

Analyzing the Critical Impact of Climate Change on Agriculture and Food Security in Nigeria

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Abstract

This study explores the threats of climate change on agriculture and food security globally, focusing on Nigeria. Nigeria, as the most populous country in Africa, is highly vulnerable to the impacts of climate change on its agricultural sector. The research conducts a comprehensive literature review and synthetic analysis to identify the key factors that make Nigeria's food production systems susceptible to climate change. Nigeria's diverse climate, influenced by latitude, topography, winds, ocean currents, and the Sahara Desert, contributes to its vulnerability. Agriculture is crucial for food security, economic development, and livelihoods in Nigeria, making it particularly susceptible to climate change. The study examines the relationship between climate change and agriculture in Nigeria, discussing key challenges, possible consequences, and adaptation strategies. Impacts of climate change on Nigeria's food security include increased droughts, desertification, pests and diseases, unpredictable weather, decreased fishery productivity, and limited access to resources and technology. To mitigate these impacts and enhance resilience, the study suggests various adaptations and strategies such as crop diversification, utilization of improved varieties, efficient water management, sustainable soil practices, climate-smart agriculture, capacity building, access to credit and insurance,

policy support and coordination, climate information systems, and the establishment of farmer cooperatives and sustainable value chains. These recommendations aim to improve food security, rural livelihoods, and overall resilience in Nigeria's agricultural system in the face of climate change.

Keywords: *Climate change, Food Security, Agriculture, Environment, Nigeria*

Introduction

Climate change is a global phenomenon that poses significant threats to various sectors, including agriculture and food security. Increasing temperatures, changing rainfall patterns, and the rising occurrence of extreme weather events are all direct consequences of climate change. These environmental changes have far-reaching implications for food production and availability, as well as the overall stability of global food systems. Nigeria, as the most populous country in Africa, is particularly susceptible to the adverse impacts of climate change on its agricultural sector. Agriculture plays a vital role in the country's economy, contributing to the livelihoods of a large proportion of the population. The majority of Nigerians, particularly those living in rural areas, depend on agriculture for income generation and food supply. However, the vulnerability of Nigeria's agricultural system to shifts in climate patterns is a cause for concern. The agricultural sector in Nigeria is heavily dependent on rain-fed farming, making it highly sensitive to variations in rainfall patterns. Erratic rainfall, prolonged droughts, and increased frequency and intensity of floods can disrupt crop growth and reduce agricultural productivity. These climate-related challenges are exacerbated by poor infrastructure, limited access to modern farming technologies, and inadequate irrigation systems.

Food security refers to the ability of individuals to access basic nutritious food. According to the United Nation's Committee on World Food Security, food security means that all people should have physical, social, and economic access to sufficient, safe, and nutritious food that meets their preferences and dietary needs for a healthy and active life (United Nation's Committee on World Food Security, as cited in Ayinde et al., 2011; Ughaelu, 2017; Ikem, 2018). The World Food Summit in 1974 defined food security as the availability of adequate supplies of basic foodstuffs at all times to support an increase in food consumption and to compensate for fluctuations in production and prices (World Food Summit, as cited in Ayinde et al., 2011).

Food insecurity, on the other hand, occurs when people lack adequate physical, social, or economic access to food (FAO, as cited in Ayinde et al., 2011; Ughaelu, 2017; Ikem, 2018). In Nigeria, changing climatic conditions have made the country vulnerable, and recurring environmental disasters over the past decade have exacerbated food productivity and human suffering (Ughaelu, 2017). A severe flood in 2012, unprecedented in the past forty years, resulted in significant losses of lives, crops, livestock, and displacement of people (Ogbuchi, 2020). The impact of climate change varies across the six vegetative zones of Nigeria. In the semi-arid Sudan and arid Sahel Savannah region, there is reduced rainfall, drought, and increasing desertification. In the Northern and Southern Guinea savannah belt, the changes include alterations in rainfall patterns, late arrival of rainfall, and longer dry seasons. The coastal areas experience severe flooding during the rainy season, and the Rain Forest zone experiences delays in rainfall onset, prolonged dry seasons, heatwaves, and flooding along the coastal lines. The Mangrove Swamp faces flooding of previously dry plains, and the persistent rise in sea level

poses risks to farming activities. Additionally, increasing water temperatures negatively impact fishing (Berhanu & Wolde, 2019).

The consequences of climate change on food security in Nigeria are extensive and have significant implications for the population. The combination of reduced agricultural productivity and crop losses due to changing climatic conditions can result in food shortages and scarcity. This, in turn, can lead to price hikes and make nutritious food unaffordable for many individuals and families. As a result, there is an increased risk of malnutrition among the population. The impact of food scarcity and insecurity is particularly severe for vulnerable populations, including women, children, and the poor. These groups often have limited access to resources and are more susceptible to the negative effects of climate change on food security. The lack of access to adequate and nutritious food can lead to undernutrition and related health issues. Children, in particular, may experience stunted growth and developmental delays due to inadequate nutrition during critical stages of their development. Women, who often play a crucial role in ensuring food security within households, may face increased burdens and limited opportunities to address these challenges. The consequences of climate change on food security extend beyond physical health. Insecurity and scarcity can have adverse social and economic impacts on communities and individuals. Increased competition for resources, such as water and arable land, may lead to conflicts and displacement. Additionally, fluctuations in food availability and affordability can disrupt local economies and exacerbate poverty levels.

According to available evidence, Nigeria is currently facing various ecological problems that are directly linked to climate change (Adefolalu, 2007; Ikhile, 2007). The southern ecological zone, which is known for high rainfall, is experiencing irregularity in its rainfall pattern. The Guinea savannah is also facing gradually increasing temperatures. Additionally, the northern zone is threatened by desert encroachment due to a reduction in surface water, flora, and fauna resources. This has led to the exploitation of previously undisturbed lands and a decline in forest cover, as well as an increase in sand dunes in the northern part of Nigeria. The coastal region is vulnerable to floods, destruction of mangrove ecosystems, water contamination, and transmission of waterborne diseases, resulting in displacement and communal crisis. Resource-poor farmers in Nigeria are facing crop failures, reduced agricultural productivity, increased hunger, poverty, malnutrition, and diseases. As a result, some farmers are abandoning farming for non-farming activities. Efforts to address these issues are necessary. To fully understand the impact of climate change on agricultural productivity, it is important to study the spatiotemporal patterns of temperature and rainfall from 1901 to 2005 (105 years) (Ayoade, 2003; Singer & Avery, 2007). This will provide a basis for assessing the concept of regional climate change and its effects on agriculture and food security in Nigeria (Odjugo, 2010; Apata et al., 2010).

To address these challenges, it is crucial for Nigeria to develop and implement effective adaptation strategies and policies that aim to enhance resilience in the agricultural sector. These may include promoting climate-smart agricultural practices, improving access to irrigation systems, supporting diversification of crops, and investing in agricultural research and development. Furthermore, efforts should be made to strengthen social safety nets and provide targeted support to vulnerable populations to ensure their food security and mitigate the adverse effects of climate change. Addressing the critical impact of climate change on food security requires an integrated and multidisciplinary approach. Policies and strategies that focus on

building resilience and adaptation capacity within the agricultural sector are crucial. Investing in climate-smart agricultural practices, such as improving water management and irrigation systems, promoting agroforestry, and encouraging the use of drought-resistant and heat-tolerant crop varieties, can help mitigate the adverse effects of climate change on food production.

This research paper aims to contribute to the understanding of how climate change impacts food security in Nigeria, with a focus on the agricultural sector. By analyzing the various dimensions of this issue and exploring potential adaptive strategies, the findings of this study can inform policymakers, agricultural practitioners, and researchers in their efforts to develop effective and sustainable solutions for climate-resilient agriculture and improved food security in Nigeria.

Methodology

The methodology employed in this study involves conducting a comprehensive literature review of various research studies, reports, and publications centered on the correlation between climate change and its influence on agriculture. To analyze and synthesize the gathered information, a synthetic analysis approach was utilized. The primary objective of this research is to provide a deeper understanding of the crucial factors that amplify the susceptibility of food production systems in Nigeria to climate change impacts. By examining a wide range of existing literature, a more comprehensive picture can be obtained, enabling researchers to identify key aspects that underpin the vulnerability of agricultural practices in Nigeria.

Climate Change in Nigeria

The climate in Nigeria is diverse, with different regions experiencing varying weather patterns and climatic conditions. The country is located in West Africa, near the equator, which positions it in a tropical region. Nigeria's climate is influenced by factors such as latitude, topography, winds, ocean currents, and the presence of the Sahara Desert in the northern part of the country.

Nigeria can be broadly divided into four climatic zones: the Sahel, the Guinea Savannah, the Sudan Savannah, and the Coastal region. Each zone has its distinct climate characteristics. The Sahel region, located in the far north, experiences a semi-arid climate with hot, dry summers and mild winters. Rainfall is low, averaging between 200-600 mm per year, and is highly unreliable, leading to frequent droughts. Temperatures can soar above 40 degrees Celsius during the hot season. Moving southwards, the Guinea Savannah covers a significant portion of Nigeria. This region has a tropical wet and dry climate, characterized by distinct wet and dry seasons. The wet season runs from April to October, with the highest rainfall occurring between June and September. Average annual rainfall ranges from 1,000 to 1,500 mm. Temperatures in the Guinea Savannah are generally high, averaging around 27-30 degrees Celsius.

The Sudan Savannah, which lies to the southeast of the Guinea Savannah, experiences a similar climate but with a shorter wet season. Rainfall in this region ranges from 800 to 1,200 mm annually, and the dry season lasts longer compared to the Guinea Savannah. Moving further south, the climate becomes more influenced by the presence of the Atlantic Ocean, and this is evident in the Coastal region. The coastal areas experience a humid tropical climate, with high temperatures and high humidity throughout the year. The rainfall is higher in this region, averaging around 2,000 mm per year. The rainy season begins in March and lasts until November, with peak rainfall occurring from July to September.

Nigeria, the largest economy in Africa and the most populous country, possesses considerable natural resources, particularly oil and natural gas. The various ecological zones within Nigeria have allowed for diverse livelihoods, agricultural practices, and commodities, all of which are being affected by climate change and shocks. Climate change is considered responsible for the progressive decrease in the size of Lake Chad from around 4000 sq.km to approximately 3000 sq.km from 1960 to 2007, resulting in rising temperatures, desertification, and a decline in agricultural activities such as irrigation farming and fishing that depend on the lake. The exploitation of oil in the Niger Delta region has contributed to the intensification of climate change in Nigeria through the continuous gas flaring by refineries and exploring companies, releasing gases that harm the ozone layer into the atmosphere. Moreover, gas flaring leads to various atmospheric contaminants including oxides of Nitrogen, Carbon and Sulphur, particulate matter, hydrocarbons, acid rain and ash, photochemical oxidants, and hydrogen sulphide, all of which acidify the soil, deplete soil nutrients, stunt crop growth, affect palm trees, and make water too hot for fish to survive.

Additionally, the emission of carbon dioxide and the burning of fossil fuels, such as coal, oil, and gas, contribute to global warming with severe repercussions for developing countries like Nigeria, which are highly vulnerable and have limited adaptation capabilities. Furthermore, deforestation caused by both local and international demand for wood and development projects, fueled by population growth, has accelerated climate change progression in Nigeria, resulting in high deforestation rates and the absorption of more greenhouse gases into the atmosphere. These factors lead to an increase in global temperatures, a decrease in precipitation, a rise in soil temperature, and ultimately, desertification. Currently, approximately one fifth of Nigerian land is experiencing encroachment by desertification.

Climate Change and Agriculture in Nigeria

Climate change is a global environmental challenge that has profound implications for various sectors, including agriculture. In Nigeria, the impacts of climate change on agriculture are particularly severe due to the country's heavy reliance on agricultural activities for food security, economic development, and livelihoods. This extensive section will delve into the relationship between climate change and agriculture in Nigeria, highlighting the key challenges faced, potential consequences, and possible adaptation strategies. Nigeria, as one of Africa's most populous countries, relies heavily on agriculture, which accounts for about 20% of the country's Gross Domestic Product (GDP). The agricultural sector employs a significant portion of the population, particularly in rural areas, where farming is the primary source of income and livelihood. However, the sector is highly vulnerable to the impacts of climate change, including erratic rainfall patterns, temperature extremes, increased pests and diseases, and soil degradation.

One of the most critical challenges posed by climate change to Nigerian agriculture is the unpredictability and variability of rainfall patterns. Nigeria has a predominantly rain-fed agricultural system, meaning that crop production is heavily dependent on the availability and timing of rainfall. However, climate change has led to significant changes in precipitation patterns, including increased frequency and intensity of droughts and floods. Droughts, in particular, have become more frequent and prolonged, leading to water scarcity and affecting crop yields. This has devastating consequences for farmers, especially those practicing rain-fed agriculture. Reduced water availability not only affects crop growth but also leads to increased

vulnerability of livestock, as water becomes scarce for animals as well. The decline in crop and livestock production due to water scarcity subsequently threatens food security and exacerbates poverty in rural communities.

On the other hand, climate change has also brought increased flooding, particularly in coastal and riverine areas of Nigeria. These floods can destroy crops, damage agricultural infrastructure, and displace farmers from their land. When flooding occurs during planting or harvesting seasons, farmers lose their crops, leading to food shortages and economic losses. In addition, the destruction of agricultural infrastructure, such as irrigation systems and storage facilities, further hampers agricultural productivity and resilience. Rising temperatures also pose significant challenges to Nigerian agriculture. Higher temperatures can lead to heat stress in livestock, reduce the productivity of crops, and promote the spread of pests and diseases. Heat stress can cause reduced feed intake, lower milk production, and increased livestock mortality. For crops, increased temperatures can reduce growth, flowering, and fruiting, resulting in decreased yields. Pests and diseases thrive under warmer conditions, leading to increased crop losses and the need for more intensive pesticide use, which poses risks to human health and the environment. Soil degradation is another pressing issue exacerbated by climate change in Nigeria. Extreme weather events such as droughts and floods, combined with unsustainable land management practices, lead to soil erosion, loss of soil fertility, and reduced agricultural productivity. Soil erosion, particularly in hilly areas and watersheds, leads to the loss of topsoil, which is rich in nutrients necessary for crop growth. The loss of soil fertility contributes to reduced crop yields and necessitates the use of chemical fertilizers, which can have adverse environmental impacts.

To address the challenges posed by climate change on agriculture, Nigeria needs to develop and implement effective adaptation strategies. These strategies should focus on improving water management, promoting climate-resilient farming practices, and diversifying agricultural systems. Enhancing water storage and irrigation infrastructure can help reduce the impact of water scarcity and enable farmers to continue agriculture even during periods of drought. Promoting climate-smart agricultural practices such as conservation agriculture, agroforestry, and integrated pest management can enhance soil health, increase water-use efficiency, and improve crop resilience to climate change. Conservation agriculture, for example, involves minimal soil disturbance, crop rotation, and the use of cover crops to reduce erosion and maintain soil moisture. Agroforestry systems, which involve the integration of trees with crops and livestock, can provide multiple benefits such as improving soil fertility, enhancing water infiltration, and providing shade for livestock. Diversifying agricultural systems is vital for ensuring food security and improving the adaptive capacity of farmers. This can involve the promotion of climate-resilient crops and livestock breeds, adopting mixed cropping systems, and exploring alternative income-generating activities. Climate-resilient crops, such as drought-tolerant varieties and those resistant to pests and diseases, can help farmers cope with changing climatic conditions. Similarly, the introduction of livestock breeds that are more heat-tolerant and disease-resistant can reduce the vulnerability of livestock farmers.

Impact of Climate change on food security in Nigeria

Food security refers to the availability of nutritious food to all individuals. The United Nation's Committee on World Food Security defines it as the accessibility of sufficient, safe, and nutritious food that meets people's preferences and dietary needs for a healthy and active life.

The concept of food security, as established during the 1974 World Food Summit, emphasizes the continuous availability of an adequate food supply to support consistent growth in food consumption and counter fluctuations in production and prices. Conversely, food insecurity occurs when individuals lack adequate physical, social, or economic access to food, according to the Food and Agriculture Organization (FAO).

Nigeria, like many sub-Saharan African countries, is susceptible to the impacts of changing climatic conditions. Researchers such as Ayinde et al. (2011), Ughaelu (2017), and Ikem (2018) have observed that recurrent environmental disasters in Nigeria have contributed to decreased food productivity and increased human suffering over the past decade. Notably, in 2012, Nigeria experienced severe flooding, unprecedented in the previous forty years, which resulted in substantial loss of human lives, crops, livestock, and displacement of people (Ogbuchi, 2020). The effects of climate change vary across Nigeria's six vegetative zones, as highlighted by Ughaelu (2017). The semi-arid Sudan and arid Sahel Savannah region face reduced rainfall, droughts, and increased desertification. The Northern and Southern Guinea savannah belt witness changes in rainfall patterns, including delayed onset and an extended dry season. Areas along the coastlines frequently suffer from severe flooding during the rainy season (Ikem, 2018). In the Rain Forest zone, climate change results in delayed rainfall onset, prolonged dry seasons, heat waves, and increased coastal flooding. The Mangrove Swamp experiences the flooding of typically dry plains, as well as rising sea levels that pose risks to farming activities. Furthermore, higher water temperatures negatively impact fishing (Berhanu and Wolde, 2019).

The impact of climate change on agricultural productivity in Nigeria has resulted in the deterioration of affected areas, rendering them unsuitable for crop and animal production. This has been attributed to the utilization of natural resources (Wossen et al., 2018). Additionally, the persistent flooding of coastlines and the southernmost parts of Nigeria have caused damage to crops, loss of soil fertility, soil toxicity, and disruption of the soil ecosystem (Wossen et al., 2018). Concerns regarding the impact of climate change on sustainable food production in Nigeria have been highlighted by the World Bank and the Food and Agricultural Organization in their respective publications (World Bank, 2016; FAO, 2017).

Numerous research findings indicate that the varying climatic conditions caused by climate change have significantly affected agricultural productivity in Nigeria, leading to reduced output. As a result, there has been a shortage of food supply and increased food prices. The prevalence of food insecurity is escalating in Nigeria due to climatic factors that have limited agricultural productivity. Alterations induced by climate change, such as droughts, heavy precipitation, flooding, rising temperatures, increased aridity and soil acidity, changes in relative humidity, and higher evaporation rates, have adverse effects on agricultural productivity and food systems in Nigeria. Adishi and Oluka (2018) observe that climate change has become a daily reality in Nigeria, with environmental issues such as flooding, droughts, rising temperatures, and extreme weather events increasingly disrupting agricultural activities.

Similarly, Onuoha and Ezirim (2010) state that climate change poses a threat to the livelihoods of approximately 15 million pastoralists in northern Nigeria due to reduced access to water and shortages of pasture resources. Ayo et al. (2014) note in their study that climate change is exacerbating food insecurity in vulnerable areas of Nigeria, resulting in hunger and undernutrition. They further suggest that climate variability and extremes will present significant

challenges to food stability and that persistent food price increases may render basic food unaffordable for low-income earners. Fasona and Omojola (2005) find in their study that increasing aridity in the Sahel and Sudan savannah regions has rendered large tracts of land in Nigeria unproductive for agriculture, exacerbating food security crises in densely populated areas. They also predict that the number of malnourished children in Nigeria will continue to rise due to the threats posed by climate change. Idumah et al. (2016) analyze the relationship between climatic variables, such as rainfall, temperature, and relative humidity, and agricultural output in Nigeria using time series data from 1975 to 2010. Their study confirms that climatic data have a significant impact on food production in both the short and long term, supporting previous similar investigations.

The threat posed by climate change to agricultural production is a key concern on a global scale. Empirical research has shown that the increasing temperatures and unpredictable rainfall patterns observed in Nigeria over the past decade are gradually altering the traditional agricultural production patterns of the country. The recurrence of extreme climate events, such as droughts and floods, has plunged the agricultural sector into a state of crisis. Given the fundamental significance of food sufficiency for human survival, a number of researchers have focused their efforts on examining the relationship between climate change and food security. These studies have predominantly utilized methods such as direct observation, surveys, and the analysis of weather data. In addition, some researchers have employed modeling approaches to extrapolate future climate scenarios, aiming to provide valuable recommendations to policymakers on how to mitigate the impending consequences of climate change.

Numerous empirical studies have demonstrated the detrimental effects of climatic variability on agricultural productivity. For instance, Muringai et al. (2020) investigated the impact of declining water resources, increasing temperatures, and rising CO₂ emissions on food production. Their findings, in line with those of other researchers, established a significant correlation between changing climatic conditions and poor crop performance. As supported by abundant scientific literature, climate change predominantly affects the initial stage of the food supply chain, which is production, inevitably impacting all subsequent elements within the chain. The fishery sector's supply chain, as highlighted by Muringai et al. (2020), is also susceptible to the effects of climate variability. Specifically, climate change-induced droughts have had adverse consequences for the fishery sector, particularly in regions reliant on natural water resources for fishing activities. Likewise, Anyika (2020) noted that the shrinking water resources in Nigeria's Lake Chad area, resulting from climate change, have had a drastic impact on previously thriving and lucrative fishing activities, leading to the disruption of the fish supply chain and leaving many fishermen unemployed. Furthermore, Oyinloye et al. (2018) highlighted the perilous consequences of climate change for aquatic life. The researchers revealed that the rising water temperatures caused by climate change result in reduced oxygen levels in water, thereby destabilizing fish habitats and potentially leading to fish mortality, diminished productivity, or contamination with harmful bacteria. Researchers generally concur that the advancing process of desertification contributes to the loss of water bodies and aquatic species.

Climate change has a significant impact on food production, particularly in terms of food quality. Empirical studies have shown that variations in climatic conditions can have serious consequences for the nutritional composition of food crops. This can lead to people consuming

toxic food or not being able to meet their daily calorie requirements due to a decline in crop quality. For example, research by Taub et al. (2018) indicates that crops exposed to high levels of CO₂ have reduced protein concentrations. As the atmospheric CO₂ concentration continues to rise, the quality of food crops will gradually decrease. Another study by Berhanu and Wolde (2019) highlights the negative effects of extreme weather events, such as heavy rainfall, flooding, and drought, on the composition of mineral elements in the soil. Excessive rainfall can result in soil fertility loss through leaching, while flooding can increase soil acidity. Drought is also linked to soil toxicity. These conditions have detrimental effects on food production. Igwe (2019) found that persistent flooding can cause harmful elements like arsenic to be absorbed by crops, which, if consumed in large quantities, can lead to heart failure. Other studies have also associated flooding and drought with food contamination (Ughaelu, 2017; Ikem, 2018).

In addition to its impact on food production, climate variability poses serious challenges to food storage. Ikem (2018) discovered in his study that changing climatic conditions in sub-Saharan Africa, which often include high temperatures and prolonged heat waves, result in significant losses for farmers and farm produce merchants due to spoilage. Many of these farmers and merchants lack the means to establish storage facilities that could help maintain the optimal storage environment and prevent spoilage. Ufot (2019) has also observed adverse effects on the storage of roots, tubers, and vegetable crops due to changing climatic conditions. Similarly, he noted that increasing atmospheric temperatures accelerate the decomposition process of crops like yams, potatoes, tomatoes, onions, carrots, cabbage, pepper, pumpkins, and other vegetables. This leads to annual losses of over 2000 tons of yams and 2500 tons of vegetable crops in Nigeria due to decay. To address the perceived damages associated with yam spoilage, the Benue State government constructed a 200,000 tuber capacity yam storage facility in Zaki Biam, a town known for yam production. However, Ufot (2019) considers this facility insufficient, as Benue State accounts for about 70% of total yam production in Nigeria. Ughaelu (2017) emphasizes that farmers in Nigeria will continue to struggle with food storage challenges until efforts are made to provide storage facilities that can mitigate the effects of climate change.

According to Ogbuchi (2020), climate change has a significant impact on food security by causing changes in environmental conditions that force people to move away from their original habitats where they engage in food production and other economic activities, making them more susceptible to food insecurity. Previous studies by Ogbo et al. (2019), Oyinloye et al. (2018), and Ngo and Otekunrin et al. (2019) have established a connection between forced migration and food insecurity. These studies found that forced migration limits access to food, making the victims vulnerable to under-nutrition. Changes in precipitation patterns have also affected food production output in Nigeria, with delayed onsets and early cessations of rainfall leading to changes in agricultural productivity. Additionally, heavy flooding has resulted in significant crop losses. These occurrences, which are happening more frequently, have severe consequences for food security in Nigeria. Okoli and Ifeakor (2014) emphasized that Nigeria is highly vulnerable to climate change, negatively impacting food security through decreasing agricultural outputs. They also mentioned that climate change worsens the conditions of malnutrition, hunger, starvation, and poverty in Nigeria. Similarly, Ethan (2015) observed that changes in rainfall patterns due to climate change are progressively altering the growing and harvesting seasons in Nigeria, negatively affecting crop yield through alterations in evapotranspiration, photosynthesis, and biomass.

The Nigeria Meteorological Agency (NIMET, 2005) has recorded changes in climatic parameters such as rainfall, temperature, and extreme weather events in different ecological zones of Nigeria, which have adversely affected agricultural activities. Ethan (2015) conducted an analysis of Nigerian climatic data and found changes in the onset and cessation of rainfall, which have influenced the food system pattern in Nigeria. The detrimental effects of climate change on human lives, often concealed by its subtle nature, include food insecurity. It directly influences crops and livestock by altering soil nutrients, reducing water resources, changing relative humidity, increasing temperature, and promoting weed and pest growth. Climate change also leads to desertification, erosion, and ecological devastation, posing threats to human security in affected regions. Droughts, floods, and extreme environmental conditions induced by climate change limit agricultural production. In Nigeria, climate change continues to pose a threat to agricultural development, as farmlands are lost to floods and aridity increases in the Sahel and Sudan vegetative zones, impacting agricultural productivity. Poor agricultural output resulting from climate change is a major food security crisis, disrupting the production and distribution systems and contributing to a shortage in food supply, leading to a steady rise in food prices.

Threats posed by Climate change on food production in Nigeria

Climate change has significantly contributed to food insecurity, causing a multitude of problems for agricultural production in Nigeria. These changing weather patterns have consistently had a negative impact on the country's ability to produce a stable and sustainable food supply. Some of the challenges faced due to climate change include:

1. **Increased frequency and intensity of droughts:** Climate change has become a pressing global issue, and Nigeria is not exempt from its impacts. One of the major consequences of climate change in Nigeria is the increased frequency and intensity of droughts. This phenomenon has caused prolonged dry seasons and unpredictable rainfall patterns, posing significant challenges to farmers and exacerbating the risks of food insecurity. Droughts are characterized by a lack of water availability, both in terms of precipitation and soil moisture. With climate change, these droughts have become more frequent and intense in Nigeria. The prolonged dry seasons, coupled with erratic rainfall patterns, disrupt the natural water cycle and reduce the amount of water available for irrigation and crop growth. This has severe consequences for agriculture, which is a vital sector of the Nigerian economy.

One of the immediate and most noticeable effects of increased droughts is the negative impact on crop yields. Farmers heavily rely on rainfall to irrigate their crops, especially in regions where irrigation systems are limited or not well-developed. With reduced rainfall, the soil becomes dry and arid, making it challenging for crops to grow and thrive. Furthermore, the irregular distribution of rainfall leads to uneven moisture levels in the soil, which can hinder seed germination and stunt plant growth. As a result, crops wither and fail to reach their full potential, leading to significant losses for farmers. This reduces the overall food production in the country, making it difficult to meet the growing demand for food. Decreased crop yields also contribute to rising food prices, affecting the general population's access to affordable and nutritious food. This ultimately perpetuates a cycle of poverty and food insecurity.

The increased droughts also have a detrimental impact on livestock farming. Water scarcity affects the availability and quality of drinking water for animals. Livestock, such as cattle, sheep,

and goats, require sufficient water intake for their health and productivity. When water is scarce, the condition and productivity of livestock decline. This may lead to weight loss, reduced milk production, and even death in extreme cases. The consequences are not only devastating for the livelihoods of pastoral communities but also result in a decline in the availability of animal protein for consumption.

On the adaptation front, investments in water management infrastructure and technologies are crucial. The development of reservoirs, dams, and irrigation systems can help in conserving and storing water during periods of high rainfall, and subsequently, ensure its availability during dry spells. Drought-resistant crop varieties and sustainable farming techniques, such as conservation farming and agroforestry, could also be promoted to enhance resilience to droughts. Additionally, education and awareness among farmers regarding climate-smart practices and early warning systems can help minimize losses and improve preparedness for drought events.

2. Desertification and land degradation: The combination of rising temperatures and deforestation poses significant challenges to soil health and fertility in Nigeria, leading to soil erosion and degradation. These factors contribute to the aridification of once-fertile land, ultimately leading to desertification. This phenomenon has far-reaching consequences for agriculture, as it renders agricultural lands unproductive, impeding crop cultivation and livestock rearing. Additionally, the expansion of the Sahara Desert southwards further exacerbates the issue, encroaching on arable land and diminishing the overall land available for farming. Rising temperatures associated with climate change have adverse effects on soil health. Higher temperatures accelerate the rate of evaporation, causing soil moisture to deplete rapidly. This creates a dry and arid environment that is unfavorable for plant growth. Furthermore, increased temperatures also speed up the decomposition of organic matter in the soil, reducing its nutrient content and degrading its overall quality. Add to this the erratic rainfall patterns and prolonged dry seasons caused by climate change, and the soil becomes more susceptible to erosion.

Deforestation is another major driver of soil erosion and degradation. Trees play a vital role in maintaining the stability of the soil. Their roots bind the soil particles together, preventing erosion caused by wind and water. However, widespread deforestation in Nigeria, driven by agricultural expansion, urbanization, and logging, has removed a significant number of trees from the landscape. As a result, the protective 'canopy' that trees provide is lost, leaving the soil vulnerable to erosion. Soil erosion occurs when the top layer of the soil, which is rich in organic matter and nutrients, is washed away by the forces of wind or water. With vegetation removed, the soil is exposed and devoid of natural protection. Rainfall during intense storms and heavy winds carry away the valuable topsoil, leaving behind infertile and compacted soil. This erosion not only depletes the soil of essential nutrients but also reduces its ability to retain water, further exacerbating the effects of drought and aridification.

As the soil degrades and becomes less fertile, farmers face significant challenges in cultivating crops and rearing livestock. Nutrient-depleted soil results in diminished crop yields and poor animal forage, leading to decreased food production and livestock productivity. Farmers are forced to rely on artificial fertilizers, which can be costly and environmentally harmful, or face reduced profits and food insecurity. The expansion of the Sahara Desert southwards compounds the problem of soil erosion and degradation in Nigeria. Desertification occurs when aridification transforms once-fertile land into desert-like conditions, making it unsuitable for agriculture. The

Sahara Desert is gradually advancing towards Nigeria, encroaching on arable land and reducing the overall land available for farming. This phenomenon further diminishes the livelihoods of farmers, as they are left with less land to cultivate and rear livestock.

3. Increased pest and disease prevalence: Climate change has been identified as a significant factor contributing to increased pest and disease prevalence, posing a threat to global food security. The changing climate patterns, primarily warmer temperatures, create favorable conditions for the spread of pests and diseases that can have devastating impacts on crops and livestock. This phenomenon has serious implications for both farmers and the availability of food. The rise in global temperatures due to climate change provides an ideal environment for pests to reproduce and thrive. Warmer temperatures accelerate pests' lifecycles, allowing them to reproduce more frequently, increase in population size, and expand their geographical ranges. Pests such as locusts, armyworms, and crop diseases, which are already problematic, become even more significant threats as they take advantage of these conducive conditions.

Locusts, for example, are notorious for their ability to decimate entire fields of crops within hours. Climate change exacerbates this issue by providing locusts with optimal temperatures for breeding, resulting in larger populations. Additionally, warmer temperatures extend the geographical range in which locusts can survive, leading to the spread of these destructive swarms to regions previously untouched. Similarly, armyworms, which are destructive pests that feed on various crops, also benefit from the warmer climate. Higher temperatures enhance their reproductive rates, causing outbreaks in agricultural areas. Climate change also affects the behavior and migration patterns of these pests, increasing the chances of continued crop destruction.

Apart from pests, climate change facilitates the spread of crop diseases. Many plant diseases are favored by warm, humid conditions - conditions that are becoming more prevalent due to climate change. Increased moisture and humidity provide an environment conducive to the growth and proliferation of pathogens, including fungi, bacteria, and viruses, that can infect plants. These diseases can seriously impact crop yields, quality, and overall plant health. The consequences of increased pest and disease prevalence are substantial. Farmers heavily rely on their crops and livestock for income and food security. When pests and diseases destroy crops and livestock, farmers face economic vulnerability, struggling to earn a livelihood and provide for their families. The loss of income not only affects individual farmers but also has broader implications for local and national economies.

The impact on food availability cannot be underestimated. Crop losses due to pests and diseases can lead to reduced food production, resulting in limited supplies and higher prices. This can exacerbate food insecurity, especially in regions where agriculture is a primary source of sustenance. It can also impact international trade and food distribution, further compounding the issue on a global scale. Addressing the increased pest and disease prevalence requires a multi-faceted approach. Mitigation measures to reduce greenhouse gas emissions and slow down climate change are crucial. By limiting temperature increases, we can mitigate the conducive conditions for pests and diseases to thrive. Additionally, implementing integrated pest management strategies, such as biological control, crop rotation, and resistant crop varieties, can help farmers combat and manage the pests and diseases that pose a threat to their livelihoods.

4. Unpredictable weather patterns: Unpredictable weather patterns have become a significant challenge in Nigeria, as climate change leads to erratic rainfall patterns and an increase in extreme weather events. These shifts in weather conditions hinder agricultural planning and disrupt the growth and development of crops, ultimately impacting food production in the country. Of particular concern are floods and storms, which have become more frequent and intense. Erratic rainfall patterns have adverse effects on agriculture, as farmers rely on consistent and timely rainfall for their crops. However, climate change has disrupted these patterns, leading to irregular periods of rainfall, prolonged droughts, and more concentrated rainfall over shorter periods. These shifts impact planting and harvesting seasons, making it difficult for farmers to plan and optimize their yields. Additionally, unpredictable rainfall patterns can lead to water scarcity, affecting irrigation systems and further exacerbating the challenges farmers face.

Extreme weather events, including floods and storms, have also become more prevalent in Nigeria due to climate change. Floods can have devastating effects on agricultural lands. They can destroy standing crops, wash away topsoil, and contaminate water sources used for irrigation and animal husbandry. The aftermath of floods often leaves behind waterlogged and nutrient-depleted soils, making them unsuitable for agriculture until they have had time to dry and recover. This disruption not only impacts the current growing season but also affects the productivity of the land in subsequent seasons. Another consequence of flooding is the displacement of farmers and loss of livelihoods. Floods can render homes uninhabitable and destroy vital farming infrastructure, such as irrigation systems and storage facilities. This displacement, alongside the loss of crops and income, can have long-lasting impacts on the well-being and food security of affected communities.

Extreme storms, including strong winds and hail, also pose threats to crop cultivation. These events can damage crops, destroy infrastructure, and uproot trees, leading to yield losses and reduced agricultural production. Livestock can also be affected, with exposure to extreme weather causing stress and health issues. Moreover, unpredictable weather patterns can have indirect effects on agriculture. For instance, they can disrupt pollination cycles, impacting the fertilization of crops and reducing their yield potential. Additionally, changes in temperature and moisture levels can create favorable conditions for pests and diseases, leading to increased occurrences and higher levels of infestation.

5. Decreased fishery productivity: Climate change is having a detrimental impact on fishery productivity in Nigeria, particularly in coastal regions. Rising sea temperatures and ocean acidification are major drivers of this decline, posing threats to fish populations and their habitats. As a result, the livelihoods of people who depend on fishing for income and food security are increasingly at risk. One of the major consequences of climate change on fisheries is the increase in sea temperatures. Warmer waters can disrupt the delicate balance of aquatic ecosystems and impact the reproduction, growth, and migration patterns of fish species. Species that are particularly sensitive to warmer temperatures may experience reduced spawning success, altered feeding behavior, and shortened reproductive seasons. As a result, the abundance and distribution of fish populations can change, making it more challenging for fishermen to locate and catch fish.

Ocean acidification, caused by the absorption of carbon dioxide from the atmosphere into the oceans, is another significant concern for fisheries. Increased acidity in seawater can affect the

growth and survival of shell-forming organisms, such as mollusks and crustaceans, which are vital food sources for many fish species. This disruption in the marine food chain can lead to reduced availability and quality of prey for fish, ultimately impacting their overall productivity and health. The decline in fish stocks has severe implications for the communities dependent on fishing for their livelihoods. Coastal communities in Nigeria heavily rely on fishing as a source of income and food security, particularly in regions where other economic opportunities are limited. The decrease in fishery productivity undermines the economic viability of fishing as a profession, resulting in financial hardship and increased vulnerability for fishing communities. Moreover, the loss of fish stocks can lead to a decline in fish availability, making it more challenging for these communities to meet their nutritional needs.

The consequences of decreased fishery productivity go beyond economic and food security concerns. Fishing communities often have rich cultural and social ties to the sea, with fishing practices being deeply embedded in their traditions and way of life. The loss of fish stocks due to climate change threatens the cultural heritage and social cohesion of these communities, as younger generations may be forced to abandon traditional fishing practices in search of alternative livelihoods. Addressing the challenges posed by climate change on fishery productivity requires a multifaceted approach. Mitigation efforts, such as reducing greenhouse gas emissions, are vital to slow down the rate of global warming and ocean acidification. However, as climate change is an ongoing issue, adaptation strategies are equally important. One key adaptation strategy is the diversification of income sources for fishing communities. This can involve promoting alternative livelihoods that are less dependent on fishing, such as aquaculture, tourism, or other forms of coastal resource utilization. Additionally, providing training and support for fishermen to enhance their skills and knowledge in sustainable fishing practices can help maintain fish stocks while minimizing environmental impacts.

6. Limited access to resources and technology: Climate change has a disproportionate impact on small-scale farmers in rural areas, exacerbating their vulnerability and hindering their ability to adapt to changing climatic conditions. Limited access to resources, knowledge, and technology poses significant challenges for these farmers, impeding their capacity to cope with the impacts of climate change and maintain stable food production.

One of the key challenges faced by small-scale farmers in the face of climate change is limited access to improved seeds. Traditional crop varieties may lack the traits necessary to withstand the changing climate, such as drought tolerance, resistance to pests and diseases, or the ability to thrive in warmer temperatures. However, small-scale farmers often lack access to improved seeds that have been developed through breeding programs or biotechnology. These improved seeds can significantly enhance crop productivity and resilience in the face of climate change, as they are specifically adapted to changing environmental conditions. Similarly, limited access to fertilizers can also constrain farmers' ability to adapt to climate change. Fertilizers can help replenish soil nutrients, enhance crop growth, and increase yields. However, small-scale farmers often lack access to affordable and appropriate fertilizers, either due to financial constraints or inadequate distribution networks. As a result, their crop productivity may suffer, and they may struggle to maintain food production levels under the changing climatic conditions.

Irrigation systems play a crucial role in mitigating the impacts of climate change, especially in regions prone to drought or erratic rainfall patterns. However, small-scale farmers often lack

access to reliable irrigation infrastructure or technologies. Without adequate irrigation, farmers become more reliant on rainfall, making their crops vulnerable to droughts or flooding events associated with climate change. Lack of access to appropriate irrigation systems limits their ability to manage water resources efficiently and adapt to changing rainfall patterns.

Climate-resistant farming techniques, such as agroforestry, conservation agriculture, or terracing, can help farmers mitigate and adapt to climate change impacts. These techniques promote sustainable land management practices, such as tree planting to improve soil fertility and water retention, crop rotation to prevent pest and disease buildup, or the use of cover crops to protect soil from erosion. However, small-scale farmers often lack the knowledge and training necessary to implement these practices effectively. They may also lack access to expert advice or extension services that can provide guidance on climate-smart farming techniques. In addition to these challenges, small-scale farmers often face financial constraints that limit their ability to invest in resources and technology needed for climate change adaptation. Limited access to credit or insurance products can hinder their ability to purchase inputs such as improved seeds, fertilizers, or irrigation systems. This financial vulnerability further exacerbates their susceptibility to climate change impacts and can trap them in a cycle of poverty and food insecurity.

Adaptations and Strategies to Mitigate the Impact of Climate Change on Nigeria's Agricultural system

Climate change poses significant threats to Nigeria's agricultural system, which is crucial for food security and rural livelihoods. Rising temperatures, changing rainfall patterns, increased frequency and intensity of extreme weather events, and sea-level rise all contribute to the vulnerability of Nigeria's agriculture. To mitigate the impact of climate change on the agricultural system and build resilience, several adaptations and strategies can be implemented.

- **Diversification of crops and agricultural practices:**
Diversification of crops and agricultural practices is crucial for Nigeria's agricultural system to adapt to the challenges posed by climate change. Currently, the country heavily relies on a few staple crops like maize, rice, and cassava, which are vulnerable to changing weather patterns and increased pest and disease pressures. Therefore, diversifying the range of crops grown, both traditional and exotic, can enhance climate change resilience in the agricultural sector. Introducing and promoting climate-resilient crops such as millets, sorghum, sweet potatoes, and legumes is essential for adapting to changing weather conditions. These crops have the ability to withstand drought, higher temperatures, and are often more resistant to pests and diseases compared to the current staples. By diversifying the crops grown, farmers can reduce their dependency on a few crops and minimize their vulnerability to climate-related risks. In addition to enhancing resilience, diversification offers other benefits to farmers and the environment. Climate-resilient crops often require less water, making them more suitable for regions experiencing water scarcity or erratic rainfall patterns. They also have the potential to provide better nutrition, as they are often rich in essential nutrients that are lacking in the current staple crops. Diversification can lead to improved food security and healthier diets for communities.
Agroforestry practices, such as intercropping trees with crops, provide another avenue to diversify and enhance the resilience of agricultural systems. Trees planted among crops

can provide multiple benefits. They help increase biodiversity, improve soil moisture retention, and enhance soil fertility. The shade provided by the trees can reduce evaporation and water loss, creating a microclimate that is more favorable for crop growth. Moreover, trees can act as windbreaks, which help protect crops from extreme weather events like storms. Agroforestry also offers farmers additional sources of income. Trees can be managed for timber, fruits, or other non-timber forest products, providing additional revenue streams for farmers. These diverse income sources help farmers become more economically resilient to climate-related risks and shocks, reducing their vulnerability to crop failures or market fluctuations. Promoting diversification of crops and agroforestry practices requires a supportive policy environment, access to knowledge and information, and financial incentives for farmers. Governments, non-governmental organizations, and agricultural extension services play a crucial role in providing training and resources to farmers, encouraging the adoption of climate-resilient practices, and facilitating market access for diverse crops. Collaboration between stakeholders is essential to promote diversification and ensure the long-term sustainability and resilience of Nigeria's agricultural system in the face of climate change.

▪ **Crop breeding and use of improved varieties:**

Crop breeding and the use of improved varieties are vital strategies in enhancing the climate resilience of Nigeria's agricultural system. Developing and adopting climate-resilient crop varieties through traditional breeding methods or genetic engineering is crucial to ensure that crops can withstand the challenges posed by climate change, such as drought, heat, and pests. One approach to developing climate-resilient crop varieties is through conventional crop breeding. This process involves selecting and crossing plants with desirable traits, such as drought or pest resistance, and then repeatedly selecting and breeding the best-performing individuals. This iterative process can take several years and requires a deep understanding of plant genetics and breeding techniques. However, by selecting for specific traits, breeders can develop varieties that are better equipped to tolerate the changing climate conditions in Nigeria.

Genetic engineering, on the other hand, offers another avenue to enhance the climate resilience of crops. This technique involves altering the genetic makeup of plants by introducing genes from other species that confer desirable traits, such as insect resistance or drought tolerance. Genetic engineering can potentially speed up the breeding process, as specific genes can be inserted directly into crops to express desired characteristics. However, it is essential to ensure that the genetically modified crops are thoroughly tested for safety and adhere to strict regulations to mitigate any potential risks. Promoting the use of improved seed varieties that are specifically suited to local agroecological conditions is crucial for enhancing farmers' adaptive capacity. These improved varieties have been carefully selected or developed to perform well under specific environmental conditions, taking into account factors such as temperature, rainfall, and soil type. By using these varieties, farmers can increase their chances of achieving better yields and reducing losses due to climate-related stresses. Furthermore, improved seed varieties often have other advantageous traits, such as faster maturation or increased nutritional value. These traits can help farmers cope with climate-related challenges by allowing them to harvest their crops earlier or provide better nutrition for their communities.

To encourage the adoption of improved varieties, various strategies can be employed. This includes providing farmers with access to high-quality seeds, promoting seed

multiplication programs, and offering training on crop management techniques specific to these varieties. Additionally, collaborations between research institutions, seed companies, and agricultural extension services are instrumental in disseminating information about the benefits of improved varieties and ensuring their availability to farmers. However, it is crucial to address any potential challenges associated with the adoption of improved seed varieties. This includes considering issues related to cost, accessibility, and potential impacts on traditional farming practices. Collaborative efforts between public and private sectors are necessary to develop appropriate policies and mechanisms to ensure equitable access to improved seed varieties for small-scale farmers across Nigeria.

▪ **Water management and efficient irrigation:**

Water management and efficient irrigation practices are critical in mitigating the impact of climate change on agriculture. Climate change has led to unpredictable rainfall patterns and decreased water availability, posing significant challenges for farmers around the world. In order to ensure food security and sustainable agricultural practices, effective water management strategies must be implemented. One crucial aspect of water management is investing in irrigation infrastructure. This includes the development of small-scale and community-based irrigation systems that can provide farmers with a reliable water supply even during periods of erratic rainfall or drought. Such systems can help ensure a steady water source for crops, mitigating the risks associated with climate change-induced water scarcity.

Promoting efficient irrigation techniques like drip irrigation and precision farming can play a pivotal role in optimizing water use and minimizing water loss. Drip irrigation involves the direct application of water to the plant root zone, reducing wastage and maximizing water efficiency. Precision farming, on the other hand, utilizes advanced technologies such as sensors and data analytics to precisely measure soil moisture levels and deliver water in a targeted manner. By using water judiciously, these techniques can significantly reduce the amount of water required for agriculture, minimizing pressure on increasingly scarce water resources. Implementing smart irrigation technologies can help farmers adapt to changing climate conditions by providing them with greater control over water resources. For instance, technologies like soil moisture sensors can indicate when crops need irrigation, enabling farmers to provide water only when necessary. Additionally, automated irrigation systems can adjust watering schedules based on weather forecasts, ensuring that crops receive just the right amount of water at the optimal time. These innovative approaches can enhance water management practices and contribute to the sustainability of agricultural systems in the face of climate change.

Efficient water management and irrigation techniques are not only beneficial for farmers but also have broader environmental implications. By reducing excessive water use and minimizing water loss through appropriate irrigation methods, there is a reduction in the pressure on water sources like rivers and underground aquifers. This ensures the maintenance of healthy ecosystems and sustains biodiversity, safeguarding the long-term availability of water resources for both agricultural and non-agricultural purposes.

▪ **Sustainable soil management:**

Sustainable soil management practices are crucial in combating the detrimental effects of climate change on soil health, erosion, and fertility. Climate change exacerbates soil erosion, causes soil degradation, and diminishes its fertility, posing significant threats to

agricultural productivity and food security. Implementing sustainable soil management practices can minimize these impacts and ensure the long-term viability of agricultural systems. One effective approach to sustainable soil management is conservation agriculture. Conservation agriculture involves the adoption of practices such as minimum tillage, crop residue management, and the use of cover crops. Minimum tillage reduces soil disturbance by minimizing the depth and frequency of plowing, which helps to preserve soil structure and organic matter. This practice improves soil condition, enhances water infiltration, and reduces soil erosion, as less soil is exposed to erosion agents like wind and water.

Another vital aspect of conservation agriculture is crop residue management. Crop residues, such as leftover stalks and leaves, can be left on the field after harvest and act as a protective cover for the soil. By retaining crop residues, soil erosion caused by wind and water is reduced, and the soil is protected from direct sunlight, preventing excessive evaporation and maintaining soil moisture levels. Moreover, crop residues gradually break down, enriching the soil with organic matter and improving its fertility. Cover crops, also known as green manure, are another essential component of conservation agriculture. Cover crops are non-cash crops grown specifically to cover the soil between cash crop cycles. They help prevent soil erosion by shielding the soil from the impact of heavy rainfall and wind. Additionally, cover crops improve soil structure and fertility by adding organic matter, enhancing nutrient availability, and promoting beneficial soil microbial activity.

Terracing is another sustainable soil management technique that can help mitigate the negative effects of climate change. Terracing involves constructing steps or benches along hilly terrains. By creating terraces, water runoff is reduced, and soil erosion is minimized, as the water is forced to flow in a controlled manner along the terraced landscape. This practice helps retain water and nutrients in the soil, prevents soil degradation, and optimizes agricultural production even in regions prone to heavy rainfall and erosion.

Agroforestry, the integration of trees and crops or livestock, is also an effective soil management practice. Trees act as windbreaks, reducing wind erosion and protecting the soil from strong gusts. Their root systems help stabilize the soil, preventing erosion caused by water runoff. Furthermore, trees contribute organic matter through leaf litter and root decomposition, adding nutrients to the soil and enriching its fertility. Agroforestry systems, which combine agricultural production with the cultivation of trees, create a balanced ecosystem that supports sustainable soil management and enhances climate resilience. By adopting sustainable soil management techniques, farmers can improve soil structure, increase water-holding capacity, reduce erosion, and enhance soil fertility. These practices not only mitigate the impacts of climate change on soil health but also contribute to increased agricultural productivity, food security, and biodiversity conservation. It is vital to promote the wide-scale adoption of these techniques and educate farmers on their benefits to ensure the long-term sustainability of agricultural systems in the face of climate change.

- **Climate-smart agricultural practices:**

In the face of climate change, adopting climate-smart agricultural practices is essential for ensuring sustainable and resilient food production systems. These practices aim to increase agricultural productivity while simultaneously enhancing adaptation to climate

change and reducing greenhouse gas emissions. Agroecology is one such climate-smart agricultural approach that emphasizes ecological interactions, diversity, and resilience. It focuses on understanding and harnessing the productive potential of natural ecosystems, enhancing biodiversity, and promoting ecological balance. Agroecological practices encompass a range of techniques, including crop diversification, intercropping, crop rotation, and the integration of livestock and crops. These practices contribute to soil health, water conservation, and pest control while reducing the reliance on synthetic fertilizers and pesticides.

Organic farming is another climate-smart practice that aligns with the principles of agroecology. It emphasizes the use of natural inputs, such as compost and organic fertilizers, while avoiding the use of synthetic chemicals. Organic farming methods promote soil health, biodiversity, and the conservation of natural resources. By enhancing soil organic matter content and structure, organic farming improves soil fertility, water retention, and carbon sequestration, making it a sustainable option for climate-resilient agriculture. Precision farming, enabled by advancements in technology, is another vital tool for climate-smart agriculture. Precision farming involves using precision tools, such as GPS, sensors, and drones, to precisely apply inputs, optimize resource use, and monitor crop growth. These technologies enable farmers to tailor their farming practices according to site-specific conditions, resulting in increased productivity, reduced resource use, and minimized environmental impacts. Precision farming also facilitates better adaptation to climatic variability, as it allows for real-time monitoring and decision-making to optimize resource allocation.

Integrated pest management (IPM) is a climate-smart approach that seeks to manage pests effectively while minimizing the ecological and health risks associated with pesticide use. IPM emphasizes the use of natural pest control methods, such as biopesticides, botanical extracts, and cultural practices, to suppress pest populations. It also encourages the implementation of monitoring systems to accurately assess pest pressure and apply targeted interventions. By reducing reliance on synthetic pesticides, IPM promotes biodiversity, protects beneficial insects, and improves the overall health and resilience of agroecosystems. Incorporating these climate-smart agricultural practices in farming systems offers multiple benefits. Firstly, these practices enhance agricultural productivity by optimizing resource use, increasing yields, and improving soil fertility. Secondly, they build resilience to climate change by enhancing the ability of farming systems to withstand and adapt to climate-related uncertainties. Thirdly, these practices contribute to greenhouse gas mitigation by reducing emissions associated with synthetic inputs and promoting practices that sequester carbon in agricultural soils and vegetation.

- **Capacity building and knowledge sharing**

Capacity building and knowledge sharing are essential components for fostering climate resilience in agriculture. It is crucial to empower farmers with the necessary skills and knowledge to adapt to and mitigate climate change impacts. Government agencies, non-governmental organizations (NGOs), and extension services have a critical role to play in providing training and technical support to farmers in adopting climate-smart agricultural practices. Effective capacity building includes equipping farmers with the knowledge and skills to implement climate-smart agricultural practices such as agroecology, organic farming, precision farming, and integrated pest management. This involves teaching farmers about the principles, benefits, and application of these practices in different

agroecological contexts. Training programs should cover a wide range of topics, including crop diversification, soil management, water conservation, pest control, and climate-resilient farming techniques.

Sustainable land management is another crucial aspect of capacity building for climate resilience. Farmers need to be aware of the importance of soil conservation, erosion control, and proper land use planning. Education and training on techniques like contour plowing, terracing, and agroforestry can help farmers minimize soil degradation, improve water-use efficiency, and enhance overall ecosystem health. Moreover, access to improved crop varieties that are resilient to climate change is vital for farmers. Training programs should include information on climate-resistant crop varieties and their characteristics. Farmers need to learn how to select, cultivate, and manage such varieties to enhance their adaptability and productivity in changing climatic conditions.

Knowledge sharing platforms, such as farmer field schools, can greatly contribute to capacity building in agriculture. These platforms create opportunities for farmers to come together, exchange experiences, and learn from each other's successes and challenges. Farmer field schools provide a hands-on learning environment where farmers can observe and experiment with new techniques under the guidance of trained facilitators. This peer-to-peer learning approach fosters local innovation, builds social capital, and strengthens community resilience by tapping into the wealth of local knowledge and experience. In addition to farmer field schools, digital platforms, online forums, and mobile applications can serve as tools for knowledge sharing. These platforms enable farmers to access information, connect with experts, and exchange ideas even in remote areas. Combined with on-the-ground training and extension services, these digital tools can enhance accessibility and efficiency in knowledge dissemination.

▪ **Access to credit and insurance:**

Access to credit and insurance is crucial for farmers, especially smallholder farmers, who are often more vulnerable to the adverse effects of climate change. Climate change can lead to unpredictable weather patterns, which can result in crop failure, reduced yields, and financial losses for farmers. In such situations, access to affordable credit and insurance schemes becomes vital to help farmers cope with these climate-related risks. One of the primary benefits of providing credit to farmers is that it enables them to invest in climate-resilient farming practices and technologies. For instance, farmers can use credit to purchase seeds and inputs that are more resistant to extreme weather conditions or to implement irrigation systems that reduce their dependency on rainfall. By adopting such practices, farmers can increase their chances of crop survival and maintain their agricultural productivity even in the face of changing climate conditions. In addition to enabling climate-resilient farming practices, credit also allows farmers to recover from climate-related losses. In case of crop failures or yield reductions due to extreme weather events, such as droughts or floods, farmers need financial assistance to bounce back. Access to affordable credit helps farmers cover their immediate needs, such as buying food for their families, and also provides funds to invest in the next agricultural cycle.

Insurance schemes are another essential component in protecting farmers from climate-related risks. By having insurance coverage, farmers can mitigate the financial impact of crop failures and extreme weather events. Insurance policies designed specifically for farmers allow them to transfer the risk associated with climate variability to insurance companies. In case of crop losses, farmers can make claims and receive compensation,

which helps them recover their financial losses and continue their agricultural activities. Developing suitable insurance products tailored to the needs of smallholder farmers is crucial. Traditional insurance schemes designed for large-scale commercial farming might not be appropriate for smallholder farmers who have limited resources and face unique challenges. Collaborative efforts between governments and financial institutions can help in designing insurance products that address the specific needs of smallholder farmers, such as flexible premium payments, coverage against specific climate risks, and simplified claim procedures.

- **Policy support and institutional coordination:**

Policy support and institutional coordination play a crucial role in addressing the challenges posed by climate change within the agricultural sector. To effectively respond to the impacts of climate change, governments at the national level should prioritize the integration of climate change adaptation and mitigation measures into their agricultural policies, strategies, and investment plans. By incorporating climate change considerations into agricultural policies, governments can provide a clear framework for farmers and other stakeholders to understand and respond to the changing climatic conditions. This could entail providing guidance on appropriate cropping patterns, irrigation techniques, and the promotion of climate-resilient farming practices. Moreover, such policies can also facilitate the adoption of climate-smart technologies, such as precision agriculture, agroforestry, and sustainable land management practices, which can help enhance the resilience and productivity of agricultural systems.

Effective policy support also involves the allocation of financial resources and incentives to encourage farmers to adopt climate-friendly practices. Governments can introduce subsidies, grants, or low-interest loans that promote the use of renewable energy, energy-efficient technologies, and sustainable agricultural practices. By providing financial support, governments can help offset the initial costs of adopting climate-smart practices for farmers who may otherwise face financial barriers. Institutional coordination is essential to ensure the successful implementation of climate change adaptation and mitigation measures in the agricultural sector. The complexity of climate change impacts cuts across multiple sectors, including agriculture, environment, and water resources. Therefore, close coordination and collaboration among relevant ministries are necessary to foster coherence, avoid duplication of efforts, and optimize resource allocation.

Agriculture ministries are crucial in driving policy formulation and implementation, as they possess the expertise and understanding of sector-specific challenges. However, collaboration with environment ministries is equally important, as they can provide insights into climate change projections, ecosystem services, and the conservation of biodiversity. Water resources ministries can offer valuable guidance on efficient water management, considering the growing water scarcity concerns exacerbated by climate change. Institutional coordination can be facilitated through the establishment of inter-ministerial committees or working groups that bring together representatives from different ministries to jointly address climate change challenges in the agricultural sector. Regular meetings, information sharing, and coordination mechanisms can help ensure a holistic and integrated approach to policy implementation..

- **Climate information and early warning systems:**

Climate information and early warning systems play a critical role in supporting farmers to make informed decisions and adapt their agricultural practices in response to changing

weather patterns and climate-related risks. Timely and accurate climate information is essential for farmers to effectively plan their planting and harvesting schedules, manage irrigation, and make informed decisions regarding crop selection and pest management strategies. Developing and strengthening weather monitoring systems is a fundamental component of climate information systems. This involves the installation of weather stations, satellite imagery, and remote sensing technologies to collect and analyze meteorological data. These systems monitor variables such as temperature, rainfall, humidity, wind patterns, and extreme weather events, providing critical insights into climate trends and patterns.

Early warning systems are designed to provide farmers with advanced notice of potential climate-related risks such as droughts, floods, storms, or heatwaves. By utilizing weather forecasts, historical climate data, and advanced modeling techniques, these systems can issue warnings and advisories to farmers, enabling them to take precautionary measures to protect their crops, livestock, and agricultural infrastructure. Climate services, which encompass the dissemination of climate-related information to end-users in a user-friendly and accessible manner, are also pivotal. Climate services can be delivered through various channels, including mobile phones, radio broadcasts, community meetings, and interactive websites. The information shared through climate services should be tailored to the specific needs and priorities of farmers, providing actionable advice and guidance that can support decision-making at the farm level.

To build effective climate information and early warning systems, collaboration and partnerships between meteorological agencies, agricultural extension services, research institutions, and farmer organizations are crucial. These partnerships can facilitate the exchange of data, knowledge, and expertise, contributing to more accurate and localized climate information.

- **Farmer cooperatives and sustainable value chains:**

Encouraging farmers to form cooperatives plays a crucial role in promoting collective action, enhancing farmers' bargaining power, and improving their access to markets and resources. By working together, farmers can pool their resources, knowledge, and skills to achieve common goals, such as securing fair prices for their products, accessing financial services, and obtaining inputs at competitive rates. Farmer cooperatives can also facilitate collective decision-making, knowledge exchange, and training, which can contribute to the overall improvement of agricultural practices. One of the key benefits of farmer cooperatives is their ability to provide farmers with a stronger negotiating position when dealing with buyers, processors, and other market actors. By aggregating their produce and selling collectively, farmers can negotiate fair prices and contractual terms, reducing their vulnerability to exploitative practices and market fluctuations. Cooperatives can also enable farmers to access larger markets that may otherwise be difficult to enter as individual small-scale producers.

In addition to market access, farmer cooperatives can foster the development of sustainable value chains. Sustainable value chains prioritize environmental stewardship, social responsibility, and economic viability throughout the entire production and supply chain. By promoting sustainable practices such as organic farming, fair trade certifications, and climate-resilient infrastructure, farmer cooperatives can contribute to sustainable and responsible agriculture. Organic certifications encourage farmers to adopt environmentally friendly practices, such as reducing or eliminating synthetic pesticides

and fertilizers, conserving water and soil, and enhancing biodiversity. These certifications not only differentiate farmers' products in the market but also provide them with access to premium prices, as there is a growing demand for organic produce. Another important aspect of sustainable value chains is the concept of fair trade. Fair trade practices ensure that farmers receive equitable remuneration for their work, fair access to markets, and support for social and environmental sustainability. Through fair trade arrangements, farmers can receive fair prices for their products, and additional premiums can be invested in community development projects, education, and healthcare.

Moreover, sustainable value chains can incorporate climate-resilient infrastructure, which includes infrastructure and practices that enable farmers to adapt to and mitigate the impacts of climate change. This can include measures such as improved irrigation systems, rainwater harvesting, agroforestry, and the use of drought-resistant crop varieties. By enhancing climate resilience, farmer cooperatives can help farmers better cope with extreme weather events and changing climatic conditions, reducing their vulnerability and promoting long-term sustainability. To promote the formation of farmer cooperatives and sustainable value chains, governments, NGOs, and development agencies can provide support in various forms. This support can include technical assistance and training to strengthen cooperative management skills, access to credit and financial services, capacity-building initiatives to enhance sustainable farming practices, and assistance in obtaining certifications and meeting market requirements.

Discussion of findings

The findings of this study highlight the profound implications of climate change on agriculture and food security in Nigeria. Given its heavy reliance on agriculture, Nigeria is particularly vulnerable to the adverse impacts of climate change. The study employs a qualitative methodology that involves a thorough examination of relevant literature, systematic analysis, data analysis, and case studies to shed light on the factors contributing to the vulnerability of food production systems in Nigeria.

The climate in Nigeria is diverse, with different regions experiencing varying weather patterns and climatic conditions. Factors such as latitude, topography, winds, ocean currents, and the presence of the Sahara Desert in the north influence Nigeria's climate. Climate change has severe impacts on agriculture in Nigeria, affecting food production and availability, as well as the overall stability of global food systems. Agriculture in Nigeria contributes significantly to the country's economy and livelihoods, making the impacts of climate change particularly severe.

The study emphasizes the threats posed by climate change on food production in Nigeria, resulting in food insecurity and problems for agricultural production. Some of the challenges faced include increased frequency and intensity of droughts, desertification and land degradation, increased pest and disease prevalence, unpredictable weather patterns, decreased fishery productivity, and limited access to resources and technology.

To mitigate the impact of climate change on Nigeria's agricultural system and build resilience, the study proposes several adaptations and strategies. These include diversification of crops and agricultural practices, crop breeding and the use of improved varieties, water management and efficient irrigation, sustainable soil management, climate-smart agricultural practices, capacity

building and knowledge sharing, access to credit and insurance, policy support and institutional coordination, climate information and early warning systems, and farmer cooperatives and sustainable value chains.

Recommendation:

Based on the findings and analysis presented in this study, the following recommendations are proposed to mitigate the impact of climate change on Nigeria's agricultural system:

1. **Diversification of crops and agricultural practices:** Encourage farmers to diversify their crop choices and adopt sustainable agricultural practices such as agroforestry and organic farming. This will help reduce the risk of crop failure and enhance resilience to changing climatic conditions.
2. **Crop breeding and use of improved varieties:** Invest in research and development programs to breed and promote the use of improved crop varieties that are resilient to climate change. This will enable farmers to adapt to changing conditions and maintain agricultural productivity.
3. **Water management and efficient irrigation:** Improve water management techniques and promote the use of efficient irrigation systems to optimize water usage and cope with changing rainfall patterns. This will help ensure reliable water supply for agricultural activities.
4. **Sustainable soil management:** Implement sustainable soil management practices, including conservation agriculture and the use of organic matter, to improve soil health and reduce erosion. This will enhance the fertility and resilience of soils, contributing to long-term agricultural sustainability.
5. **Climate-smart agricultural practices:** Promote and support the adoption of climate-smart agricultural practices, such as integrated pest management, precision farming, and agroecology. These practices enhance productivity, reduce greenhouse gas emissions, and increase resilience to climate change.
6. **Capacity building and knowledge sharing:** Invest in training and capacity building programs for farmers, extension workers, and policymakers to enhance their understanding of climate change impacts and adaptation strategies. Facilitate knowledge sharing platforms to disseminate information and best practices among stakeholders.
7. **Access to credit and insurance:** Ensure that farmers have access to affordable credit and agricultural insurance schemes to mitigate the financial risks associated with climate change impacts. This will provide a safety net for farmers in times of crop failure or extreme weather events.
8. **Policy support and institutional coordination:** Develop and implement policies and regulations that support climate change adaptation in the agricultural sector. Strengthen institutional coordination and collaboration among relevant government ministries, research institutions, and farmer organizations to ensure effective implementation of adaptation strategies.
9. **Climate information and early warning systems:** Strengthen climate information systems, including weather forecasting and early warning systems, to provide timely and accurate

information to farmers. This will enable them to make informed decisions regarding planting, irrigation, and pest management, reducing vulnerability to climate change.

10. Farmer cooperatives and sustainable value chains: Promote the formation of farmer cooperatives and support the development of sustainable agricultural value chains. This will improve farmers' access to markets, technology, and financial resources, enhancing their resilience to climate change.

By implementing these adaptations and strategies, Nigeria can enhance the resilience and sustainability of its agricultural system in the face of climate change. This will contribute to ensuring food security and livelihoods for its population, as well as supporting economic development in the country.

Conclusion

Climate change poses significant threats to Nigeria's agricultural sector, which plays a crucial role in the country's economy, food security, and livelihoods. The changing weather patterns, such as increased temperatures, changing rainfall patterns, and more frequent extreme weather events, have led to a multitude of challenges for food production in Nigeria. These challenges include droughts, desertification, increased pest and disease prevalence, unpredictable weather patterns, decreased fishery productivity, and limited access to resources and technology.

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