rainy season elevates humidity levels. Olofin (1985) posits that changes in temperature correspond with changes in humidity.

1.6.4 Evapotranspiration

Evapotranspiration, comprising both evaporation (the vertical movement of water from the Earth to the atmosphere) and transpiration (the process by which plants release water into the atmosphere), is a pivotal element of the region's hydrological cycle. The study area generally experiences a high rate of evapotranspiration. Using the sunken pan method, the mean annual evapotranspiration measures approximately 2538 mm, exhibiting a decline in the south and an increase in the north. Olofin's estimates in 1985 suggest that actual evapotranspiration is between 60% (in the south) and 75% (in the north) of the annual rainfall, deviating from theoretical calculations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Climate Change in the 21st Century

Policies, among other areas. Some studies concentrated on the economic impact of climate change at a regional (country) level, like Mendelsohn and Neumann's work in 2004, which focused on the United States' economy. Simultaneously, more global studies emerged, reflecting a trend towards considering climate change as a global issue transcending national borders, as advocated by Tanner and Allouche (2011), who proposed a new framework for climate change political economy and development. Additionally, Sovacool and Linnér (2016) delved into the political economy of climate change adaptation, while Batten (2018) examined the macroeconomic consequences of climate change, emphasizing the need for economic analysts to understand its impact. Fekete et al. (2021) provided a review of effective climate change mitigation policies in major emitting economies, including China, the European Union, India, Japan, and the United States. Benadetti et al. (2021) explored the investment risks during the transition to a lower-carbon economy, anticipating government interventions in fossil fuel markets.

One particular focus of recent research has been carbon taxation, which has attracted the attention of financial institutions. Crecente et al. (2021) argued that public funds could be a tool for countries to shift from older, unsustainable growth economies to more sustainable development paths. Stepanakis et al. (2021) introduced a novel approach incorporating the circular economy concept of nature-based solutions for climate change adaptation, highlighting the limitations of a linear economic model in the face of climate change threats.

Moreover, studies based on co-benefits have emerged, examining the advantages of addressing climate change and atmospheric pollution problems simultaneously (Sharifi et al., 2021). However, despite the evident connection, Markandya et al. (2018) noted a lack of evidence comparing the costs of mitigating air pollution and the economic benefits with alternative methods to achieve greenhouse gas targets. They investigated the extent to which health co-benefits could offset the mitigation costs of meeting the Paris Agreement targets, revealing substantial health gains from climate change prevention actions.

Shifting the focus to climate patterns, historical data reveals sequential "cold" and "hot" waves over past centuries, significantly affecting ecosystems and societies (Olesen & Bindi, 2002). The average surface temperature increased by over 0.7°C in the last century, with the period between 1995 and 2007 being the warmest since 1850 (Founda & Giannakopoulos, 2009). Future climate projections, incorporating available time series data, paint a different picture from current averages, indicating global warming coupled with moderate decreases in rainfall and localized, severe changes in various meteorological parameters (Sivakumar, 2007; Founda & Giannakopoulos, 2009). This increased variability exacerbates the vulnerability of land to both droughts and floods (Ceccarelli et al., 2014).

The Mediterranean basin, located between tropical and polar climatic systems, is highly susceptible to climate change due to its geographical features such as elevation and distance from the sea coast, resulting in significant rainfall and temperature variability along elevation gradients (Gualdi & Navarra, 2005). Climate variability in this region is linked to rising temperatures and increased vegetation stress caused by factors like higher summer temperatures, lower air humidity, reduced rainfall rates, and more extreme weather events (Sivakumar, 2007). Climate change, along with factors like land-use changes and increased human activity, has given rise to environmental issues, including land degradation, which negatively impacts soil quality, leading to decreased land productivity, loss of biodiversity, and diminished ecosystem services (Zdruli, 2014). Consequently, effective mitigation and adaptation policies are required to address these life-threatening ecological conditions (Montanarella, 2007).

Urbanization has further complicated matters, as it plays a crucial role in landscape transformations in Mediterranean Europe. It is particularly intriguing to compare long-term trends in climate regimes between urban and peri-urban areas, taking into account the concept of the Urban Heat Island (UHI), which results in local climate changes, including temperature increases and extreme rainfall events (Palme et al., 2017). This poses planning challenges that necessitate considering the combined impacts of climate change and urbanization, as urban areas experience more rapid temperature increases compared to their peri-urban counterparts (Ward et al., 2016). While previous studies focused on inner cities due to the more pronounced UHI effect, there is a notable gap in research on long-term trends in rainfall and temperature, comparing urban and peri-urban sites in large Mediterranean cities experiencing rapid urban expansion.

In this context, mitigation and adaptation strategies incorporated into urban planning must account for the anticipated increase in urban heat stress (Stewart & Oke, 2012). Nevertheless, identifying climate change signals and increased variability in rainfall and temperature regimes requires advanced tools and analysis of extensive datasets, ideally using multidimensional approaches (Jacob et al., 2018). Establishing a consistent temporal framework is a prerequisite for analyzing linear and non-linear long-term temperature and rainfall trends, identifying time series breakpoints, and exploring latent relationships among meteorological variables. This knowledge serves as the foundation for implementing effective policies addressing climate change mitigation and adaptation in large urban regions.

With these considerations in mind, this study investigates rainfall spatial and temporal variability over an extended period (1992–2022) in Kano Region. The study compare trends between an urban site (Kano Metropolis) and rural areas (other LGAs in the Kano region).

2.2 Rainfall Variability in Africa

Rainfall patterns across Africa exhibit substantial variations spanning various time scales, ranging from year-to-year fluctuations to multi-decadal shifts. The majority of Africa is situated in tropical and subtropical latitudes, resulting in consistently high temperatures throughout the year. Temperature fluctuations are more noticeable between day and night than between seasons. Except for desert regions, the diurnal temperature range typically falls within 0 to 15°C. In over one-third of the continent, the annual temperature range is less than 6°C, rarely exceeding 10°C in most regions south of the Sahara. With the exception of the extreme northern latitudes, north of the Sahara, and a small portion of the southern regions, temperatures remain relatively stable from year to year.

Africa displays a wide array of climates. In specific tropical rainforest areas, the mean annual rainfall can drop below 1 mm per year, while certain regions, such as the Cameroonian mountains (Debundascha), witness mean annual rainfall exceeding 1000 mm. The majority of the continent falls under the sub-humid category, yet it often contends with lengthy dry seasons, especially in arid regions where the rainy season may last only one or two months.

Historically, rainfall patterns have closely followed the seasonal movement of the inter-tropical convergence zone (ITCZ), although exceptions exist along the continent's extratropical borders. However, this description provides only a partial perspective. Several elements of the general atmospheric circulation, which, in turn, influence the location and characteristics of the ITCZ, play pivotal roles in driving the seasonal formation of Africa's tropical rain belt.

These factors encompass high- and low-pressure systems and an equatorial westerly shallow belt in the lower atmosphere.

The inter-annual variability of Africa's climate is significantly impacted by these atmospheric features (Buytaert, 2005). Meteorological records for Africa have a relatively limited time span. Only a few instrumental temperature records on the continent date back to the 20th century, with exceptions in South Africa and Algeria. The most comprehensive dataset pertains to rainfall.

Temperature records are accessible for a smaller number of sites, and, like rainfall records, they cover shorter durations. Stations that recorded rainfall data were operational in 1885, 1895, 1815, 1925, 1955, and 1985. Most of the records related to agriculture that relies on Niger floodwaters, including wheat cultivation and transportation to neighboring countries, date back to the first two years.

Around 1895, rainfall in the global tropics began to diminish, coinciding with another trend (Kraus, 1955). Consequently, albeit less severe, the 20th century witnessed an arid phase akin to the previous century. This culminated in a severe and widespread drought, especially during the 1910s, prompting discussions on potential solutions, such as flooding the Kalahari to restore normal rainfall (as proposed by hydrologist Schwarz in 1920). However, this anomaly proved relatively brief, with "good" rains returning within a decade, resembling the 19th-century pattern.

Societies in arid regions have always grappled with adapting to rainfall variability and its annual reliability. Present concerns center on the possibility of contemporary climate change exceeding the capacity for adaptation, as indicated by Adger and Vincent (2005) and IPCC (Stringer, Dyer, Reed et al., 2009).

Buba (2009) employed an analysis of temperature and rainfall variations to highlight fluctuations and potential climate changes in northern Nigeria on both yearly and seasonal time scales, providing clear evidence of climate change in that region.

In the Sudan Sahel Zone of Nigeria, current studies, including Borokini (2010), report a decrease in rainfall by 30 to 40%, equivalent to 3 to 4 percent per decade, since the early 19th century. These savannah and semi-arid areas have experienced significant droughts and desertification processes, particularly since the 1960s. These regions already contend with seasonal and inter-annual climate variations, and the expected decrease in precipitation may worsen the situation by increasing the likelihood of droughts and intensifying the variability and unpredictability of rainfall.

Climate change is imposing constraints on agriculture in the region, including more pronounced seasonal rainfall patterns, disrupting the traditional seasonal water supply. Studies by Adefolalu (1986), Anyadike (1993), Aondover et al. (1998), Ekpoh (1999), Dai et al. (2004), and Anyanwole (2007) indicate that most droughts exhibit characteristics such as delayed onset of rains, false onset of rains, extended breaks during the rainy season, and early cessation of rains.

In some years, an excess of rain can lead to dangerous floods, while in other years, the same region may suffer from drought conditions. Water, being essential for life, serves as both drinking water and irrigation for agricultural food production. Effective water resources management and protection against hydrological natural hazards require a profound understanding of natural rainfall variability and its potential drivers. Over the past 25 years, substantial efforts have been made to unravel the dynamics of African rainfall and its relationship with oceanic modes of variability, alongside anthropogenic and other natural influences (Nicholson, 2000, 2014). Some of the primary influencing factors are now well understood. For instance, the negative phase of the North Atlantic Oscillation (NAO) typically leads to increased rainfall in Morocco (Lamb & Peppler, 1987), the positive phase of the Atlantic Multidecadal Oscillation (AMO) results in above-average rainfall in the Sahel zone (Zhang & Delworth, 2006), and La Niña (negative El Niño Southern Oscillation, ENSO) is typically associated with drought conditions in parts of East Africa (Lott et al., 2013).

It is also acknowledged that the relationships between rainfall and oceanic modes of variability vary significantly from region to region and from season to season. Different variability indices exert their influence on rainfall during different times of the year. Many of these relations are characterized by a time-dependent, non-stationary nature (Nicholson, 2017). Correlations that were strong over several decades may suddenly weaken or disappear. Occasional phase reversals, as well as multi-month to multi-year time lags between climatic triggers and rainfall, further add to the complexity of the situation.

2.3 The Hydroclimate of Africa and Rainfall Patterns

Africa's hydroclimate is a diverse tapestry with varying rainfall patterns. Across extensive regions of North Africa, southern Africa, and the Horn of Africa, one encounters hot, arid desert and steppe climates, classified as per Köppen's system dating back to 1918. In stark contrast, equatorial Africa boasts humid tropical climates, while select areas in southern Africa are under the influence of temperate climates. The annual monsoon rhythm in Africa orchestrates the migration of the rain belt, commencing in West Africa and the Sahel during boreal summer and shifting to southern Africa during austral summer. Along the equatorial coastal stretch of East Africa, we witness two distinct rainy seasons: the 'long rains' spanning March to May and the 'short rains' commencing in September, reaching their peak in October and November. While the daily mean rainfall during the short rains tends to be lower than that of the long rains, the former is marked by greater interannual variability, as highlighted by Black (2005). Further, the Gulf of Guinea coast experiences two rainy seasons, stretching from January to March and July to September. In the southwestern tip of South Africa, rainfall graces the region during the austral winter.

Tracking the historical records, only a few significant long-term rainfall trends have surfaced across Africa in recent decades and over the past century, as elucidated by Nicholson et al. in 2018. West Africa and the Sahel, for instance, witnessed severe droughts during the 1970s and 1980s, followed by a noticeable shift towards increased rainfall around 1992 (as detailed by Badou et al. in 2017 and Park et al. in 2016). Conversely, different trends were noted in equatorial eastern Africa for the short and long rainfall seasons, as reported by Cattani et al. in 2018 and Gitau et al. in 2017. Regionally aggregated rainfall in South Africa displayed no discernible trends, according to MacKellar et al. in 2014. The past 2000 years of African hydroclimatic variability have been meticulously compiled by Nash et al. in 2016, and Lüning et al. in 2018 have meticulously delineated the changes in African rainfall during the Medieval Climate Anomaly (MCA, 1000–1200 AD).

2.4 Elements of Natural Rainfall Variability

Africa, the world's second-largest continent, is uniquely bordered by oceans, except for the Sinai land bridge connecting it to Asia. As shown in Figure 2, Africa's rainfall is shaped by an intricate interplay of natural drivers linked to oceanic modes of variability in the Atlantic (NAO, AMO), Indian Ocean (IOD), and the Pacific (PDO, ENSO), in addition to solar activity fluctuations (as highlighted by van Loon et al. in 2004). This complex web of natural influences on African rainfall is elaborated upon in the following sections, ranging from 3.1 to 3.7. While human activities also impact precipitation, this discussion is centered on the realm of natural factors.

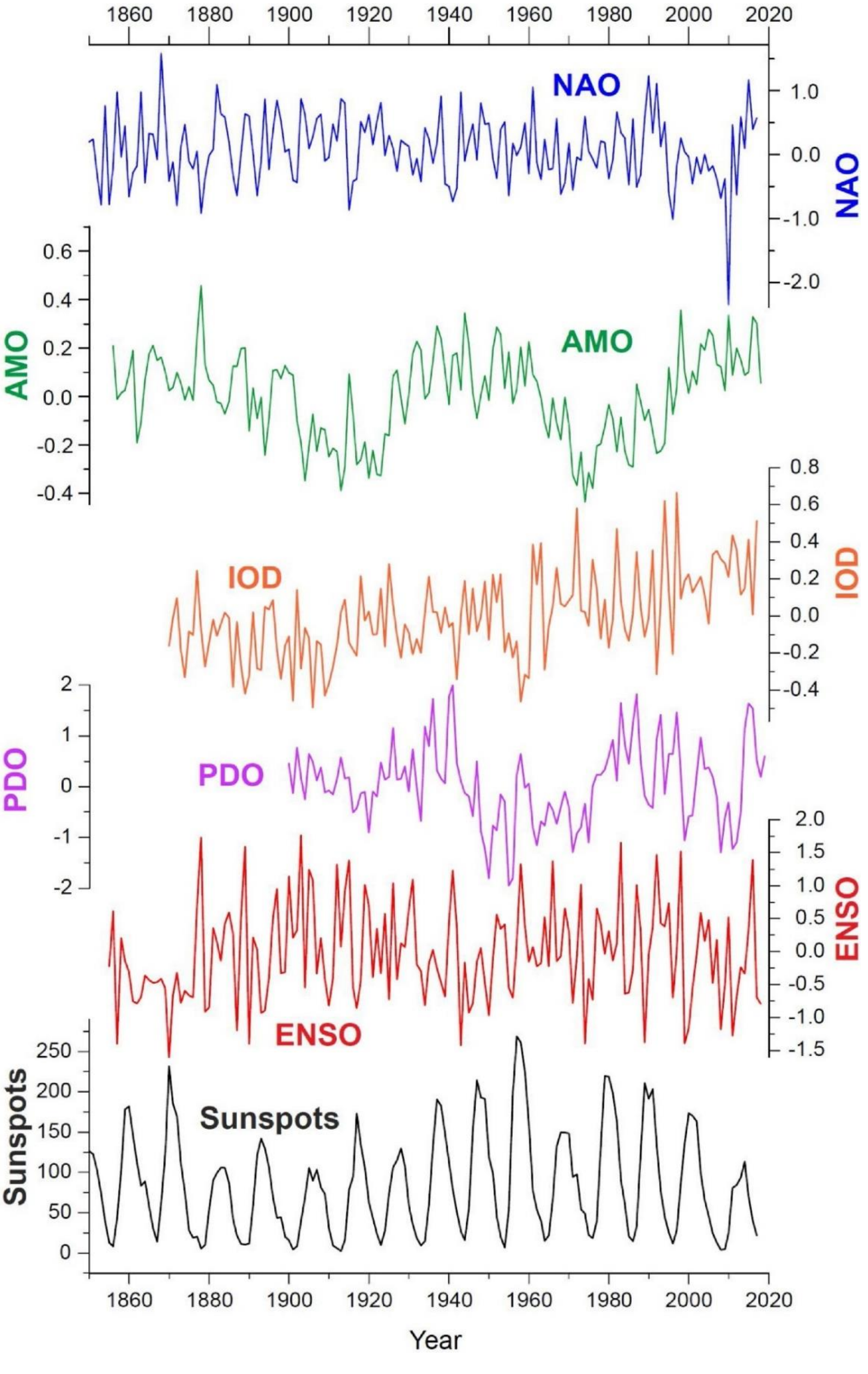


Figure 2: Element of Rainfall Variability in Africa.

2.4.1 North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) characterizes variations in surface sea-level pressure between the subtropical Azores High and the subpolar Icelandic Low. During boreal winter, rainfall in Morocco and northwestern Algeria demonstrates a negative correlation with the NAO. In contrast, winter rainfall in Libya and northern Egypt exhibits a positive correlation. The NAO's impact on northwestern Africa is further intertwined with North Atlantic sea surface temperature (SST) patterns, with the influence varying with the sign and season of the SST, as expounded upon by Li et al. in 2003. Boreal winter rainfall in Uganda is marked by negative correlations with the NAO, while the West African summer monsoon rainfall registers a negative correlation with the boreal spring NAO, according to Li et al. in 2012.

2.4.2 Atlantic Multidecadal Oscillation (AMO)

The Atlantic Multidecadal Oscillation (AMO) delineates a low-frequency oceanic cycle spanning approximately 60–80 years, driven by SST anomalies in the North Atlantic basin. The Sahel's boreal summer rainfall is notably positively correlated with the AMO, while central equatorial Africa showcases a negative correlation with boreal summer/autumn rainfall and the AMO. Rainfall maps also indicate positive AMO correlations along the Atlantic coast from October to December (OND) and in East Africa from January to March (JFM). Nevertheless, contrary AMO correlations have been documented for the southeastern African Indian Ocean coastline and Madagascar. Interestingly, a positive correlation between Ethiopian rainfall and the AMO during the dry season (October-May) has been suggested by Taye and Willems in 2012.

2.4.3 Indian Ocean Dipole (IOD)

The Indian Ocean Dipole (IOD) is defined by differences in sea surface temperatures between the western and eastern equatorial Indian Ocean. The short rain season in East Africa, ranging from October to December (OND), is strongly positively correlated with the IOD. This phenomenon leads to more frequent floods in East Africa during the positive phase of the IOD and heightened droughts during its negative phase. Intriguingly, the long rain season in East Africa, spanning from March to May (MAM), does not exhibit significant correlations with the IOD, as noted by Owiti et al. in 2008. Notably, a positive IOD also exerts its influence on rainfall along the Angolan Atlantic coast and parts of western West Africa. However, it may simultaneously diminish rainfall in Central and southeastern Africa, creating IOD dipoles. Positive IOD correlations have been recorded in southern Africa during the austral spring-summer transition (October-December), albeit with some variability noted after 1997. The southern African region experiences intricate interactions between the IOD and ENSO, shaping rainfall dynamics during the austral summer (December-February). The phase of the IOD is instrumental in modulating southern Africa's precipitation response to ENSO (Hoell et al., 2017).

2.4.4 Pacific Decadal Oscillation (PDO)

The Pacific Decadal Oscillation (PDO) represents a climate variability pattern within the northeast and tropical Pacific Ocean. Notably, boreal summer rainfall in Ethiopia, the Sahel, and the Gulf of Guinea coast exhibits a negative correlation with the PDO.

2.4.5 El Niño–Southern Oscillation (ENSO)

The El Niño–Southern Oscillation (ENSO) is characterized by variations in central and eastern equatorial Pacific SST, leading to warmer (El Niño) or cooler (La Niña) states. The influence of ENSO on African rainfall is a complex tapestry, exhibiting significant regional and seasonal variations. Morocco, Northwest Algeria, and Tunisia, for instance, register negative correlations between ENSO and rainfall. However, these correlations tend to fluctuate over time and may involve time lags of up to 2 years. In the Sahel region, ENSO showcases differential impacts across different seasons. Ethiopia, in particular, observes negative correlations between ENSO and summer rainfall, except in the easternmost region and Somalia, where positive correlations have been identified. East Africa experiences a spectrum of correlations with ENSO, both positive and negative, contingent upon the region and season. Importantly, rainfall modulation in East Africa is influenced by the combined interplay of ENSO and IOD, with dynamic, time-dependent correlations. In the case of southern Africa, austral summer rainfall demonstrates a negative correlation with ENSO, whereas austral winter rainfall displays a positive correlation.

2.4.6 Solar Activity Changes

Solar activity variations have been associated with African rainfall patterns across diverse timescales, spanning decades to multi-centuries. Different solar cycles, encompassing the Schwabe cycle (11 years), Hale cycle (22 years), Gleissberg cycle (90 years), and Suess-de Vries cycle (200 years), have been discerned in relation to African rainfall dynamics. It is noteworthy that solar activity likely contributes to rainfall variability indirectly, in a nonlinear manner, underscoring the intricate interplay between solar forces and African hydroclimatic shifts.

2.5 Factors Influencing the Climate of West Africa

The West African monsoon, which moves seasonally, dominates the climate of West Africa, but what causes the monsoon? There appears to be a growing body of evidence supporting the idea that the Atlantic Ocean's (north and south) and the Indian Ocean's differential increases in SSTs are the main cause of climatic change in the region (for reviews, see Hulme 2001; IPCC 2001; Brooks 2004). Secondary feedback processes may be used to explain changes in dust production, vegetation dynamics, moisture flux, and changes in the land surface. One of the more recent literature assessments on the topic of causes of rainfall variability in the Sahel, recent droughts, and future prediction was conducted by Nick Brooks of the Tyndall Climate Center; he mentions a significant amount of the pertinent research that led to this broad consensus (Brooks, 2004).

This oceanic forcing seems to consist of two separate parts. One describes the continental monsoon and is associated with the oceanic Inter-Tropical Convergence Zone (ITCZ), while the other represents the Sahel and the Gulf of Guinea coast (Giannini, 2005). This also contributes to the explanation of the high level of intra-seasonal variability because of the nature of convection along the Gulf of Guinea at 50 N and across the Sahel at 150 N, with a "jump" between the two being observed in June from the Gulf of Guinea poleward into the Sahel. In Southern West Africa (about latitude 50N), Migan (2000) lists three meteorological conditions that affect precipitation:

a) the northern meeting point of the eastward-moving Harmattan winds and the westward-moving monsoon, which share cloud-bearing structures that hinder rain;
b) the inter-tropical convergence zone (ITZ), where the convergent motion of the southern trade winds and the boreal trade winds leads to the production of heavy rain-bearing clouds;
c) The typical southern trade structure to the south of the ICS is defined by strict layering, and its midsummer absorption into the coastal regions causes the brief dry summer season (August) in the coastal Zones (Buba, 2010).

2.6 Spatial and Temporal Variability of Rainfall

According to Hulme et al. (2005), rainfall varies noticeably in both space and time. Over most of Africa, inter-annual rainfall variability is significant, and multi-decadal variability is also significant in some places. Since the end of the 1960s, there has been a loss in annual rainfall in West Africa (40 20 0N; 200 W 400 E), with a 20%–40% decrease documented between the years 1931–1960 and 1968–1990 (Nicholson et al., 2000; Chapel and Agnew, Dai et al., 2004).

in Mortimore (2010), Hulme et al. According to a falling gradient of mean annual rainfall in the Sahel of roughly 145mm/km, aridity and rainfall variability rise with latitude.

According to location, annual rainfall decreased by 25–30% during the mid–1960s and the mid–1990s. For instance, the average annual rainfall in Kano ranged from 853mm in 1931 to 1960 to 826mm in 1941 to 1970 to 807mm in 1951 to 1980 to 714mm in 1961 to 1990. Between 1940 and 1976 and 1968 and 2000, the Isohyets of mean annual rainfall moved up to 100 km south. Events involving droughts occurred more frequently.

Within a trend of increased seasonal and inter-annual variability. Late beginnings and early endings resulted in drastically shorter growing seasons. These changes had an impact that was comparable to anything projected in global climate change projections until 2050. For the years 1960 to 1998, there were decreases in mean annual precipitation of about 4% in West Africa, 3% in North Congo, and 2% in South Congo in the tropical rain-forest zone (Malhi and Wright, 2004).

However, over the past 30 years, a 10% increase in yearly rainfall has also been noted along the Guinean Coast (Nicholson et al., 2000). There is no longer-term trend in other areas, such as southern Africa. In contrast, larger rainfall anomalies and more severe and extensive droughts have been reported since 1970, indicating increased interannual variability (Fauchereau et al., 2003). In Uganda, Manning (1956) believed that the distribution of yearly precipitation was statistically normal. When it comes to yearly rainfall series that have mild skewnesses and kurtosis (Elderton, 1938; Fisher, 1922). According to Gommes and Houssiau (1982), the distribution of rainfall is noticeably skewed in the majority of Tanzanian stations, and log transformations should be used as the degree of skewness and kurtosis grows.

According to Obasi (2003), intra-annual rainfall variability describes how much rain falls during a year. Inter-annual rainfall changes have put a lot of strain on farming operations, crop yield, and crop output over the past ten years in Nigeria's Guinea Savanna (Adejuwon, 2004). Previous research (Awosika et al., 1994; FAO, 2001; Obasi, 2003; Adejuwon, 2004) have looked at inter-annual rainfall variability in Nigeria and other parts of West Africa. The numerous facets of plant growth and yields are impacted, which changes crop productivity. According to Awosika et al. (1994), between 4% and 6% of Nigeria's GDP was lost to drought-related economic effects in 1992. The semi-arid and sub-humid regions of West Africa have experienced a long-term change in rainfall, according to an FAO (2001) examination of recent rainfall conditions in the region. Despite the fact that the majority of its causes are natural, it may seem as though there is little that can be done to reduce rainfall variability.

The complicated factors causing rainfall variability have become better understood (Reason et al., 2005; Warren et al., 2006; Washington and Preston, 2006; Christensen et al., 2007). It is crucial to comprehend how potential changes in the climate regime (such those caused by El Nino-Southern Oscillation (ENSO) events) may affect future climate variability. For instance, equatorial Indian Ocean Sea surface temperature (SST) has been positively trending since the 1970s, which has been connected to the drying of the Sahel region. Meanwhile, ENSO has a major impact on rainfall at inter-annual periods (Giannini et al., 2003; Christensen et al., 2007). The intensity and localization of the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ) in the same region also affect rainfall variability (Nicholson and Grist, 2003), as do SSTs in the Gulf of Guinea (Vizy and Cook, 2001), and a link with the warm Mediterranean Sea and abundant rainfall has also been found (Rowell, 2003). In South-West Africa, where the North Atlantic Oscillation (NOA) has some influence, the impact of ENSO decadal oscillations has also been noted (Nicholson and Selato, 2000).

2.7 Rainfall Variability in Northern Nigeria

As a consequence of numerous investigations, the temporal and spatial features of rainfall climatology have been confirmed. There are temporal variations in rainfall that are not merely seasonal fluctuations, in addition to the south to north differences from the southern Guinea, Sudan, and the Sahel savannah. The study of two climatologically typical times was extensive. According to Buba (1995), these timespans were 1931–1960 and 1961–1990. 2002's Ingram, Roncoli, and Kristen. The variation in Sokoto's annual total precipitation is apparent. Two climatic eras are apparent when Sokoto changes are closely examined. The first era began in 1915 and continued until the mean rainfall stabilized at roughly 680mm in 1967. The second climatic era began in 1968 and lasted until 2008, when the average annual rainfall dropped to 600 mm. A five year running mean for the long-term rainfall from 1915 to 2008 highlights the problem of diminishing rainfall during the 1968 to 2008 decade.

According to studies, rainfall in the Sokoto region has significantly decreased between 1968 and 2008, to the point where a new mean that is 8.8 percent lower than the long-term mean has been established. Inter-annual rainfall fluctuations affect the standard deviation and coefficient of variation in addition to the mean-state conditions.

According to the study, inter-annual rainfall between 1967 and 2007 varied greatly in terms of total receipts as well as the dates that rain began and stopped falling as well as the duration of the rainy season. Since rainfall tends to decrease from south to north, thorough research of each component is required to get an understanding of the nature of climatic variability within the climate system. For instance, rainfall records often include a complicated mix of variances. These fluctuations can be distinguished as long-term trends, yearly and semi-annual cycles, quasi-cyclical discontinuities, inter-annual variabilities, and intra-annual variabilities by separating or filtering them out. Rainfall is the most changeable climatic factor in northern Nigeria, both temporally and spatially, according to previous studies, and these variations can have a big impact on economic activity. (Ekpoh, 1991, Adefolalu, 1986, Mortimore and Adams, 2001; Kowal and Kanabe, 1972; Kowal and Kassam, 1978; Kowal and Kassam, 1973). According to the information that is currently available, there isn't a single overall mean periodicity for rainfall variability in northern Nigeria. Instead, a number of non-symmetric cycles of anomalies with variable magnitudes best describe rainfall.

These findings support those made earlier by Bunting et al. (1976). In some places, the cycles are 3 to 5 years, whereas in others, they are 10, 20, and 30 to 40 years (Kalu, 16 1987). However, Winstanley (2003) has noted that from roughly 1900 to 1930, the climatic zones in the northern hemisphere gradually migrated northward. Since then, the Sudano-Sahelian region of West Africa has moved southward, resulting in a decrease in rainfall. According to the argument, the southerly trend will probably continue for another 200 years, or until about 2030. The area has also seen a string of dry years dating back to the early 1970s (Olaniran and Sumner, 1988; Olaniran, 1991; Easterling and Peterson, 1995).

Some alterations were found by (Fukui, 1979; Parry, 1985a). The first kind of climate change takes into account a change in the standard deviation but not a change in the mean amount of rainfall. There would be an increased risk from both insufficient and excessive rainfall if the shift causes the standard deviation to grow. The third form of climate change involves changes to both the mean and the standard deviation. This more severe form of climate change has the potential to seriously disrupt economic activity.

Adefolalu's (2007) rainfall analysis also revealed that the secondary rainfall maximum in Nigeria in latitudes 900 and 1010 N has decreased over time in terms of both volume and surface area. The belt of relative minimal rainfall also seems to be growing in time at the same time. These anomalies, which signal that the dry season's contribution to yearly rainfall is declining, point to a longer-term trend of drier conditions. Tarhule and Woo (1998) also examined recent variations in a number of rainfall features in northern Nigeria using climate records from 25 locations.

Pettitt's work, which employed the Mann-Kendall tests to examine patterns and jarring shifts in the rainfall data. In particular for areas north of latitude 1100 N, the results show rapid changes in the annual rainfall time series and a large decrease in the number of rainy days. Ekpoh (2007) performed station analysis on long-term rainfall data from Zaria, Kano, and Katsina in another study in order to test for trend using the 5-year running means.

The study's findings showed that from 1969 to 1999, the three stations' annual rainfall decreased.

2.8 Rainfall variability of Kano Region

Because it is so scarce during the dry season, rainfall is a crucial component in the region. The average annual rainfall in the region's southernmost areas averages around 1000 mm, falling to approximately 800 mm around Kano's metropolitan area, and to about 600 mm in the north and northeast. Anywhere in the region, there are significant temporal changes in the amount of rainfall.

According to Olofin (1985), averages calculated for any two periods are never the same and no two successive years record the same amount.

In only approximately five months of the year, particularly between May and September (Ati, Iguisi & Afolayan, 2007), the average annual rainfall in this zone varies from less than 500mm in the far northeastern area to 1000mm in the southern sub-region (Abaje, Ati & Iguisi, 2011). Between July and August, there is a lot of rain with a high intensity.

With an annually changing variability of between 15 and 20%, the pattern of rainfall in the zone is highly changeable in both spatial and temporal dimensions (Oladipo, 1993).

Three main meteorological elements—the tropical maritime (mT) air mass, the tropical continental (cT) air mass, and the equatorial easterlies—have the greatest influence on the climate. Along a sloped surface known as the Inter-tropical Discontinuity (ITD), the first two air masses (mT & cT) collide. The upper troposphere along the ITD is dominated by irregular, somewhat chilly equatorial easterlies (Odekunle, 2006; Odekunle et al., 2008). The ITD's position varies significantly over short time periods depending on the season. But in July and August, it is typically located far enough north of the SSEZ to completely be under the influence of the mT air mass. It is south of the zone from October to May, which has the effect of engulfing the entire SSEZ in the cT air mass during this time (Odekunle et al., 2008). As one moves northward, the quantity of trees and other plants decreases, leaving the entire area covered in savanna vegetation made up of Sudan and Sahel flora. The collective name for these two zones is SSEZ.

The duration, volume, seasonality of the rainfall system, and fluctuation from year to year are the most significant aspects of rainfall in the Kano metropolitan area and in the entire region in general. Olofin. 1987. The lack of rainfall during the dry season, it was stated, makes it a highly important factor in Kano's metropolis.

According to additional research, the highest and lowest rainfall levels between 1930 and 2007 were recorded in metropolitan Kano during the 1930s, 1940s, 1960s, and 1980s, respectively, while the 1980s, 1990s, and 2000 saw the lowest amounts. As compared to other years, this demonstrates a reduction.

CHAPTER THREE

METHDODOLOGY

3.1 Introduction

It is apparent that there is always a relationship between the topic of a research and the methodology of collecting the data, as Zugachi (1987) would suggest; the methodology primarily explains the approach used in conducting the study.

3.2 Types, Nature and Sources of Data

The Kano State Agricultural Development Agency (KNARDA), the Nigerian Meteorological Agency (NIMET), the Jigawa Agricultural and Development Agency (JARDA), and Water Resources and Construction Company (WRECA) as well as NASA Power will be the sources of the data.

3.3 Data Collection

A letter will be written to the agency to seek for data collection while the data from NASA power will be downloaded online via (https://power.larc.nasa.gov/).

3.4 Data Analysis

The variability of rainfall is a topic that the study covers. Statistical analysis of rainfall variation and trend will be performed as described below

All of the stations in the research region will have their long-term monthly rainfall and long-term yearly rainfall calculated, and the following descriptive statistics will be produced:

Mean:

$$X = \sum\left(\frac{x}{n}\right)$$

Where X is the mean, x is the summation of all the monthly pixels values in column *ith* and row *jth*, and n is the monthly averages.

Standard deviation:

$$SD = \frac{\sum(x_i - x_j)^2}{n}$$

Where SD stands for standard deviation, x_i represents the area's yearly rainfall total over the years, x_j represents the mean annual rainfall, and n represents the number of years covered.SD calculates the total amount of rainfall dispersion.

Coefficient of variation:

$$CV = \frac{SD}{XJ} \times 100$$

1. Where SD is the standard deviation, XJ is the mean annual rainfall, and CV is the coefficient of variation expressed in percentages. Independent of the measurement units, the coefficient of variation quantifies the distribution's relative dispersion.

Skewness:

$$g1 = m_3/m_2^{3/2}$$

2. The right tail of the distribution is longer than the left if skewness is positive, which means that the data are positively skewed or skewed right. The data are negatively skewed or skewed left if skewness is negative, and this results in a larger left tail.

   The data are completely symmetrical if skewness is equal to 0. However, real-world data rarely have a skewness of exactly zero.

a. The distribution is severely skewed if skewness is larger than $+1$ or less than-1.

b. The distribution is considered significantly skewed if the skewness falls between -1 and $-\frac{1}{2}$ or $+\frac{1}{2}$ and$+1$.

The kurtosis:

$$a4 = \frac{m_4}{m_2^2}$$

3. A distribution's peak is measured by kurtosis, which shows how high the distribution is around the mean. One of three classification types applies to the kurtosis of a distribution.

Variance:

$$Var(X) = E[(X - \mu)^2]$$

4. Determines the degree to which a set of numbers is dispersed. The values are all equal when the variance is zero. There is never a negative variance. A low variance implies that the data points are typically extremely close to the mean (expected value) and hence to one another, whereas a high variance shows that the data points are widely dispersed both from the mean and from one another.
   The expected value of the squared departure from the mean, $\mu = E[X]$, is a random variable's second central moment, and it is called variance:
   Two techniques for geographical analysis and two techniques for temporal analysis were used:

a. To explore the spatial variance of rainfall in the Kano region, isohyetal maps will be created for all of the stations.
b. Additionally, using ArcGIS 9.3 Geographic Information System (GIS) Software, maps of the area will be produced using long-term yearly values for each station. The GIS methodology of inferences uses the Kriging interpolation method for spatial analysis, with which data for unrecorded areas will be generated by examining the adjacent recorded data. The maps

will also be vectorized in order to reflect the color map-producing raster procedures Kriging and Spline.

c. In accordance with the pattern of rainfall in the study area, a bar-graph representing the mean rainfall per month will be used.

To display the temporal fluctuations, trends, and moving averages for the stations, line graphs for the inter-annual mean rainfall will also generated.

CHAPTER FOUR

NUMERICAL DATA ON THE TEMPORAL AND SPATIAL PATTERNS OF RAINFALL IN KANO REGION

The spatial distribution of rainfall in the region has shown a drastic fluctuation. In 2010, rainfall ranges between 436 – 1525mm with little increase in 2011. In 2012 the rainfall distribution increased in all the location (1503 – 519mm) which affected the agricultural activities in the region. Though, the rate of flooding increases and in 2013 reduced between 445 – 1420mm and lower in 2014 with 360 – 1389mm which drastically affected the affected the socioeconomic actives. In 2015, the distribution of rainfall increased to 433.7 – 1362.3mm and lower in 2016 with 379 – 1572mm. In this period, the rainfall distribution has indicated to have less rain in some central and northeastern part. In 2017, the distribution shows within 396.4 – 1310.3mm indicating little increase of rainfall and this has affected areas that are usually having low rain. In 2018, rain continued to decrease in the southern part.

Erratic rainfall can lead to fluctuations in crop yields. In years with excessively high rainfall, crops might suffer from waterlogging and diseases, affecting their quality and quantity. Conversely, drought conditions due to reduced rainfall can result in crop failure and decreased agricultural output (A.Ayandale, 2018). Inconsistent rainfall affects water availability for irrigation and drinking purposes. Farmers heavily rely on predictable rainfall patterns for their agricultural practices. Unreliable rainfall can result in water scarcity, impacting both crop cultivation and livestock rearing. Intense rainfall events, especially following dry periods, can lead to soil erosion, washing away valuable topsoil nutrients. This can reduce the soil's fertility, making it less suitable for agriculture and affecting long-term productivity. The changes in rainfall patterns can influence the prevalence and distribution of pests and diseases. Wet conditions can promote the spread of certain pests and diseases, posing a threat to crops and livestock. Fluctuating agricultural output due to unpredictable rainfall directly affects the income and livelihoods of farmers. It can lead to economic instability in rural communities dependent on agriculture, affecting food security and overall socio-economic development. Furthermore, constant changes in rainfall patterns make it challenging for farmers to adapt their agricultural practices. Implementing new techniques or investing in drought-resistant crops requires resources and time, which may not be readily available to small-scale farmers (MS mcmillen,2022) While in areas of decreased rainfall and subsequent water scarcity can lead to increased competition and conflicts among communities and stakeholders over access to water resources, exacerbating existing socio-political tensions (A. mdee,2022) Overall, the erratic and unpredictable nature of rainfall due to climate change poses significant challenges for agricultural development in dry land areas. Sustainable and adaptive strategies, including water management techniques, resilient crop varieties, and community-based adaptation measures, are crucial for mitigating the adverse impacts on agriculture in these regions.

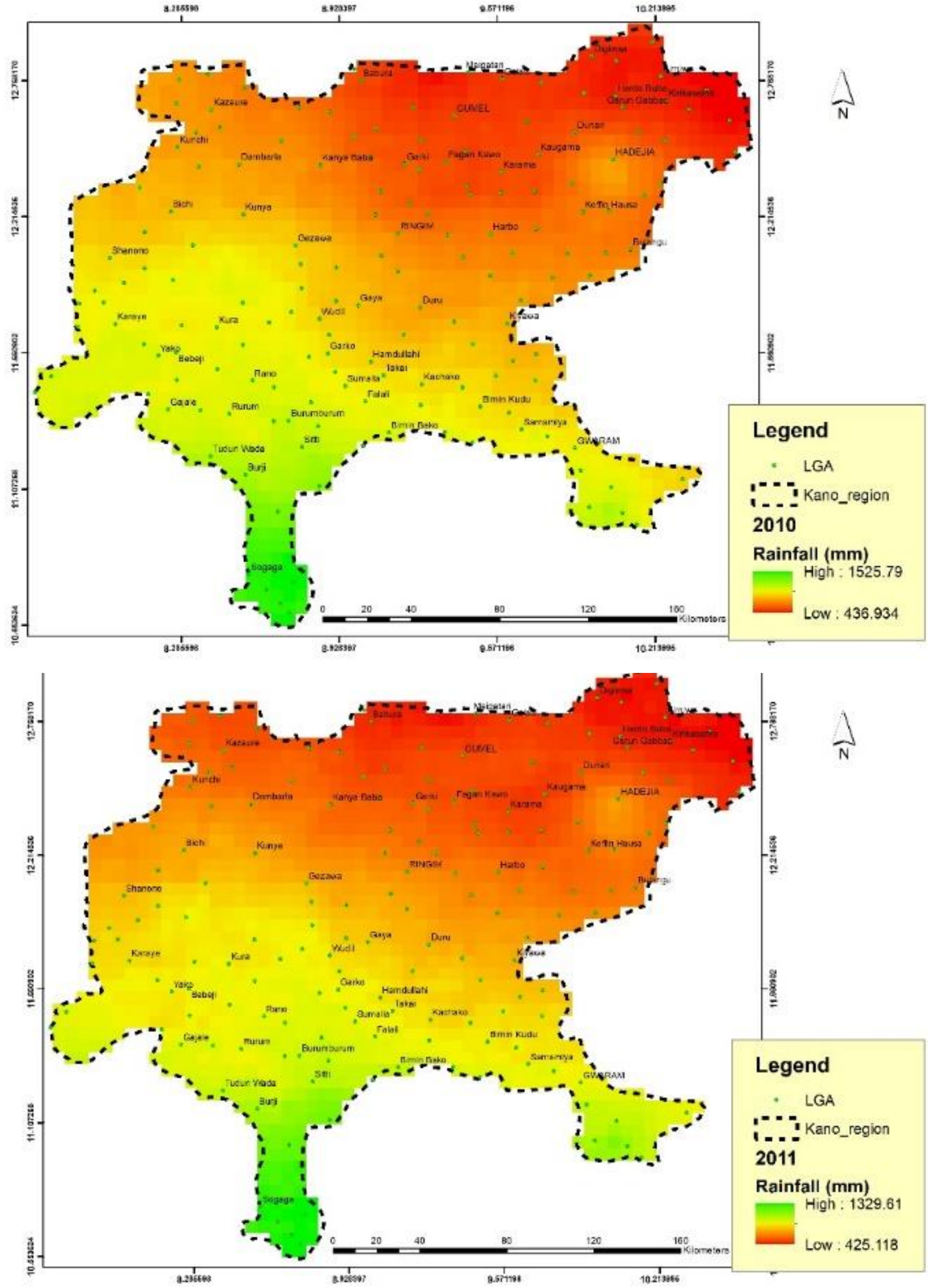


Figure 3: SPATIAL DISTRIBUTION OF RAINFALL.

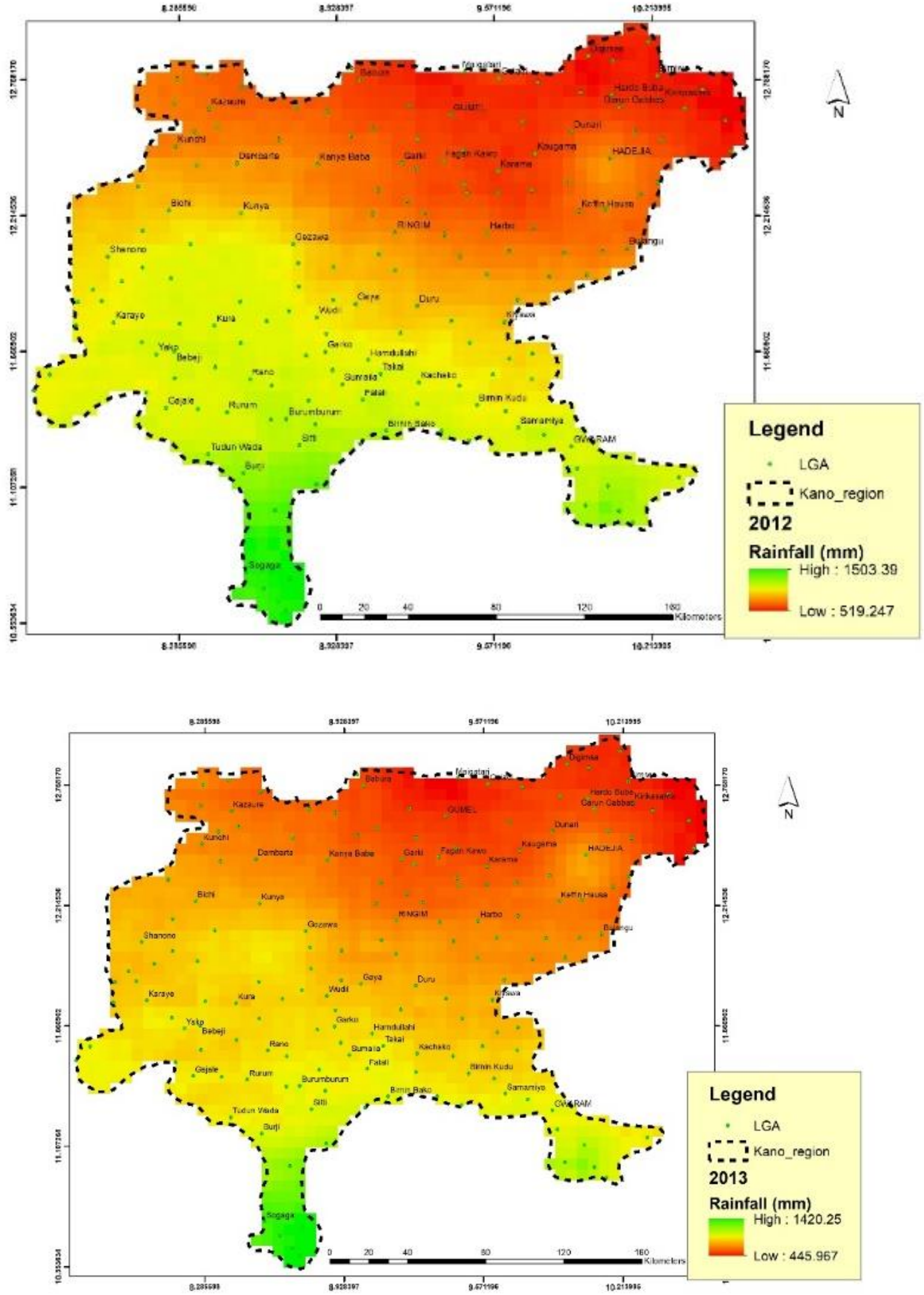


Figure 4: SPATIAL DISTRIBUTION OF RAINFALL.

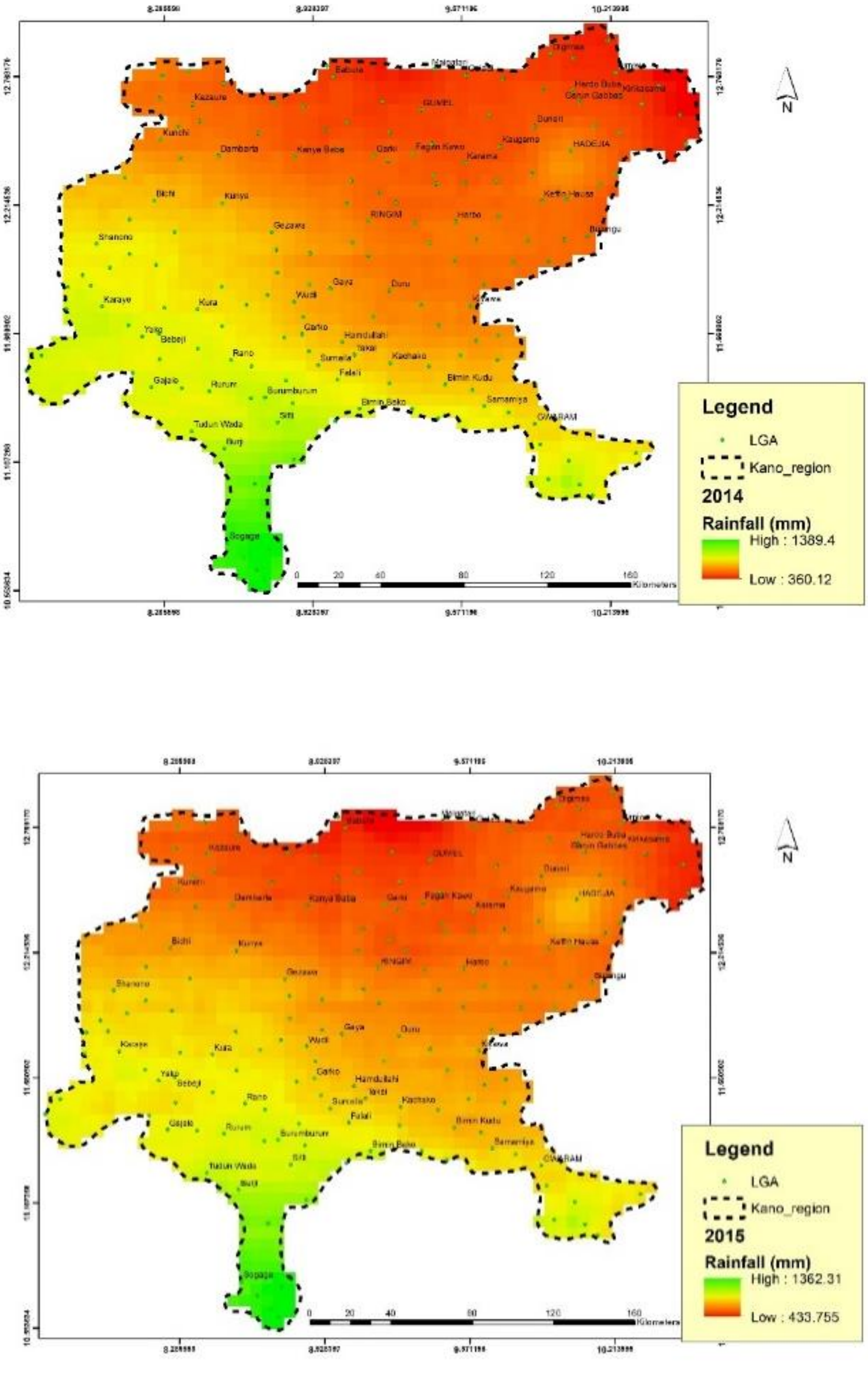


Figure 5: SPATIAL DISTRIBUTION OF RAINFALL.

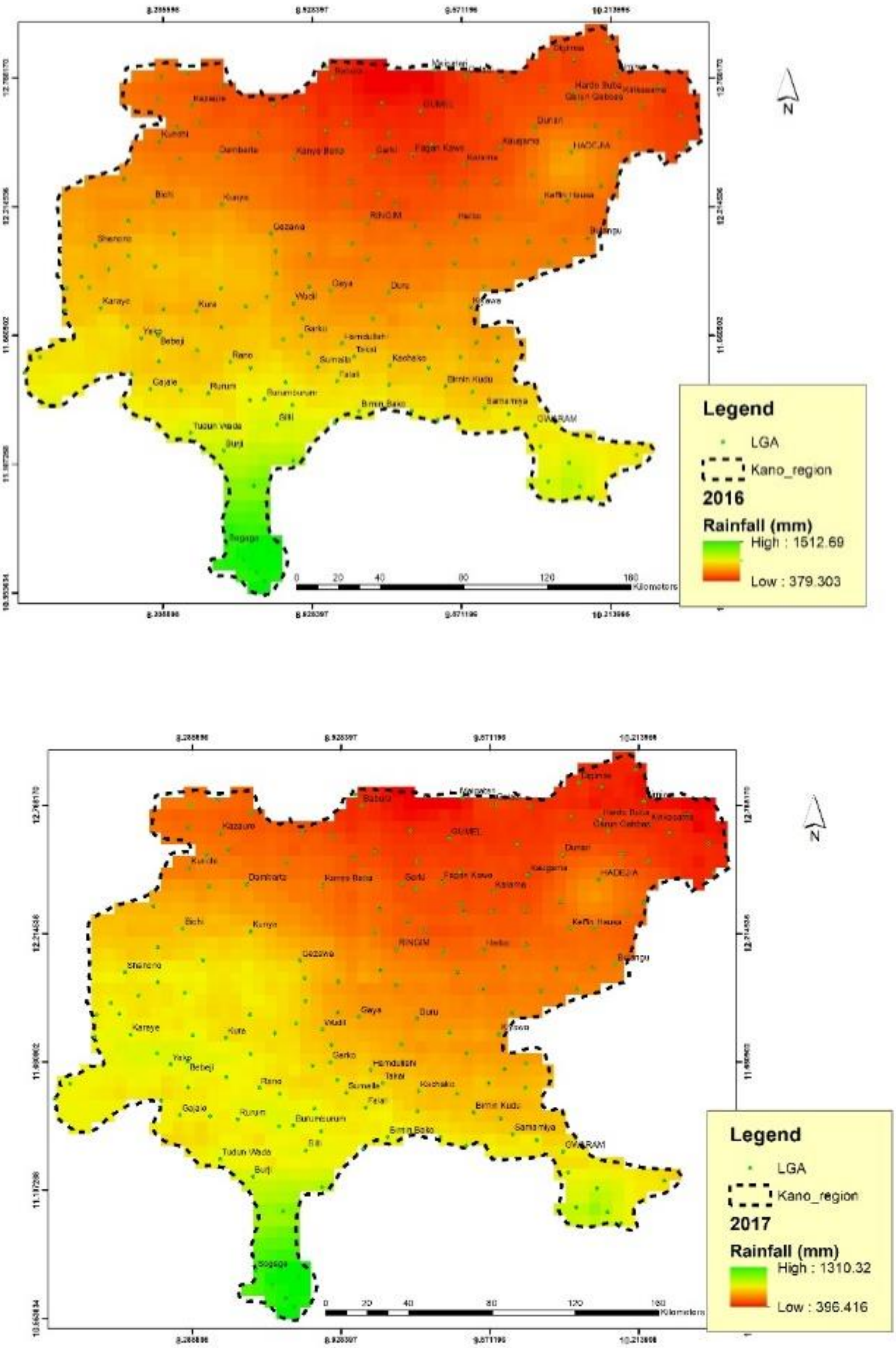


Figure 6: SPATIAL DISTRIBUTION OF RAINFALL.

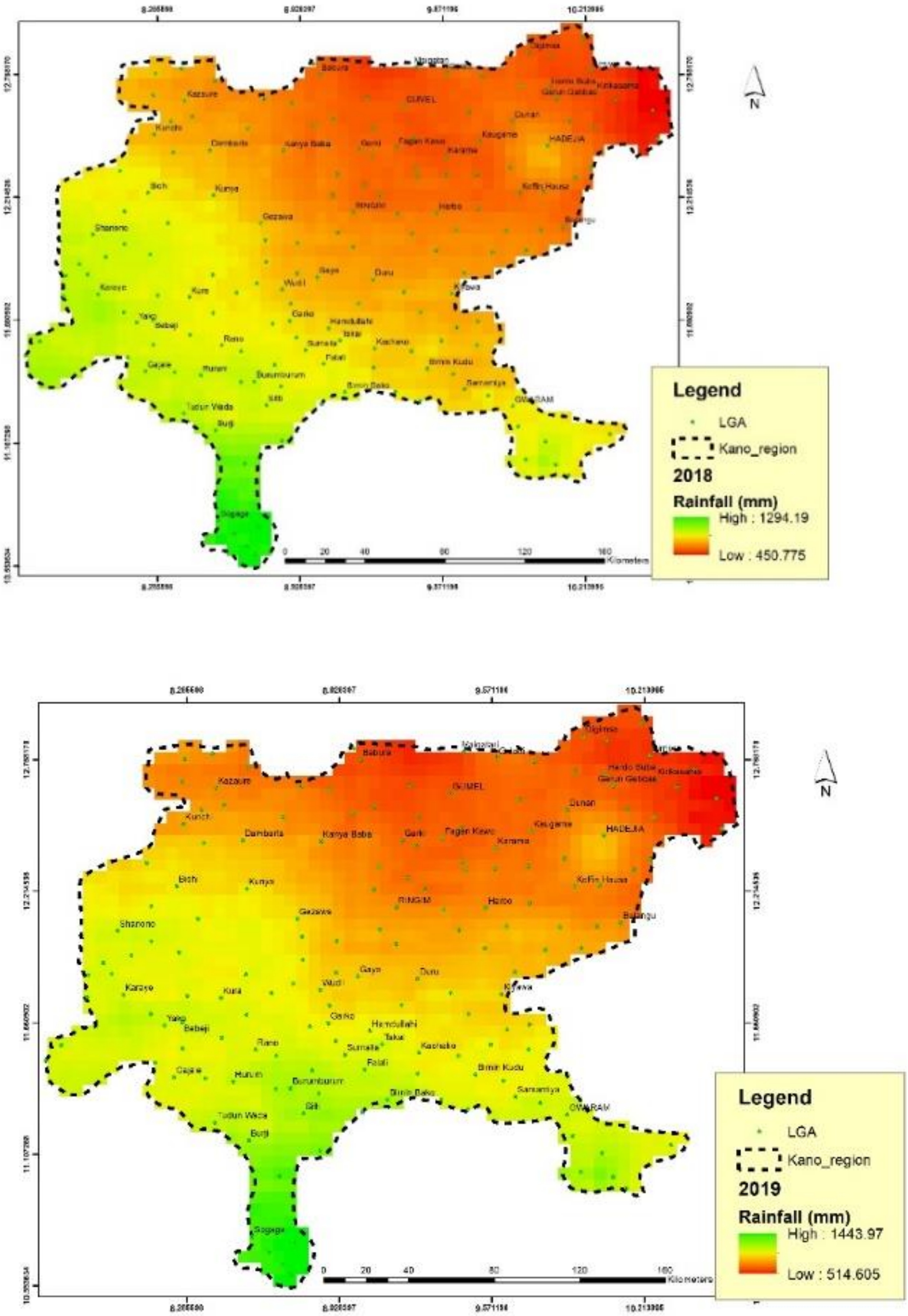


Figure 7: SPATIAL DISTRIBUTION OF RAINFALL.

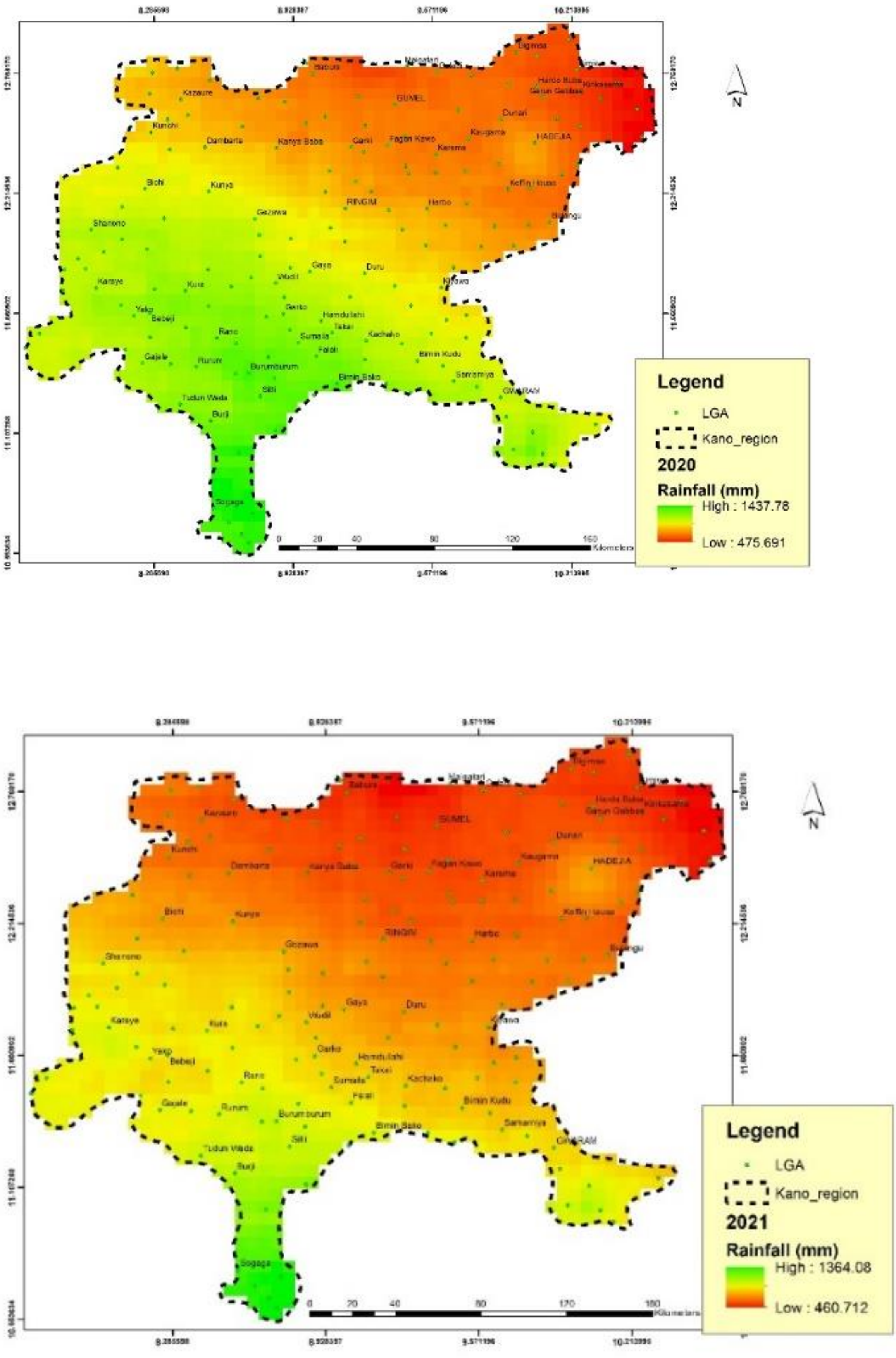


Figure 8: SPATIAL DISTRIBUTION OF RAINFALL.

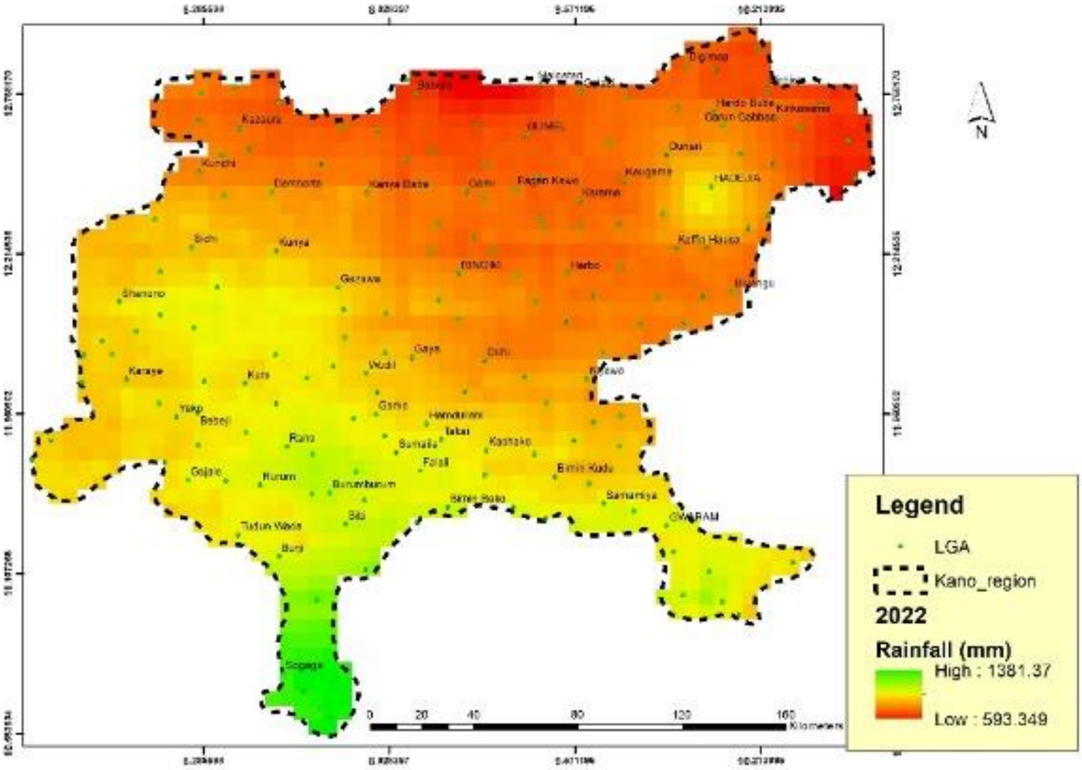


Figure 9: SPATIAL DISTRIBUTION OF RAINFALL.

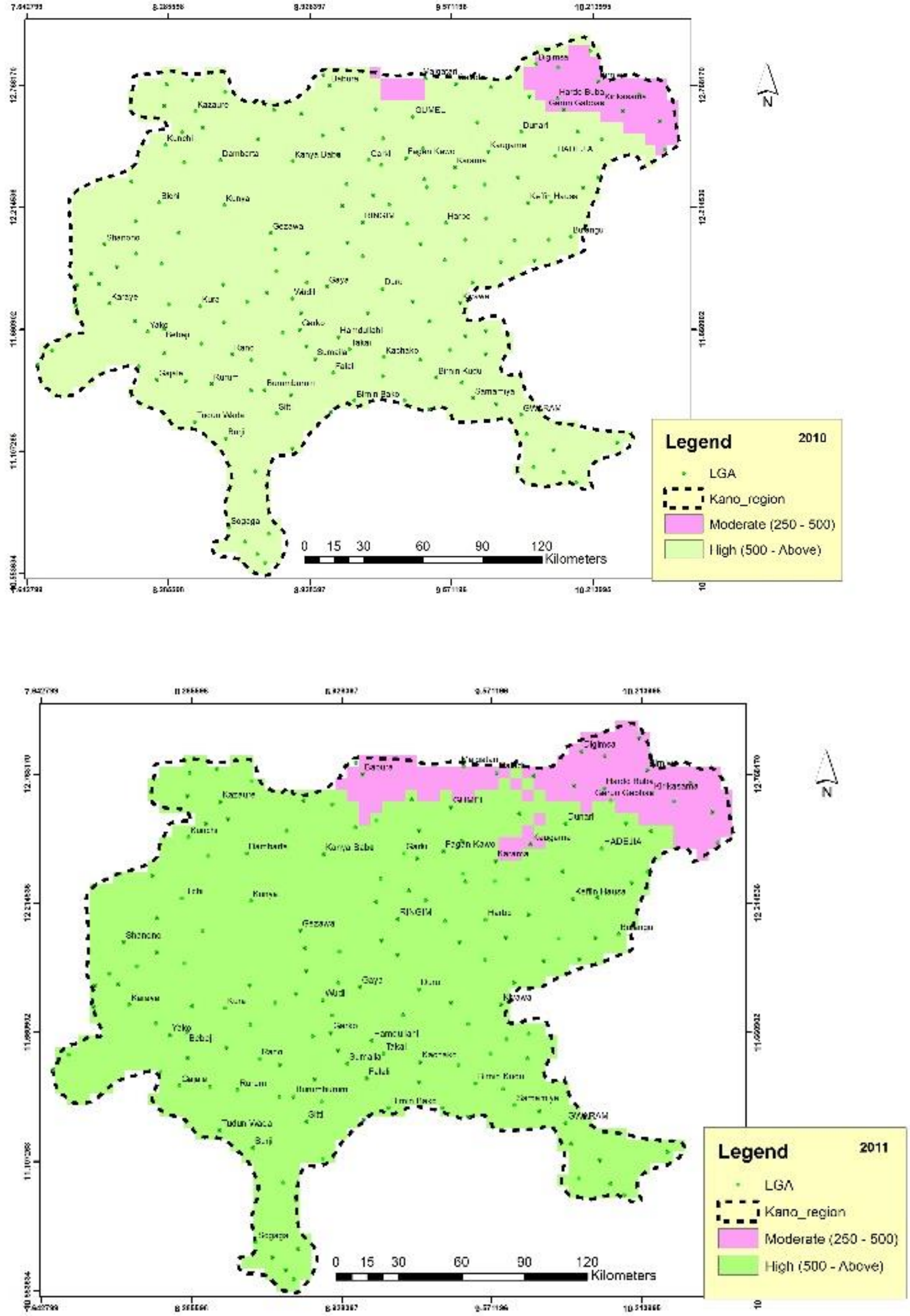


Figure 10: TEMPORAL DISTRIBUTION OF RAINFALL.

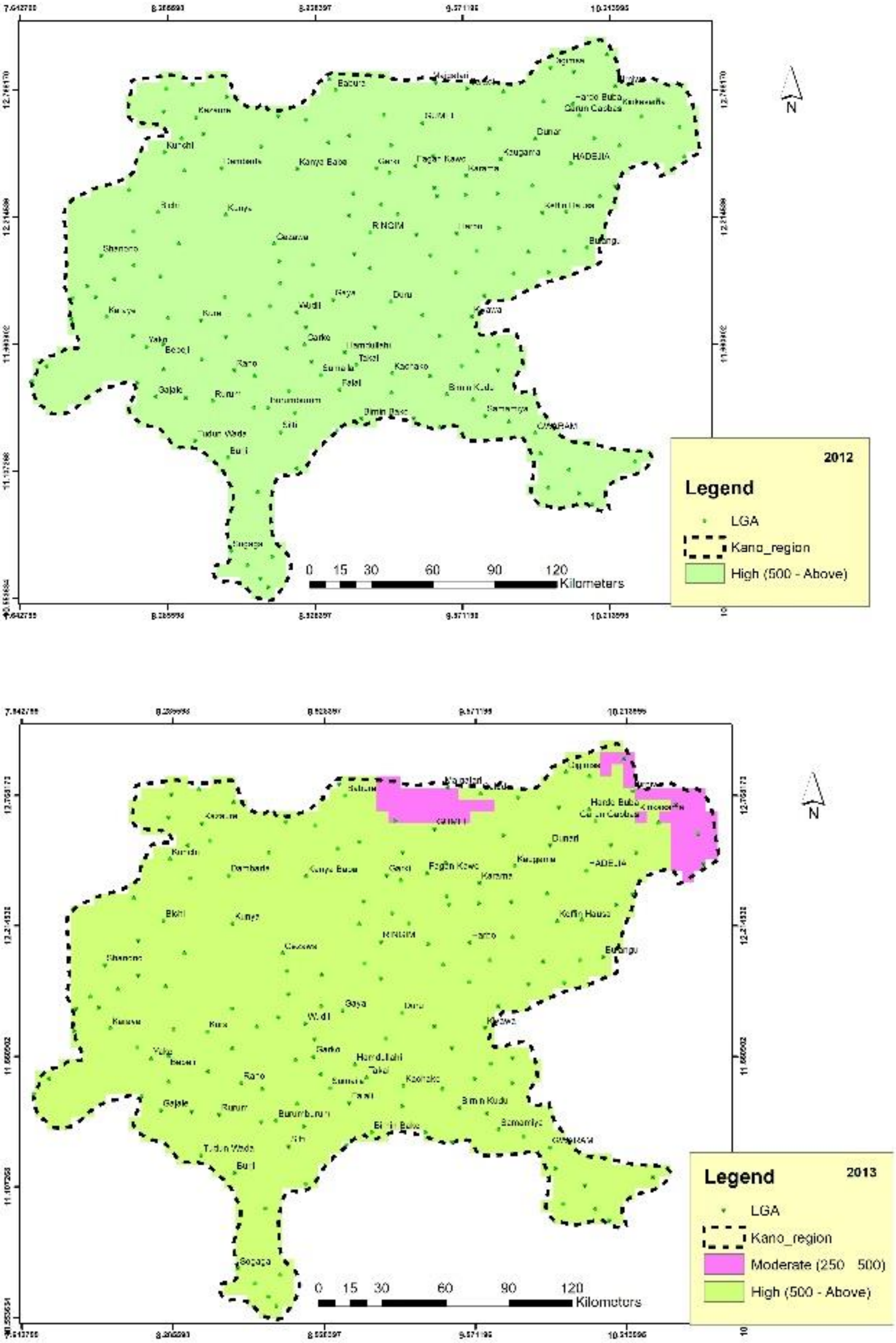


Figure 11: TEMPORAL DISTRIBUTION OF RAINFALL.

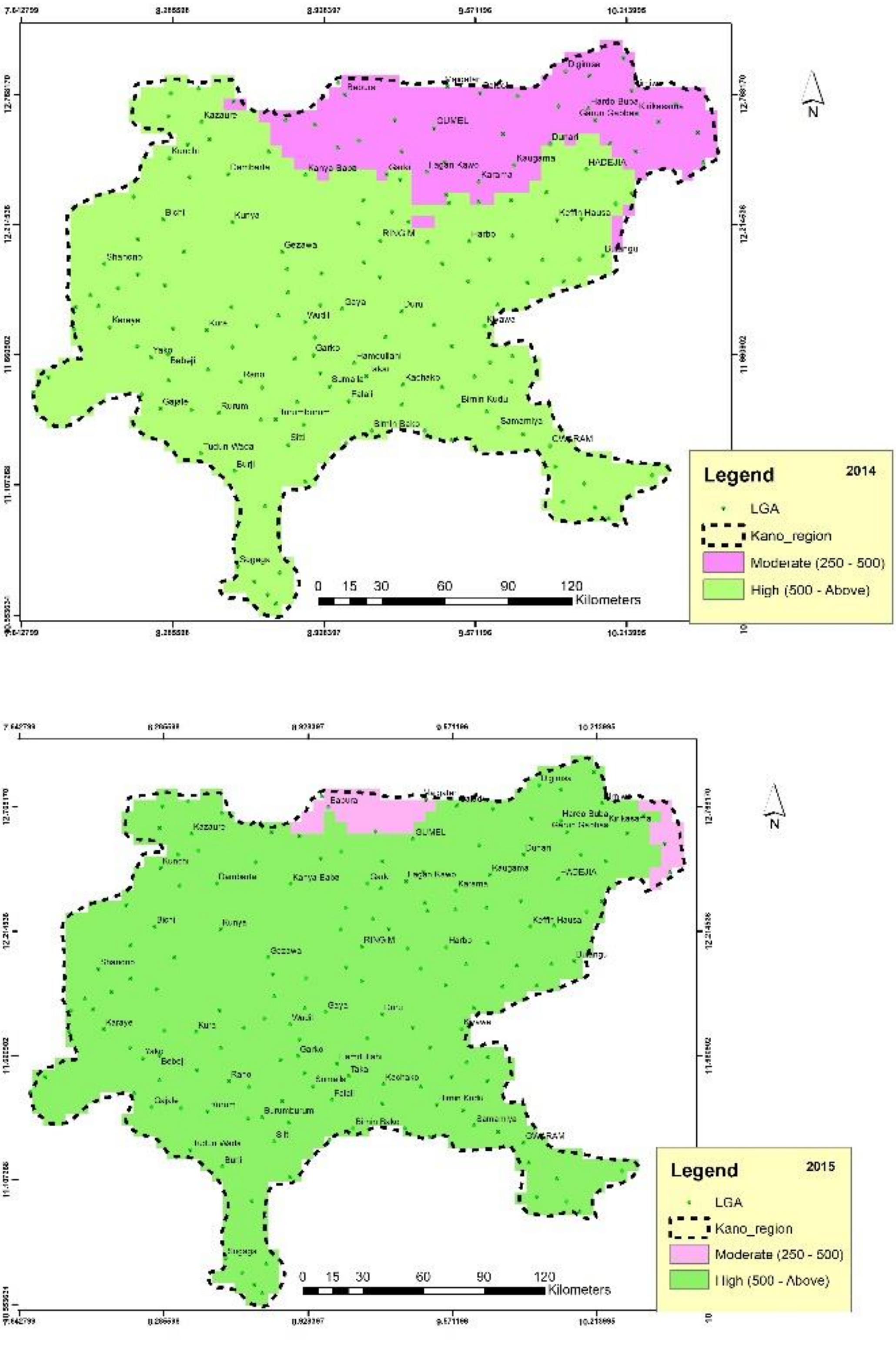


Figure 12: TEMPORAL DISTRIBUTION OF RAINFALL.

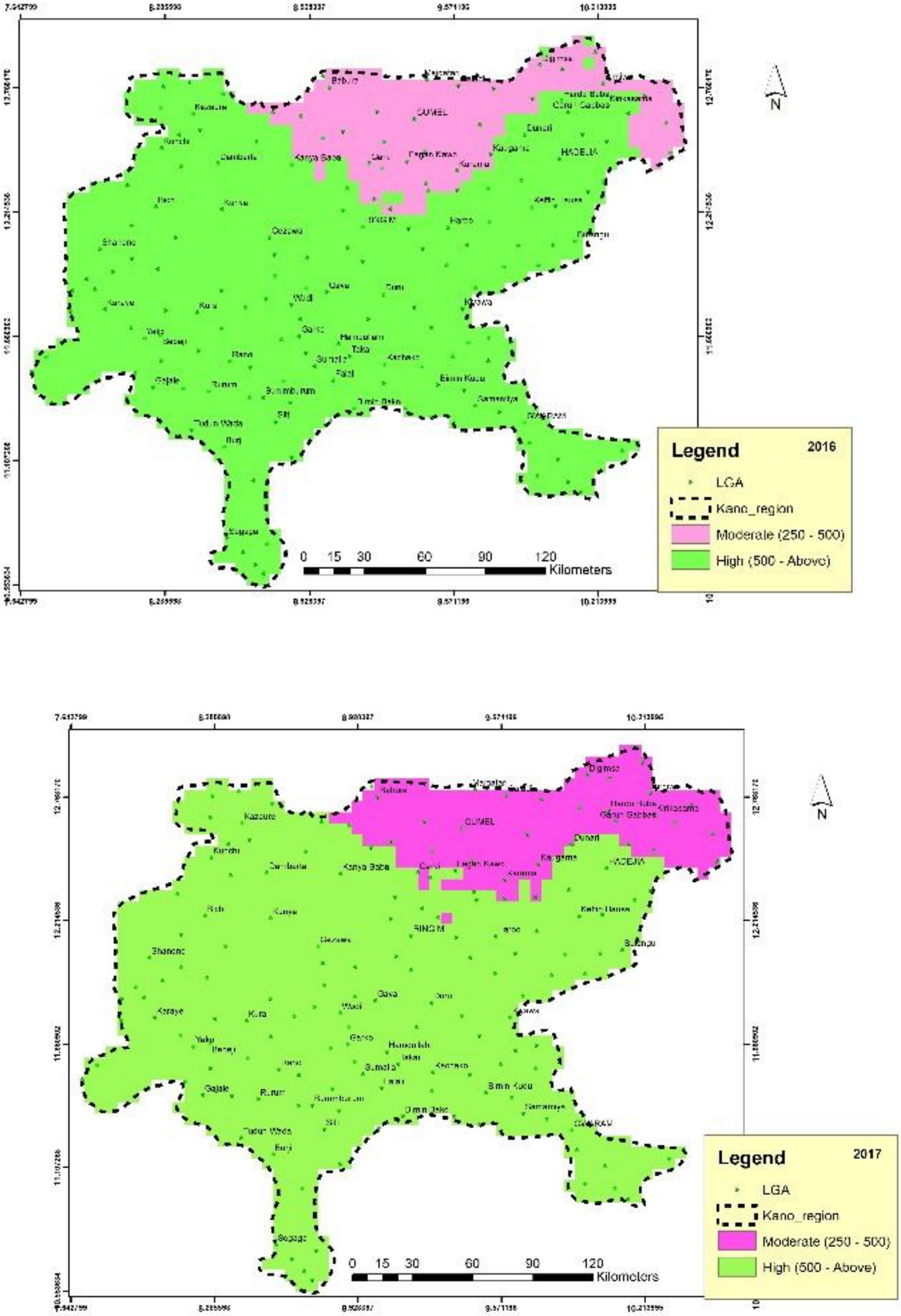


Figure 13: TEMPORAL DISTRIBUTION OF RAINFALL.

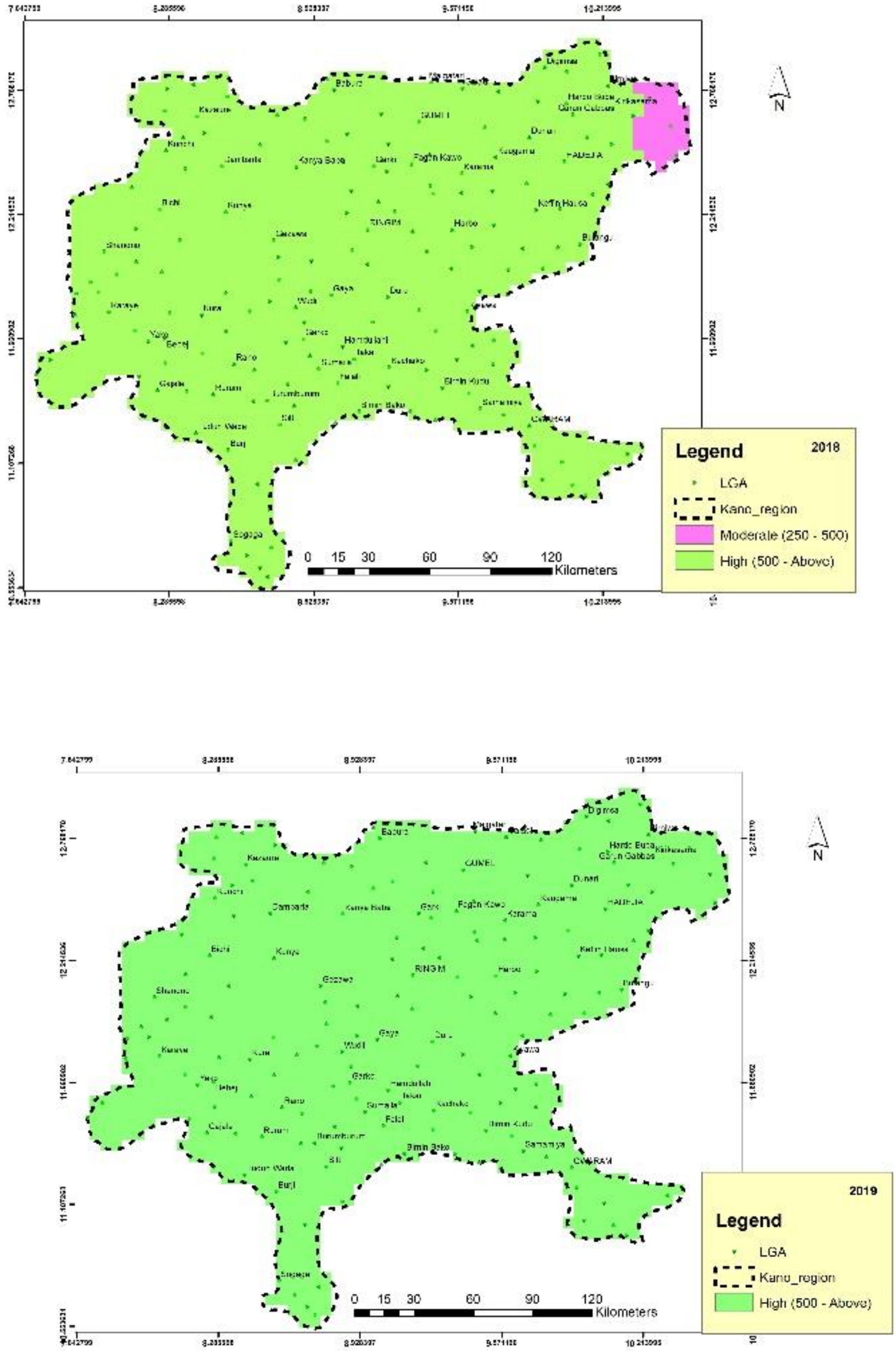


Figure 14: TEMPORAL DISTRIBUTION OF RAINFALL.

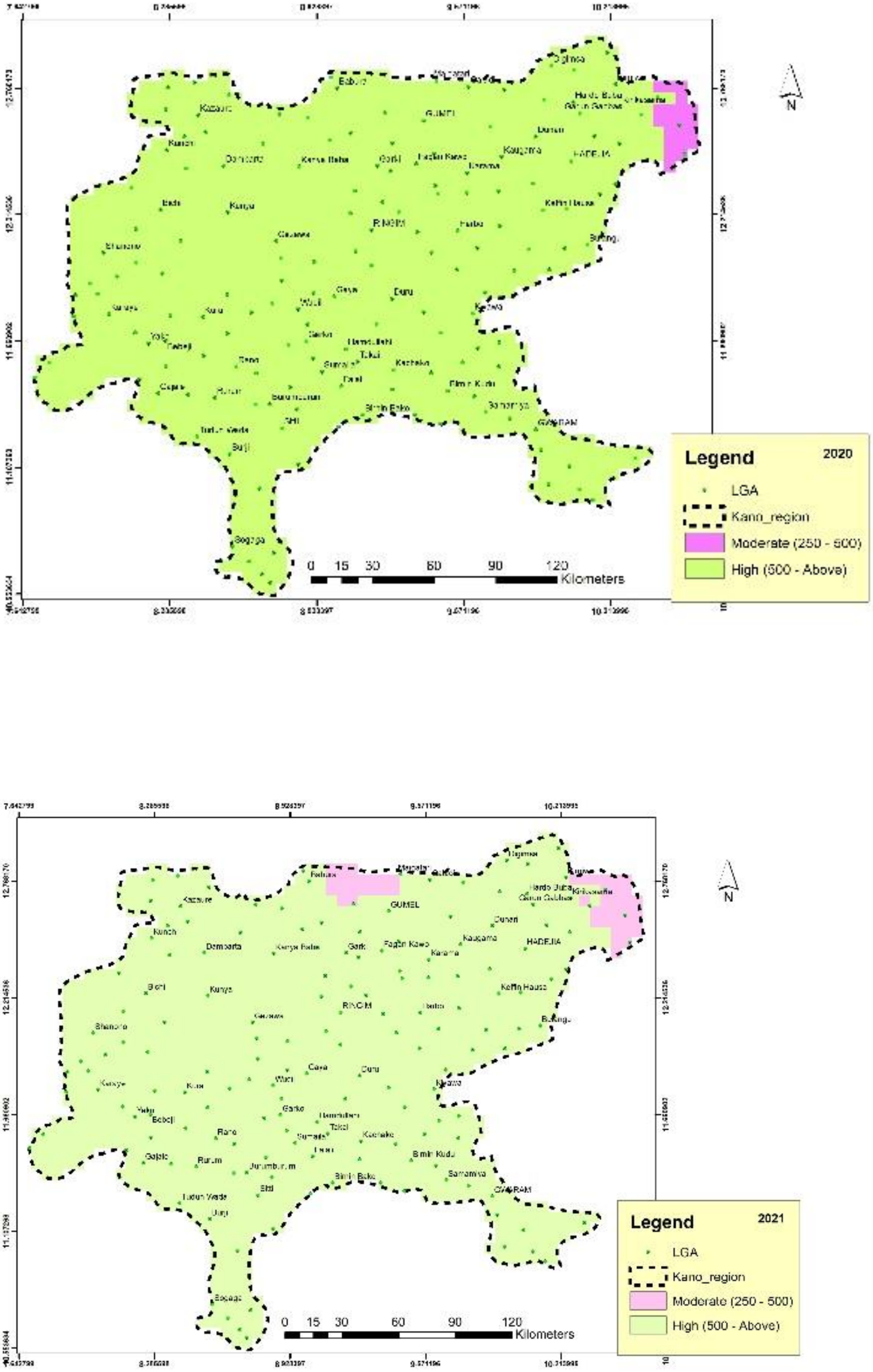


Figure 15: TEMPORAL DISTRIBUTION OF RAINFALL.

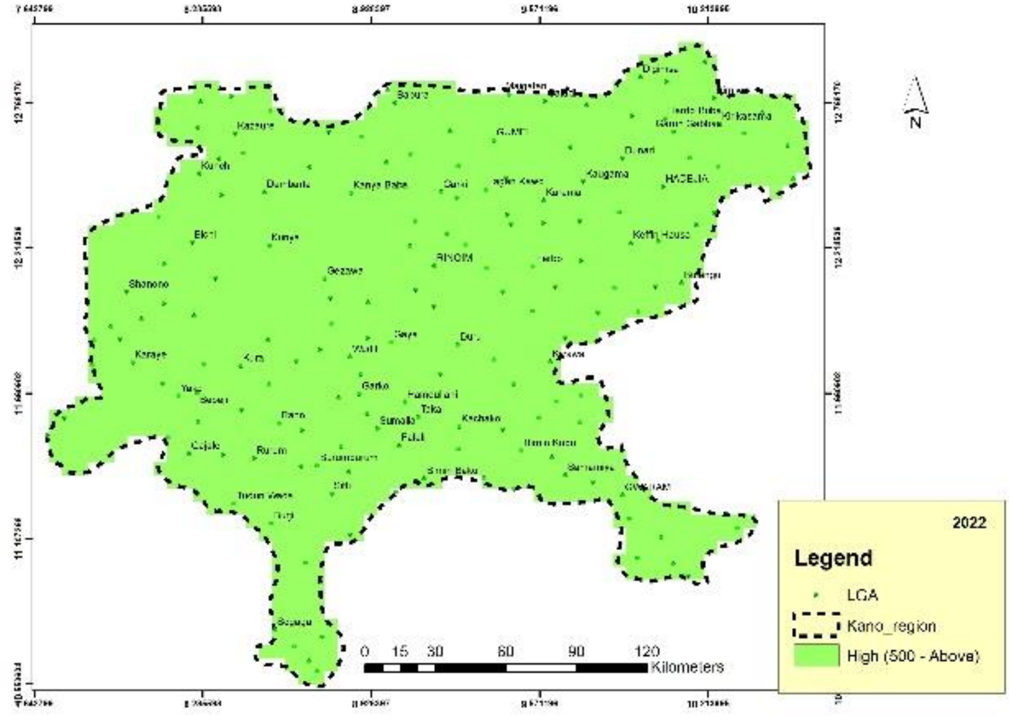


Figure 16: TEMPORAL DISTRIBUTION OF RAINFALL

Table 1 showing the classification of Rainfall distribution

Class	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
High	85	80	100	85	70	85	73	70	90	100	100	95	82
Modera	15	20	0	15	30	15	27	30	10	0	0	5	18
Low	0	0	0	0	0	0	0	0	0	0	0	0	0

The Table: 1 explain the distribution of rainfall within Nigeria's dry Land areas for each year from 2010 to 2022, categorized into three classes: High, Moderate, and Low. The values in the table represent the percentage distribution of rainfall in each class for each respective year.

The values in this class are relatively high, ranging from 70% to 100%. In most years, the percentage of rainfall in the high class is dominant, suggesting that a significant portion of the dry land areas experienced high levels of rainfall. This class represents moderate levels of rainfall, with values ranging from 0% to 30%. There is variability in the percentage of rainfall falling into the moderate class across the years. For example, in 2012 and 2019, there was no rainfall classified as moderate, while in other years, there is some presence of moderate rainfall. The low class consistently shows 0% rainfall across all years. This suggests that, according to the classification system, there were no instances where the rainfall in the dry land areas fell into the low category during the specified years.

The distribution of rainfall within Nigeria's dry land areas over the specified years, classifying the rainfall into high, moderate, and low categories. The data suggests that, in general, a significant proportion of the dry land areas experienced high rainfall, with some variability in the presence of moderate rainfall. The absence of rainfall in the low class indicates a consistent lack of extremely low rainfall in the given period.

CHAPTER FIVE

TRENDS IN THE SPATIO-TEMPORAL DISTRIBUTION AND VARIABILITY OF RAINFALL IN KANO REGION

The trend analysis of rainfall in different parts of the described region, indicating varying patterns as one moves from north to south and eastward. The R-squared values denote the strength of the relationship between the movement eastward within each region and the corresponding change in rainfall.

As one moves eastwards in the northern part (Figure 17), there's a moderate negative correlation between eastward movement and rainfall. The R-squared value of 0.53 suggests that approximately 53% of the variation in rainfall in this region can be explained by the eastward movement, indicating a decreasing trend. This decrease might be due to shifting weather patterns, changes in atmospheric circulation, or local geographic factors affecting rainfall distribution.

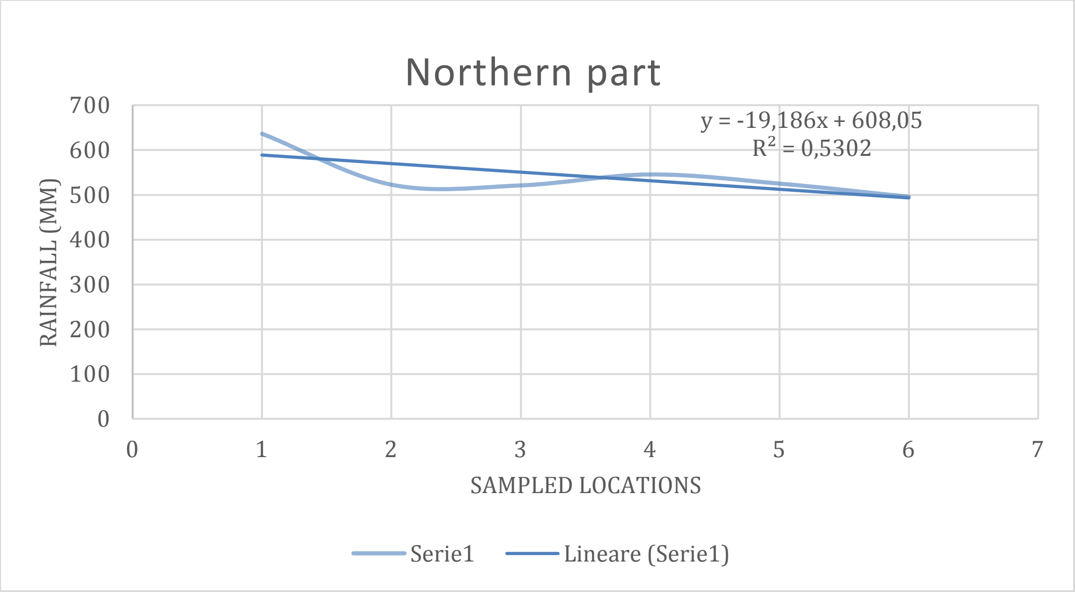
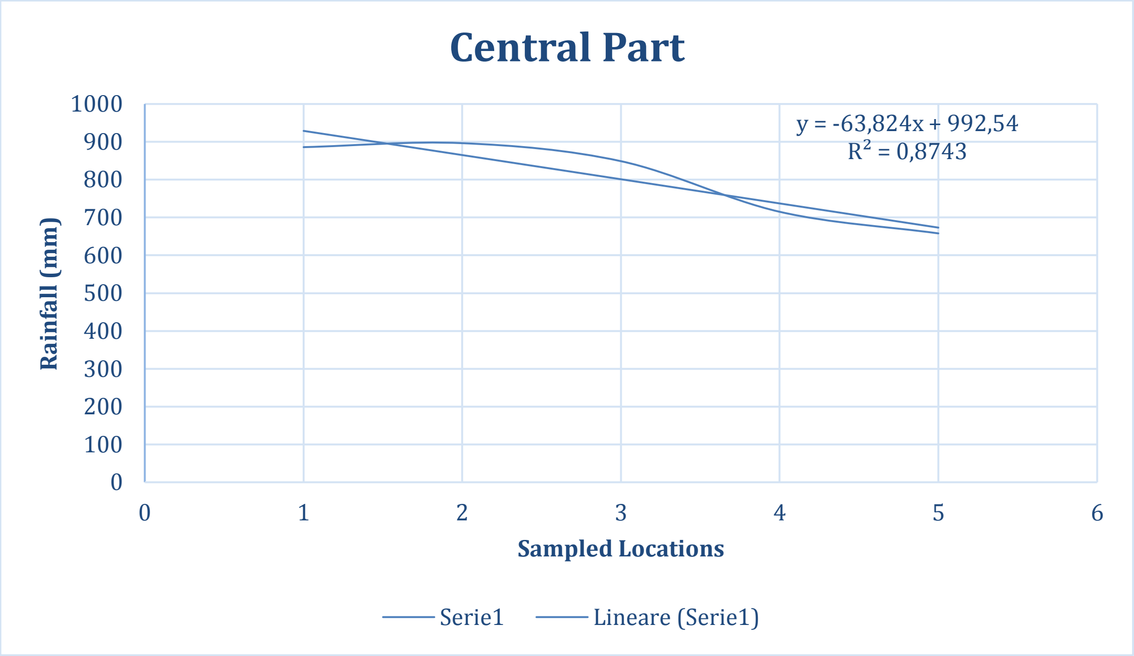


Figure 17


Central Part
1000
900
800
700
600
500
400
300
200
100
0
Rainfall (mm)
0
1
2
3
4
5
6
Sampled Locations
y = -63,824x + 992,54
R² = 0,8743
Serie1
Lineare (Serie1)

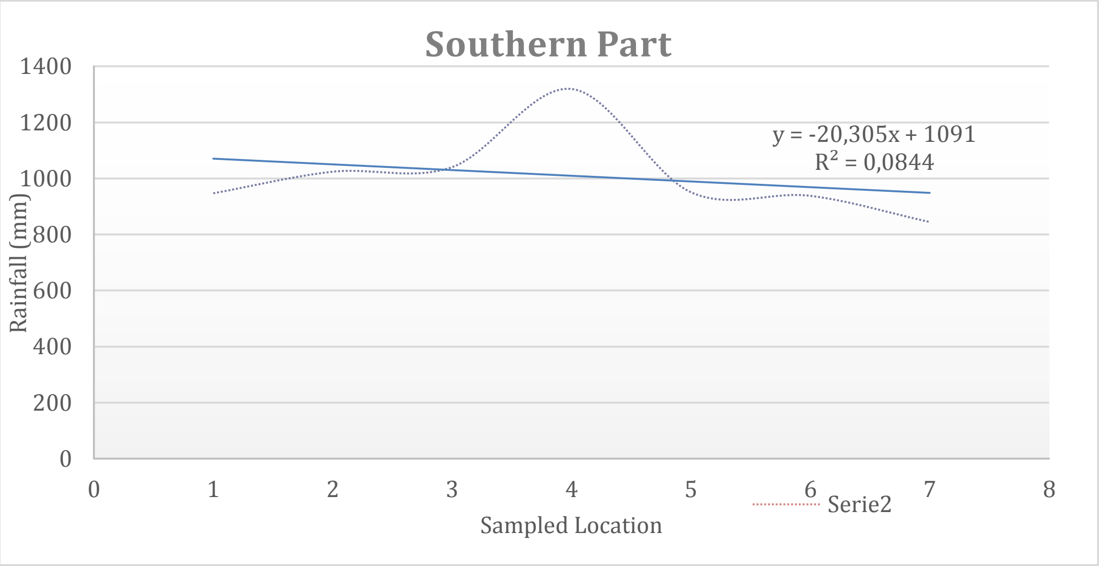

Southern Part
1400
1200
1000
800
600
400
200
0
Rainfall (mm)
0
1
2
3
4
5
6
7
8
Sampled Location
y = -20,305x + 1091
R² = 0,0844
Serie2

Figure 18

In the central part, the relationship between eastward movement and rainfall shows a strong negative correlation. The higher R-squared value of 0.87 indicates that around 87% of the variation in rainfall can be explained by moving eastward. This region experiences a more pronounced decrease in rainfall as one moves east, potentially due to environmental changes or local climate dynamics affecting precipitation patterns.

Contrary to the northern and central parts, the southern region displays a weak positive correlation between eastward movement and rainfall. The low R-squared value of 0.08 suggests that only about 8% of the variation in rainfall is explained by eastward movement. However, this small positive correlation indicates a slight increase in rainfall as one moves eastward in the southern part, potentially influenced by different weather systems or local geographical factors unique to this area.

These trends illustrate spatial variations in rainfall patterns across different parts of the region. The varying R-squared values highlight the differing degrees of correlation between eastward movement and rainfall change in each area, reflecting the complex nature of how climate and geographical factors interact to influence precipitation distribution.

CHAPTER SIX

DISCUSSION

These fluctuating rainfall patterns emphasizes the complexity of climate variability within the region. Such variability poses challenges for agricultural planning, water resource management, and socio-economic stability. Strategies focusing on adaptation, water conservation, drought-resistant crops, and community-based resilience become crucial to mitigate the impacts of such erratic rainfall patterns. Additionally, long-term planning considering the potential effects of climate change on precipitation patterns is essential for sustainable development within the region.

The implications of the observed rainfall trends across different parts of the region can have various consequences on agriculture, ecosystems, water management, and socio-economic activities. It shows a decreasing trend in rainfall towards the east can pose challenges for agriculture. Farmers may face water scarcity issues, impacting crop cultivation and livestock rearing. Strategies like water conservation, drought-resistant crops, and efficient irrigation systems might be crucial (P.w Unger, 2010). A more pronounced decrease indicates potentially severe agricultural impacts. This region might experience more frequent droughts, leading to crop failures, reduced yields, and increased vulnerability for farmers. Adaptation strategies and government support for alternative livelihoods become essential. A slight increase in rainfall might initially benefit agriculture by providing more water. Show ever, this could also bring challenges like soil erosion due to intense rain, necessitating soil conservation methods and adjustments in farming techniques (www.fao.org) Changes in rainfall patterns can significantly affect local ecosystems. Decreased rainfall in certain areas might lead to desertification or changes in vegetation cover. Conversely, increased rainfall might alter local habitats, affecting flora and fauna distribution. The variability in rainfall across the region impacts water availability. In areas experiencing decreased rainfall, water resources might become scarce, affecting drinking water supplies and irrigation. Effective water management strategies are crucial to mitigate these challenges. Reduced agricultural productivity due to decreased rainfall can lead to food insecurity, income loss for farming communities, and potential migration from affected areas. Government interventions, such as diversification of livelihoods or support for alternative income sources, may be necessary (B.Andreosso, O Callaghan, 2003). Infrastructure planning needs to account for changing rainfall patterns. Areas prone to increased rainfall might face challenges like flooding, necessitating better drainage systems and flood-resistant infrastructure.

Policymakers need to develop adaptive strategies considering the regional variations in rainfall trends. This might involve climate-resilient agriculture, water conservation policies, land use planning, and community-based adaptation measures. Understanding these implications is crucial for policymakers, local communities, and stakeholders to develop proactive measures and adaptation strategies to mitigate the adverse effects and capitalize on potential benefits stemming from changing rainfall patterns in different parts of the region (I. Ahmed, 2019).

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

Conclusion

The wide range of rainfall values, ranging from 436mm to 1525mm in 2010, signifies the significant variability experienced within a single year. This variability persisted throughout the years, leading to extreme fluctuations in subsequent years. The fluctuations significantly impacted agricultural activities. While increased rainfall in 2012 might initially seem positive for agriculture, the subsequent decrease in rainfall in 2013 and 2014 led to adverse effects, affecting crop yields and socio-economic activities dependent on agriculture. The variations in rainfall distribution had implications beyond agriculture, affecting the environment and ecosystems. Changes in precipitation patterns can impact soil health, water availability, and biodiversity, potentially leading to soil erosion, reduced water resources, and alterations in ecological balances. The uneven distribution of rainfall, particularly noting less rain in central and northeastern parts during certain years, highlights localized impacts within the region. Such variations can create disparities in resource availability, potentially affecting communities differently based on their geographic location.

The erratic nature of rainfall patterns poses challenges for long-term planning and adaptation strategies. Communities reliant on predictable rainfall for agricultural practices and water management face heightened uncertainty, requiring adaptive measures to cope with changing conditions. The fluctuations in rainfall patterns directly affected socio-economic activities. Decreased rainfall impacted livelihoods, food security, and economic stability, particularly in regions heavily dependent on agriculture. While not explicitly stated, the observed fluctuating rainfall aligns with patterns associated with climate change. These erratic changes in precipitation emphasize the need for greater attention to climate adaptation and mitigation strategies.

Also, from the analysis of rainfall trends across different parts of the region suggests a clear spatial variation in how rainfall changes concerning eastward movement. There's a moderate decrease in rainfall as one moves eastward, signifying a notable but not drastic reduction in precipitation in this region. The trend indicates a significant decrease in rainfall towards the east, suggesting a more pronounced decline in precipitation compared to the northern part. Contrasting the other regions, there's a slight increase in rainfall as one moves eastward, though this increase is relatively small.

Overall, the conclusion highlights the diverse and region-specific nature of rainfall trends within the area. This variability in rainfall patterns suggests that different parts of the region might experience contrasting impacts due to changing precipitation, with implications for agriculture, ecosystems, water management, and socio-economic activities. Understanding these regional variations is crucial for effective planning, resource management, and adaptation strategies to mitigate the potential adverse effects and leverage any beneficial aspects stemming from these rainfall trends.

Recommendations

The study recommends for;

i) Encouraging diversification of crops and farming practices that are resilient to varying rainfall patterns. Promote the cultivation of drought-resistant crops and techniques like rainwater harvesting to enhance water availability during dry periods.

ii) Implement efficient water management practices such as irrigation systems, water conservation, and storage facilities to optimize water use during periods of both excess and scarcity.

iii) Invest in infrastructure resilient to extreme weather conditions. Develop better drainage systems to manage excess rainfall and prevent flooding.

Construct water storage facilities to retain water during rainy seasons for use in drier periods.

iv) Foster community involvement in adaptation strategies. Establish community-driven initiatives that address local vulnerabilities and promote sustainable practices suited to the specific challenges faced in different areas of the region.

v) Increase awareness and provide education about climate change and its impacts on rainfall patterns. Empower local communities and farmers with knowledge about adaptive agricultural techniques and water conservation methods.

vi) Develop and implement policies that support climate adaptation and mitigation efforts. These policies should encourage sustainable land use practices, promote afforestation, and incentivize the adoption of climate-resilient technologies.

vii) Support research initiatives focused on understanding local climate patterns and their impacts. Invest in innovation and technology that can aid in predicting rainfall patterns and developing adaptive solutions.

viii) Foster collaboration among governmental bodies, NGOs, research institutions, and local communities. Networking and sharing best practices can facilitate the exchange of knowledge and resources, enhancing resilience efforts.

ix) Develop and implement effective early warning systems for floods and droughts. Timely alerts and preparedness can mitigate risks and reduce the impact of extreme weather events.

x) Integrate climate change considerations into long-term development plans. Ensure that climate resilience is a core component of regional development strategies and policies.

xi) By implementing these recommendations, stakeholders can work towards building resilience, adapting to changing rainfall patterns, and mitigating the adverse effects of unpredictable fluctuations in precipitation within the region.

REFERENCES

Abtew, W., Melesse, A. M., & Dessalegne, T. (2009). El Niño Southern Oscillation link to the Blue Nile River Basin hydrology. *Hydrological Processes*, *23*(26), 3653–3660. https://doi.org/10.1002/hyp.7367

Adejuwon, J. O. (2004). Crop yields Response to Climate Variability in Sudano-Sahelian Ecological Zones of Nigeria. *AICC Report on Workshop for Africa and India Ocean Island*, 16–16.

Ahmed, I. (2019). Climate change impacts and adaptation strategies for agronomic crops.

Andreosso, B. & Challagan, O. (2003): Government intervention in agriculture

Ait Brahim, Y., Wassenburg, J. A., Cruz, F. W., Sifeddine, A., Scholz, D., Bouchaou, L., Dassié, E. P., Jochum, K. P., Edwards, R. L., & Cheng, H. (2018). Multi-decadal to centennial hydro-climate variability and linkage to solar forcing in the Western Mediterranean during the last 1000 years. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-35498-x

Alexander, W. J. R., & Emeritus, W. J. R. (2005). Linkages between solar activity and climatic responses. *Energy & Environment*, *16*(2), 239–253. https://doi.org/10.1260/0958305053749462

Alexander, W. J., Bailey, F., Bredenkamp, D. B., Van Der Merwe, A., & Willemse, N. (2007). Linkages between solar activity, climate predictability and water resource development. *Journal of the South African Institution of Civil Engineering= Joernaal van Die Suid-Afrikaanse Instituut van Siviele Ingenieurswese*, *49*(2), 32–44.

Amarasekera, K. N., Lee, R. F., Williams, E. R., & Eltahir, E. A. B. (1997). ENSO and the natural variability in the flow of tropical rivers. *Journal of Hydrology*, *200*(1–4), 24–39. https://doi.org/10.1016/s0022-1694(96)03340-9

Badou, D. F., Kapangaziwiri, E., Diekkrüger, B., Hounkpè, J., & Afouda, A. (2017). Evaluation of recent hydro-climatic changes in four tributaries of the Niger River Basin (West Africa). *Journal Des Sciences Hydrologiques [Hydrological Sciences Journal]*, *62*(5), 715–728. https://doi.org/10.1080/02626667.2016.1250898

Ayandale, A.A (2018) Rainfall variability and drought characteristics in two agro – climatic zones: An assessment of climate changes in Africa.

Bahaga, T. K., Mengistu Tsidu, G., Kucharski, F., & Diro, G. T. (2015). Potential predictability of the sea- surface temperature forced equatorial East African short rains interannual variability in the 20th century. *Quarterly Journal of the Royal Meteorological Society. Royal Meteorological Society (Great Britain)*, *141*(686), 16–26. https://doi.org/10.1002/qj.2338

Balas, N., Nicholson, S. E., & Klotter, D. (2007). The relationship of rainfall variability in West Central Africa to sea-surface temperature fluctuations. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *27*(10), 1335–1349. https://doi.org/10.1002/joc.1456

Bates, P. (2008). Climate and Water. Technical paper of the Intergovernmental panel on Climate Change.

Batten, S. (2018). *Climate Change and the Macro-Economy: A Critical Review; Bank of England Working Paper no. 706;* Bank of England: London, UK.

Behera, S. K., Luo, J.-J., Masson, S., Delecluse, P., Gualdi, S., Navarra, A., & Yamagata, T. (2005). Paramount impact of the Indian Ocean dipole on the East African short rains: A CGCM study. *Journal of Climate*, *18*(21), 4514–4530. https://doi.org/10.1175/jcli3541.1

Benedetti, D., Biffis, E., Chatzimichalakis, F., Fedele, L. L., & Simm, I. (2021). Climate change investment risk: optimal portfolio construction ahead of the transition to a lower-carbon economy. *Annals of Operations Research*, *299*(1–2), 847–871. https://doi.org/10.1007/s10479-019-03458-x

Biasutti, M. (2019). Rainfall trends in the African Sahel: Characteristics, processes, and causes. *Wiley Interdisciplinary Reviews. Climate Change*, *10*(4). https://doi.org/10.1002/wcc.591

Black, E. (2005). The relationship between Indian Ocean sea–surface temperature and East African rainfall. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *363*(1826), 43–47. https://doi.org/10.1098/rsta.2004.1474

Black, E., Slingo, J., & Sperber, K. R. (2003). An observational study of the relationship between excessively strong short rains in coastal east Africa and Indian ocean SST. *Monthly Weather Review*, *131*(1), 74–94. https://doi.org/10.1175/1520-0493(2003)131<0074:aosotr>2.0.co;2

Bougara, H., Hamed, K. B., Borgemeister, C., Tischbein, B., & Kumar, N. (2020). Analyzing trend and variability of rainfall in the Tafna basin (northwestern Algeria). *Atmosphere*, *11*(4), 347. https://doi.org/10.3390/atmos11040347

Brandimarte, L., Di Baldassarre, G., Bruni, G., D’Odorico, P., & Montanari, A. (2011). Relation between the north-Atlantic oscillation and hydroclimatic conditions in Mediterranean areas. *Water Resources*

Management, *25*(5), 1269–1279. https://doi.org/10.1007/s11269-010-9742-5

Cattani, E., Merino, A., Guijarro, J., & Levizzani, V. (2018). East Africa rainfall trends and variability 1983–2015 using three long-term satellite products. *Remote Sensing*, *10*(6), 931. https://doi.org/10.3390/rs10060931

Ceccarelli, T., Bajocco, S., Luigi, P. L., & Luca, S. L. (2014). *Urbanisation and land take of high quality agricultural soils-exploring long*.

Clark, C. O., Webster, P. J., & Cole, J. E. (2003). Interdecadal variability of the relationship between the Indian ocean zonal mode and east African coastal rainfall anomalies. *Journal of Climate*, *16*(3), 548–554. https://doi.org/10.1175/1520-0442(2003)016<0548:ivotrb>2.0.co;2

Colantoni, A., Ferrara, C., Perini, L., & Salvati, L. (2015). Assessing trends in climate aridity and vulnerability to soil degradation in Italy. *Ecological Indicators*, *48*, 599–604. https://doi.org/10.1016/j.ecolind.2014.09.031

Crecente, F., Sarabia, M., & Teresa del Val, M. (2021). Climate change policy and entrepreneurial opportunities. *Technological Forecasting and Social Change*, *163*(120446), 120446. https://doi.org/10.1016/j.techfore.2020.120446

Cubasch, U., Meehl, G. A., Boer, G. J., Stouffer, R. J., Dix, M., Noda, A., & Yap. (2001). Projections of future climate change. In *The scientific basis. Contribution of WG1 to the Third Assessment Report of the IPCC (TAR)* (pp. 525–582). Cambridge University Press.

Currie, R. G. (1993). Luni-solar 18.6- and 10–11-year solar cycle signals in South African rainfall. *International Journal of Climatology: A Journal* *of the Royal Meteorological Society*, *13*(3), 237–256. https://doi.org/10.1002/joc.3370130302

Dezfuli, A. K., & Nicholson, S. E. (2013). The relationship of rainfall variability in western equatorial Africa to the tropical oceans and atmospheric circulation. Part II: The boreal autumn. *Journal of Climate*, *26*(1), 66–84. https://doi.org/10.1175/jcli-d-11-00686.1

Diatta, S., & Fink, A. H. (2014). Statistical relationship between remote climate indices and West African monsoon variability: REMOTE CLIMATE INDICES AND WEST AFRICAN MONSOON VARIABILITY. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *34*(12), 3348–3367. https://doi.org/10.1002/joc.3912

Djaman, K., Koudahe, K., Bodian, A., Diop, L., & Ndiaye, P. M. (2020). Long-term trend analysis in annual and seasonal precipitation, maximum and minimum temperatures in the southwest United States. *Climate*, *8*(12), 142. https://doi.org/10.3390/cli8120142

Eltahir, E. A. B. (1996). El Niño and the natural variability in the flow of the Nile River. *Water Resources Research*, *32*(1), 131–137. https://doi.org/10.1029/95wr02968

Fekete, H., Kuramochi, T., Roelfsema, M., Elzen, M. den, Forsell, N., Höhne, N., Luna, L., Hans, F., Sterl, S., Olivier, J., van Soest, H., Frank, S., & Gusti, M. (2021). A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. *Renewable and Sustainable Energy Reviews*, *137*(110602), 110602. https://doi.org/10.1016/j.rser.2020.110602

Folland, C. K., Palmer, T. N., & Parker, D. E. (1986). Sahel rainfall and worldwide sea temperatures, 1901–85. *Nature*, *320*(6063), 602–607. https://doi.org/10.1038/320602a0

Founda, D., & Giannakopoulos, C. (2009). The exceptionally hot summer of 2007 in Athens, Greece — A typical summer in the future climate? *Global and Planetary Change*, *67*(3–4), 227–236. https://doi.org/10.1016/j.gloplacha.2009.03.013

Fox, P., & Rockstrom, J. (2003). Supplemental Irrigation for Dry - spell mitigation of rainfed agriculture in the Sahel. *Agric. Water Manage, 61*, 29–50.

Funk, C. (2011). We thought trouble was coming. *Nature*, *476*(7358), 7–7. https://doi.org/10.1038/476007a

Funk, C., Harrison, L., Shukla, S., Pomposi, C., Galu, G., Korecha, D., Husak, G., Magadzire, T., Davenport, F., Hillbruner, C., Eilerts, G., Zaitchik, B., & Verdin, J. (2018). Examining the role of unusually warm Indo-Pacific sea- surface temperatures in recent African droughts. *Quarterly Journal of the Royal Meteorological Society. Royal Meteorological Society (Great Britain)*, *144*(S1), 360–383. https://doi.org/10.1002/qj.3266

Gachari, F., Mulati, D. M., & Mutuku, J. N. (2014). Sunspot numbers: Implications on Eastern African rainfall. *South African Journal of Science*, *110*(1/2), 1–5. https://doi.org/10.1590/sajs.2014/20130050

Gaglio, M., Aschonitis, V., Pieretti, L., Santos, L., Gissi, E., Castaldelli, G., & Fano, E. A. (2019). Modelling past, present and future Ecosystem Services supply in a protected floodplain under land use and climate changes. *Ecological Modelling*, *403*, 23–34. https://doi.org/10.1016/j.ecolmodel.2019.04.019

Gartland, L. M. (2012). *Heat Islands : Understanding and Mitigating Heat in Urban Areas*. Routledge London, UK, p. 208.

Gitau, W., Camberlin, P., Ogallo, L., & Bosire, E. (2018). Trends of intraseasonal descriptors of wet and dry spells over equatorial eastern Africa. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *38*(3), 1189–1200. https://doi.org/10.1002/joc.5234

Gualdi, S., & Navarra, A. (2005). Scenari climatici nel bacino mediterraneo. *Forest@-Journal of Silviculture and Forest Ecology*, *2*(1).

Gvero, P., M., Tica, G., S., Petrovic, S., I., Papuga, S., V., Jaksic, B., M., & Roljic, L., M. (2010). Renewable energy sources and their potential role in mitigation of climate changes and as a sustainable development driver in Bosnia and Herzegovina. *Thermal Science*, *14*(3), 641–654. https://doi.org/10.2298/tsci1003641g

Haywood, J. M., Jones, A., Bellouin, N., & Stephenson, D. (2013). Asymmetric forcing from stratospheric aerosols impacts Sahelian rainfall. *Nature Climate Change*, *3*(7), 660–665. https://doi.org/10.1038/nclimate1857

Heine, K., & Völke, J. (2011). Extreme floods around ad 1700 in the northeern Namib Desert, Namibia, and in the Orange River catchment, South Africa - were they forced by a decrease of solar irradiance during the Little Ice Age? *Geographia Polonica*, 61–80. https://doi.org/10.7163/gpol.2011.s1.5

Helama, S., & Holopainen, J. (2012). Spring temperature variability relative to the North Atlantic Oscillation and sunspots — A correlation analysis with a Monte Carlo implementation. *Palaeogeography,* *Palaeoclimatology, Palaeoecology*, *326–328*, 128–134. https://doi.org/10.1016/j.palaeo.2012.02.013

Hennekam, R., Jilbert, T., Schnetger, B., & de Lange, G. J. (2014). Solar forcing of Nile discharge and sapropel S1 formation in the early to middle Holocene eastern Mediterranean. *Paleoceanography*, *29*(5), 343–356. https://doi.org/10.1002/2013pa002553

Hoell, A., & Funk, C. (2014). Indo-Pacific sea surface temperature influences on failed consecutive rainy seasons over eastern Africa. *Climate Dynamics*, *43*(5–6), 1645–1660. https://doi.org/10.1007/s00382-013-1991-6

Hoell, A., Funk, C., & Barlow, M. (2014). La Niña diversity and Northwest Indian Ocean Rim teleconnections. *Climate Dynamics*, *43*(9–10), 2707–2724. https://doi.org/10.1007/s00382-014-2083-y

Hoell, A., Funk, C., Magadzire, T., Zinke, J., & Husak, G. (2015). El Niño–Southern Oscillation diversity and Southern Africa teleconnections during Austral Summer. *Climate Dynamics*, *45*(5–6), 1583–1599. https://doi.org/10.1007/s00382-014-2414-z

Hoell, A., Funk, C., Zinke, J., & Harrison, L. (2017). Modulation of the Southern Africa precipitation response to the El Niño Southern Oscillation by the subtropical Indian Ocean Dipole. *Climate Dynamics*, *48*(7–8), 2529–2540. https://doi.org/10.1007/s00382-016-3220-6

Huo, W.-J., & Xiao, Z.-N. (2016). The impact of solar activity on the 2015/16 El Niño event. *Atmospheric and Oceanic Science Letters*, *9*(6), 428–435. https://doi.org/10.1080/16742834.2016.1231567

Hurrell, J. W., Kushnir, Y., Ottersen, G., & Visbeck, M. (2003). An overview of the north Atlantic oscillation. In *The North Atlantic Oscillation: Climatic Significance and Environmental Impact* (pp. 1–35). American Geophysical Union.

Hutchinson, P. (1992). The southern oscillation and prediction of "Der" season rainfall in Somalia. *Journal of Climate*, *5*(5), 525–531. https://doi.org/10.1175/1520-0442(1992)005<0525:tsoapo>2.0.co;2

Indeje, M., Semazzi, F. H. M., & Ogallo, L. J. (2000). ENSO signals in East African rainfall seasons. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *20*(1), 19–46. https://doi.org/10.1002/(sici)1097-0088(200001)20:1<19::aid-joc449>3.0.co;2-0

Indira, D., & Srinagesh, B. (2021). Review on Mitigation Technologies for Controlling Urban Heat Island Effect in Housing and Settlement Areas in Housing and Settlement Areas in Hyderabad. *J. Emerg. Technol. Innov. Res.(JETIR)*, *8*, 836–845.

Jacob, D., Kotova, L., Teichmann, C., Sobolowski, S. P., Vautard, R., Donnelly, C., Koutroulis, A. G., Grillakis, M. G., Tsanis, I. K., Damm, A., Sakalli, A., & van Vliet, M. T. H. (2018). Climate impacts in Europe under +1.5°C global warming. *Earth's Future*, *6*(2), 264–285. https://doi.org/10.1002/2017ef000710

Junginger, A., Roller, S., Olaka, L. A., & Trauth, M. H. (2014). The effects of solar irradiation changes on the migration of the Congo Air Boundary and water levels of paleo-Lake Suguta, Northern Kenya Rift, during the African Humid Period (15–5ka BP). *Palaeogeography, Palaeoclimatology, Palaeoecology*, *396*, 1–16. https://doi.org/10.1016/j.palaeo.2013.12.007

Kane, R. P. (2009). Periodicities, ENSO effects and trends of some South African rainfall series: an update. *South African Journal of Science*, *105*(5/6). https://doi.org/10.4102/sajs.v105i5/6.90

Karl, T. R., & Trenberth, K. E. (2003). Modern global climate change. *Science (New York, N.Y.)*, *302*(5651), 1719–1723. https://doi.org/10.1126/science.1090228

Kerr, R. A. (2000). A north Atlantic climate pacemaker for the centuries. *Science (New York, N.Y.)*, *288*(5473), 1984–1985. https://doi.org/10.1126/science.288.5473.1984

Kiladis, G. N., & Diaz, H. F. (1989). Global climatic anomalies associated with extremes in the southern oscillation. *Journal of Climate*, *2*(9), 1069–1090. https://doi.org/10.1175/1520-0442(1989)002<1069:gcaawe>2.0.co;2

Kirov, B., & Georgieva, K. (2002). Long-term variations and interrelations of ENSO, NAO and solar activity. *Physics and Chemistry of the Earth (2002)*, *27*(6–8), 441–448. https://doi.org/10.1016/s1474-7065(02)00024-4

Knippertz, P., Christoph, M., & Speth, P. (2003). Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. *Meteorology and Atmospheric Physics*, *83*(1–2), 67–88. https://doi.org/10.1007/s00703-002-0561-y

Knippertz, Peter, Ulbrich, U., Marques, F., & Corte-Real, J. (2003). Decadal changes in the link between El Niño and springtime North Atlantic oscillation and European-North African rainfall: EL NIÑO, NAO, EUROPEAN-NORTH AFRICAN RAINFALL. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *23*(11), 1293–1311. https://doi.org/10.1002/joc.944

Knudsen, M. F., Jacobsen, B. H., Seidenkrantz, M.-S., & Olsen, J. (2014). Evidence for external forcing of the Atlantic Multidecadal Oscillation since termination of the Little Ice Age. *Nature Communications*, *5*(1). https://doi.org/10.1038/ncomms4323

Kodera, K., Coughlin, K., & Arakawa, O. (2007). Possible modulation of the connection between the Pacific and Indian Ocean variability by the solar cycle. *Geophysical Research Letters*, *34*(3). https://doi.org/10.1029/2006gl027827

Kodera, Kunihiko. (2002). Solar cycle modulation of the North Atlantic Oscillation: Implication in the spatial structure of the NAO. *Geophysical Research Letters*, *29*(8). https://doi.org/10.1029/2001gl014557

Kodera, Kunihiko. (2005). Possible solar modulation of the ENSO cycle. *Papers in Meteorology and Geophysics*, *55*(1/2), 21–32. https://doi.org/10.2467/mripapers.55.21

Koeppen, W. (1918). Klassifikation der Klima nach Temperatur, Niederschlag und Jahreslauf. *Pet. Mitt.*, *64*, 243–248. https://cir.nii.ac.jp/crid/1571417124712445824

Korecha, D., & Barnston, A. G. (2007). Predictability of June–September rainfall in Ethiopia. *Monthly Weather Review*, *135*(2), 628–650. https://doi.org/10.1175/mwr3304.1

Kovacevic, D., Oljaca, S., Dolijanovic, Z., & Milic, V. (2012). Climate changes: Ecological and agronomic options for mitigating the consequences of drought in Serbia. In *Proceedings of the Third International Scientific Symposium "Agrosym*.

Lamb, P. J., & Peppler, R. A. (1987). North Atlantic oscillation: Concept and an application. *Bulletin of the American Meteorological Society*, *68*(10), 1218–1225. https://doi.org/10.1175/1520-0477(1987)068<1218:naocaa>2.0.co;2

Li, H., Wang, H., & Yin, Y. (2012). Interdecadal variation of the West African summer monsoon during 1979–2010 and associated variability. *Climate Dynamics*, *39*(12), 2883–2894. https://doi.org/10.1007/s00382-012-1426-9

Li, S. (2003). Influence of the North Atlantic SST tripole on northwest African rainfall. *Journal of Geophysical Research*, *108*(D19). https://doi.org/10.1029/2002jd003130

Liebmann, B., Hoerling, M. P., Funk, C., Bladé, I., Dole, R. M., Allured, D., Quan, X., Pegion, P., & Eischeid, J. K. (2014). Understanding recent eastern Horn of Africa rainfall variability and change. *Journal of Climate*, *27*(23), 8630–8645. https://doi.org/10.1175/jcli-d-13-00714.1

Lim, E.-P., & Hendon, H. H. (2017). Causes and predictability of the negative Indian Ocean Dipole and its impact on La Niña during 2016. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-12674-z

López-Moreno, J. I., Vicente-Serrano, S. M., Morán-Tejeda, E., Lorenzo-Lacruz, J., Kenawy, A., & Beniston, M. (2011). Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: Observed relationships and projections for the 21st century. *Global and Planetary Change*, *77*(1–2), 62–76. https://doi.org/10.1016/j.gloplacha.2011.03.003

Lott, F. C., Christidis, N., & Stott, P. A. (2013). Can the 2011 East African drought be attributed to human-induced climate change?: THE 2011

EAST AFRICAN DROUGHT ATTRIBUTION. *Geophysical Research Letters*, *40*(6), 1177–1181. https://doi.org/10.1002/grl.50235

Loua, R. T., Bencherif, H., Mbatha, N., Bègue, N., Hauchecorne, A., Bamba, Z., & Sivakumar, V. (2019). Study on temporal variations of surface temperature and rainfall at Conakry Airport, Guinea: 1960–2016. *Climate*, *7*(7), 93. https://doi.org/10.3390/cli7070093

Lüning, S., Gałka, M., Danladi, I. B., Adagunodo, T. A., & Vahrenholt, F. (2018). Hydroclimate in Africa during the Medieval Climate Anomaly. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *495*, 309–322. https://doi.org/10.1016/j.palaeo.2018.01.025

Lyon, B., & DeWitt, D. G. (2012). A recent and abrupt decline in the East African long rains: EAST AFRICAN LONG RAINS DECLINE. *Geophysical Research Letters*, *39*(2). https://doi.org/10.1029/2011gl050337

MacKellar, N., Mark New, & Jack, C. (2014). Observed and modelled trends in rainfall and temperature for South Africa: 1960–2010. *South African Journal of Science*, *110*(7/8), 13. https://doi.org/10.1590/sajs.2014/20130353

Malik, A., Brönnimann, S., & Perona, P. (2018). Statistical link between external climate forcings and modes of ocean variability. *Climate Dynamics*, *50*(9–10), 3649–3670. https://doi.org/10.1007/s00382-017-3832-5

Manatsa, D., & Mukwada, G. (2012). Rainfall mechanisms for the dominant rainfall mode over Zimbabwe relative to ENSO and/or IODZM. *TheScientificWorldJournal*, *2012*, 1–15. https://doi.org/10.1100/2012/926310

Manatsa, D., Reason, C. J. C., & Mukwada, G. (2012). On the decoupling of the IODZM from southern Africa Summer rainfall variability: SOUTHERN AFRICA RAINFALL VARIABILITY. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *32*(5), 727–746. https://doi.org/10.1002/joc.2306

Mantua, N. J., & Hare, S. R. (2002). The Pacific decadal oscillation. *Journal of Oceanography*, *58*(1), 35–44. https://doi.org/10.1023/a:1015820616384

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., & Francis, R. C. (1997). A pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, *78*(6), 1069–1079. https://doi.org/10.1175/1520-0477(1997)078<1069:apicow>2.0.co;2

Marchane, A., Jarlan, L., Boudhar, A., Tramblay, Y., & Hanich, L. (2016). Linkages between snow cover, temperature and rainfall and the North Atlantic Oscillation over Morocco. *Climate Research*, *69*(3), 229–238. https://doi.org/10.3354/cr01409

Marchant, R., Mumbi, C., Behera, S., & Yamagata, T. (2007). The Indian Ocean dipole ? the unsung driver of climatic variability in East Africa. *African Journal of Ecology*, *45*(1), 4–16. https://doi.org/10.1111/j.1365-2028.2006.00707.x

Markandya, A., Sampedro, J., Smith, S. J., Van Dingenen, R., Pizarro-Irizar, C., Arto, I., & González-Eguino, M. (2018). Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study. *The Lancet. Planetary Health*, *2*(3), e126–e133. https://doi.org/10.1016/s2542-5196(18)30029-9

Martin, E. R., & Thorncroft, C. D. (2014). The impact of the AMO on the West African monsoon annual cycle: Impact of AMO on West African Monsoon. *Quarterly Journal of the Royal Meteorological Society. Royal Meteorological Society (Great Britain)*, *140*(678), 31–46. https://doi.org/10.1002/qj.2107

Martin, E. R., Thorncroft, C., & Booth, B. B. B. (2014). The multidecadal Atlantic SST—Sahel rainfall teleconnection in CMIP5 simulations. *Journal of Climate*, *27*(2), 784–806. https://doi.org/10.1175/jcli-d-13-00242.1

Maruyama, F., Kai, K., & Morimoto, H. (2017). Wavelet-based multifractal analysis on a time series of solar activity and PDO climate index. *Advances in Space Research: The Official Journal of the Committee on Space Research (COSPAR)*, *60*(6), 1363–1372. https://doi.org/10.1016/j.asr.2017.06.004

Mason, S. J., & Tyson, P. D. (1992). The modulation of sea surface temperature and rainfall associations over southern Africa with solar activity and the quasi- biennial oscillation. *Journal of Geophysical Research*, *97*(D5), 5847–5856. https://doi.org/10.1029/91jd02189

Mason, Simon J., & Goddard, L. (2001). Probabilistic precipitation anomalies associated with ENSO. *Bulletin of the American Meteorological Society*, *82*(4), 619–638. https://doi.org/10.1175/1520-0477(2001)082<0619:ppaawe>2.3.co;2

Mc Carthy, J. J., Cianziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (2001). Climate change 2001 : Impacts, Adaptation, and vulnerability. In *Contribution of working Group II to the third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Mc millen, M.S. (2022): Improving drought tolerance in maize: tools an techniques.

Mdee, A(2022): The top 100 global water questions: Results of a scoping exercise.

McHugh, M. J., & Rogers, J. C. (2001). North Atlantic oscillation influence on precipitation variability around the southeast African convergence zone. *Journal of Climate*, *14*(17), 3631–3642. https://doi.org/10.1175/1520-0442(2001)014<3631:naoiop>2.0.co;2

Meddi, M. M., Assani, A. A., & Meddi, H. (2010). Temporal variability of annual rainfall in the macta and tafna catchments, northwestern Algeria. *Water Resources Management*, *24*(14), 3817–3833. https://doi.org/10.1007/s11269-010-9635-7

Mendelsohn, R., & Neumann, J. E. (2004). *The impact of climate change on the United States economy*. Cambridge University Press.

Mirzaei, P. A. (2015). Recent challenges in modeling of urban heat island. *Sustainable Cities and Society*, *19*, 200–206. https://doi.org/10.1016/j.scs.2015.04.001

Mohino, E., Janicot, S., & Bader, J. (2011). Sahel rainfall and decadal to multi-decadal sea surface temperature variability. *Climate Dynamics*, *37*(3–4), 419–440. https://doi.org/10.1007/s00382-010-0867-2

Montanarella, L. (2007). Trends in Land Degradation in Europe. In *Climate and Land Degradation* (pp. 83–104). Springer Berlin Heidelberg.

Mpelasoka, F., Awange, J. L., & Zerihun, A. (2018). Influence of coupled ocean-atmosphere phenomena on the Greater Horn of Africa droughts and their implications. *The Science of the Total Environment*, *610–611*, 691–702. https://doi.org/10.1016/j.scitotenv.2017.08.109

Muthers, S., Raible, C. C., Rozanov, E., & Stocker, T. F. (2016). Response of the AMOC to reduced solar radiation – the modulating role of atmospheric chemistry. *Earth System Dynamics*, *7*(4), 877–892. https://doi.org/10.5194/esd-7-877-2016

Nash, D. L., Crouch, E. R., & Crouch, E. R. (2017). Comparison of EX-PRESS shunt and trabeculectomy with mitomycin-C in congenital and juvenile glaucoma. *Journal of Glaucoma*, *26*(2), e58–e63. https://doi.org/10.1097/ijg.0000000000000547

National Oceanic and Atmospheric Administration, (2007). Observing climate variability and change. Retrieved from :http://www.org.oar.noaa.gov/climate/t_observing.html.(accessed date : May 11. 2009).November 2003.

Niasse, M. (2005). *Climate - induced water conflict Risks in West Africa: Recognizing and coping with increasing Climate impacts on shared Watercourses*.

Nicholson, S. (2000). The nature of rainfall variability over Africa on time scales of decades to millenia. *Global and Planetary Change*, *26*(1–3), 137–158. https://doi.org/10.1016/s0921-8181(00)00040-0

Nicholson, S. E. (2014). Spatial teleconnections in African rainfall: A comparison of 19th and 20th century patterns. *The Holocene, 24*(12), 1840–1848. https://doi.org/10.1177/0959683614551230

Nicholson, S. E. (2015). Long- term variability of the East African ‘short rains’ and its links to large- scale factors. *International Journal of*

Climatology: A Journal of the Royal Meteorological Society, *35*(13), 3979–3990. https://doi.org/10.1002/joc.4259

Nicholson, S. E. (2017). Climate and climatic variability of rainfall over eastern Africa. *Reviews of Geophysics (Washington, D.C.: 1985)*, *55*(3), 590–635. https://doi.org/10.1002/2016rg000544

Nicholson, S. E., & Kim, J. (1997). The relationship of the El Niño–southern oscillation to African rainfall. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *17*(2), 117–135. https://doi.org/10.1002/(sici)1097-0088(199702)17:2<117::aid-joc84>3.0.co;2-o

Nicholson, S. E., Funk, C., & Fink, A. H. (2018). Rainfall over the African continent from the 19th through the 21st century. *Global and Planetary Change*, *165*, 114–127. https://doi.org/10.1016/j.gloplacha.2017.12.014

Nugroho, J. T. (2007). Appearance of solar activity signals in Indian Ocean Dipole (IOD) phenomena and monsoon climate pattern over Indonesia. *Bulletin of the Astronomical Society of India*, *35*(1), 575–579.

Ogou, F. K., Yang, Q., Duan, Y., & Ma, Z. (2019). Comparative analysis of interdecadal precipitation variability over central North China and sub Saharan Africa. *Atmospheric and Oceanic Science Letters*, *12*(3), 201–207. https://doi.org/10.1080/16742834.2019.1593040

Ogwang, B. A., Ongoma, V., Xing, L., & Ogou, K. F. (2015). Influence of Mascarene High and Indian Ocean dipole on East African extreme weather events. *Geographica Pannonica*, *19*(2), 64–72. https://doi.org/10.5937/geopan1502064o

Okorie, F. C. (2003). *Studies on Drought in the sub saharan Region in Nigeria using satellite Remote sensing and precipitation data*.

Oladipo, E. O. (1993). *Some aspects of the spatial characteristics of drought in Northern Nigeria Hazards*. *8*, 171–188.

Olesen, J. E., & Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy: The Journal of the European Society for Agronomy*, *16*(4), 239–262. https://doi.org/10.1016/s1161-0301(02)00004-7

Olofin, E. A. (1987). *Some aspects of the physical Geograghy of the Kano Region and related human responses*.

Otterå, O. H., Bentsen, M., Drange, H., & Suo, L. (2010). External forcing as a metronome for Atlantic multidecadal variability. *Nature Geoscience*, *3*(10), 688–694. https://doi.org/10.1038/ngeo955

Otto, F. E. L., Wolski, P., Lehner, F., Tebaldi, C., van Oldenborgh, G. J., Hogesteeger, S., Singh, R., Holden, P., Fučkar, N. S., Odoulami, R. C., & Mark New. (2018). Anthropogenic influence on the drivers of the Western Cape drought 2015–2017. *Environmental Research Letters*, *13*(12), 124010. https://doi.org/10.1088/1748-9326/aae9f9

Ouachani, R., Bargaoui, Z., & Ouarda, T. (2013). Power of teleconnection patterns on precipitation and streamflow variability of upper Medjerda Basin. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *33*(1), 58–76. https://doi.org/10.1002/joc.3407

Owiti, Z., Ogallo, L. A., & Mutemi, J. (2008). Linkages between the Indian Ocean Dipole and East African seasonal rainfall anomalies. *Journal of Kenya Meteorological Society*, *2*(1).

Palme, M., Inostroza, L., Villacreses, G., Lobato-Cordero, A., & Carrasco, C. (2017). From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect. *Energy and Buildings*, *145*, 107–120. https://doi.org/10.1016/j.enbuild.2017.03.069

Pandey, S., Mishra, R., & Tiwari, K. (2016). Impact Assessment and Mitigation of Sources Responsible for Climate Changes. *Int. J. Adv. Res. Innov. Ideas Educ*, *2*, 193–198.

Park, J.-Y., Bader, J., & Matei, D. (2016). Anthropogenic Mediterranean warming essential driver for present and future Sahel rainfall. *Nature Climate Change*, *6*(10), 941–945. https://doi.org/10.1038/nclimate3065

Perminova, T., Sirina, N., Laratte, B., Baranovskaya, N., & Rikhvanov, L. (2016). Methods for land use impact assessment: A review. *Environmental Impact Assessment Review*, *60*, 64–74. https://doi.org/10.1016/j.eiar.2016.02.002

Philippon, N., Rouault, M., Richard, Y., & Favre, A. (2012). The influence of ENSO on winter rainfall in South Africa: THE INFLUENCE OF ENSO ON WINTER RAINFALL IN SOUTH AFRICA. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *32*(15), 2333–2347. https://doi.org/10.1002/joc.3403

Reason, C. J. C. (2001). Subtropical Indian Ocean SST dipole events and southern African rainfall. *Geophysical Research Letters*, *28*(11), 2225–2227. https://doi.org/10.1029/2000gl012735

Rodó, X., Baert, E., & Comín, F. A. (1997). Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern

Oscillation. *Climate Dynamics*, *13*(4), 275–284. https://doi.org/10.1007/s003820050165

Ropelewski, C. F., & Halpert, M. S. (1987). Global and regional scale precipitation patterns associated with the El Niño/southern oscillation. *Monthly Weather Review*, *115*(8), 1606–1626. https://doi.org/10.1175/1520-0493(1987)115<1606:garspp>2.0.co;2

Ruzmaikin, A., Feynman, J., & Yung, Y. L. (2006). Is solar variability reflected in the Nile River? *Journal of Geophysical Research*, *111*(D21). https://doi.org/10.1029/2006jd007462

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., & Yamagata, T. (1999). A dipole mode in the tropical Indian Ocean. *Nature*, *401*(6751), 360–363. https://doi.org/10.1038/43854

Schlesinger, M. E., & Ramankutty, N. (1994). An oscillation in the global climate system of period 65–70 years. *Nature*, *367*(6465), 723–726. https://doi.org/10.1038/367723a0

Segele, Z. T., Lamb, P. J., & Leslie, L. M. (2009). Large-scale atmospheric circulation and global sea surface temperature associations with Horn of Africa June-September rainfall. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *29*(8), 1075–1100. https://doi.org/10.1002/joc.1751

Shanahan, T. M., Overpeck, J. T., Anchukaitis, K. J., Beck, J. W., Cole, J. E., Dettman, D. L., Peck, J. A., Scholz, C. A., & King, J. W. (2009). Atlantic forcing of persistent drought in West Africa. *Science (New York, N.Y.)*, *324*(5925), 377–380. https://doi.org/10.1126/science.1166352

Sharifi, A., Pathak, M., Joshi, C., & He, B.-J. (2021). A systematic review of the health co-benefits of urban climate change adaptation. *Sustainable Cities and Society*, *74*(103190), 103190. https://doi.org/10.1016/j.scs.2021.103190

Sivakumar, M. V. K. (2007). Interactions between climate and desertification. *Agricultural and Forest Meteorology*, *142*(2–4), 143–155. https://doi.org/10.1016/j.agrformet.2006.03.025

Sovacool, B. K., & Linnér, B.-O. (2016). *The Political Economy of Climate Change Adaptation; Springer*. Berlin/Heidelberg, Germany.

Stager, J. C., Cumming, B. F., & Meeker, L. D. (2003). A 10,000-year high-resolution diatom record from Pilkington Bay, Lake Victoria, East Africa. *Quaternary Research*, *59*(2), 172–181. https://doi.org/10.1016/s0033-5894(03)00008-5

Stefanakis, A. I., Calheiros, C. S. C., & Nikolaou, I. (2021). Nature-based solutions as a tool in the new circular economic model for climate change adaptation. *Circular Economy and Sustainability*, *1*(1), 303–318. https://doi.org/10.1007/s43615-021-00022-3

Stephenson, D. B., Wanner, H., Brönnimann, S., & Luterbacher, J. (2003). The history of scientific research on the North Atlantic Oscillation. In *The North Atlantic Oscillation: Climatic Significance and Environmental Impact* (pp. 37–50). American Geophysical Union.

Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, *93*(12), 1879–1900. https://doi.org/10.1175/bams-d-11-00019.1

Taibi, S., Meddi, M., Mahé, G., & Assani, A. (2017). Relationships between atmospheric circulation indices and rainfall in Northern Algeria and comparison of observed and RCM-generated rainfall. *Theoretical and Applied Climatology*, *127*(1–2), 241–257. https://doi.org/10.1007/s00704-015-1626-4

Tanner, T., & Allouche, J. (2011). Towards a new political economy of climate change and development. *IDS Bulletin (University of Sussex. Institute of Development Studies : 1985)*, *42*(3), 1–14. https://doi.org/10.1111/j.1759-5436.2011.00217.x

Taye, M. T., & Willems, P. (2012). Temporal variability of hydroclimatic extremes in the Blue Nile basin: TEMPORAL VARIABILITY OF HYDROCLIMATIC EXTREMES. *Water Resources Research*, *48*(3). https://doi.org/10.1029/2011wr011466

Thiéblemont, R., Matthes, K., Omrani, N.-E., Kodera, K., & Hansen, F. (2015). Solar forcing synchronizes decadal North Atlantic climate variability. *Nature Communications*, *6*(1). https://doi.org/10.1038/ncomms9268

Tierney, J. E., Smerdon, J. E., Anchukaitis, K. J., & Seager, R. (2013). Multidecadal variability in East African hydroclimate controlled by the Indian Ocean. *Nature*, *493*(7432), 389–392. https://doi.org/10.1038/nature11785

Trenberth, K. E. (2007). *Observations : Surface and atmospheric Climate change* (D. Qin, M. Maning, Z. Chen, & M. Marquis, Eds.).

Trenberth, K. E., & Shea, D. J. (2006). Atlantic hurricanes and natural variability in 2005. *Geophysical Research Letters*, *33*(12). https://doi.org/10.1029/2006gl026894

Tukur, A., Nabegu, A., Abba Umar, D., Olofin, E., & Sulaiman, W. (2018). Groundwater condition and management in Kano region, northwestern

Nigeria. *Hydrology*, *5*(1), 16. https://doi.org/10.3390/hydrology5010016

Unger, P.W. (2010): Water conservation for agriculture.

Ummenhofer, C. C., Sen Gupta, A., England, M. H., & Reason, C. J. C. (2009). Contributions of Indian Ocean sea surface temperatures to enhanced East African rainfall. *Journal of Climate*, *22*(4), 993–1013. https://doi.org/10.1175/2008jcli2493.1

van Loon, H., Meehl, G. A., & Arblaster, J. M. (2004). A decadal solar effect in the tropics in July–August. *Journal of Atmospheric and Solar-Terrestrial Physics*, *66*(18), 1767–1778. https://doi.org/10.1016/j.jastp.2004.06.003

Verschuren, D., Laird, K. R., & Cumming, B. F. (2000). Rainfall and drought in equatorial east Africa during the past 1,100 years. *Nature*, *403*(6768), 410–414. https://doi.org/10.1038/35000179

Wallace, M. G. (2019). Application of lagged correlations between solar cycles and hydrosphere components towards sub-decadal forecasts of streamflows in the Western USA. *Journal Des Sciences Hydrologiques [Hydrological Sciences Journal]*, *64*(2), 137–164. https://doi.org/10.1080/02626667.2019.1567925

Wang, J., Yang, B., Ljungqvist, F. C., Luterbacher, J., Osborn, T. J., Briffa, K. R., & Zorita, E. (2017). Internal and external forcing of multidecadal Atlantic climate variability over the past 1,200 years. *Nature Geoscience*, *10*(7), 512–517. https://doi.org/10.1038/ngeo2962

Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. *The Science* *of the Total Environment*, *569–570*, 527–539. https://doi.org/10.1016/j.scitotenv.2016.06.119

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science (New York, N.Y.)*, *341*(6145), 508–513. https://doi.org/10.1126/science.1239402

www.fao.org. : soil and water conservation.

Yamakawa, S., Inoue, M., & Suppiah, R. (2016). Relationships between solar activity and variations in SST and atmospheric circulation in the stratosphere and troposphere. *Quaternary International: The Journal of the International Union for Quaternary Research*, *397*, 289–299. https://doi.org/10.1016/j.quaint.2015.11.018

Young, S. S., & Young, J. S. (2021). Overall warming with reduced seasonality: Temperature change in New England, USA, 1900–2020. *Climate*, *9*(12), 176. https://doi.org/10.3390/cli9120176

Zaroug, M. A. H., Giorgi, F., Coppola, E., Abdo, G. M., & Eltahir, E. A. B. (2014). Simulating the connections of ENSO and the rainfall regime of East Africa and the upper Blue Nile region using a climate model of the Tropics. *Hydrology and Earth System Sciences*, *18*(11), 4311–4323. https://doi.org/10.5194/hess-18-4311-2014

Zdruli, P. (2014). Land resources of the Mediterranean: Status, pressures, trends and impacts on future regional development: Land resources, population growth and Mediterranean region development. *Land Degradation and Development*, *25*(4), 373–384. https://doi.org/10.1002/ldr.2150

Zeroual, A., Assani, A. A., & Meddi, M. (2017). Combined analysis of temperature and rainfall variability as they relate to climate indices in

Northern Algeria over the 1972–2013 period. *Hydrology Research*, *48*(2), 584–595. https://doi.org/10.2166/nh.2016.244

Zhang, R., & Delworth

, T. L. (2006). Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes. *Geophysical Research Letters*, *33*(17). https://doi.org/10.1029/2006gl026267

Zhang, R., Sutton, R., Danabasoglu, G., Kwon, Y.-O., Marsh, R., Yeager, S. G., Amrhein, D. E., & Little, C. M. (2019). A review of the role of the Atlantic Meridional Overturning Circulation in Atlantic Multidecadal Variability and associated climate impacts. *Reviews of Geophysics (Washington, D.C.: 1985)*, *57*(2), 316–375. https://doi.org/10.1029/2019rg000644

Zinzi, M., Carnielo, E., & Mattoni, B. (2018). On the relation between urban climate and energy performance of buildings. A three-years experience in Rome, Italy. *Applied Energy*, *221*, 148–160. https://doi.org/10.1016/j.apenergy.2018.03.192