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Faculty of Tropical AgriSciences

Climatic Dynamics and Its Impact on Food Security and Livelihood in Northern Kaduna, Kaduna State, Federal Republic of Nigeria

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled “Climatic Dynamics and Its Impact on Food Security and Livelihood in Northern Kaduna, Kaduna State, Federal Republic of Nigeria” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague date

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Oluwatobiloba Elijah Adu

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Abstract

Cereal crops amount for the highest fraction of the global human caloric intake thus accounting for the highest crop production in the world. Climate change is a cumbersome topic of discussion in the 21st continuously having an adverse effect on the rainfall patterns globally thus posing a threat to the global food production leading to disturbances of temperature and precipitation, thereby posing socio-economic threat to rural farmers.

Trends data on temperature, rainfall and yield of 3 cereal crops (Maize, Sorghum & Rice) in Kaduna, Northern Nigeria was used for a period of 23years (1999-2021). The yield data was obtained from Michigan State University, Kaduna State Agricultural Production data in the USAID development data library while climatic data was obtained from the archive of the Nigerian Meteorological Agency. The primary objective of this research was to investigate the vulnerability of climate change impacts on Kaduna crop yields, land use, production and environmental variables to adaptations in crops requirements through empirical analysis to shed more light on these factors as literatures on this region are scanty. The time series data was tested for stationarity using the Cointegrating Regression Durbin-Watson (CRDW) test method as expounded by Gujarati 2003. Multiple linear regression was then carried out to determine the relationships between climatic variables and crops yield.

Analysis of the result showed that mean yield of the three crops in descending order are as follows Sorghum < Rice < Maize. However the descending order of the mean cropping area can be ranked as Rice < Sorghum < Maize and the production output in descending order was as follows as Rice < Sorghum < Maize. The minimum temperature had a statistically significant positive impact on the yield of the three crops. However, increased temperature at maximum level resulted in the declination of Rice. Rainfall also showed a negative but not statistically significant impact on the cereals.

Conclusively, this study discovered that climatic changes had occurred over the years which reflected in the variability of rainfall pattern as well as the minimum and maximum temperature over this time period. It also showed that minimum temperatures favoured crop yield while increased temperature negatively affects it. The land use change images over the course of the time period of (2000 -2021) illustrated more afforestation practices in the region. It is important that climatic variables are carefully monitored to forecast changes and inform farmers accordingly. Farmers should also be given more education on climate change and supported to adopt climate smart agriculture.

Keywords: Climate change, Food security, The great green wall, Afforestation

Table of Contents

List of figures

List of tables

List of the abbreviations used in the thesis

ETC - Etcetera

HA - Hectare

PH - Potential Hydrogen

FM - Fresh Matter

CM - Centimetre

LULC - Land Use Land Cover

KM -Kilometre

TM - Thematic Mapper

ETM+ - Enhanced Thematic Mapper Plus

OLI - Operational Land Imager

MSS - Multi-spectral Scanner

GIS - Geographic Information System

SQ - Square

RS – Remote Sensing

GMS - Geosynchronous Meteorological Satellite

M - Metre

MM - Millimetres

DW - Durbin-Watson

CRDW - Cointegrating Regression Durbin-Watson

TOA - Top of Atmosphere

FLAASH - Fast line of sight Atmospheric Analysis of Hypercubes

TM - Thematic Mapper

SWOT ¬ Strength, Weakness, Opportunities and Threats

1. Introduction

1.1. Introduction

Food is life and it has a momentous value to the sustenance of livelihood. It has undisputedly become an instrument of national power, such that in recent times, concerns have been growing over the dire consequences of food shortages all over the world, especially developing countries with Nigeria as one of the countries of discussion (Attah 2012). The term “food security” first came to limelight at the World Food Summit of 1974, where it was established that food security is paramount for instilling political stability (Jones *et al.* 2013). According to the Food and Agricultural Organization during the World Food Summit, it is believed that food security is proposed situation when people have unforeseeable physical and economic access to and adequate, safe and nutritious foods to meet their daily demand of balanced diet and numerous food preferences for an active and healthy life (FAO 1996). Also, according to (FAO, 1996) at the International Conference on Nutrition held in Rome in 1992, food security measures the unlimited access of individuals to nutritious food needed for a healthy life. The International Federation of the Red Cross reported this year that the north western and north central states of Nigeria are already facing high levels of food insecurity (IFRC 2021), as this is an evidence of the rising population in Nigerian who are malnourished and impoverished which is a factual indicator that food security in Nigeria are in their lowest ebb (Kelechi *et al.* 2021).

Climate change is a global phenomenon causing extreme weather and climate events on natural and human systems either driven by natural or anthropogenic activities. It is defined as any substantial shift in meteorological components such as temperature, rainfall, wind pattern, and so on over a timespan (NIMET 2017). Over the decades, climate change has influenced natural and human systems in different continents, including the land and ocean. Natural systems have the best and most extensive evidence of climate change impacts, according to the IPCC (2022). Alteration in precipitation, including melting snow and ice, are visible changes in hydrological systems around the world, having effect on both the amount and quality of water supplies. Permafrost warming and thawing in high latitude and high elevation regions are also results of climate change. Over the decades, evidence of climate change from atmospheric and surface observations has increased drastically (Stocker *et al.* 2013). Anthropogenic activities accounting for climate change can be exacerbated by behavioural patterns such as epidemic land use and deforestation, large technical and social transformations with minimal reliance on organic fuel, and the rapid adoption of fossil fuels (Alcamo *et al.*, 2003). Crop farmers, livestock keepers, people in poor health, those who are undernourished, people with low economic power, women and children, including women headed households, people with high level of illiteracy, and inadequate technological experience in rural communities tend to be the most vulnerable to climate change in Nigeria, just as the residence of developing countries in the subtropical region (Barber 2003). According to the IPCC (2022) assessment, the negative effects of climate change on crop yield outnumbers the beneficial effects. Positive effects are primarily seen in high-latitude areas. Impact of climate change vary based on locations and sectors in northern part of Nigeria but will be more drastic where sensitivity to climate change is higher, stress causes are numerous, and adaptive capacity is poor. Impoverished regions are more vulnerable, particularly in perilous areas, due to inadequate adaptive ability and reliance on local ecological services (World Bank Group 2015). Drought consistency, and extreme floods, causing alteration both surface and underground water supplies, affecting agriculture and food security; surge in pests and diseases infesting of crops, increased rural-urban migration, high loss of biodiversity, declination in soil quality, increased health risks and the spread of infectious diseases, and changing livelihood systems are a list of the detrimental effects of climate change in northern Nigeria (World Bank Group 2015).

1950, a British Explorer once proposed a “green front” to act as tree buffer to contain the expanding desert that stretches throughout the entire width of Africa called the Sahel and Sahara. This idea re-emerged again at a Special Summit in Chad in the year 2005 tagged “World Day to Combat Desertification and Drought” but it wasn’t approved by the African Union until 2007 when it was named the “Great Green Wall for the Sahara and Sahel Initiative (FAO 2019). This mission was masterminded to mitigate the rabid desertification of the Sahel and also holding back the expansion of the Sahara by planting an estimate of about 8000 trees across the entire width of Africa (Akhtar *et al.* 2022). As the population of the Sahel is expected to double by 2039, emphasizing the importance of maintaining food production and environmental protection was necessary as a combined effect to curb natural resources degradation and drought in the affected areas. Since the initiative was put into practice in 2007, the land fertility has improved thus having a positive influence on food security, jobs and stability in people's lives, and also, the Great Green Wall has helped communities mitigate and adapt to climate changes (Akhtar *et al.* 2022).

1.2. Problem Statement

Available evidences suggest that climate change has induced food crises in some parts of the world and may also create some livelihood challenges due to resulting consequence of food shortages and unavailability altogether that arises from the loss of livestock and arable lands to natural disasters and unforeseen climatic circumstances (Kelechi et al. 2021). In 2006, the African Union met in Libya to endorse the Green Wall Sahara Program, which aims to control land degradation, improve environmental sustainability, promote integrated natural resource management, contribute to poverty reduction, and create jobs and wealth for 23 African countries affected by drought and desertification (UNCCD, 2020). Nigeria, according to researchers is considered a place where crisis complexes associated with climate change are playing out without any significant measures in place to mitigate the effects (Kelechi et al. 2021). The Food and Agricultural Organization (FAO) in its 2017, 2018 and 2019 articles titled "The State of Food Security and Nutrition in the World" stated that the main contributing elements of food insecurity in the world are climate change, economic and political instability and insurgency or terrorism (FAO, IFAD, UNICEF, WFP and WHO 2022). Nigeria was categorized as one of the countries where the three drivers noted by the FAO play very significant role in the decline of the food security (Kralovec 2020). The initiative of the Great Green Wall is to sustain land use practices by implementing agro-forestry to increase tree density and address the region's lack of social and economic resiliency to climatic change impacts (Tristan, 2021). It is from this background that this study is designed to evaluate the effectiveness of The Great Green Wall Project with disproportionate impact on the extent at which climate change has affected food security and livelihoods in Kaduna state of Nigeria.

1.3. Research Objectives

This research is going to investigate the impact of climatic factors on the yield of three cereals namely Maize, Sorghum and Rice in Kaduna State.

1.3.1. Specific Objectives

These include;

i. To determine the meteorological changes in the study area over a time span of 23 years (1999-2021).
ii. To assess the impact of some climatic factors (temperature and precipitation) on the crop yield of 3 important crops (Maize, Sorghum and Rice) cultivated in the region over a period of 23 years (1999-2021).
iii. To investigate the Land Use Changes in the study area and its impact on climate change over the last 22 years (2000-2021).
iv. To suggest sustainable alternative methods to increase agricultural production to meet the national and regional demands.

1.4. Hypothesis

This study will be testing the following hypothesis:

H_0: There is no significant impact of temperature and precipitation on crop yield in Kaduna State between 1999-2021.

H_1: There is a significant impact of temperature and precipitation on crop yield in Kaduna State between 1999-2021.

1.5. Significance of the Study

The significance of this study was to reverberate the benefit of alternative sustainable methods to increase agricultural productivity in Kaduna State which is the hub of Agriculture in Nigeria. During the recent years Kaduna state has experienced ecological and socio-economic problem ranging from deforestation, migration to other rural and urban areas for grazing and dependence on other means of living due to climate change. Increase in food production in this region is complimentary to more than 70 percent of the Sustainable Development Goals. This research is aimed at covering critical areas yet to be explored which is scanty in several literatures.

1.6. Scope and Limitations of Data Acquisition

In Nigeria the Land Survey Methods in relation to topographical survey of geospatial locations are quiet outdated especially with the use of cartographical maps on paper thus posing as a huge constraints in determining the spatial changes of the location. However with the use of remote sensing, data acquisition is up-to-date but there are also few constraints as it is requires a lot of technical knowledge and it is fairly expensive.

Meanwhile for meteorological data, despite data being stored and collected over the years by government agency in the country. Numerous consultation and documentation was conducted pending on its availability.

Literature on yield data of the region is quite scanty in several literatures as numerous studies conducted in the region focuses on certain municipalities which are affected by trends of food security and climate change. Requests and consultation was conducted on the access to the yield data of the region and future forecast was done based on the data to make it up-to-date.

2. Literature Review

2.1. Climate Change and Food Security in Nigeria

Nigeria is observed to be one of the major countries in sub-Sahara Africa affected by severe changes in climatic conditions (Ayinde 2010). A few studies reported that prevalent environmental disasters in some parts of the country have caused drastic decrease in food production and standards of living (Tarhule & Lamb 2003). Further studies have also evidently proven that extreme climatic conditions such as flooding, drought and desertification often affects negatively the level of food production (FAO 2021).

Moreover, the reason for food shortages and scarcity currently ravaging the country is basically as a result of unfavourable and unbearable climatic factors (FAO 2021). Persistent rainfall and flooding have increasingly affected mostly the northern parts of Nigeria and have caused it to be unproductive for arable farming and animal production by leading to crop damages, soil fertility and toxicity to mention a few (Wossen *et al.* 2018). This is the bane of the constant warnings by the World Bank and the Food and Agricultural Organization through their publications in Nigeria that climate changes will continue to pose serious dangers to sustainable food production in the country (World Bank Group 2015; FAO 2017).

Impoverished areas, particularly in northern Nigeria, are most likely vulnerable to the effects of climate change, particularly because they are situated in high-risk locations, since they have minimal coping capacity with high dependence on the natural environment, which is climate-sensitive, for their livelihoods (World Bank Group 2015). Human and environmental systems have the potential to cope with adversity, however adaptation is required to sustain this capability as climate change persists (Field *et al.* 2014). Certain system characteristics recognized as determinants of adaptation influence the propensity of systems to adjust to climate change impacts (IPCC 2022).

Sensitivity (the degree of effect or its responsiveness to climate stimulus in a system); vulnerability (the degree of vulnerability of a system to injury, damage, or harm); resilience (the degree of resistance and recovery of a system from a stimulus); and adaptive capacity (the degree of adaptability, potential and efficiency of a system to a stimuli). The process of adaptation is highly dependent on a system's, region, or community's ability to withstand the impacts and hazards associated with climate change (IPCC 2022). As a result, increasing adaptive capability minimizes a region's, community's, or household's susceptibility and supports sustainable development. Individuals, households, and communities' adaptive capacity to minimize risk, withstand and adapt to increased risk levels of climate change is mostly determined at the local or rural level by their livelihood assets, which include monetary, physical, natural, social, and labor force (Deressa *et al.* 2008a; Deressa *et al.* 2008b).

Adaptive capacity differs across countries, states, communities, households, social groups, and people, and over the years. It does not only differ in terms of its monetary value, but also in natural terms. Adaptive capacity scales are not independent or separate. The ability of a household to cope with climatic changes or risks is somewhat influenced by enabling environment of the community, and their adaptive capacity is an indicative of the region's resources and processes (Yohe & Tol 2002).

2.2. Elements of Climatic Factors

A. Temperature

Temperature is a physical quantity that detects the degree of hotness and coldness of certain objects and expresses it quantitatively using arbitrary scales such as the Celsius scale, the Fahrenheit scale, and the Kelvin scale (Quinn 1983). Temperature is measured using a physical object called thermometer. In addition to having a direct impact other climatic factors, temperature has a considerable impact on other climatic factors like humidity, precipitation, and atmospheric pressure (Seneviratne *et al.* 2012). Thus, the earth’s surface is largely influenced by the level of temperature, which in turn affects the earth’s yield. The warmer the earth, the less productive it becomes and the more susceptible it is to natural disasters such as floods, hurricanes, heat waves, and droughts (NRDC 2016).

B. Atmospheric Pressure

Atmospheric pressure or Air pressure is the weight the air carries and it presses against everything the air touches (National Geographic 2022). In more scientific terms, Atmospheric pressure is the force released on a surface by the air around it as the weight of gravity pulls it towards the earth (National Geographic 2022). Air pressure is measured by an object called the barometer which contains mercury in a columnar form placed within a glass tube and indicates the pressure in the atmosphere by rising or falling (National Geographic 2022). The higher the mercury indicates, the higher the pressure. As an important element in determining weather conditions, high atmospheric pressure is associated with visible skies and serene weather, while low atmospheric pressure is associated with high winds, cloudiness, and precipitation (National Geographic 2022). Thus, high air pressure is beneficial for agricultural production because it helps produce carbon dioxide faster in plants – a crucial ingredient needed for plant growth (Hatfield & Prueger 2015).

C. Humidity

The concentration of water vapor in the air is what is known as Humidity. Water vapor is water at its gaseous state and it is not visible to the human eye. The presence of humidity is usually associated with precipitation, fog, or dew. Furthermore, the level of air temperature also determines the effect of humidity on the weather. When the air is cooler, humidity is relatively high and vice-versa (Perry & Green 2007). According to Ford and Thorne (1974), in highly humid areas, mold and bacteria spread very quickly, hurting the growth of plants and killing crops. Several pests thrive in high levels of humidity and agricultural production suffers as a result. Therefore, it is accurate to conclude that areas with low levels of humidity are the best for growing crops and developing land . Of note, the object utilized in measuring humidity is called the hygrometer.

D. Precipitation

Precipitation is the degree of liquid or frozen water that forms in the air and falls back to the earth. It is a result of condensation of water vapor into big droplets of water that become too heavy to hold together and then falls to the earth (American

Meteorological Society 2009). The water could fall back to the earth in the form of rain, snow, ice and drizzle. In short, precipitation increases the moisture on the surface level of the earth by transferring water from the upper levels (Yunfei *et al.* 2020). Therefore, the more the precipitation, the wetter the earth. Enough rainfall is good for the soil but it must not be too little or too much (Robert and Ariel 2003).

2.3. Causes of Climatic Changes

Climate changes are the long-term modifications in temperatures and other weather patterns. These changes may be natural, but since the 1800s, human activities have been the main driver of climate change, primarily due to the burning of fossil fuels (like coal, oil and gas), which produces heat-trapping gases. Since the Industrial Revolution, human activities have significantly altered the atmospheric composition with regard to greenhouse gases like carbon dioxide and other ozone depleting substances which are factors contributing factors to climate change (National Academy of Sciences 2020). The earth's climate is influenced by both anthropogenic and non-anthropogenic activities, but the long-term pattern seen over the previous decades can only be explained by how human activities have an impact on the climate (CCSP 2008).

The United States Environmental Protection Agency indicated that greenhouse gas emissions and the reflectivity or absorption of solar energy are two ways in which human activities significantly contribute to climate change (EPA 2022a). These have happened through the following avenues:

1) **Use of Chemicals in Agricultural Production**

   In order to enhance food production, civilization and advancement in science and technology has allowed the use of chemicals such as fertilizers and pesticides to accelerate plant growth rate and protect plants from pests, mold, and parasites respectively. However, despite the advantages of chemicals, there’s overwhelming evidence that these pesticides and fertilizers could be doing more harm than good (Forget 1991). In particular, pesticides directly contribute to the deaths of over 1 million people every year by poisoning and contaminating plants (EPA 2022b). Also, pesticides could disrupt the quality of plants being grown, as studies suggest that plants grown in good conditions without the use of chemicals are more nutritious than the plants that have been protected by pesticides and other forms of chemical substances (Stamati *et al.* 2016). Therefore, there's an urgency in the agricultural industry to find more sustainable and ecological approaches to plant growth and protection without the use of chemicals.

2) **Use of Large Machinery in Agricultural Production**

Many research studies back the usage of machinery for agricultural production. It accelerates the rate of food production, harvesting, and distribution. However, recent research reports suggest that using heavy machinery on agricultural land can have negative effects (The Research Council of Norway 2011). The continuous passage of heavy-duty machines on arable land can have permanent damage on the land, increase land pollution and render the land ineffective for agricultural production (The Research Council of Norway 2011). In essence, these machines cause the soil to compact overtime by losing its air volume and increasing density, a situation that reduces the ability of the soil to put out excess water, thus making it poorly set up to produce quality crops (Shah *et al.* 2017).

3) **Deforestation**

Deforestation is the permanent clearing of trees from land in order to make the land available for other uses, mostly for industrialization purposes (Leblois *et al.* 2017). Farmers, crops, and animals suffer a great deal from the felling of trees, especially when it is accompanied by poor soil management. Forested land tends to be the most quality land for agricultural production but deforestation degrades the land and causes ecological imbalance (IPCC 2019). More so, deforestation also causes increase in greenhouse gas emissions which is harmful to the planet and contributes specifically to the acceleration of climate change. Other effects of deforestation include flooding, soil erosion, desertification, and fewer crop production (Lee *et al.* 2011).

4) **Construction**

The development of roads and buildings on rural lands previously being utilized for agricultural purposes could have positive and negative effects on the production of food and the state of the climate. In a study done in Anambra state, Nigeria in 1988, it was observed that the construction of roads improved agricultural production and commercial activities in the area due to the improved methods of transportation and distribution (Amadi 1988). However, it was also observed that the erection of commercial buildings affected the quality of the land and brought about land degradation (Amadi 1988). In essence, the land following the construction of roads and buildings were not as fertile as they were without the buildings and roads. Additionally, environments characterized by many buildings and roads contribute about 50% of the annual global carbon dioxide emissions (EPA 2022c). Of these emissions, operations that are particularly involved with buildings are responsible for over 27% every year, while the materials used in building account for over 20% of these emissions annually (EPA 2022c). Consequently, the constant operations of building and construction contributes heavily to the change in weather conditions and the state of the climate.

5) **Rural-Urban Migration**

Rural-Urban Migration involves the movement of people from rural areas to more urban, civilized areas for greener pastures and a significant improvement in lifestyle and standard of living. In a study carried out in Nigeria, it was discovered that households that were engaged in temporary migration from rural to urban had significantly reduced the volume and quality of food being produced in those areas. Though one of the major drivers of people migrating from rural to urban environments is the devastating effects of climate change in the rural areas, however, these forms of migration also contribute to climate change (Okon *et al.* 2021). More people in urban zones mean more usage of greenhouse gas-emitting equipment such as gas-powered vehicles, which in turn increases the release of carbon in the area, thus contributing to climate change (EPA 2022a).

2.4. Effects of Climatic Changes

2.4.1. Global Perspective

The most significant effect of climatic change is often expressed in the quality of food produced and its security (Kelechi et al. 2021). A study by (IPCC 2019) investigated how dwindling water supplies, rising temperatures, and rising carbon dioxide emissions affected food production. Their research, along with the majority of previous studies, found a strong connection between low crop production and shifting climatic conditions. The production phase of the food supply chain is the first to be impacted by climate change, according to the majority of scientific research. As a result, its impacts necessarily have an impact on every other component of a food supply chain.

Badjeck *et al.* (2010) stated that climate variability also has an impact on the supply chain of the fishery sector. They also stated that drought brought on by climate change has had a significant impact on the fishery industry, particularly in regions where fishing is dependent on natural water supplies.

2.4.2. Sub-Saharan Africa

In the semi-arid Sudan and arid Sahel Savannah region, climate change has brought about reduced rainfall, drought and increased desertification. In the Northern and Southern Guinea savannah belt, it has brought about changes in rainfall pattern, often late arrival of rainfall and longer dry season, places along the shorelines experience severe flooding during the rainy season (Tarhule & Lamb 2003). In a study conducted by Lotanna *et al.* 2022 in the Sub-Saharan region, it was stated that climate change which has brought about delays in rainfall onset, prolonged dry season, heat waves and flooding across the region thus posing a high risk to farming activities, also leading increasing water loss for crops.

2.4.3. Nigeria

Nigeria is listed as one of the sub-Saharan African countries that are vulnerable to changing climatic conditions (Ayinde 2010). Researchers such as Tarhule & Lamb (2003) have noted that recurring environmental disasters in parts of Nigeria have worsened food productivity and human suffering in the past decade. In 2012, severe flooding that has not been recorded in the country in the past four decades occurred in many parts of Nigeria leading to heavy losses in human lives, crops and livestock as well as human displacement (Nkechi *et al.* 2016). The changes in environmental conditions brought about by climate change affect the six vegetative zones of Nigeria differently (Ayinde 2010).

Studies have shown that extreme climatic conditions that manifest as desertification, high rainfall and flooding have very adverse consequences for food production (FAO 2017). Numerous scientific studies (Ayinde 2010; World Bank Group 2015; FAO 2017) have also concluded that the climatic impulses that are brought about by climate change have adverse effect on agricultural productivity in Nigeria leading to lowered productive outputs. These scenarios have led to shortage in food supply which has brought about hiking food prices

The age of food insecurity is consistently escalating across Nigeria due to climatic factors which have limited agricultural productivity. Climate change induced alterations such as droughts, heavy precipitation, flooding of farmlands, rising temperature, changes in relative humidity, increase evaporation, among others have adverse effect on agricultural productivity and food systems in Nigeria (Kelechi et al. 2021). Climate change was reported to be an everyday reality in Nigeria due to intensive population growth thus resulting to a high frequency of environmental issues such as floods, droughts, rising temperature and extreme weather events which disrupt agricultural productive activities (Adelekan 2010). Mangodo *et al.* (2016) used time series data from 1975 to 2010 to explore the short- and long-term relationships between some meteorological factors, such as rainfall, temperature, and relative humidity, and agricultural output in Nigeria. According to their research, both short- and long-term climate data are connected to food production. Their findings are consistent with those of a few other researchers who conducted related research. The threat that climate change poses to agricultural productivity is one of the key reasons it has continued to be a global issue. The typical agricultural production pattern in Nigeria is gradually changing as a result of the higher and more variable temperatures and rainfall patterns that have been observed in Nigeria over the past ten years (Tarhule & Lamb 2003; Wossen *et al.* 2018).

Some researchers have also extrapolated future climate scenarios using modelling techniques in an effort to provide policymakers with sound advice on how to avoid the effects of climate change in the future (Wossen *et al.* 2018).

2.4.4. Northern Nigeria

According to a research study carried out in Northern Nigeria in 2019, cereal crops such as rice, maize and sorghum are severely affected by the changing climate and unpredictable weather conditions. It was observed that the variability in rainfall and inconsistent climate has affected the flowering and fruiting times of these crops . Also, there has notably been flowering abortions and low crop yield as a result of the effects of climate change (Tajudeen *et al.* 2022). Additionally, a study in 2014 concluded that the climate change in Northern Nigeria has a significant effect on the net revenue generated from maize production in the area (Ibrahim et al. 2014). The study showed that as precipitation levels varied in the northern belt of the Nigeria metropolis, the production and quality of maize fluctuated in the area and as a result the income for maize farmers were severely disrupted (Ibrahim et al. 2014). Therefore, the effects of climate change especially on cereal crops in Northern Nigeria cannot be underestimated, and measures should be put in place to properly manage the situation.

2.5. Methods of Measuring Climatic Changes

i. Meteorological indications are deemed necessarily, either conjoined or dependent, regionally or worldwide for records in arithmetic weather models which is then used for hydrological and agricultural purposes, serving as visible indicators for climatic differences (Shako 2015). For further comprehension on the variability in local, national, and regional climate these climatic variations are observed.

ii. To further evaluate the impact of these climatic variables in relation to societal factors.

iii. To further project strategies on adaptation and to eliminate current and rising effects of climate change.

The following are some of the major indicators of climate change:

- **Sea-Level Rise:** This refers to increasing levels of the world's oceans primarily due to the effects of global warming. The higher the rate of Sea Level rise, the more the climate change and the more the threat is to agricultural production. In more coastal areas with rising sea levels, there may be complete loss of agricultural land (EPA 2022a).
- **Surface Temperature:** Global Warming is specifically the increase in surface land and sea temperature levels. When the earth heats up, it's usually as a result of the increase in greenhouse gas emissions due to the increasing activities of humans. Rising Land and Sea temperature affects the vegetation of the ecosystem, which in turn severely disrupts agricultural production (CCSP 2008).
- **Atmospheric Carbon dioxide:** The level of concentration of carbon dioxide in the air is a hugely significant indicator of climate change. The higher the atmospheric carbon dioxide, the higher the earth's global temperature and vice-versa (Warrick 1988). On the other hand, moderate increase in atmospheric carbon dioxide boosts crop growth by allowing for more photosynthesis and it helps reduce the degree of water that is lost during transpiration (Warrick 1988). However, too much carbon dioxide will have negative effects on the nutrient concentration in plants (Warrick 1988).
- **Ocean Acidification:** An increase in the level of atmospheric carbon dioxide results in the increase in the pH value of the earth's oceans, which is what is known as Ocean Acidification (Godbold & Calosi 2013). The higher the ocean acidification, the lesser it can absorb carbon dioxide, thereby leading to the earth becoming warmer (Godbold & Calosi 2013). As the

earth warms up, the quality of land degrades and quality of agricultural produce is hampered.

- **Increasing Humidity:** The higher the humidity, the more the rainfall. Rainfall is essential in the growth of plants and production of food. However, when areas are too humid, it allows for the emergence of harmful bacteria, pests and mold that may hamper plant growth (Grankem & Hausbeck 2010).

According to the World Meteorological Organization the convention in Geneva earlier in 2022, increased concentration of greenhouse gas, rise in sea level, warming of the ocean and ocean acidification are signs of climate change around the globe. These signs illustrates how anthropogenic activities are altering the atmosphere, ocean, and land ecosystems negatively and permanently to a downward spiral (WMO 2021).

2.6. Effects of Heat Stress and Precipitation on the Growth and Cultivation of Cereals and Grains (Rice, Maize and Sorghum).

As previously established, environmental temperature level is an important element in the growth and cultivation of cereals and grains. The effects of temperature on a variety of plant processes, including seed germination, growth, respiration, photosynthesis, transpiration, dry matter partitioning, and grain maturity, are significant (Yiping *et al*. 2013). Therefore, temperatures play a key role in regulating how quickly plants grow. However, there can be irregular bursts in level of temperature that can negatively affect crop yield tremendously. These conditions where temperature temporarily rises to unhelpful levels is called **Heat Stress.**

Heat Stress have a devastating impact on the productivity of cereal and grain crops. In high temperature levels, crops like maize and rice suffer disruptions to their organizational levels leading to inconsistent responses in physiology, gene expression, morphology, and biochemistry (Wahid *et al.* 2007). As a result, at vegetative stage, the crops stunt in growth, their leaves shed chlorophyll, and they begin to experience tip necrosis and senescence. At reproductive stage, it gets worse, with the flower and buds abscising, leading to a reduction in pod set which ultimately decreases seed yield (Giaveno & Ferrero 2003). Other effects of heat stress include protein denaturation, protein degradation, inactivation of enzymes in chloroplasts and mitochondria, loss of membrane integrity, and inhibition of protein synthesis (Cheng-hsiang & Jei 2016).

In determining the impact of heat stress on crop yield across the world, agronomists, scientists, and environmentalists have employed different methods of which many have been unsuccessful. A particular approach that has found considerable success across multiple research studies is simulating crop growth using what is popularly termed as "crop growth model" (Keating *et al.* 2003). Crop growth model is a simulation methodology for the growth and development of a crop using relevant plant parameters in specific environmental conditions. Previously, these crop growth models have been utilized in assisting plant breeding, especially of sole crops (Rötter *et al.* 2015). However, despite the rapid success, creating and using crop models to simulate heat stress remains a difficult task, especially when applied at wider spatial scales. In contrast to multiple applications of crop growth models at single crop growth areas, there has not been many applications in areas where intercrop growth is being practiced as a result of its poor success rate (Chimonyo *et al.* 2015). These limitations on a wider front have suggested that data gathered from experiments with crop growth models may not be as reliable as it was once thought it was.

Many regions of the world are predicted to experience increased climate variability, which will lead to higher mean temperatures and more frequent extreme high temperature events. Short bursts of high temperature around blooming (heat stress) can have significant detrimental effects on cereal grain yields, according to increasing amounts of empirical research. Although the necessity to consider the impacts of heat stress has only recently been acknowledged, crop models still remain the greatest instruments available to study how crops will grow under future climatic circumstances (Rezaei *et al.* 2015). A little variation in temperature can have an impact on the rate of plant growth and development since growth mechanisms in plants typically require a specific range of temperatures. The rate of primary and secondary metabolism is one of the routes that is altered by heat stress in plants. Plants increase their defensive mechanisms in response to main and secondary metabolite dysfunction.

The ability for plants to tolerate, prevent, and/or escape heat stress damage during flowering is provided by a variety of mechanisms. A successful technique for plants to adapt to higher and combined heat and drought stress conditions is to maintain a cooler canopy through enhanced transpiration (Hua *et al.* 2017; Lawas *et al.* 2018). Heat stress during flowering has differing effects on the survival of male and female reproductive organs, thus lowering field crop yields. In order to minimize heat stress damage during flowering, dry land cereals, unlike flooded rice, have optimized their flower opening during cooler early morning or late evening hours. Recent research has shown that sorghum and pearl millet pistils are equally vulnerable to heat stress, contrary to earlier studies' results that pollen viability influences seed set under heat stress. Under current and future harsher climate circumstances, heat stress-induced damage during blooming will be prevented by integrating flower opening time during cooler hours with higher pollen and pistil viability (Jagadish 2020).

2.6.1. Rice (*Oryza sativa*)

2.6.1.1. Effect of Heat Stress on Rice Growth in World Agricultural Production

Rice is a staple food crop consumed annually by over half of the world's population. Rice cultivation has been reported to occupy about 167 million hectares in land mass and production capacity reached 782 million tonnes in 2018. In West Africa, rice is the mostly cultivated staple crop by 10–15 million people in various communities across the country. Rice is also grown today as a commercial crop in Ghana and Nigeria (Georges 1998). In Nigeria, rice production is critical in national food security and also in the generation of income and provision of employment. However, the rice production industry in Nigeria has found it very difficult to meet the demands of the market in recent times. One of the reasons for this is the climate variation challenges such as heat stress and inconsistent precipitation levels that the rice-producing regions in the nation faces.

Rice yield and quality are often reduced by increased heat stress (Xu *et al.* 2021). It is estimated that for every 1℃ increase in global mean temperature, rice yields will decrease by 3.2% (Shuai *et al.* 2016). Studies in 2013 indicated that 1℃ increase in average temperature during rice cultivation reduced paddy rice by 6.2% (Lyman *et al.* 2013). Further research in Southern Asia, East Asia, and Southwest Asia have also shown that heat stress events in such areas have had huge negative effects on the production of rice (Kurogochi *et al.* 1979; Wassmann *et al.* 2009). As a result of constant exposure to heat stress in such regions including Northern Nigeria, the cultivation of cereals like rice are under serious threat as global warming intensifies and there's continuous variability in climate operations (Tebaldi *et al.* 2006).

Although, the optimum growth temperature of rice at the seedling stage is 25 – 28° C (Liu *et al.* 2016; 2018), heat stress at 42 – 45° C during the seedling stage may increase moisture depletion, withered leaves, impaired seedling and root growth and even death of the plant. Physiological effects of heat stress may cause heat damage, reactive oxygen. Specie accumulation, photosynthesis damage, disturbance of carbohydrate metabolism and partitioning, and phyto-hormone imbalance (Xu *et al.* 2021).

Given the economic importance of rice in world food security and the adverse consequence of global warming on rice production, the questions on how to breed heat resistant rice gain more importance in rice growth discussions day by day. However, rice plant resistant to heat stress at the seedling stage varies with genetic backgrounds according to various research (Ezin *et al.* 2022). With these variations noted, reliance cannot be placed on breeding heat-resistant rice only, instead, more efforts should be channelled towards limiting the impact of heat stress on rice or avoiding heat stress entirely

2.6.1.2. Effect of Heat Stress on Rice Growth in Sub-Saharan Africa

Most rice grown in Sub-Saharan Africa are rain-fed, therefore high temperature levels have tremendous negative effects on rice cultivation and growth. In 2018, a study carried out on effects of high temperature levels on rice growth in Sub-Saharan Africa showed that in dry season rice yield decreased by about 45% (Van Oort & Zwart 2018). The study concluded that the decline was as a result of the disruption of the hypothesis process as a result of extreme increases in level of temperature (Van Oort & Zwart 2018).

2.6.1.3. Effect of Heat Stress on Rice Growth in Nigeria

The growth of rice seedlings become stagnated in environments with high levels of temperature. In a 2014 study on rice growth in Nigeria and other countries, it was discovered that rice plantlets exposed to high levels of temperature at about had a significant decrease in growth, quality and yield thus demonstrating the difficulty in growing rice in the presence of heat stress in Nigeria (Iloh *et al.* 2018).

2.6.1.4. Effect of Precipitation on Rice yield

Nigerian rice production is mainly rain-fed and naturally prone to varying amounts of rainfall (Tiamiyu *et al.* 2015). A 22-year study carried out in Nigeria between 1992 and 2013 showed the prevalence of rainfall variability in areas where rice is cultivated in Nigeria. Although, there was no statistical significance of rainfall variability on rice cultivation during the period of study, it however showed adverse effects of inconsistent precipitation levels on the yields of rice in the Sudan Savannah which could be a warning signal to rice farmers and stakeholders to take precautionary measures in order to mitigate against unfavourable adverse effects on rain variability on rice yields (Tiamiyu *et al.* 2015).

In a research conducted between the year 2000 – 2015 in North East Thailand, effects of rainfall variability was examined on the duration of rice growing period and grain yield (Sujariya *et al.* 2020). The variability in rainfall between the years investigated showed that delayed planting time was necessary and optimum for achieving maximum rice yield as there was a general delay in rainfall season. Late season drought occurrence was significantly reduced which consequently also increased grain yield (Sujariya *et al.* 2020).

Another more recent study was conducted in Bangladesh by (Sachul *et al.* 2017) which concluded that rice production especially rain-fed rice was at risk of yield decline due to frequent drought. The study showed that the extreme variability in precipitation levels in rice-dominated production regions is a major threat to the continuity of rice cultivation in the world today. Therefore, recommendations were made that stress tolerant varieties requiring less irrigation water should be introduced.

2.6.2. Maize (*Zea mays*)

2.6.2.1. Effect of Heat Stress on Maize Growth in Global Agricultural Production

Maize, a top-ranking cereal food also known as corn and is an important component of human foods, animal feed and biofuel for industries (Shiferaw *et al.* 2011). It provides approximately 19.5% of global calorie intake from all sources (Watto *et al.* 2014). In 2022, the total world production of milled rice is approximately 503 million metric tonnes (Statistica 2023).

Although, maize is an essential economic crop, temperature extremes during the growth period may be threatening the yield sustainability of maize. Maize plants are documented to be highly sensitive to heat stress greater than 30° C and there may be a strong decline in plant yield over time as the plant faces heat stress for a prolonged duration (Schauberger *et al.* 2017). Maize plant grows best at a temperature of 25 – 28° C (Farooq *et al.* 2018), a swing from the optimal temperature thereby causing heat stress may dramatically decrease the growth rate and grain yield by a decline in seed setting ratio and also the altering and disturbance of several other physiological process. However, low temperatures negatively affects gaseous exchange, water use efficiency, morphology and physiology of maize (Waqas *et al.* 2017). Therefore, farmers are encouraged to sow maize early to escape heat stress at the reproductive stage.

2.6.2.2. Effect of Heat Stress on Maize Growth in Sub-Saharan Africa

Generally, maize seeds are severely affected by increasing temperature levels in Sub-Saharan Africa. Maize is a brand of cereal crop that grows best at a temperature of 25 – 28º C (Farooq *et al.* 2018), so high temperature levels definitely harm its production. In a study conducted on this topic in the Sub-Saharan Africa in 2022, the researcher concluded from findings that increased temperature negatively impact maize seed germination, pollination, seed formation, plant growth, fertilization, gamete formation, and seed filling (Baskin 2022). In another study in 2021, results showed that in the Sub-Saharan region, heat stress has a depressive effect on the growth and production of maize (Chukwudi *et al.* 2021). The study further discovered that heat stress reduces the chlorophyll content of the maize leaf and also stiffens the leaf area, plant height, and stem diameter (Chukwudi *et al.* 2021).

2.6.2.3. Effect of Heat Stress on Maize Growth in Nigeria

In Nigeria, maize production is also significantly affected by heat stress as evidenced in several studies across the topic in the nation. A particular study in 2021 showed that heat stress reduce the maize cob weight by 64%, grain weight by 73%, grain number by 69%, and stover FM dry weight by 23% (Chukwudi *et al.* 2021). All these effects severely hamper the growth and production of maize plants in the Nigerian hemisphere.

2.6.2.4. Effect of Precipitation on Maize yield

According to (Tajudeen *et al.* 2022) several reports illustrate that increasing droughts and extreme rainfall are major threats to maize production in Africa. A recent study recently conducted by (Tajudeen *et al.* 2022) on the effect of rainfall variability on maize production in Lagos State, Nigeria which looked into rainfall data and maize yield spanning across a decade from 1998 – 2018 showed that an increase in rainfall impacted positively on maize yield.

2.6.3. Sorghum (*Sorghum* bicolor)

2.6.3.1. Effects of Heat Stress on Sorghum Growth in Global Agricultural Production

In the semi-arid tropics, where droughts frequently result in the failure of other crops, sorghum (Sorghum bicolor (L.) Moench) provides a staple food for the poor. With nearly 70% of the world's total cereal production, West Africa is where it is most significant (Axtell *et al.* 1998). Sorghum is grown on 45 million of the 700 million acres of cereal-planting land in the globe, 80% of which are in poor nations (Dendy 1995).

Sorghum is an essential component of World's food security since it is the only cereal that can tolerate prolonged droughts and hot temperatures (Virmani 1984). Sorghum performs best at an air temperature range of 26 to 34°C during the vegetative phase and 25 to 28 degrees Celsius during the reproductive phase. When the temperature rises above a threshold of 32°C, the yield of the plant decreases (Prasad *et al.* 2006, 2008, 2017).

2.6.3.2. Effects of Heat Stress on Sorghum Growth in Sub-Saharan Africa

Considered a staple crop in Sub-Saharan Africa, sorghum growth is severely hampered in high temperature levels. In a study done in Burkina Faso, it was shown that sorghum plants grown in higher temperature periods (March, 41.1/23.9°C) performed poorly compared to sorghum seeds grown in lower temperature periods (July, 31.08/21.8 °C). The plants grown in March yielded 46.36% lesser than the plants grown in July (Okae-Anti *et al.* 2018). The same study compared the plants grown in March to plants grown in October at an even lower temperature of 31.08/21.8 °C and the March sorghum plants yielded 68.26% lesser than the October plants (Okae-Anti *et al.* 2018).

2.6.3.3. Effects of Heat Stress on Sorghum Growth in Nigeria and Northern Nigeria

A 2017 study on the effects of heat stress on Sorghum plant growth in Northern Nigeria showed numerous negative effects (Jerome et al. 2019). In the research, some sorghum plants were exposed to high temperature stress (>36-38°C) at their flowering stage for ten to fifteen days. Following the experiment, the sorghum plants experienced heavy reductions in pollen germination, some plants' flowering stage was aborted, and most of the seeds failed to fertilize (Jerome et al. 2019). The study concluded that sorghum will fail to produce effectively in high temperature situations and innovative methods must be sought to grow sorghum plants in increasing temperature areas in Northern Nigeria.

2.6.3.4. Precipitation and Sorghum growth

The best growing conditions for sorghum are in regions with an average annual rainfall of 45 to 65 cm (17 to 25 inches) (Agropedia 2009). Rainwater harvesting practices and its impact on sorghum yield was studied in Zimbabwe and it was discovered that there was significant grain yield response compared to the conventional practice using the weighed mean yield difference approach (Kubiku *et al.* 2022).

2.7. Agriculture and Livelihood in Nigeria

Land preparation starts within the month of April or May whereby when the farmers clear and stump the land. Pastures that have been uncultivated by livestock are sometimes cleared by burning. The majority of planting starts in June or July, the start of the rainy season, while some farmers may dry-plant prior to the rains. Bean harvest follows millet harvest in September. Sorghum is harvested in late October or early November. Importantly, over 70 percent of the Nigerian population work in the agriculture sector, mostly for subsistence, and more to note, between January and March 2021, agriculture accounted for 22.35 percent of the nation's total Gross Domestic Product (FAO 2023).

Nigeria's agricultural sector, despite its economic significance, confronts numerous obstacles that have an impact on its output. These include a bad system of land tenure, insufficient irrigation for agricultural, climate change, and land degradation. Others include a lack of technology, high production costs, uneven input distribution, restricted funding, significant post-harvest losses, and difficult market access (FAO 2022).

These difficulties have reduced agricultural production, thus diminishing the sector's contribution to the nation's GDP and resulting to increase in food importation due to population growth, leading to inadequate level of food sufficiency. For example, between the year 2016 and 2019 Nigeria's total agricultural imports was N3.35 trillion, which is four times the country's total agricultural export of N803 billion in the same period (FAO 2023).

In order to solve the issue, the government has established a number of initiatives and programs, including the Nigeria-Africa Trade and Investment Promotion Programme, the Presidential Economic Diversification Initiative, Economic and Export Promotion Incentives and the Zero Reject Initiative, Reducing Emission from Deforestation and Forest Degradation (REDD+); Nigeria Erosion and Watershed Management Project (NEWMAP); Action Against Desertification (AAD) Programme, among others. All of these initiatives are geared towards increasing agricultural productivity in order to meet domestic food demand while also producing a large number of commodity crops for export on the global market. Furthermore, they seek to reverse forest loss and degradation, support sustainable resource management, restore degraded areas, and lessen erosion and climate vulnerability. Nigeria is blessed with a vast land area of 70.8 million hectares for agricultural production, with maize, cassava, guinea corn, yam beans, millet, and rice being the main cultivated crops. Despite this, only 57 percent of the 6.7 million metric tons Nigeria’s annual consumption of rice is produced locally, leaving a margin of around 3 million metric tons which is either imported or smuggled into the country. In order to boost domestic production, the government prohibited rice imports in 2019 (FAO 2022).

It is impossible to overstate the importance of forestry to agriculture and prosperity in general. According to an assessment by FAO (2018) , Nigeria's forest ecosystems are threatened by rapid economic expansion and population growth, with an annual deforestation rate that ranges between 0.72 and 2.38 percent. Among the causes of this trend include increased grazing, increased reliance on firewood and charcoal for energy, unsustainable timber extraction, urbanization, infrastructure development, and agricultural growth.

Increased agricultural production through the use of new technology and innovations is required to provide food security and nutrition due to the growing population, which is projected to reach 400 million by 2050. It is crucial for accomplishing these goals that all partners support the work of the federal and state governments.

2.8. Combative Approach for Land-use changes, Climate change for Agriculture

2.8.1. Land Use Change

“Land use” and “land cover” are segregated conceptual frameworks which interchangeably designates the multifaceted interrelations of humans and their physical environment (Shahfahad et al. 2022). Land cover can be defined as the physical characteristics of the Earth’s surfaces, while land use illustrates the extent of anthropogenic activities on land cover (Anila & Haroon 2017). The increasing impact of land use/land cover (LULC) has recently become a cumbersome discussion over the years due to progressed urbanization of most urban centres and cities (Koko et al. 2021b). The exacerbation of interaction with relation to human activities has increased the pressure over the previous decades considering the limited land resources. The consequential impact of these rapid development has a hand in the challenges encountered on the local, regional and global environment in this century due to the tremendous alteration of land uses (Sajjad et al. 2022). All these factors have led to environmental issues relating to, loss of soil fertility and habitats, desertification, environmental pollution, alteration of climatic and hydrological cycles (Tadese et al. 2021).

The level of desertification in the Sahelian region of Nigeria is a massive enabler to the extreme poverty stereotype on a global scale with desertification accounting for 580, 841 km^2 loss of Nigeria’s landmass (Tiffen & Mortimore 2002), rationalizing for almost 63.8% of the country’s landmass. Almost 30 million people (17% of the national population, and 15 out of 36 States of the Nigerian Federation) are victims of the increasing desertification in Nigeria (Nigerian Tribune 2021). The Sahelian-Saharan region of the Niger Republic, one of the world's most fragile ecosystems, is bordered with the impacted states. (UNHCR 2022). In Nigeria, the effects of desertification are moving southward at a rate of 0.6 km annually, destroying around 351,000 ha of agriculture and rangeland every year. (Ibrahim et al. 2022). This has produced negative impact socioeconomically and ecologically in numerous ways ranging from increased human migrations, high level of erosion, alteration of geochemical composition of soils, surface and groundwater depletion, loss of biodiversity and species extinction, diminishing agricultural yields, increased unemployment and rural poverty rates, in addition to rise in social vices and civil conflicts [e.g., kidnapping, armed robbery, religious extremism, insurgency, land/territory grabbing, etc.,] (Apata et al. 2011).

Despite numerous international, national, and local initiatives and policies aimed at reducing desertification in Nigeria, its negative impact are still limitless, thus posing a serious threat to the states that are most severely impacted in achieving food security and other important sustainable development goals. The impacted regions are the most fertile regions which the prospect of producing the largest amounts of crops and livestock (Lal 2012). Despite the widespread effects of desertification globally, literatures on assessing, monitoring, and predicting its progression and impacts with precision is scanty. For solution and strategies to combat aridity, timely and precise monitoring and detection of degradation processes is required (Ahmad et al. 2022). Thus, there is need for appropriate geo-management of land and the concomitant availability of a detailed, accurate and up-to-date geo-information. Understanding the dynamics of forest loss is vital for planning and biodiversity protection (Gomez et al. 2011).

Insights into patterns, rates, and trends of landscape changes are vital to realize forest dynamics, enable preservation, and assess the effectiveness of management approaches (Rahman & Saha 2009; Gomez et al. 2011). Land cover changes can be as a result of anthropogenic activities, i.e. climatic variability and natural disturbances (Bartholome 2007). Previous approaches have demonstrated the effectiveness of using coarse spatial resolution remote sensing imagery to evaluate tropical forest over large areas. Remotely sensed data over the past four decades has gradually become a thing of value to source information on ecological characterization and survey. This is a result of the effective use of air-borne and space-borne remote sensing platforms and sensors that facilitate observation of biophysical attributes over massive landscapes at multiple spatial, spectral and temporal scales (Aplin 2005).

LULC changes has profound importance in achieving sustainable urban development as well as efficient land allocation purpose. Landsat satellites have been widely used to assess the spatiotemporal land use/land cover information in numerous environmental research of local and regional scales due to its free cost and historical archive of providing uninterrupted global data (Alam et al. 2020; Abdulla et al. 2021). Land cover and land use changes are main indicators of global change through their interactions with climate, ecological processes, biogeochemical cycles, biodiversity and human activities (IGBP 2009). Change detection is a theoretical framework that observes and identifies contrasts or discrepancies in the state of a phenomenon at different timeframe (Gallego 2004). Change detection studies are core factors in identifying the biotic and abiotic components of the spectral and temporal changes that are occurring within ecosystems (Fox & Emsell 2004). Macleod and Congation (1998) listed four key features of change detection which are vital when monitoring natural resources: i. Sensing the changes over time ii. Identifying the situation of transformation iii. Surveying the scale of the change iv. Analyzing the spatiotemporal changes.

The processing of LULC change dynamics is mostly accessed through the Landsat multi-temporal and multi-spectral satellite data (Namugize et al. 2018). These data provide the images required to determine the distribution pattern of land uses in a study area (Hussain et al. 2020). Landsat sensors are widely used to utilize change detection including the Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI), and Multi-spectral Scanner (MSS) (Koko et al. 2021b). Land use change detection measurably analyzes the LULC class characteristics based on the previous decades by visualizing the properties inherent in the satellite images (Gaurav & Peter 2018). A geographic information system (GIS) provides an accurate and relevant environment for amassing, storing, visualizing, and analyzing satellite images required to detect land use changes (Khan et al. 2016; Sajjad et al. 2019). In order to analyze spatiotemporal LULC data on the state of the natural and built environment, satellite data and advanced GIS techniques have recently been available as affordable tools (Mondal et al. 2015).

2.8.2. Kaduna, Northern Nigeria: Land Use Changes Impact on Climate Change

2.8.2.1. Global Perspective

The climatic conditions of urban environments around the world have been substantially influenced by changes in Land Use–a result of the recent fleeting increase in the global rate of urbanization (Parnell & Walawege 2011). The astonishing expansion and growth experienced in urban areas, particularly in developed and developing countries, has had tremendous impact on Land use, causing unwanted modifications in local climatic conditions, development of urban heat islands, and huge reductions in biodiversity (Jiang & Tian 2010). These developments have attracted widespread global concern majorly because they have led to rapid increases in energy consumption, harmful air consumption, complicated water sources, and severely affected human health due to increased Land Surface Temperature in urban centers that has resulted in high levels of heat stress unconducive for humans (Grimm *et al.* 2008; Li & Bou-Zeid 2013). Furthermore, Land Use changes have led to other environmental consequences such as greenhouse gas emissions increase and disruptions of ecological cycles that have contributed to climate change (Coutts 2010). Therefore, the recent transformation of the urban climate can evidently be attributed to urban expansion, population growth and utilization of Land for modern, civilized purposes.

Over the last few decades, urban areas have globally become increasingly populated. Urban population sat at 30% in 1950, but according to statistics in 2018, 55% of the entire world population is urban (World Bank 2022). In fact, estimations from the United Nations suggest that by 2050, the urban population will be above 68%, with much of that increase expected in developing regions like Africa and Asia. These geographical areas, as a result of the growth in urban population, could experience increases in Land Surface Temperature, thereby prompting the emergence of Urban Heat Islands – urban areas significantly warmer than neighbouring rural areas due to human activities (Koko *et al.* 2021b). The development of these urban heat islands is further attributed to the rapid urbanization of cities and changes in the usage of land (Karakuş 2019). Formerly Vegetative lands are being transitioned into impermeable surfaces home to roads, building, and other infrastructures. Toxic, anthropogenic heat are being generated from automobiles, industrial buildings, and other heating and cooling materials. These trends have played a significant role in the development of Urban Heating Islands' effects, and thus, have contributed to disruption of urban environment and quality of life (Luo *et al.* 2020). Therefore, research studies investigating the impact of Land Use Changes on climate change in developing regions like Africa has become more imperative, with growing demands for innovations on climatic management and sustainable urban development especially in rapidly growing cities such as Kaduna in Northern Nigeria.

2.8.2.2. Kaduna

In Northern Nigeria, changes in the landscape have been observed as a result of the growing rate of diversification of human activities and rapid increase in population (Koko et al. 2021b). The population growth has given way to the emergence of new, commercial activities which has forced transitions of formerly agriculture-focused lands to be basis of roads and buildings that foster commercial and industrial activities. Between 1993 and 1997, residential land use in Kaduna experienced a remarkable increase due to the population growth and growing rate of urbanization (Koko et al. 2021b). Furthermore, Land Cover in Kaduna has been subject to considerable change as a result of urbanization, thus increasing Land Surface Temperature and affecting local climate conditions severely (Koko et al. 2021b). The heat stress suffered by this region has also brought about significant disruptions to the quality of natural resources like water bodies and peripheral arable land, thereby posing a huge threat to the sustainability of the environment.

A research study on a Forest Reserve in Kaduna showed significant reductions in Vegetative Land Cover and concerning changes in Land Use (Aliyu 2020). The paper concluded that the changes in Land use observed within the stated timeframe could be attributed in part to the rapid urban expansion witnessed in the region, that has brought about encroachment of rather arable land within and around the forest (Aliyu 2020). Of note, this has been primarily motivated by the state's desire to meet the growing needs and demands of its growing population.

Another study conducted by (Saleh *et al.* 2014), on Land Use change in Kaduna metropolis showed that between 1980 and 2012, the region's agricultural land use was significantly reduced and other land uses such as water body, open space, vegetation, and rock outcrop were also negatively impacted. This disruption to Land Use has had a tremendous impact on the livelihood of small-scale farmers in urban areas as a result of the depletion of agricultural land which were sources of income for the farmers. Also, high levels of food insecurity have been recorded and significant reduction in urban food supply has been observed. According to the study, these changes were brought about by rapid population growth, politico-administrative changes, urban expansion, socio-economic factors, environmental variables and other natural factors.

2.8.2.3. GIS and Remote Sensing Application in Agriculture

For the purpose of performing crop surveys and mapping, vital technologies include remote sensing (RS) and geographic information systems (GIS). This creates opportunity for the identification of crops as well as regions undergoing changes in cropping patterns (Mahlayeye *et al.* 2022). It is essential for the government of a country in which agriculture is the primary industry to have access to up-to-date and accurate information on the types of crops planted, the area under cultivation, and the anticipated yield. The spectral data is an essential part of the remote sensing data used for crop modelling, and it has a tight connection to the canopy characteristics, which are markers of the crop's state of health and the stage it has reached in its growth. Agribusinesses like seed and fertilizer companies can benefit from crop-specific maps, which are produced by integrating satellite images, survey data, and information on the layout of the land and its owners. Crop-specific maps are produced by integrating satellite images, survey data, and information on the ownership of the land (farmers). When it comes to accumulating information on a variety of crops, the study of remote sensing can be of great use. Numerous experiments that made use of aerial photography and other digital image processing techniques have been detailed in the published research. It contributes to a reduction in the amount of field data that must be acquired, which in turn serves to raise the accuracy of the estimate (Kingra, *et al*. 2016).

2.8.2.4. Agro-meteorological application

Agriculture is significantly impacted by both the climate and the weather. The meteorological data is collected by using several different point station observation networks spread over space. Conventional agro-meteorological methods are severely limited in their capacity to utilise their data for predicting yields and performing agricultural monitoring in real time. Satellite metrology has made it possible to conduct precise and frequent measurements of a number of fundamental agrometeorological characteristics (example surface albedo, surface temperature, evapotranspiration, solar radiation, rain fall). Significant rainfall at biweekly intervals, minimum and maximum temperatures, and other agrometeorology inputs would make up the bulk of those that would be included in the correlation weighted regression model. Tracking the Earth's flora, weather, and climate during the last 25 years has seen a number of significant advancements, the single most significant of which is the use of geostationary satellites for the purposes of remote sensing of weather and climate. These satellites collect data on the temperatures of the water and the plants on land. The data on the vegetation and the information on the weather are two of the most important inputs for the field of agricultural meteorology. There are two primary categories of meteorological satellites that are currently operational (European Commission 2003). The first is a polar orbiting satellite that is located in a low Earth orbit of 750 kilometres, and the second is the Geosynchronous Meteorological Satellite (GMS), which circles at an altitude of around 36,000 kilometres. Both of these satellites monitor the weather on Earth (National Weather Service 2023).

2.8.2.5. The Significance of the Green Wall Project

The Great Green Wall for the Sahara and the Sahel Program is Africa's flagship initiative to help more than 20 countries in the Sahara region establish wealth and resilience. It was established to battle climate change and desertification, as well as food insecurity and poverty. The initiative was accredited by the African Union in 2007 as a game-changer in Africa's drylands with the intent to improve the lives of millions of people across North Africa, the Sahel, and the Horn of Africa by building 15 km wide mosaic of trees, grasslands, flora and fauna across the continent to rehabilitate damaged lands and enable the region's population to produce enough food, generate employment, and improve tourism, According to the United Nations Convention to Combat

Desertification (UNCCD 2020). The Great Green Wall core area encompasses 780 million hectares in arid and semiarid zones encircling the Sahara, with an estimated 21 percent in need of restoration (Berrahmouni *et al.* 2016).

Currently, the Great Green Wall for the Sahara and Sahel Initiative in Nigeria is in the works at the national level. The Great Green Wall project is a recent regional effort in Africa to focus on desertification in a more coordinated manner. The program was conceived as a conceptual project, with the goal of constructing a 15-kilometer-wide, 7,775-kilometer-long tree wall stretching from Dakar to Djibouti, passing through 11 northern African countries and eleven frontline Nigerian states. The Green Wall Sahara Nigeria Programme is geographically situated in Nigeria's dry area, between 11o 00'N and 13o 40', and 3o 30'E and 14o 40', and is bordered by the West African tropics. Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, Bauchi, Yobe, Borno, Adamawa, and Gombe are the current states (11 Frontline States of the North). They receive inadequate rainfall annually due to their latitudinal and geographical settings, sometimes as little as 250mm, whilst certain southern states receive up to 3500mm. The vegetation in the location is predictably a result of a ground reduction of mangrove and rain forest from the south. As expected, the soil lacks rich soil nutrition of the rain forest due to the minimal afforestation. The vegetation view is grassland with bushes strewn about. This makes it difficult for the ecology to endure the dual threats of drought and desert expansion, which result in siltation of surface waterways, soil fuel infertility, wood extraction for construction, bush burning, grazing, and marginal land agriculture (Federal Government of Nigeria 2012).

The Nigerian viewpoint of the Green Wall Sahara Nigeria Programme program, has the following design components to achieve its goals: 1500km by 10km major shelterbelt, 1500km by 1km desert farming, 1500km by 500m minor shelterbelt, 37000 hectares of jatropha plants (about 3500 hectares each state in the 11 northern frontline states), 37000 hectares of Cactus opuntia, 37000 hectares of Neem tree. In addition, the concept included 37000 hectares of desert for food, or around 3500 hectares each state. However, it is intended that each parcel of land in the state will be lined with trees on the inside and outside with 3-meter hedges. The 37000 hectares of cattle plots are the same. This is also factual on the 3000km international channel for cars and bicycles in Oasis. The hedges will be lined up as indicated above for the 11,000 dwellings and 22 industries which will be established in this green wall belt. Fast surviving grasses like vetiver will be utilized to cover 1.5 million hectares of land vulnerable to land cover vulnerability to keep the soil firm and prevent it from being moved by the violent North-East Trade Wind. Overall, the plan is to create a sustainably green environment, supporting the brown to green concept. It was estimated that the project will create jobs for up to 4.5 million Nigerians over the next 5-8 years, improve biodiversity and minimize desert encroachment from 0.6km annually to 0.1km annually (Federal Government of Nigeria 2012).

The Kaduna State Government in Northern Nigeria is actively expanding (and plans to continue increasing) its infrastructure (rural roads, highways, train, solid waste management plants, agricultural productivity, airport, water, energy, and so on) throughout the state. Given the state's location in northern Nigeria, an ecologically sensitive region of the country (where climate change consequences, especially desertification and drought, are rapidly approaching), an ecological modelling framework is very essential. This will integrate sensible development and conservation planning into the state's infrastructure deployment process without an iota of doubt. The goal should require implementation of a methodical, accountable, and sustainable land use and spatial development model in both urban and rural areas. This project is expected to complement the Federal Ministry of Environment's ongoing initiatives, particularly the Great Green Wall for the Sahara and Sahel Initiative in Northern Nigeria, which has eight major pillars.

As a result, it is critical that the Great Green Wall Initiative moves beyond or farther from the perimeter thus shielding or forming regional or local corridors ensuring ecological connectivity within and across the nation's various regions, particularly in the northern states, and thus localize the initiative's gains (Federal Government of Nigeria 2012). From a national point of view, it is very compelling to invest in Green Infrastructure. According to the Federal Government of Nigeria and UN-REDD+ (2013), the country has lost more than half of its forest cover since 1990 which is currently than 10 percent of the country is forested area, with a current deforestation rate of about 3.7 percent per year, one of the highest in the world. As a result, smart measures must be adopted to help in the rehabilitation of agricultural and pastoral lands, as well as to help safeguard natural habitat from grazing. Perhaps re-igniting the fundamental intentions of grazing reserves and seeing them realized will bring success toward ensuring that green investment projects like the State-based Green Wall (SGW) are not jeopardized.

2.9. Aims

Given the above review of relevant studies to the topic of climatic and land use changes as well as its resultant effect on agricultural yield. It has become imperative to investigate the impact of these changes on the yield of some major cereals in Kaduna State, Northern Nigeria. Kaduna state is a notable in Nigeria for high production of some cereals such as maize, rice and sorghum; however, there is not much information on how productivity has been affected by climatic and land use changes over the years. This research paper will attempt to close that gap by employing descriptive and inferential statistics to investigate the impact of some climatic and land use factors on the yield of these cereals.

3. Methodology

3.1. Description of Study Area

Kaduna, a city located in North Western Nigeria on Longitude 10.3123˚N and Latitude 7.2625˚E is the capital of Kaduna State and the former political capital of Northern Nigeria with a land mass of about 45,567 square kilometres. It has a projected population of about 8.9 million. The city was founded by the British Colonists in 1900 (Falola *et al.* 2011). It is instrumental to the agricultural economy of Northern Nigeria. Agriculture is a predominant industry in the state because it’s environmental and climatic conditions are suitable for cereal crop production and is becoming notable. The five major crops cultivated in the state during the wet seasons are Maize, Rice, Guinea and Soya Bean cultivated at household level at during wet season at 31.80%, 12.4%, 9% and 8.4% respectively (KDBS 2018).

3.2. Method of data collection

The data collection method used in this study involves the use of secondary sources of data. Time series data included climatic data (monthly rainfall, maximum and minimum temperature) and agricultural data, specifically crop yield data (rice, maize and sorghum) covering a period of twenty-two years, 1999 to 2021 was acquired from the Archive of the Nigerian Meteorological Agency (NIMET 2022).

Climatic data (monthly rainfall, maximum and minimum temperature) was obtained from the archives of the Nigerian Meteorological Agency while crop yield data was obtained from the Michigan State University, Kaduna State Agricultural Production data in the USAID development data library. Data on crop yield data was obtained from the (Michigan State University 2019).

Land Use Change date was obtained using the USGS EarthExplorer

3.3. Techniques for data analysis

Future forecast was conducted for yield data to cover the gap for missing years using the below formular.

Yield = Output in Tonnes ÷ Area in Hectares while

Mean and total annual rainfall was estimated from the monthly rainfall data. Heat stress was evaluated based on the minimum and maximum temperature recorded monthly.

This study was conducted using both descriptive and inferential statistics to analyse the data. Objective 1 was achieved through frequency counts, percentages, mean & standard deviation scores; objective 2 will be realized with multiple regression analysis. Regression analysis will both used to establish the relationship between climatic data and crop yield; and also, to show the percentage contribution of the variables in the crop yield; Objective 3 will be achieved by comparing spectral images with crop yield over that time period.

The model specification

The Multiple Regression Analysis is explicitly specified as:

$$Y_t = a + b_1R_1 + b_2T_2 + b_3T_3 + e_t$$

Where: Y = Mean annual yield of crop (tons/ha); R1, = Mean annual rainfall (mm); T1= mean annual minimum temperature; T2= mean annual maximum temperature; a= constant term; b1, b2, b3 = regression coefficients and e = random error term.

Estimation of model: Several literatures have stated that the empirical analysis of time series data poses numerous challenges as there has to be a confirmation that the assumption that the time series is stationary and not violated (Enders, 1995; Patterson, 2000; Tiamiyu *et al.* 2015). Gujarati (2003) proposed that by establishing the stationarity of the residuals from regression equation, the traditional regression methodology is applicable to data involving non stationary time series. This was tested using the Cointegrating Regression Durbin-Watson (CRDW) Test method as expounded by Gujarati (2003). The model was estimated and the residuals obtained.

The rule of thumb for stationarity is that R^2 <DW statistics; also, R^2 should not be more than 0.9. The Durbin-Watson (DW) statistic for the multiple regression analysis was 0.91, 0.80 and 1.08 for the test between climatic variables and sorghum, maize and Rice yield. With R^2 being 0.41 ,0.40 and 0.40 respectively, the two conditions are met and stationarity is established thus the regression is not spurious and can be accepted. The data test was carried out using SPSS Version 20.

3.4. Remote Sensing Method

3.4.1. Image Pre-processing

Satellite based data required for this study will be obtained from different sources. A multiple temporal Landsat multispectral imagery which will be cloud free was downloaded from the US geological survey agencies (earthexplorer.usgs.gov). These images were put through atmospheric and radiometric corrections. The radiometric correction and conversion of image brightness to Top of Atmosphere (TOA) reflectance was created using the atmospheric correction in the Fast line of sight Atmospheric Analysis of Hypercubes (FLAASH). This also required a set of image information such as Sensor type, Sensor Altitude, ground elevation, Flight time and date, pixel size (m), Sun zenith and azimuth angle which will be extracted from Landsat images metadata (Patil *et al.* 2015).

3.4.2. Land cover classification

In order to map land-use and land cover classes within the study area, the iterative, ISOCLUST/maximum likelihood unsupervised/supervised classification methodology detailed at length in Benson *et al*. (2015) was adopted. This protocol is well tested and published for wetland studies such as in detailed mapping of wetland land ecological land covers (Al Sghair 2013; Benson *et al.* 2018) and as such is only summarized here.

Using the ISOCLUST classification algorithm, an unsupervised classification was performed on the Landsat images (Liu & Mason 2009). Landsat 5 TM, 7 ETM+ bands 1–5 and 7, and the equivalent Landsat 8 bands 2–7 was used as inputs. The aim of these initial classifications is to define spectrally and ecologically distinct classes, refining the classes defined in Jones *et al*. (2016). The field information on the existing land use land cover in addition to high spatial resolution imagery available on Google earth was also used to aggregate and delineate the final land cover classes.

Table 1: Land use cover classes

Land cover classification	Class Name
Class 1	Water
Class 2	Trees/Forest
Class 3	Wetland
Class 4	Cropland
Class 5	Built-up area
Class 6	Bare surface
Class 7	Grassland

4. Results

4.1. Meteorological changes in Kaduna over a time span of 23 years (1999-2021)

Figures 1, 2 and 3 show the variations and changes in trend (upward or downward) of the climatic factors with time as an explanatory variable. The total annual rainfall in Kaduna over the period in consideration varied from as low as 762.2mm in 2019 to as high as 1780.8mm in 2016. Sharp reductions in total rainfall were noticed in the year 2001, 2005 and 2018 when compared with the previous year.

The mean rainfall, mean minimum temperature and mean maximum temperature over the period of 23 years was 108.9mm, 28.2ºC and 32.1ºC respectively. The mean minimum and maximum temperatures did not vary too widely with the lowest mean minimum temperature at 26.8ºC and the highest mean minimum temperature at 29.2ºC. The lowest and highest mean maximum temperature were 31.2ºC and 32.6ºC respectively.

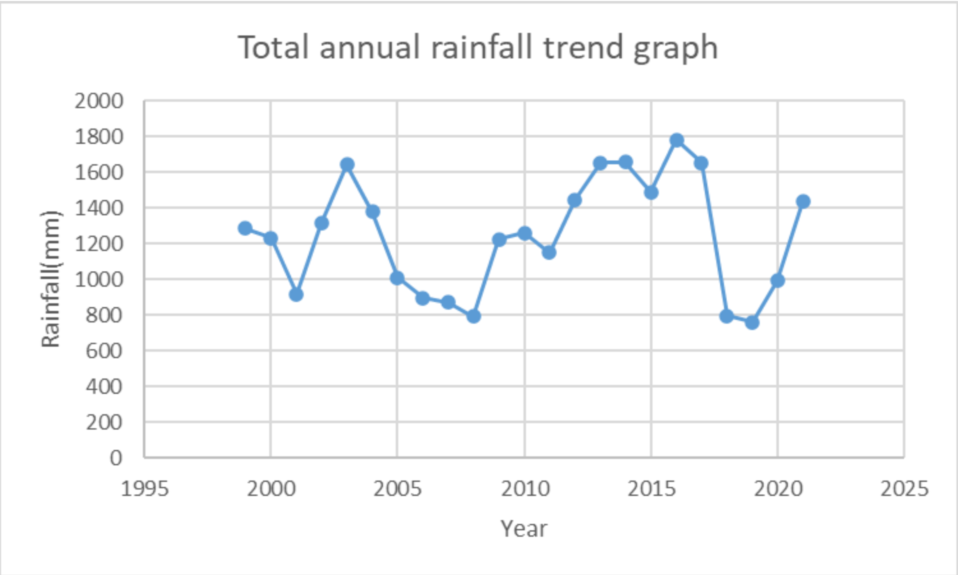

Figure 1: Trend graph of total annual rainfall in Kaduna over a period of 23 years (1999-2021)

Source: Nigerian Meteorological Agency 2022

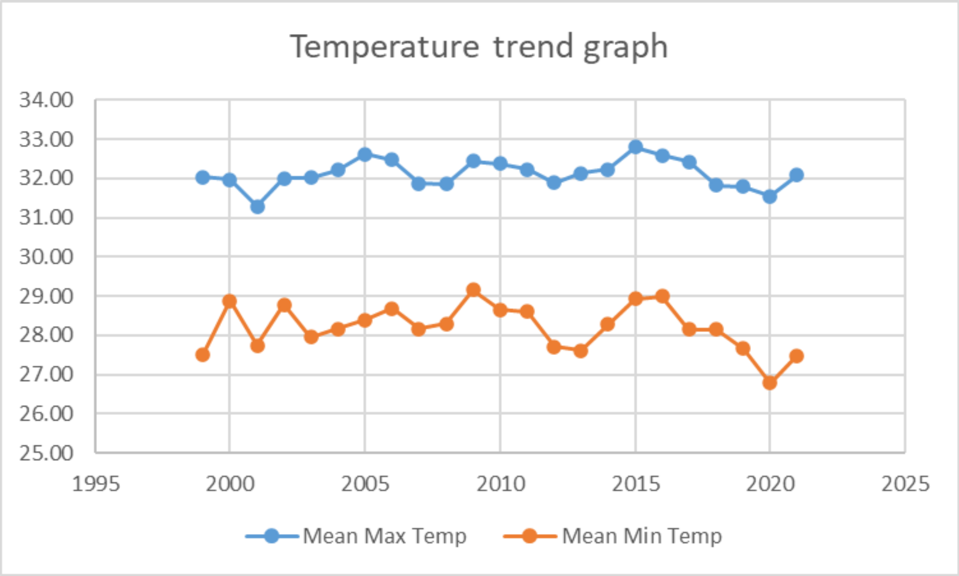

Figure 2: Trend graph of Mean minimum and maximum temperature in Kaduna over a period of 23 years (1999-2021)

Source: Nigerian Meteorological Agency 2022

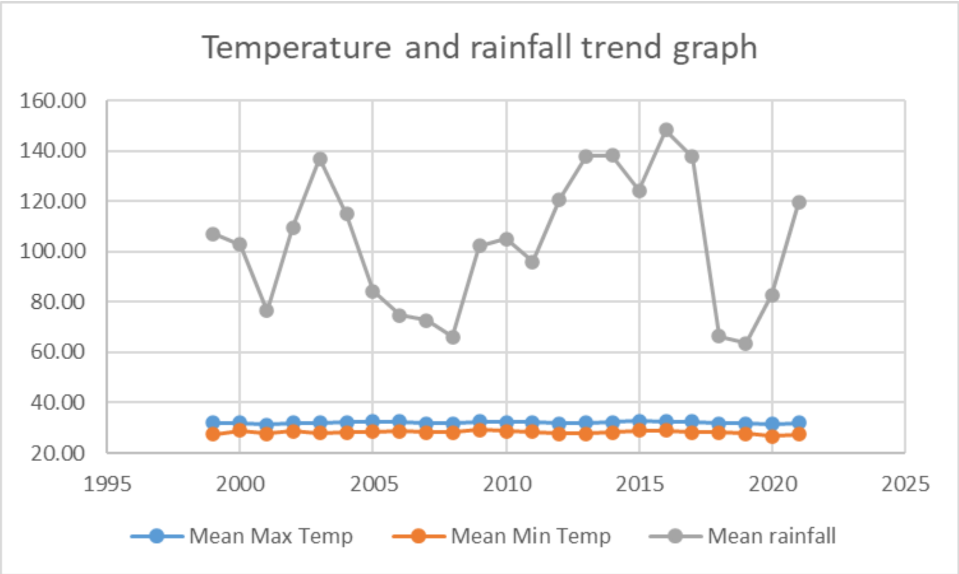

Figure 3: Mean rainfall and temperature pattern in Kaduna over a period of 23 years (1999-2021)

Source: Nigerian Meteorological Agency 2022

4.2. Descriptive statistics of Maize, Sorghum and Rice

The mean cropping area for Maize within the period of 23 years (1999-2021) was 287,062ha with a mean production output of 767,887tonnnes. Over that time period, Maize had a minimum yield of 1.5ton/ha and a maximum yield of 6.3ton/ha; mean yield was 3.3ton/ha. The mean cropping area for Sorghum over the period of 23 years (199-2021) was 241032.8ha and the mean output was 488083.4tonnes. Minimum, maximum and mean yield was 1.2, 4.0 and 2.3ton/ha respectively.

Mean cropping area for Rice over this time period was 100662.8ha, production output was 272690.1tonnes. The least yield over this time period was 1.9ton/ha, the highest yield was 3.6ton/ha and the mean yield was 2.7ton/ha.

When putting yield into consideration, of the three cereals, Maize had the highest mean yield, followed by Rice and then Sorghum. In terms of cropping area, Maize had the highest mean cropping area, followed by Sorghum and then Rice. Production output data showed that Maize had the highest mean output, followed by Sorghum and then Rice.

Table 2: Descriptive statistics of Cereals (1999-2021)

Crop Productivity	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
Maize cropping area (ha)	287,062.9	119,534.9	141,640	448,830	-0.111	-1.694
Production output (tonnes)	767,887.4	160,500.6	547,100	1,011,800	-0.001	-1.545
Yield (ton/ha)	3.3	1.8	1.5	6.3	0.741	1.160
Sorghum cropping area (ha)	241,032.8	92,496.1	115,560	333,637	-0.561	-1.688
Production output (tonnes)	488,083.4	94,413.3	318,600	640,600	-0.148	-0.83
Yield (ton/ha)	2.3	0.9	1.2	4.0	0.858	-0.802

Rice cropping area (ha)	100,662.8	55,169.04	22,000	168,531	-0.563	-1.556
Production output (tonnes)	272,690.1	160,128	57,000	487,412.1	-0.378	-1.537
Yield (ton/ha)	2.7	0.5	1.9	3.6	0.904	-0.129

4.3. Annual yield of Maize, Sorghum and Rice in Kaduna over a period of 23 years (1999-2021)

Figure 4 shows that of the three cereals, Maize had the highest yield in 1999, it then experienced a sharp drop in year 2000. Between 2000 and 2003, Maize had the lowest yield while Rice had the highest. From 2004-2013, Sorghum had the lowest yield of all the cereals while Rice recorded the highest yield. In 2014, Maize experienced a sharp increase in yield and continued to produce the highest yield of all the three cereals until 2021. It can be seen that all the three cereals experienced an increase in yield from the year 2014-2021

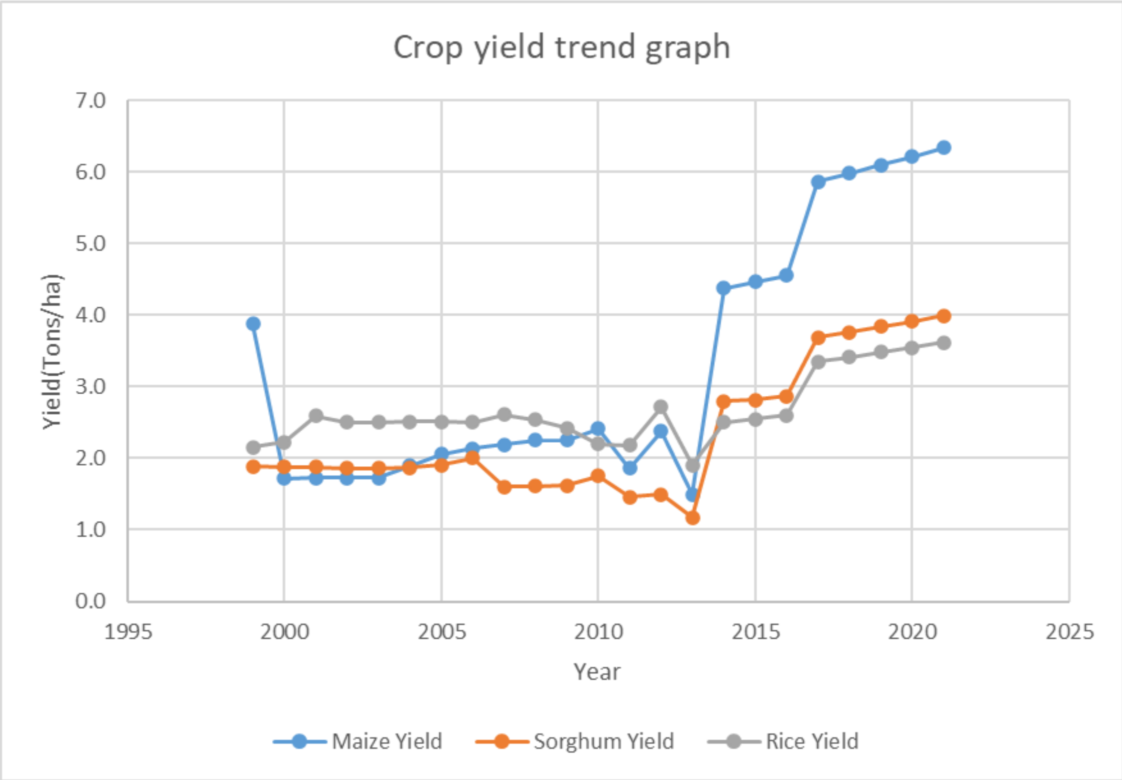

Figure 4: Trend graph of the yield of Maize, Sorghum and Rice in Kaduna over a period of 23 years (1999-2021).

Source: Michigan State University, Kaduna State Agricultural Production data in the USAID development data library

4.4. Land cover changes of Kaduna (2000-2021)

Table 3: Land cover characteristics of Kaduna from 2000 – 2021

LULC	2000 Area (km sq.)	200 Area (%)	2021 Area (km sq.)	2021 Area (%)	Area km sq. 200 -2021
Water	231.1	0.52	250.5	0.57	19.4
Tree/Forest	5,760.1	13.03	6,159.8	13.93	399.7
Wetland	4.2	0.01	3.7	0.01	-0.5
Cropland	5,405.4	12.22	8,513.5	19.25	3,108.1
Built up area	655.4	1.48	919.7	20.8	264.3
Bare surface	6.6	0.01	8.3	0.02	1.7
Grassland	32,158.1	72.72	28,365.5	64.14	-3,792.6
Total	**44,221**	**100**	**44,221**	**100**	

The land cover characterization of Kaduna in year 2000 and 2021 revealed that waterbody accounted for 0.52% (231.km^2) and slightly increased in 2021 to 0.57% (250.5km^2), the forest cover estimated for 13.03% (5760.1km^2) in 2000 and increased in 2021 to 6159.8km^2 (13.93%). The wetland cover was relatively stable, from 4.2km^2 in 2000 to 3.7km^2. But most notably is the cropland class, wherein it 12.22% which represents 5405.4km^2 in 2000 while it significantly increased to 19.25%, depicting a net area gain of 3108.1km^2. The built-up area due to increase in population significantly increased from 655.4km^2 (1.48) in 2000 to 919.7km^2 (2.08%) and an overall net gain of 264.3km^2. The bare surface areas in year 2000 accounted for about 6.6km^2 (0.01%) but was relatively stable in the recent image year of 2021 which became 0.02% (8.3km^2) with a net classification gain of 1.7km^2. Then the largest land cover was grassland 72.7km^2 (32158.1km^2) in 2000 then significantly reduced in 2021 to 64.14% (28365.5km^2) with a net loss of -3792.6km^2. this can be further depicted in the Figure below

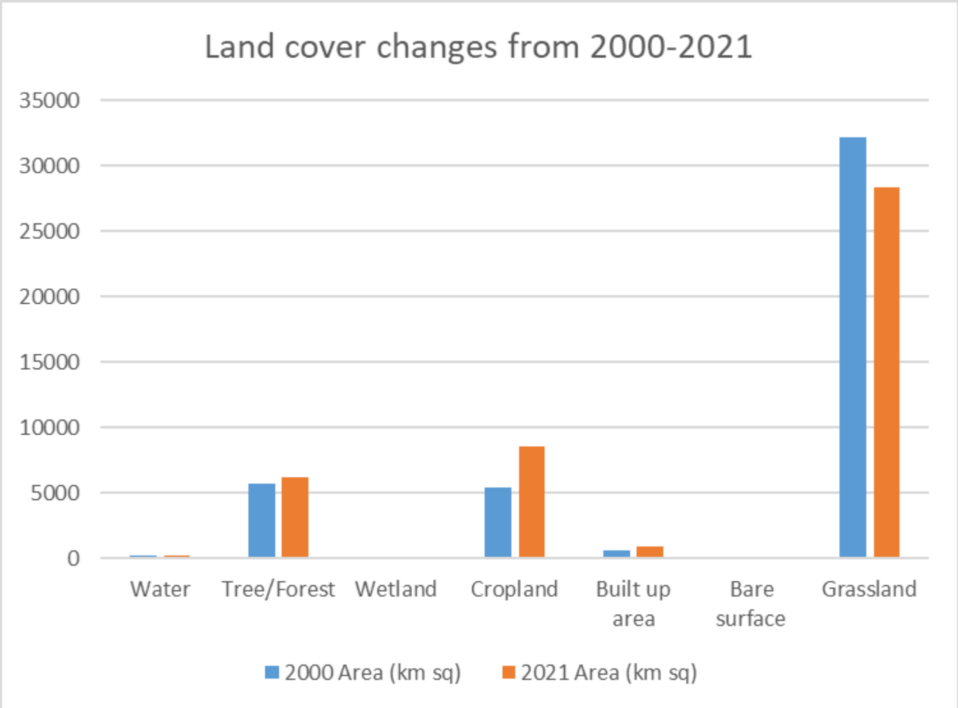

Figure 5: Land use cover changes of Kaduna (2000-2021).

Source: USGS EarthExplorer

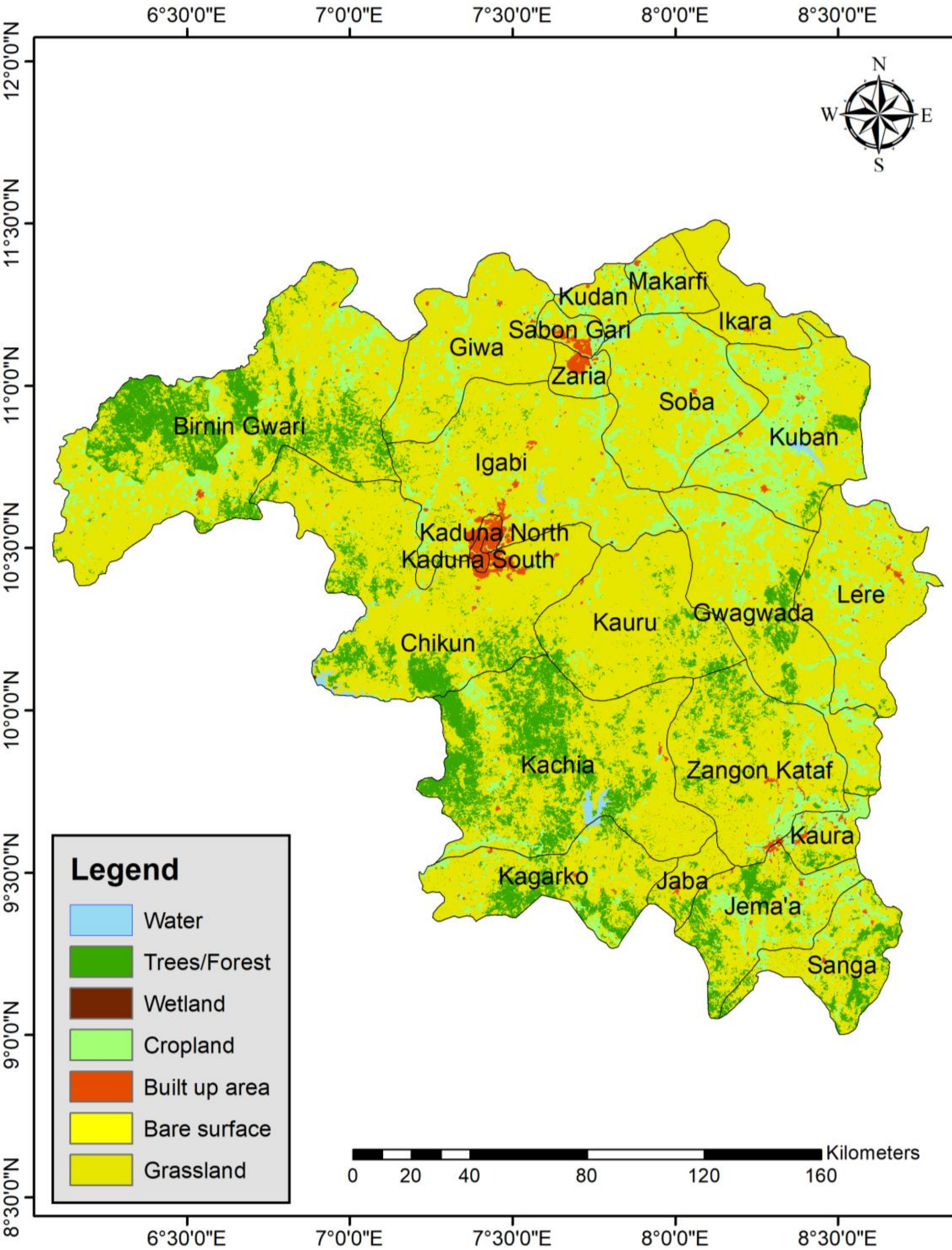

Figure 6: Kaduna land cover characterization of 2000

Source: USGS EarthExplorer

The land cover characterization of year 2000 showed the presence of a vast area of grassland almost in every local government area with less in Birin Gwari and Kachia, which had notable dense trees/ forest cover. The densely populated local government were Kaduna North and Kaduna South, which is the capital and one time capital of the Northern region. Northward is Zaria which also had a dense population, though not as much as the Kaduna metropolis (Kaduna North and Kaduna South). From the land cover classification, it is revealed that the vast area of grassland was later lost to arable cropland and forest cover in the later year (2021).

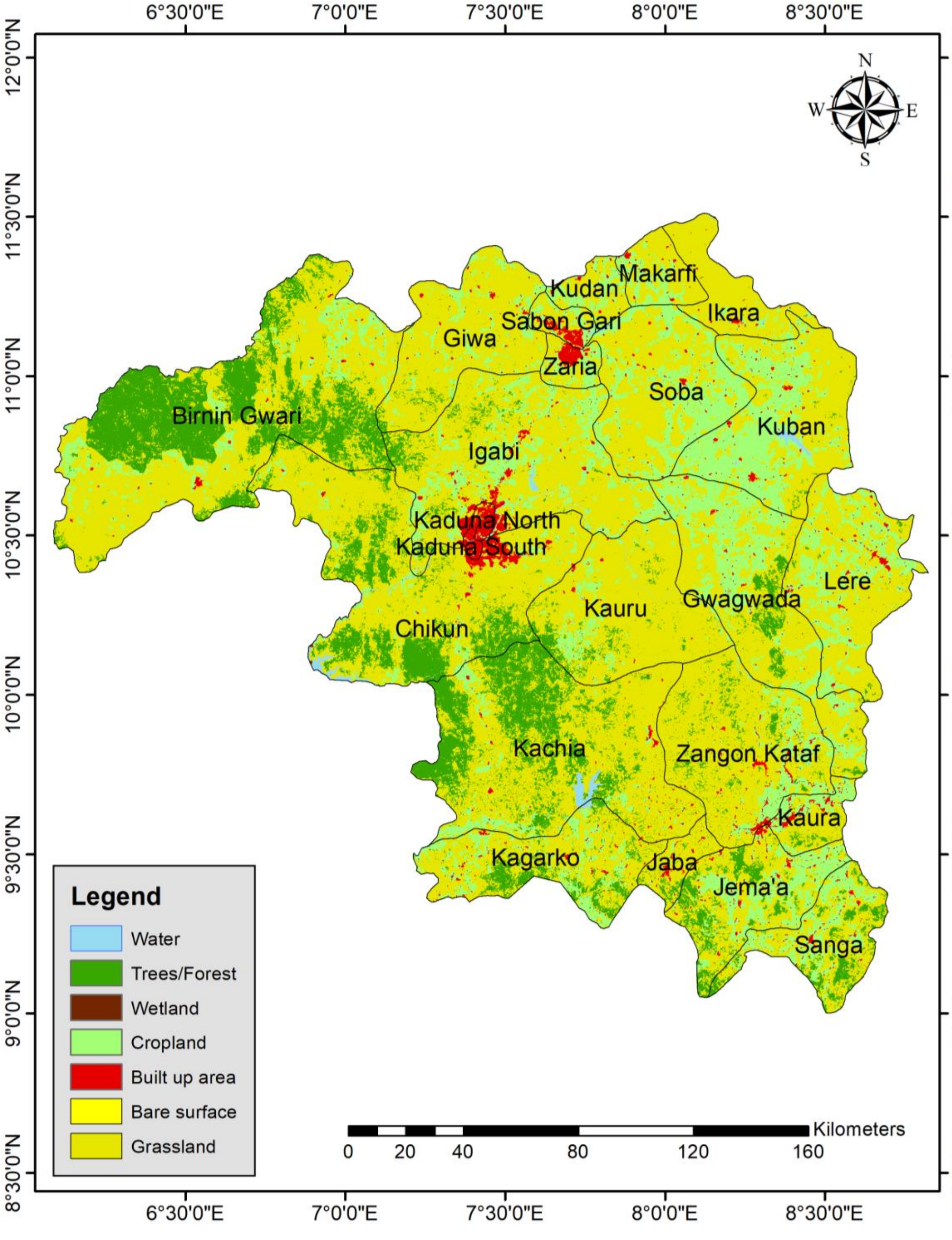

Figure 7: Kaduna land cover characterization of 2021

Source: USGS EarthExplorer

From the Land cover characterization of Kaduna state in the Figure above it can be revealed that the built-up areas sporadically increased in Kaduna metropolis, Zaria and Sabon-Gari, much more than in 2000. Another important changes in the 2021 map were increase in afforestation practices to curb the menace of desertification through the green wall project. Wherein vast area of grassland was converted into forest cover in the state. Interestingly, within the last two decades there the current map has revealed increase in arable land as showing in the table above.

4.5. Relationship between Maize yield and Climatic factors (mean minimum temperature, mean maximum temperature and mean rainfall)

The hypothesis being tested (H_1) is that climatic factors (mean minimum temperature, mean maximum temperature and mean rainfall) have a significant impact on crop yield. To test if climatic factors had an impact on maize yield, the dependent variable, maize yield was regressed on predicting variables, climatic factors.

Climatic factors significantly predicted maize yield, $F(3,19) = 4.24$, $p<0.05$. Findings revealed that mean minimum temperature has a statistically significant impact on maize yield ($b=2.97$, $p<0.05$), mean maximum temperature and rainfall did not have a statistically significant impact on maize yield however a negative relationship was noticed between mean maximum temperature and yield which indicates that an increase in mean maximum temperature would lead to a reduction in yield. The same was noticed for rainfall and maize yield. The R^2 value is 0.40 which means that 40% of the variance noticed in maize yield can be attributed to the climatic factors investigated. Table 4. presents a summary of these findings.

Table 4: Relationship between Maize yield and Climatic factors (mean minimum temperature, mean maximum temperature and mean rainfall)

Variable	Beta coefficient	t-value	R^2	F-statistics	P-value
Mean minimum temperature	2.97	3.55	0.40	4.24	**0.00***
Mean maximum temperature	-1.58	-1.46			0.16
Mean annual rainfall	-0.00	-0.06			0.95

$*p<0.05$

4.6. Relationship between Sorghum yield and Climatic factors (minimum temperature, maximum temperature and mean rainfall)

Table 5 shows a summary of the findings, when the hypothesis that climatic factors significantly impact crop yield (H_1) was tested. After testing for a relationship using linear regression, climatic factors significantly predicted sorghum yield, F (3,19) = 4.37, $p<0.05$. A statistically significant relationship was noticed between mean minimum temperature and maize yield (b=1.54, $p<0.05$).

Mean maximum temperature and rainfall did not have a statistically significant impact on maize yield (b=-0.88, $p>0.05$; b=-0.00, $p>0.05$), however, a negative relationship indicating that an increase in mean maximum temperature and rainfall would lead to a reduction in yield was noticed. The R^2 value is 0.401 which means that 40% of the variance noticed in sorghum yield can be attributed to the climatic factors investigated.

Table 5: Relationship between Sorghum yield and Climatic factors (minimum temperature, maximum temperature and mean rainfall)

Variable	Regression coefficient	t-value	R^2	F-statistics	P-value
Mean minimum temperature	1.54	3.59	0.41	4.37	**0.00***
Mean maximum temperature	-0.88	-1.59			0.13
Mean annual rainfall	-0.00	-0.22			0.83

***p<0.05**

4.7. Relationship between Rice yield and Climatic factors (minimum temperature, maximum temperature and mean rainfall)

As shown in Table 6, climatic factors significantly predicted sorghum yield, $F(3,19) = 4.15$, $p<0.05$. Mean minimum and maximum temperature showed statistically significant relationships with maize yield ($b=0.70$ and -0.63 respectively, $p<0.05$). Maximum temperature showed a negative relationship which means that the rice yield is affected negatively when temperature soars; excessive rainfall also negatively affects rice yield. Rainfall didn't show a statistically significant impact on rice yield. The R^2 value is 0.40 which implies that 40% of the variance noticed in Rice yield is due to temperature and rainfall.

Table 6: Relationship between Rice yield and Climatic factors (minimum temperature, maximum temperature and mean rainfall)

Variable	Beta coefficient	t-value	R^2	F-statistics	P-value
Mean minimum temperature	0.70	3.04	0.40	4.15	**0.00***

Mean maximum temperature	-0.63	-2.12	**0.04**
Mean annual rainfall	-0.00	-0.83	0.42

***p<0.05**

5. Discussion

Finding from this study showed variability in the mean annual rainfall over the 23-year period. Total annual rainfall ranged from 762mm in 2019 to 1780.8mm in 2016. There were also sharp reductions and increase in rainfall over the years. This variability is similar to what was noticed by (Tiamiyu *et al.* 2015) in their study on rainfall variability in the four zones in Nigeria. It was reported that this variability could have adverse effects on crop yield and thus it was important to put measures in place to mitigate rainfall variability

Temperature didn't vary too widely and remained within the required range for the growth of the cereals, however, it was noticed that over the years, the lowest minimum and highest maximum temperature slightly increased indicating increased hotness. Total rainfall reduced over the years with Year 2018, 2019 and 2020 getting only 795.8, 762.2 and 993.1mm respectively. It also started raining later than previous years. This could be a resultant effect of climate changes that occurred within that period. Climatic variability affects crop yield, increase in temperature reduces the yields and quality of grain crops by shortening the life cycle resulting in a shorter grain filling period, so the plants produce smaller and lighter grains, culminating in lower yields and perhaps poorer grain quality (Oguntunde *et al.* 2016)

When ranked in ascending order, the mean yield of the four crops can be ranked as follows: Sorghum < Rice < Maize. Mean cropping area can be ranked as Rice < Sorghum < Maize and production output can be ranked as Rice < Sorghum < Maize. This means that Sorghum had a low yield compared to the number of hectares used to cultivate it within this time period. Maize being the highest yielding cereal of the three aligns with findings from Bamiro et al. 2020 & Sunday *et al.* 2022. All the three cereals experienced substantial increase in yield from the year 2014-2021.

Findings of the study reveal that minimum temperature showed a statistically significant impact and positive influence on rice yield. Maximum temperature also showed a statistically significant but negative influence on rice yield. This outcome agrees with previous studies such as that of Arshad *et al*. (2017) who studied the effects of crop management practices and climatic conditions on yield for wheat and rice and found evidence that short or long-term heat stress affects rice and wheat yield. Sajjad *et al.* (2017) had similar results in their study on the effect of climate change on food crops in Pakistan. They came to the conclusion that increasing temperature negatively affects Rice yield. Other studies are also in agreement with this conclusion, it was reported that minimum temperature had a substantial positive impact on rice yield during the vegetative stage; whereas, higher maximum temperature during the vegetative and ripening stages negatively impacted rice yield (Welch *et al.* 2010; Zhang *et al.* 2016)

The effect of rainfall on rice yield in this study was negative but not statistically significant. This implies that excessive rainfall would negatively impact rice yield. This outcome is similar to what was noticed by Zhang *et al.* (2016) in their study which evaluated rice yield responses to climate change based on 20 experiment stations in China. Their study revealed that rainfall had no significant effect on rice yield in regions with abundant water availability but rainfall had a positive effect on rice yield in regions that were prone to drought. Akinbile *et al.* (2020) in their study in Nigeria also found no significant positive correlation between rainfall and rice yield. The R^2 value is 0.40 which indicates that temperature and rainfall explain 40% of the variations noticed in rice yield. Other factors not considered in this study contributed the remaining 60%.

Minimum temperature had a statistically significant influence on maize yield while rainfall had a negative but not statistically significant influence on Maize yield. Sajjad *et al.* (2017) had similar results in their study of climate change and its effect on major food crops in Pakistan. In their study investigating climate change and maize production in Kaduna, Amani *et al.* (2012) concluded that there is a significant and positive relationship between the aggregate maize output and total annual rainfall. They indicated that rainfall had a positive significant contribution to maize production. Our study does not agree with this conclusion and this is probably due to the climatic changes that have occurred since their study was conducted. It could be seen from the rainfall trend graphs that rainfall had reduced over the years and farmers must have resorted to irrigation systems to provide water for their farm. This study showed a negative non-statistically significant influence which indicates that excessive rainfall would negatively affect maize yield.

Similar to what was noticed with maize, mean minimum temperature had a positive statistically significant effect on sorghum yield. Mean maximum temperature and mean annual rainfall had negative but statistically negligible impact on sorghum yield. Okae-Anti *et al.* (2018) in their study had similar results with sorghum plants grown in higher temperature periods (March, 41.1/23.9°C) performing poorly compared to sorghum seeds grown in lower temperature periods (July, 31.08/21.8 °C). In their study on the effects of heat stress on Sorghum plant growth in Northern Nigeria, Jerome et al. (2019) experimented with different temperatures at different growing stages and showed numerous negative effects of increased temperature on yield. The study concluded that sorghum will fail to produce effectively in high temperature situations and innovative methods must be sought to grow sorghum plants in increasing temperature areas in Northern Nigeria.

5.1. Conclusion

This study presents findings on the impact of climatic factors on the yield of three major grains cultivated in Kaduna state, Nigeria between 1999-2021. It discovered that climatic changes had occurred over the years which reflected in the variability of rainfall pattern as well as the minimum and maximum temperature over this time period. Crop yield data showed that maize was the most cultivated of the three cereals and that sorghum output was low compared to the land used to cultivate it. Multiple regression analysis showed that minimum temperature influenced the yield of the three grains positively, while maximum temperature and rainfall had a negative but statistically negligible impact on crop yield except for rice which was significant.

5.2. Recommendations

Due to the outcome of this study, the following recommendations are suggested:

- More research should be done to identify better cultivars of each grain that will be less susceptible to climate variability.

- Adequate documentation of climatic variables should be done to be able to forecast changes and inform farmers ahead of optimal planting dates and conditions.
- Future research work should investigate climate change impact on crop yield under different conditions to aid the development of strategies for sustainable production of these grains.
- Studies investigating a combination of other variables (such as solar radiation, hectarage, fertilizer, soil quality etc.) and their impact on yield should be carried out.
- Finally, based on the result a SWOT Analysis (Strength, Weaknesses, Threats and Opportunities) was carried highlighting the needs, potential growth and the structural hindrances within the region in the tables below.

Table 7: SWOT Analysis for Kaduna, Nigeria.

KADUNA
Strengths • Kaduna state has a huge landmass suitable for agriculture, with a diverse range of crops that can be cultivated in the region such as Rice, Millet and various vegetables. • The state has a demography that constitutes mainly of young people which if maximized will boost agricultural productivity. • The government is committed to promoting and investing in agriculture. • There is an increased awareness of the effect of climate change among farmers as well as a drive to adopt climate-smart agricultural practices such as changing planting dates, diversifying crops, adopting water conservation practices and more
Weaknesses • Agricultural sector is highly dependent on rain-fed agriculture making it highly sensitive to rainfall variability. It is also susceptible to droughts and floods as well as temperature changes and disease outbreaks which are expected to increase in frequency and intensity due to

climate change. • Agricultural sector has low adaptive capacity because practices are largely traditional and poorly suited to cope with climate change due to poor infrastructure, inadequate financial resources and poor adoption of technology • The majority of farmers in the state are smallholders who often lack access to credit, information and other resources and technologies that can help them adapt to changing climate conditions.
Opportunities • Improving market access for smallholder farmers, encouraging sustainable land use practices and investing in transferable research and development could increase the adoption of climate smart agriculture • If adequately maximized, the potential for increased investment in sustainable agriculture could mitigate the effects of climate change and enhance food security. • The state can support farmers with finance, technology, information and education to leverage user-friendly new technologies for weather forecasting and land management similar to the use remote sensing and precision agriculture to mitigate the effects of climate change
Threats • Due to Kaduna state's agricultural sector's high sensitivity to climate change, its productivity could reduce leading to increased food insecurity. • Insecurity in the state can impede investment in the agricultural sector and frustrate efforts to adopt climate smart agriculture. • Climate change could result in floods and droughts which could worsen existing challenges such as insecurity, poverty and political instability, which could have negative impacts on food security.

Source: (Abaje et al. 2016, Anurika & Precious 2017, Onyeneke et al. 2018, Laura et al. 2020 & Adeosun et al. 2021)

Table 8: SWOT Analysis for the Federal Republic of Nigeria

NIGERIA
Strengths • Nigeria is becoming increasingly aware of the effect of climate change on agriculture and food security leading to greater investments in adaptation strategies. • Nigeria has developed numerous policies and programs to support the adoption of climate-smart agricultural practices such as the National Adaptation Strategy and Plan of Action on Climate Change for Nigeria, the Agricultural Transformation Agenda, the global Alliance for Climate-Smart Agriculture and the African Climate-Smart Agriculture Alliance. • Nigeria has a population that consists of a high number of young people who if properly mobilized and incentivized can work to increase agricultural productivity and resilience. • Nigeria's agricultural sector has a high potential for expansion and diversification of crops and livestock in order to build resilience. • The country has a large population of smallholder farmers who have traditionally been resilient in the face of adverse climate events.
Weaknesses • Nigeria is already experiencing climate variability and extreme weather events. Due to the high adaptation of rain-fed agriculture, this is expected to significantly affect its food security • Rising temperatures and changing rainfall patterns will negatively affect crop yields and livestock productivity with the northern and central parts of the country being the most vulnerable. • Widespread corruption leading to a diversion of resources that should be used to provide access to technologies and information that can help farmers adapt to changing climatic conditions. • Poor agricultural infrastructure such as irrigation, remote sensing technologies, conservation agriculture etc. which can limit agricultural productivity.
Opportunities • Sustainable agriculture is a possibility if a coordinated approach involving investments in institutional capacity, research and development, extension services and policies to support

smallholder farmers are adopted to promote climate-smart agriculture. • If policy makers can take a holistic approach to climate change adaptation in the agriculture sector by taking into account the multiple factors that increase vulnerability to climate change, they will be able to build a resilient agricultural sector and adapt to climate change realities.
Threats • Worsening insecurity, political instability, conflict and economic challenges may limit the ability of government and other stakeholders to implement needed adaptation strategies. It could also discourage investment in the agricultural sector. • Degradation of natural resources including land and water, uncontrolled pollution and poor agricultural waste management can critically affect agricultural productivity and food security. • The effects of climate change could potentially worsen existing challenges such as poverty, malnutrition, food insecurity and political instability

Source: (IFPRI 2009, Shuaib et al. 2015, Adesina & Loboguerrero, 2021, UNDP 2021 & UNDP 2022)

Table 9: SWOT Analysis for West African Region

WEST AFRICA
Strengths • West Africa already has case studies of successful adaptation strategies such as the use of agroforestry and conservation agriculture practices, establishment of early warning systems, promotion of drought resistant crops. All these can be scaled up to achieve lasting food security in the region. • Governments and farmers are realizing the increasing effects of climate change and pledging their commitment to adopt climate-smart practices • There are numerous ongoing initiatives and interventions targeted at improving food security in West Africa. Examples include the ECOWAS Agricultural Policy and the West Africa Agricultural productivity program.

- The region has a demography rich in young people which if adequately maximized, can be used to expand the agricultural sector and become sustainable.
- There is an encouraging increase in investment in climate-smart agriculture to address the impacts of climate change in food security.

Weaknesses

- Overfishing, forest loss and other harmful practices developing policies will worsen the effects of climate change in the region.
- Poor political will, limited funding resources and weak institutional capacity are key challenges to implementing effective policies to address climate change.
- Poor coordinated efforts across sectors and countries to achieve sustainable development.
- Continued reliance on unsustainable farming practices and inadequate access to markets might limit efforts to build resilience and improve food security in this region.

Opportunities

- Diversification of crops and livestock species , as well as the use of drought-resistant varieties and improved breeds can help farmers adapt to changing weather patterns.
- Increased education and training of farmers on water management practices such as harvesting rain water and small-scale irrigation can improve resilience.
- Providing credit facilities to farmers can encourage investment in climate-resilient practices and technologies.
- Increased regional coordination and cooperation to address common challenges related to food security and climate change.

Threats

- Climate change will worsen the problem of water scarcity in the region which will in turn hamper crop and livestock production.
- Pest and diseases will become more prevalent in plants and animals due to changing weather patterns (especially increasing temperature and humidity) resulting in reduced yields and increased food insecurity.
- Quality and quantity of pasture will be affected by changes in temperature and rainfall patterns leading to low productivity in livestock.
- Failure to address the impact of climate change on agriculture and food security in West Africa will lead to even poorer poverty, food insecurity and malnutrition indices. It could also

negatively affect the region's economy, social and political stability, inequality as well as overall development.

Source: (IFPRI 2009, Thomas 2012, Vwy et al. 2012, Ncube et al. 2014, Shuaib et al. 2015, Laura et al. 2020 & Raissa et al. 2020)

5.3. Limitations of Study

This study only investigated the impact of two climatic variables (rainfall and temperature) on the yield of three grains (Maize, Sorghum and rice) in Kaduna state. These results may not be the same for other states or countries because the conditions may differ.

- The land cover classification embeds some measures of limitation due to the assumption of land cover classification devoid of field inventory to cross validate. The use of high spatial resolution images from Google earth was used to define the training areas used for the supervised classification. Further research could employ high spatial resolution imagery which would reveal variations in crop types, phenology and yield projections.

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