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Effect of climate change adaptation strategies on food security of farming households in Nigeria

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Declaration

I hereby declare that I have done this dissertation entitled "**Effect of climate change adaptation strategies on food security of farming households in Nigeria**" independently, all texts in this dissertation 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, 22 August 2023

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Mustapha Yakubu Madaki

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Abstract in English

Climate risk is a major threat to the sustainable food production of many farmers who depend on rainfed agricultural systems also, the livestock sector is affected by climate variability due to climate change. Farmers must adapt to achieve economic viability and food security. Nigeria is committed to achieving a 20% unconditional and 45% conditional reduction of GHGs emissions by 2030 through a strong focus on awareness and preparedness for climate change impacts via the mobilization of local communities for climate change mitigation and adaptation actions. As a response to this threat, climate-smart agricultural innovations, such as insurance, livestock adaptations, drought-tolerant, and early mature varieties, have been promoted. It is well-known that adopting innovations and improved technologies positively impact on adopters' well-being. This study first, assessed the knowledge of agriculturally related practices associated with climate change and its relation to their climate change perception and the determinants of climate change awareness and knowledge using Logistic and Poisson regression analysis. Secondly, the study analyzed the drivers of awareness and adoption of agricultural insurance in Nigeria using Logistic regression models. Thirdly, the study also investigated the effect of the agroecological and institutional factors on the adoption of livestock climate risk adaptation strategies using Logistic regression models. Finally, this study sought to analyze the factors that influence the adoption of crop adaptations and subsequently estimate how the food security of farming households is affected by the adoption using treatment effect estimation techniques that address selection bias and endogeneity factors. One thousand and eighty (1,080) farming households were interviewed across six agroecological zones (AEZs) of Nigeria, data were collected in face-to-face interviews from October 2020 to February 2021. The result revealed that most farmers know that deforestation and land clearance by bush burning contributes to climate change. However, many farmers did not know that methane emissions from livestock (enteric fermentation) can cause climate change. Our results further show that the farmers' perception of climate change is associated with climate change knowledge. Information received from government extension services and environmental NGOs, radio, as well as experiencing extreme weather events affects climate change awareness and knowledge of farmers. Farmers of dry AEZs were more aware and knowledgeable of the agricultural practices contributing to the changing environment. Awareness and adoption of agricultural insurance were found to affect positively by education, herds size, access to a bank, weather information, and flood experiences. Livestock farmers of dry AEZs are more likely to adopt irrigation, destocking, and preserving of crop residues and hay, and are less likely to switch to crop production and off-farm income generation than farmers of humid AEZs. Preserving of crop residues and hay, irrigation, and destocking adaptations are affected by extension services, climate change awareness, and livestock-related information in a positive way. Access to extension, crop-related and weather information, access to credit and climate change awareness of farmers increase the adoption likelihood of the crop adaptation strategies. The adoption of climate risk adaptation strategies has a positive impact on the food security of farming households. Using extension, environmental NGOs and radio to disseminate climate change information will help further guide and shape farmers' perceptions of scientific findings for appropriate actions. We suggest access to weather information and increasing banks' accessibility to smallholder farmers to promote the use of insurance policies. Disseminating improved knowledge of preserving crop residues such as silage and provision of credit and marketing information to avoid unprofitable destocking, and construction of water-efficient irrigation facilities in moisture-stressed AEZs will help adopt livestock climate-smart practices. Enhancing the accessibility of the drought-tolerant and early mature varieties, promoting crop-related and weather information through extension services, and empowering farmers through credit accessibility would strengthen the adoption of climate risk adaptation strategies to increase agricultural resilience against changing environment for sustainable food security.

Keywords: Climate change awareness and knowledge, Agricultural insurance, Livestock adaptation, Crop adaptation, Agroecological zones, Dietary diversity score, Coping strategy index, Weather information, Endogenous switching regression.

Abstract in Czech

Klimatické riziko je velkou hrozbou pro udržitelnou produkci potravin mnoha zemědělců, kteří jsou závislí na zemědělských systémech zavlažovaných deštěm. Zemědělci se musí přizpůsobit, aby dosáhli hospodářské životaschopnosti a potravinové bezpečnosti. Nigérie se zavázala dosáhnout 20% bezpodmínečného a 45% podmíněného snížení emisí skleníkových plynů do roku 2030 prostřednictvím silného zaměření na povědomí a připravenost na dopady změny klimatu prostřednictvím mobilizace místních komunit pro opatření ke zmírnění změny klimatu a přizpůsobení se této změně. V reakci na tuto hrozbu se prosazují klimaticky inteligentní zemědělské inovace, jako je pojištění, adaptace hospodářských zvířat, odolné vůči suchu a rané zralé odrůdy. Je dobře známo, že zavádění inovací a zdokonalených technologií má pozitivní dopad na pohodu uživatelů. Tato studie nejprve zhodnotila znalosti zemědělských postupů spojených se změnou klimatu a jejich vztah k jejich vnímání změny klimatu a determinanty povědomí a znalostí o změně klimatu pomocí logistické a Poissonovy regresní analýzy. Za druhé, studie analyzovala hnací síly povědomí a přijetí zemědělského pojištění v Nigérii pomocí logistických regresních modelů. Za třetí, studie také zkoumala vliv agroekologických a institucionálních faktorů na přijetí strategií adaptace rizik spojených s klimatickým rizikem hospodářských zvířat pomocí logistických regresních modelů. Nakonec se tato studie snažila analyzovat faktory, které ovlivňují přijetí adaptací plodin, a následně odhadnout, jak je potravinová bezpečnost zemědělských domácností ovlivněna přijetím pomocí technik odhadu účinku léčby, které se zabývají výběrovým zkreslením a faktory endogenity. Tisíc osmdesát (1 080) zemědělských domácností bylo dotazováno v šesti agroekologických zónách (AEZ) Nigérie, údaje byly shromážděny v osobních rozhovorech od října 2020 do února 2021. Výsledek ukázal, že většina zemědělců ví, že odlesňování a mýcení půdy vypalováním keřů přispívá ke změně klimatu. Mnoho zemědělců však nevědělo, že emise metanu z hospodářských zvířat (enterické kvašení) mohou způsobit změnu klimatu. Naše výsledky dále ukazují, že vnímání změny klimatu zemědělci je spojeno se znalostmi o změně klimatu. Informace získané od vládních nástavbových služeb a ekologických nevládních organizací, rozhlasu, stejně jako zkušenosti s extrémními povětrnostními událostmi ovlivňují povědomí o změně klimatu a znalosti zemědělců. Zemědělci suchých vývozních zpracovatelských zón byli více informováni a informováni o zemědělských postupech, které přispívají k měnícímu se prostředí. Bylo zjištěno, že

povědomí a přijetí zemědělského pojištění pozitivně ovlivňuje vzdělání, velikost stáda, přístup k bance, informace o počasí a zkušenosti s povodněmi. Chovatelé hospodářských zvířat v suchých AEZ s větší pravděpodobností přijmou zavlažování, vyskladňování a konzervaci zbytků plodin a sena a je méně pravděpodobné, že přejdou na produkci plodin a tvorbu příjmů mimo zemědělský podnik než zemědělci s vlhkými AEZ. Zachování zbytků plodin a sena, zavlažování a vysazování ryb je pozitivně ovlivněno nástavbovými službami, povědomím o změně klimatu a informacemi o hospodářských zvířatech. Přístup k informacím o rozšíření, informacím o plodinách a počasí, přístupu k úvěrům a povědomí zemědělců o změně klimatu zvyšují pravděpodobnost přijetí strategií pro přizpůsobení se plodinám. Přijetí strategií pro přizpůsobení se klimatickým rizikům má pozitivní dopad na zabezpečení potravin v zemědělských domácnostech. Využívání rozšíření, environmentálních nevládních organizací a rádia k šíření informací o změně klimatu pomůže zemědělcům dále řídit a formovat vnímání vědeckých poznatků pro vhodná opatření. Navrhujeme přístup k informacím o počasí a zvýšení dostupnosti bank pro drobné zemědělce, aby se podpořilo využívání pojistných smluv. Šíření lepších znalostí o zachování zbytků plodin, jako je siláž, poskytování úvěrových a marketingových informací, aby se zabránilo neziskovému vysazování, a výstavba zavlažovacích zařízení účinně využívajících vodu v AEZ s nedostatkem vlhkosti pomůže přijmout postupy šetrné ke klimatu hospodářských zvířat. Zlepšení dostupnosti odrůd odolných vůči suchu a odrůd zralých v raném věku, podpora informací o plodinách a počasí prostřednictvím nástavbových služeb a posílení postavení zemědělců prostřednictvím dostupnosti úvěrů by posílilo přijetí strategií pro přizpůsobení se rizikům spojeným s klimatem s cílem zvýšit odolnost zemědělství vůči měnícímu se prostředí pro udržitelné zabezpečení potravin.

Klíčová slova: povědomí a znalosti o změně klimatu, Zemědělské pojištění, Adaptace hospodářských zvířat, Adaptace plodin, Agroekologické zóny, Skóre dietní diverzity, Index strategie zvládání, Informace o počasí, Endogenní regrese přepínání.

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List of the abbreviations used in the Dissertation

ACGSF	Agricultural Credit Guarantee Scheme Fund
AEZs	Agroecological Zones
AIETA	Awareness Interest Evaluation Trial and Adoption
ATE	Average Treatment Effect
ATT	Average Treatment Effect of the Treated
BNRCC	Building Nigeria's Response to Climate Change
CBFRMP	Community-Based Forest Resource Management Programme
CC	Climate Change
CCAI	Climate Change Awareness Index
CCEIAI	Climate Change Environmental Impact Awareness Index
CH_4	Methane
CIRAD	French Agricultural Research Centre for International Development
CO_2	Carbon dioxides
CSA	Climate-Smart Agriculture
CSI	Coping Strategy Index
CSOs	Community Service Organizations
DDS	Dietary Diversity Score
ELCSA	Latin American and Caribbean Household Food Security Scale
EPA	Environmental Protection Agency
eq.	Eques solution
ESR	Endogeneity Switching Regression
FANTA	Food and Nutrition Technical Assistance Project
FAO	Food and Agricultural Organization
FCS	Food Consumption Score
FME	Federal Ministry of Environment
GACSA	Global Alliance for Climate-Smart Agriculture
GDP	Gross Domestic Product
GFCS	Global Framework for Climate Services
GHGs	Green House Gases
GWP	Global Warming Potentials
HDI	Human Development Indicators
HFCs	Hydrofluorocarbons
HFIAS	Household Food Insecurity Access Scale

HFSSM	Households Food Security Survey Module
HHS	Households Hunger Scale
IAEA	International Atomic Energy Agency
IFAD	International Fund for Agricultural Development
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel for Climate Change
IPWRA	Inverse Probability Weighted Regression Adjustment
IWMI	International Water Management Institute
Km	Kilometre
LCA	Livestock Climate Adaptation
LGAs	Local Government Areas
mm	millimetre of mercury
N_2O	Nitrous of Oxide
NAIC	National Agricultural Insurance Corporation
NARF	National Agricultural Resilience Framework
NBSAP	National Biodiversity Strategy Action Plan
NCISN	National Corporation Insurance Society of Nigeria
NGOs	Non-governmental Organizations
NICON	National Insurance Corporation of Nigeria
NiMet	Nigerian Metrological Agency
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
OECD	The Organization for Economic Cooperation and Development
OIG	Off-Income Generation
PCSH	Preserving Crop Straw and Residue
PFLCs	Perfluorocarbons
ppm	part per million
PSM	Propensity Score Matching
RCTs	Randomised Control Trials
SF_6	Sulphur hexafluoride
SOC	Soil Organic Carbon
UN	United Nations
UNDP	United Nation Development Programme
UNFCCC	United Nation Framework Committee on Climate Change

UNICEF	United Nation Children Emergency Fund
UNSTAT	United Nation Statistics
US	United State
USAID	United State Agency for International Development
VIF	Variance Inflation Factor
WFP	World Food Programme
WMO	World Metrological Organization

1 Introduction

Climate changes (CC) affect the global temperature, quantity and precipitation pattern resulting in heatwaves, erratic rainfall, and other weather extremes (IPCC 2020). These events negatively affect agri-food production yields and quality (Arora 2019 OECD 2016), cause deterioration of rural livelihoods, and increase food insecurity (FAO ECA and AUC 2021; Zewdie 2014). As a result, the number of hungry people in the world and Africa in particular, has risen. Food insecurity in Africa risen by 47 million since 2014 and now stands at 250 million, or nearly one-fifth of the region (FAO ECA and AUC 2021). In that way, small-holder farmers constituted a greater portion of food-insecure families of the region (FAO 2021a).

To keep her agreement on global change action and reduce the worrisome effect of CC, Nigeria is committed to reduce GHGs emission as the country identified as a CC hotspot (UN 2018). The country faces the deleterious effects of CC such as changes in rainfall patterns, desertification, flooding and drought (IPCC 2014). These will negatively have an impact on the environment and result in a loss to Nigeria's GDP of 1.27% by 2027 and 3.42% by the year 2037 (Kompas et al. 2018). As a condition of the Paris Agreement climate actions, Nigeria formulated an Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) with the objective of achieving a 20% unconditional and 45% conditional reduction of GHGs-emissions by 2030. This includes a strong focus on awareness and preparedness for climate CC impacts via the mobilization of local communities for CC mitigation and adaptation actions (Li et al. 2017). In addition, it is intended to integrate CC mitigation and adaptation into national, sectoral, state and local government planning as well as into the plans of universities, research and educational organizations, civil society organizations, the private sector and the media (UNFCCC 2015).

The National climate actions regarding agricultural sector includes: improve awareness and preparedness of farmers for CC impacts; adopt improved agricultural systems for both crops and livestock (for example, diversify livestock and improve range management; increase access to drought-resistant crops and livestock feeds; agricultural insurance; adopt better soil management practices); provide early warning/meteorological forecasts and related information; implement strategies for improved resource management (for example, increase the use of irrigation; increase rainwater and sustainable ground water harvesting for use in agriculture); focus on agricultural impacts in the savanna zones, particularly the Sahel, the areas that are likely to be most affected by the impacts of climate change (UNFCCC 2015).

Supports were given to farmers in terms weather forecasting services and its implications on agriculture as well suitable advice such as adjusting planting date, promoting early mature varieties, drought-tolerant varieties, supplementary feedings etc. Despite these supports given to the CC stakeholders and potential benefits for farmers, low patronage and adoption of some adaptations prevailed in the country (Olajide-Adedamola and Akinbile 2019; Akinola 2014; Falola et al. 2013; Ibitoye 2013). In addition, livestock adaptation strategies and their drivers' studies are still sparse in the literature (Godde et al. 2021; Leclère et al. 2014). Therefore, analysis based on site-specific findings as some of the regions in the country are more vulnerable to others that may lead to the selection and promotion of practices appropriate for different sites (FAO 2021c). Study on site-specific livestock adaptation strategies help to make climate-smart agriculture feasible, unique, and suitable to local conditions.

The ultimate goal of the National agricultural climate actions was to make the agricultural sector more resilient to changing environment that will improve the farmers' welfare including food security. As some climate risk adaptation strategies are suggested and promoted as a solution to the effect of environmental changes on agriculture (FAO 2021b; Wassmann et al. 2019; Campbell et al. 2016). While some of the adaptation strategies are not appreciably adopted, some that were adopted is well observed, the impact of these strategies in achieving the food security is yet very scanty. Some studies investigated the impact of climate change adaptations on food security (Di Falco 2011; Islam et al. 2016; Oyinbo et al. 2019; Lemessa et al. 2019). But they typically used farm productivity as a proxy for food security which might be vague and blurred, as small-scale farm productivity alone does not always guarantee household food security (Campbell et al. 2016; Oluwatayo 2019; Pawlak and Kołodziejczak 2020). As the awareness of adaptation is pre-requisite for the adoption, this study added knowledge to the CC adaptation studies in five aspects which includes:

Firstly, as experience demonstrates that small-scale farmers are not so much concerned with questions related to causes and effects but rely more on their own perception and awareness of changes (FAO 2014). Farmers respond to CC according to their perception of the causes of the environmental changes rather than scientific facts and evidence as conventional media trust is not guaranteed among farmers (Hyland et al. 2015; Arbuckle et al. 2015). The actions taken towards CC mitigation and adaptation thus imply, that the farmers experience the negative effects of CC on their farm operations. The awareness of CC among farmers has been a focus of interest in recent scientific discussions (Bryan et al. 2013; Ibrahim et al. 2015; Kutir et al. 2015; Keneilwe et al. 2018; Oduniyi and Tekana 2019; Abdallah et al. 2019 and Mahamadou et al. 2019). However, studies that investigate how the knowledge of CC is associated with the farmers' CC perception are scanty despite its paramount importance, as it can be used to guide and shape the farmers' climate change perception for appropriate mitigation and adaptation decisions.

Also, while up to 37% of global GHG emissions are caused by the global food system (Mbow et al. 2019), almost 24% of the total global greenhouse gas emissions were caused by the agricultural sector in 2010 alone (EPA 2018). In Nigeria, changes in land cover and forestry contribute 38.2% and agriculture contributes 13% and the emissions increased by 25% between 1990 and 2014 (USAID 2019). Investigating not only farmer awareness but also knowledge of the causes of climate change in the context of the need for appropriate mitigations, is of the utmost relevance, but very few studies elicit such information (Madhuri and Sharma 2020). According to the *knowledge gap theory*, which hypothesized that when an information is disseminated to a social system increases, segments of the population with higher socioeconomic status tend to acquire this information at a faster rate than the lower status segments so that the gap in knowledge between these segments tends to increase rather than decrease (Tichenor et al. 1970).

In this way, farmers with high social status will be likely to be more knowledgeable on CC as they have access to a variety of information sources/channels that broadcast or publish governmental and non-governmental programs on CC. This indicates the effect of socio-economic variables such as education, income, etc. as well as the role of information sources and channels on the knowledge of climate change of farmers. *Regarding this aspect, this subchapter provides information on climate change knowledge of farmers and how is associated with the farmers' climate change* *perception as well as the determinants of climate awareness and knowledge in the light of knowledge-gap theory.*

Secondly, agricultural insurance could play a key role in protecting vulnerable households. It increases resilience, including the adaptive capacity, as it is designed to cover financial losses incurred due to a reduction in expected outputs, and also serves as security for banks for servicing loans which may result in increase in food security (Nnadi et al. 2013). Cash payments from an insurer improve opportunities for farmers to make the capital investments needed to adapt or to maintain their current production strategies and insurance can encourage adaptation by being bundled with new technologies (Collier et al. 2009). Insurance positively affects the resilience of livestock herders, food security and risk management during climate risk (Thornton and Herrero 2014; Biglari et al. 2019). Agricultural insurance is expected to lead to an increase in the area planted and encourage investment in a profitable way that affect food security of faming households (Elabed et al. 2013), and also, proved to increase household consumption (De Nicola, 2015; De Nicola and Hill 2013).

As the number of studies investigated different aspects of agricultural insurance, such as appropriate agricultural financial management in a changing environment (Daron and Stainford 2014; Turvey et al. 2006; Woodard et al. 2016; Zhu et al. 2018). Other studies analysed, how insurance contributes to social protection (Devereux 2016; Jensen et al. 2017), increases welfare of farmers (Chantarat et al. 2017), how the insurance used in providing subsidies to farmers (Ricome et al. 2017; Freudenreich and Musshoff 2018). Some studies investigated how the insurance help in rural poverty reduction (Hansen et al. 2018) and social equity (Fisher et al. 2018). Less attention was given to agricultural insurance awareness and adoption of farmers and the reasons for the low adoption (Carter et al. 2016; Jin et al. 2016; Ntukamazina et al. 2017), despite the low patronage and adoption of agricultural insurance prevailing in the country (Olajide-Adedamola and Akinbile 2019; Akinola 2014; Falola et al. 2013; Ibitoye 2013). Literature in other developing countries such as South Africa, Iran, Nepal and Kenya revealed a similar situation (Oduniyi et al. 2020; Biglari et al. 2019; Budkathoki et al. 2019; Jensen and Barrett 2017; Jensen et al. 2017; Elum et al. 2017; Marr et al. 2016).

In an attempt to elicit the information regarding the awareness and adoption of agricultural insurance in the country. There is a consensus that awareness of an innovation is a prerequisite and the first stage for the adoption based on Awareness, Interest, Evaluation, Trial and Adoption [AIETA] processes (Daberkow and Mcbride 2003) which are influenced by the information channels as postulated by *diffusion of innovation theory* (Rogers 2003). It is a paramount to investigate the insurance awareness of farmers before taking adoption into consideration. Financial capability of the farmer may also influence the adoption behaviour of farmers, this emphasized the role of wealth such as income, livestock ownership and other assets as depicted by *resource-based theory* (Below et al. 2014). As the needs and necessity to upset the effect of emerging threats such as drought and flooding experience, that will make farmers to seek a new knowledge and techniques that will help them to overcome these constraints as highlighted by *protection motivation theory* (Floyd et al. 2000). *In regard to this aspect, this subchapter provided information on the awareness and adoption of agricultural insurance drivers in the light of the theories, reasons for not adopting and the challenges encountered by the users of the insurance product.*

Thirdly, it was expected in the climate plan action of the country that livestock adaptations strategies such as supplementary feeding will make the livestock sector resilient to climate risk that will turn into the improvement in food security of farming households. Livestock production contributes to the improvement of food security and the achievement of sustainable development goals such as no poverty, gender equality, zero hunger, and climate action (UNSTAT 2020). Livestock constitutes about 40% of agricultural output in developed countries and 20% in developing countries, supports the livelihood of 1.3 billion people worldwide, and supplies about 34% of the global protein (FAO 2021a). About 30% of global meat and 6% of milk production originate from grazing systems on land that is often poorly suited for cropping (Herrero et al. 2013). Further, livestock provides a range of other services: a source of draught power, a means of transportation, source of nutrients for poor soils, source of income generation and diversification, and a form of investment all of which contribute to the overall well-being of many communities (CIRAD 2016).

In Nigeria, livestock yields are decreasing due to pressure from climate change particularly in the semiarid region of the country (USAID 2019). In general, agricultural productivity is projected to decline between 10 to 25% by 2080 in some parts of the north, while the yield decline in rain-fed agriculture would be as much as 50% (UNFCCC 2015). Adaptation strategies adopted by farmers in the livestock sector and their drivers are still sparse in the literature (Godde et al. 2021; Leclère et al. 2014). Therefore, analysis based on site-specific findings may lead to the selection and promotion of practices appropriate for different sites (FAO 2021c). Site-specific livestock adaptation strategies help to make climate-smart agriculture feasible, unique, and suitable to local conditions. As the country has divers agroecological zones (AEZs) the study added knowledge to the field of livestock adaptation studies by unveiled the effect of different AEZs and institutional factors on livestock climate risk adaptations. The study sheds light in particular on the influence of agroecological features as postulated by *protection motivation theory* (Netra et al. 2004; Ndambiri et al. 2012). As we considered six different AEZs in the study. They were grouped into Dry Cluster AEZs (Semi-arid, Sudan savannah, and Guinea savannah) and Humid Cluster AEZs (Tropical rainforest, Mangrove, and Swamp forest) based on metrological data homogeneity.

We also expected that despite AEZ conditions institutional factors may play a significant role in the adoption behaviour of farmers, as explained by *institutional theory* (North 1990). Which explained that institutional factors create an enabling environment for technology adoption as it regulates and modifies resource rights and access to services such as rights to land, irrigation water, weather forecast information, credit, and livestock information that may facilitate the adoption of climate risk adaptation strategies. Previous studies (Deressa et al. 2009; Hisali et al. 2011; Tambo and Abdoulaye 2012; Bryan et al. 2013; Comoé & Siegrist 2015; Asfaw et al. 2018) investigated the effect of AEZs and institutional factors on climate change adaptation behaviour of farmers, with a focus on the crop sector. The livestock sector needs the same scientific attention and priority to better understand the adoption of livestock climate-smart practices that will make the system resilient. Further, we acknowledged the effect of farmers' demography and farm characteristics on the climate risk adaptation strategies as explained by *Resource-based* and *Diffusion of Innovation theory*; however, our study gave emphasis to the effect of AEZs and institutional factors on the adoption of livestock climate risk adaptation. *Regarding this aspect, this subchapter provides information on the effect of AEZs on the choice of livestock climate risk adaptation strategies, the influence of institutional factors on the adoption of livestock climate risk adaptation strategies and the perceived constraint of livestock adaptation.*

Fourthly, as the country heavily depend on crops for food security, it is important to enabling the crop production to continue providing high yields by making the crop aspect more resilience to changing environment for enhancing food security. It is therefore critical to adopt appropriate measures to deal with the fragile nature of mainly rain-fed farming systems of the county. Ziervogel et al. (2006) point out that the crop sector has been affected heavily by the changing climate, especially in sub-Saharan Africa (SSA) including Nigeria. This makes the crop adaptations to constitute a part of the national climate action plan that is also expected to adapt with changing environment that will improve the farm yield of farming households that will turn to households' food security. Different crop adaptations were found to adapt with changing environment. For example, adjusting planting dates found to be of importance in adaptation studies (Asrat and Simane 2017; Asrat and Simane 2018; Ali et al. 2021), shifting to another crop or variety (Tessema et al. 2019), moving to planting early mature variety were the key adaptive response to climate change in areas where rainfall is erratic (Asrat and Simane 2017) and choosing drought-tolerant varieties that are resilience to weather anomalies (Tesfaye et al. 2018).

Various theoretical and conceptual basics were used to study farmers' behaviours toward crop adaptation strategies. This subchapter used the *induced innovation theory*, *resource-based theory* and *diffusion of innovation theory* as theoretical background (Netra et al. 2004; Ndambiri et al. 2012; Wescott et al. 2017; Adger 2003; Rogers 2003). The *induce innovation theory* highlights the important roles of risk and other environmental threats such as moisture stress and floods; *resource-based theory* that relate adoption with income, assets, and other financial capabilities of farmers and *diffusion of innovation theory* which links adoption to socio-demographic and access to institutional services (Netra et al. 2004; Ndambiri et al. 2012; Wescott et al. 2017; Adger 2003; Rogers 2003). In the light of these theories, four groups of factors explain the choices to apply the crop adaptation strategies. *This subchapter added knowledge to crop adaptation studies in the light of these theories by providing an information how the adaptation affected by sociodemographic characteristics of farmers, farm characteristics, access to institutional services as well as the perceived crop adaptation constraint of farmers.*

Finally, as food production from agriculture is extremely dependent on temperature and rainfall especially in countries where agriculture is predominantly rainfed systems. This makes climate change to have an effect on food availability and other food security dimensions. For example, the cereal crops like maize, sorghum, rice and millage that constituted the major source of calories in sub-Saharan African are negatively affected by the climate change (Ray et al. 2019). The impacts of climate change on agriculture and human well-being are complex which include the effects on crop yields that has resulting outcomes including prices of production and the impacts on per capita energy consumption and child malnutrition (Nelson et al. 2009). Nelson et al. (2009) further reported that climate change caused yield decline for the most important rainfed crops in developing countries and have various effects on irrigated yields; result in price increases for rice, wheat, maize, soyabeans and other important agricultural crops. Based on this, higher feed prices were projected that will result in higher meat prices, reducing the meat consumption and causing a more substantial fall in cereal consumption in 2050 to the 2000 levels throughout the developing world including Nigeria, which will increase child malnutrition by 20% relative to a world with no climate change (Nelson et al. 2009)

This subchapter provides information on the link between the crop adaptation strategies used and food security of the farming households using the *Dietary Diversity Score (DDS)* which reflect a level of energy and nutrient intakes (Kant 2004; Rose et al. 2002) and anthropometric outcomes for adults, women and children (Arimond and Ruel 2004; Rah et al. 2010; Ruel 2003) and *Coping Strategy Index (CSI)* indicator which capture the behaviours people engage in when they cannot access enough food (Leroy et al. (2015). This impact of crop adaptation strategies adoption on household food security was estimated by employing treatment effect approaches (Propensity Score Matching (PSM), Inverse Probability Weighted Regression Adjustment (IPWRA) and Endogeneous Switching Regression (ESR). This approach ensures that the farming household that adopted the crop adaptation is fully counterfactual to non-adopting farming households that is well assured that the only difference between the groups (adopters and non-adopters) is the adaptation, hence, any difference in food security between the two groups can be attributable to the effect of the adaptation. *This subchapter added knowledge to the field of climate change studies on the impact of crop adaptation strategies on farming households' food security in the case of Nigeria.*

2 Literature Review

This chapter reviewed relevant information related to the research from the concept of climate change and its causes as well as a relationship between agriculture and climate change in the world and SSA including Nigeria, as well as the concept of food security. This subchapter also, provided an information on climate change action plan of Nigeria, the climate change adaptations, and their drivers furthermore the theoretical framework of the study.

2.1 Concept of Climate Change

There are different definations of climate change in literature, but the all revolved around a significant long time changes in atmospheric conditions. For example, climate change is a long-term shift in the average of weather conditions of a region, such as its real temperature, precipitate and windiness (Government of Canada 2018). This means that there will also be changes in extreme conditions, climate change refers to the variation in the earth's global climate or in regional climates over time (IPCC 2001). In other words, climate is an average weather condition of an area or region over a long period of time (at least 30 years). Climate change means a significant variation and changes in the different aspects of climate measures, such as temperature, precipitation, or wind, lasting for an extended period, decades or longer (EPA 2020). The earth's climate has changed many times during the planet's history, with events ranging from the ice ages to long periods of warmth.

The sun’s energy warms the earth and the warmed earth releases heat to the atmosphere. Certain gases in the atmosphere trap this heat and act like the glass of a greenhouse. Such gases are called greenhouse gases (GHGs). The main greenhouse gases are water vapour, carbon dioxide and methane. Greenhouse gases absorb heat and radiate some of it back to the earth, raising surface temperatures (IPCC 2018). This process is often called the greenhouse effect (Figure 1). Climate change has been identified as the leading human and environmental crises of the 21st century (Tadesse 2010). Globally, it adversely affects livelihood activities such as farming through the occurrence of diverse extreme events such as floods, cyclones, droughts, and unpredictable rainfall patterns (Urama and Ozor 2010). Changes in temperature and rainfall patterns affect agriculture, especially in tropical regions. Consequently, rainfed agriculture is seriously threatened resulting in an imminent global food insecurity (FAO

2008). For instance, in 2005, 777 million people experience food insecurity in 70 lower income countries in the world, many of which were African countries (Hùng 2009).

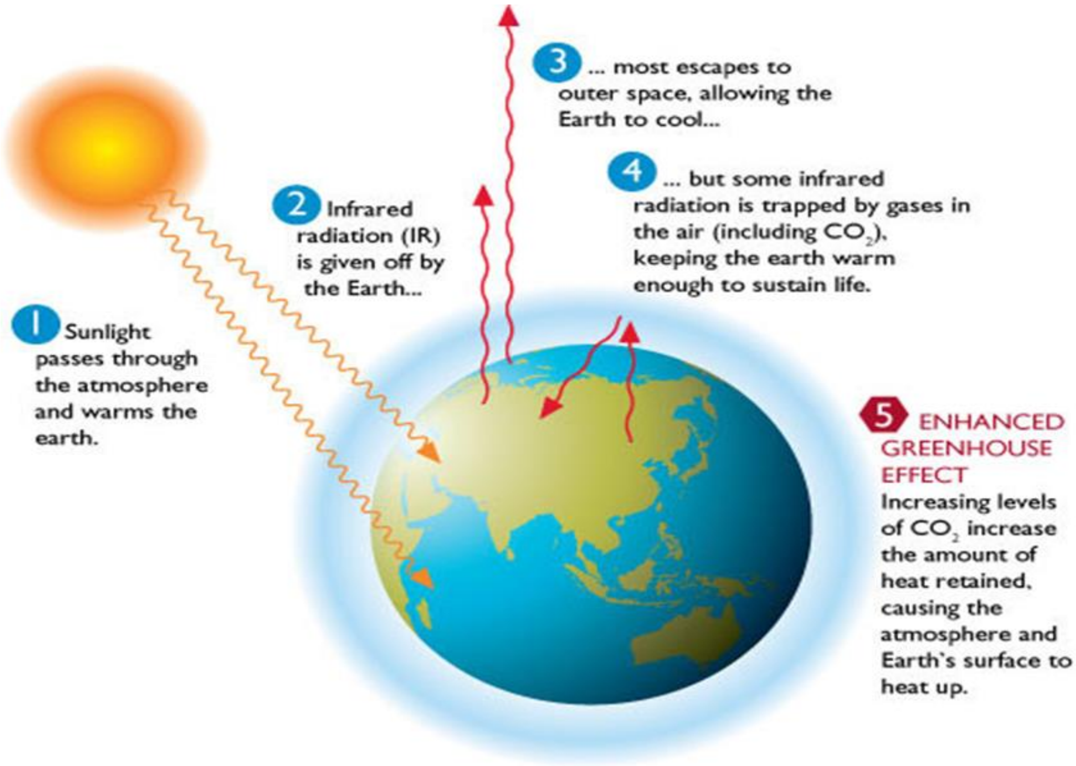

Figure 1: Effect of greenhouse gases

Source: NOAA 2018

The greenhouse effect is a natural process, but it is being intensified by human activities that increase greenhouse gas levels in the atmosphere, especially carbon dioxide. Increasing greenhouse gas levels in the atmosphere makes it more effective at trapping heat, resulting in overall warming of the earth. Climate change caused by human activity is referred to as anthropogenic climate change (IPCC 2001). The major human activities that cause climate changes such as the burning of fossil fuels and the conversion of land cover and agriculture. Since the beginning of the industrial revolution, these human activities influence on the climate system have increased substantially (EPA 2020).

In addition to other environmental impacts, these activities change the land surface condition and emit various substances to the atmosphere. These in turn can influence both the amount of incoming energy and the amount of outgoing energy and can have both warming and cooling effects on the climate (IPCC 2018). The dominant product of fossil fuel combustion is carbon dioxide, a greenhouse gas. The overall effect of human activities since the industrial revolution has been a warming effect, driven primarily by emissions of carbon dioxide and enhanced by emissions of other greenhouse gases (Government of Canada 2018). The build-up of greenhouse gases in the atmosphere has led to an enhancement of the natural greenhouse effect. It is this human-induced enhancement of the greenhouse effect that is of concern because ongoing emissions of greenhouse gases have the potential to warm the planet to levels that have never been experienced in the history of human civilization. Such climate change could have far-reaching and/or unpredictable environmental, social, and economic consequences (Government of Canada 2018).

2.1.1 Causes of climate change and effects

The Intergovernmental Panel on Climate Change (IPCC) is assessing the effect of anthropogenic causes and its impact on human endeavors and developing a climate change adaptation recommendations and policies at global, regional and country levels (IPCC 2020). Carbon dioxide is the main cause of human-induced climate change. It has been emitted in vast quantities from the burning of fossil fuels and it is a very long-lived gas, which means it continues to affect the climate system during its long residence time in the atmosphere. However, fossil fuel combustion, industrial processes, agriculture, and forestry-related activities emit other substances that also act as climate forcers. Some, such as nitrous oxide, are long-lived GHG like carbon dioxide, and so contribute to long-term climate change (IPCC 2014).

Other substances have shorter atmospheric lifetimes because they are removed quickly from the atmosphere. Therefore, their effect on the climate system is similarly short-lived. Together, these short-lived climate forcers are responsible for a significant amount of current climate forcing from anthropogenic substances. Some short-lived climate forcers have a climate warming effect (‘positive climate forcers') while others have a cooling effect (‘negative climate forcers') (Government of Canada 2018). The causes of this current climate change can be divided broadly into:

i. *Natural process*
   - Change in sun’s intensity
   - Volcanic eruptions and slow changes in the earth’s orbit around the sun
   - Natural processes within the climate system such as changes in ocean current circulation

ii. Anthropogenic (Human activities)

- Carbon dioxide emissions through burning fossil fuels such as coal, oil and gas and peat
- Emissions through land use changes such as deforestation, reforestation, urbanization, desertification,
- Methane and nitrous of oxide emission from agriculture

If atmospheric levels of short-lived climate forcers are continually replenished by ongoing emissions, these continue to exert a climate forcing. However, reducing emissions will quite quickly lead to reduced atmospheric levels of such substances (IPCC 2020). A number of short-lived climate forcers have climate warming effects and together are the most important contributors to the human enhancement of the greenhouse effect after carbon dioxide (IPCC 2020). This includes methane and tropospheric ozone both greenhouse gases and black carbon, a small solid particle formed from the incomplete combustion of carbon-based fuels (coal, oil and wood for example) (Government of Canada 2018). Numerous GHG causes this climate change, the prominent among them are:

Carbon dioxide (CO_2): use of fossil fuel is the primary source of CO_2, to sometimes emitted directly from human-induced impacts on forestry and other land use, such as through deforestation, land clearing for agriculture, and degradation of soils. The concentration of CO_2 in atmosphere is 410.79 ppm (IPCC 2017) which constituted 65% of all the GHGs (IPCC 2020).

Methane (CH_4): Agricultural activities, waste management, energy use, and biomass burning are the major contributors of CH_4 emissions. The concentration of CH_4 in the atmosphere is 1.8 ppm (IPCC 2017) and constituted 16% of GHGs in the atmosphere (IPCC 2020). Fossil-fuel-related emissions and major reductions of other anthropogenic sources are needed to save millions of lives, restore aerosol-perturbed rainfall patterns, and limit global warming to 2°C.

Nitrous Oxide (N_2O): Agricultural practices/system, such as fertilizer use, are the primary source of N_2O emissions and fossil fuel combustion also generates N_2O. There is 323 ppm N_2O in the atmosphere (in 2017) and constituted 6% of all emission (IPCC 2020). The N_2O that emits from various agricultural management practices on agricultural soils can lead to increased availability of nitrogen in the soil and result in emissions of Nitrous Oxide. Specific agricultural practices that contribute to N_2O

emissions from agricultural lands include the application of chemical and organic fertilizers, the growth of leguminous (nitrogen-fixing).

Fluorinated gases: Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of fluorinated gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) this constituted 2% (IPCC 2020).

2.1.2 Agricultural practices contribute to climate change

At the time when climate change affects agricultural production negatively, there also farming practices that contribute to the causes of that climate change. Agricultural practices/system contributed 24% of the global GHGs that causes climate change which is higher than those contributed by industrial and other sectors (Figure 2) except electricity and heat production that contributed 25% which is more than the contribution of agricultural sector by 1%. Availability of these GHGs in the atmosphere created Troposphere Ozone in the atmosphere that absorbs the reflected radiation and infrared from the surface of the earth and emits heat that created global warming. Hassan et al. (2019) finds out that farmers agreed that some of agricultural practices contributed to drought such as bush burning, over harvesting and over grazing, and deforestation.

Bush burning: farmers in northern Nigeria mostly practised bush burning prior to the rainy season. This is a process where farmers clear their farmlands to prepare for the rainy season (Hassan et al. 2019). In other word, bush burning is a process where farmers clear their farmlands using fire to prepare for the rainy season. Bush burning can deplete top-soils nutrients, potentially causing crop yields to decrease (Hassan et al., 2019). Furthermore, it changes organic nitrogen into mobile nitrates which makes it very volatile, causes air pollution through the release of carbon stored in plant leaves, stems and branches into the atmosphere (Sciencing, 2017). This practice can deplete top-soil nutrients, which can decrease crop yields. Farmers mentioned that they had no knowledge of the negative impacts of bush-burning, also, they learned from their ancestors, and they believe it is the most cost-effective way of clearing farmland (Hassan et al. 2019).

Deforestation: is the process of cutting down plants and crops which has been practiced for decades in many parts of northern Nigeria, farmers highlighted that they cut trees to cater some of their daily needs in coping with drought (drought-shock). In other words, this is the process of cutting down plants and crops and this breaks the carbon cycle by stopping the CO_2 absorption function of plants. Between 2015-2017, the global loss of tropical forests contributed to about 4.8 billion tonnes of CO_2 per year (or about 8-10% of annual human emissions of carbon dioxide) (Climate Council 2018). Farmers mentioned that if there were alternative sources of income, they will not practice deforestation and commented that government officials had been warning them of the consequences of their actions (Hassan et al. 2019). Some farmers highlighted that over 30-40 years ago there was a very thick forest in their areas, moving 200 meters within the forest could not be seen from outside but during the data collection, no plantation was observed in the area (Hassan et al. 2019). A problem farmer confirmed numerous times is the issue of desert encroachment on their farms. Communities find it difficult to adapt to these environmentally stressed conditions in sustainable ways. Environmental consciousness will remain an issue if poverty and drought impacts are not mitigated in arid areas. Farmers generally find achieving the appropriate balance between their survival and environmental protection is extremely difficult, farmers stated that sand often covered their farms after a year of harvests, this decreases soil fertility, thus resulting in poor crop yields (Hassan et al. 2019).

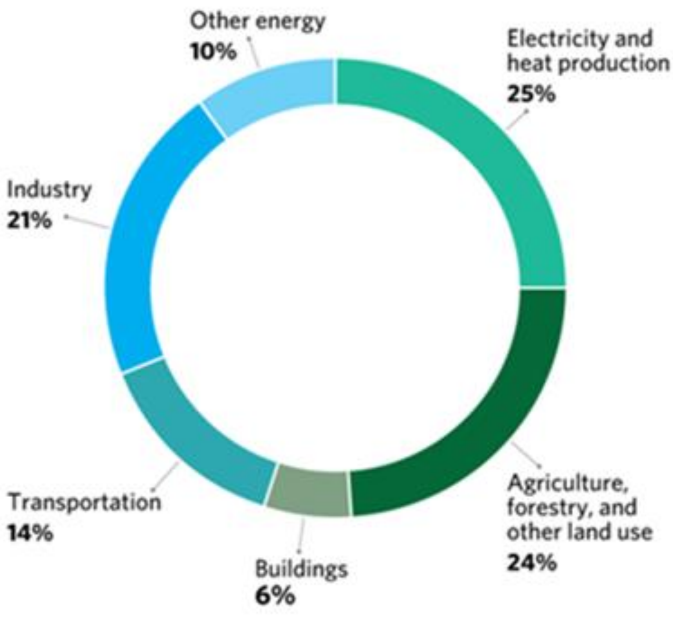

Figure 1: Global greenhouse gas emission by economic sectors

Source: IPCC 2014

Mohamad et al. (2016) assessed the effect of different agricultural practices on carbon emission and carbon stock in organic and conventional olive systems. There was a higher environmental impact on Global Warming Potentials (GWP) in the organic system because of higher global GHG emissions resulting from manure fertilisation rather than the synthetic foliar fertilisers used in the conventional system. However, manure was the main reason behind the higher soil organic carbon (SOC) content and soil carbon sequestration in the organic system. Fertilisation activity was the main contributor of carbon emissions, accounting for approximately 80% of total emissions in the organic system and 45% in the conventional system (Figure 3). Conversely the result of the study indicated that, given the similarity of other factors (land use, residues management, soil cover) that may affect soil carbon content, manure was the primary contributor to increased SOC in the organic system, resulting in a higher efficiency of carbon sequestration in the soil following the addition of soil organic matter.

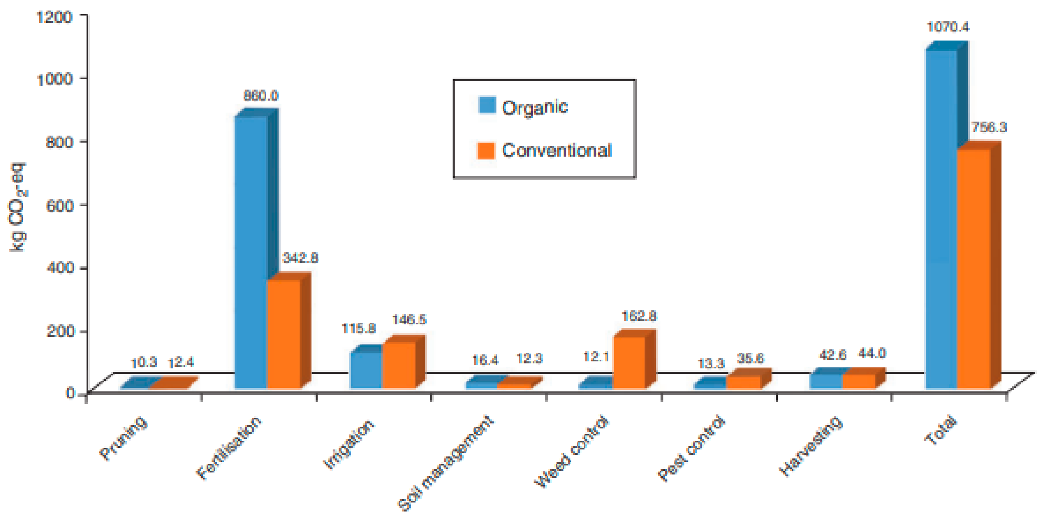

Figure 3: Annual environmental impact of the agricultural practices on global warming potential. Source: Mohamad et al. (2016)

The contribution of the manure to increased SOC compensated for the higher carbon emission from the organic system, resulting in higher negative net carbon flux in the organic versus the conventional system and higher efficiency of CO_2 mitigation in the organic system.

Fossil fuel use: is the primary source of CO_2 that is emitted directly from human-induced impacts. The total CO_2 contribution from fossil fuel use and other industrial processes including agricultural mechanization contribute 65% of the global greenhouse gas emissions (EPA 2018). Fossil-fuel related emissions reductions are needed to save millions of lives, restore aerosol-perturbed rainfall patterns, and limit global warming to 2 °C (Lelieveld et al. 2019).

Methane (CH_4) from livestock production: methane makes up most emissions that come from farmed livestock, such as sheep and cattle; animals naturally produce methane as a by-product of their digestive processes and release it into the air (NIWA, 2018). Between 1970 and 2010, emissions of CH_4 from enteric fermentation and rice cultivation increased by 20 % (IPCC, 2014). Livestock emissions from gastroenteric releases account for roughly 32 per cent of human-caused methane emissions, contribute to the formation of ground-level ozone, a hazardous air pollutant and exposure to it causes a million premature deaths every year (UNDP 2021). Methane is also a powerful greenhouse gas which over a 20-year life period, it is 80 times more potent at warming than carbon dioxide and accounted for roughly 30 per cent of global warming since pre-industrial times and is proliferating faster than at any other time since record keeping began in the 1980s (UNDP 2021).

Use of manure: inappropriate manure handling and application lead to the emission of CH_4 and Nitrous Oxide (N_2O) this agricultural activity contributes to climate change (EPA, 2018). The application of poultry and cattle manure to agricultural soils significantly increased GWP (Shakoor et al. 2020)

2.1.3 Effect of climate change on agriculture

The effect of climate change on agriculture is dependent on the region, sector and the dimension. Climate change related risk for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (IPCC 2018). The level and the severity of these risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (IPCC 2018). Impacts on nature and agriculture from global warming have already been observed.

For example, climate changes have an adverse effect on Northern hemisphere of which the main risks associated with agricultural systems are water scarcity, flooding and drought as shown in Figure 4. In general, the common climate change risks that affect agriculture directly are land degradation resulting in water and wind erosion of land, drought and the creation of deserts, acid and salt accumulation, depletion of minerals, and heavy-metal contamination; deforestation; contributing to environmental decay and pollution (IPCC 2018). All these influences agricultural systems especially ren-fed agriculture.

Climate models projected robust differences in regional climate characteristics between present-day and global warming of 1.5°C, and between 1.5°C and 2°C. These differences include increases in mean temperature in most land, hot extremes in most dwelling regions, heavy rainfall in several regions and the probability of drought and shortage of rainfall in some regions (IPCC 2018). Temperature extremes on land are projected, extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (IPCC 2018).

The number of hot days is projected to increase in most land regions, with highest increases in the tropics (IPCC 2018). Heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming as a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (IPCC 2018). Populations at disproportionately higher risk of adverse consequences with global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods.

Figure 4: Global distribution of risk associated with agricultural production system

Source: FAO 2012

Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small island developing states, and least developed countries. Poverty and disadvantage are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (IPCC 2020).

Limiting warming to 1.5°C compared with 2ºC is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in Sub-Saharan Africa, Southeast Asia, and Central and South America, and in the CO_2-dependent nutritional quality of rice and wheat (IPCC 2018). Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (IPCC 2018) see Figure 5.

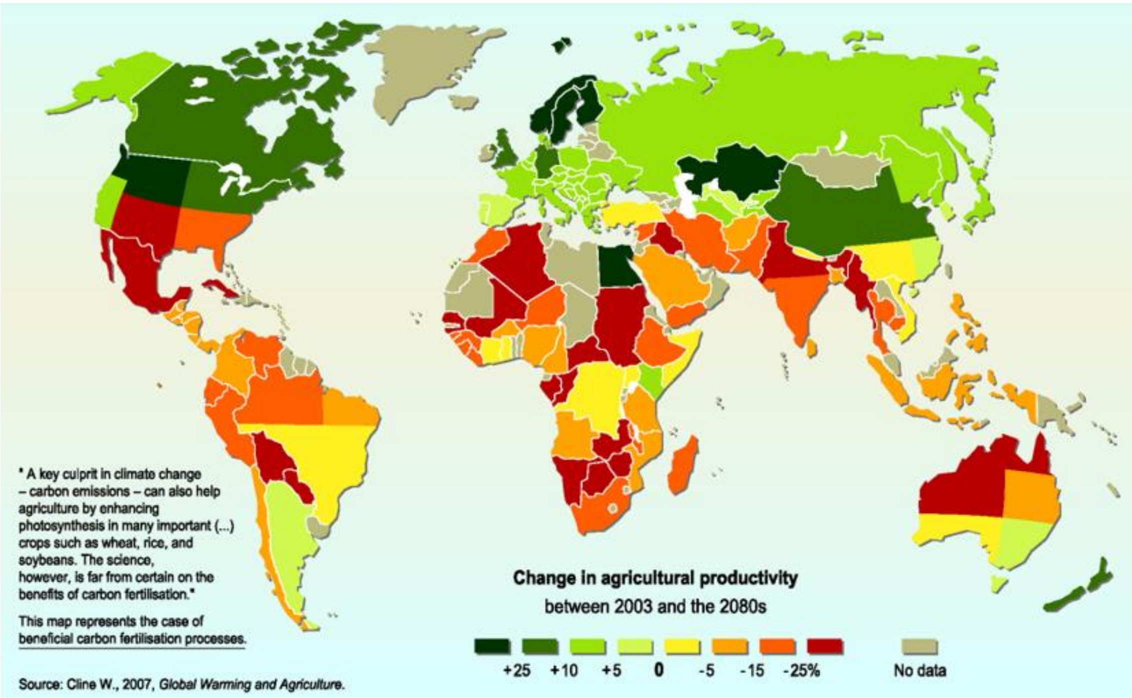

Figure 5: Projected effect of climate change on agricultural productivity

Source: Cline 2007

Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability, this excludes the costs of mitigation, adaptation investments and the benefits of adaptation. Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change of global warming increase from 1.5°C to 2°C (IPCC 2018). Cline 2007 projected the impact of climate change on agricultural productivity from 2003-2080 at global level taking each country in isolation. The authour revealed that south America and African continents will experience the negative effect of climate change on their agricultural productivity than north America and Europe.

2.1.4 Effect of climate change on livelihood in SSA

Although the impact of climate change is global, Sub-Saharan Africa (SSA) is noted to be the region that is most vulnerable to many adverse effects of climate change because of her high dependence on rain-fed agriculture for food security, economic growth, coupled with low adaptive capability (Kotir 2011). In SSA, 93% of cultivated land is rain-fed (Sharma 2011) and over 80% of the rural households derive their livelihoods from rain-fed agriculture (Gbetibouo and Mills 2012) with about a one-third of the people in this region living in drought prone dry lands (Singh et al. 2009). Climate change has resulted in low crop productivity, and climate change related losses in crop yield are projected to reach 50% in some countries of SSA by 2050 (IPCC 2007). This would severely compromise food security in many African countries including SSA (Zinyengere et al. 2014).

The results of the changing climate on livelihood activities, especially agricultural activities, tend to impact the entire populations in the continent with women and children being the most affected. This is because their livelihood activities are based on natural resources (Alexander et al. 2011). According to Gaard (2015) women produce most of the world’s food yet the majority of the world’s hungry are women and children. Also, an estimated 146 million children in developing countries are underweight due to acute or chronic malnutrition and 60% of the world's hungriest are women (FAO 2013). The Sahel region is referred to as the ‘desert edge’ which constitutes the West African arid countries, ranging from Chad to Senegal (some including Sudan).

Drought has been a problem not only in sub-Saharan countries but also in West Africa for many decades but did not receive adequate attention until during the Great Sahelian droughts of the 1970s (Abdullahi et al. 2016). Drought has not been well documented in recent years and the impacts are increasing in complexity and magnitude (Hassan et al. 2019). Mortimore (1989) mentioned that severe drought struck the Sahel region of west Africa in the 1970s, this leaved millions of people in starvation. The author reported that drought incidences continue for about consecutive five-six years in the region, this it affected millions of people in northern Nigeria. The drought episodes have caused poor agricultural output that led to famine in the region and have produced millions of environmental refugees (Mortimore 1989).

Sub-Saharan African such as Sahelian countries, including Senegal, Mauritania, Mali and the Niger Republic, have received much international attention and support. The number of people affected in northern Nigeria is more than those affected in the other Sahelian countries combined (Mortimore 1989). Abubakar and Yamusa (2013) attributed the lack of international media attention was due to Nigeria's economic stability, which is related to national oil wealth. The northern Nigerian states severely affected by the 1970s droughts especially those state that are adjacent to the Niger Republic. In Nigeria, agriculture contributes 18.4% of national GDP, but after the droughts of the 1970s, crop production declined to contribute only 7.3% of GDP, leaving many Nigerians from the northern part in acute poverty and starvation (Abubakar and Yamusa 2013). Hassan et al. (2019) found out that farmers in Sahelian part of Nigeria sown their seeds 30-60 days before the coming of the first rainfall and experience up to 40 days interval between first rain and subsequent one, the rain cease before the maturity of the crops for over 12 years.

2.1.5 Climate change and agroecological zones of Nigeria

Climate change impact depends on a range of the climatic parameters such as the country’s socio-cultural, geographical, and economic backgrounds. The location and the topographical characteristics of Nigeria give rise to a variety of climates, ranging from tropical rainforest climate along the coasts to the Sahel climate in the northern parts of the country. The climate of the country strides from a very wet coastal area with an annual rainfall greater than 3,500mm to the Sahel region in the north-western and north-eastern parts with annual rainfall less than 600mm (World Climate Guide 2019). The inter-annual variability of rainfall, particularly in the northern parts is large; often result in climate hazards, especially floods and droughts with their devastating effects on food production and associated calamities and sufferings. Often, certain parts of Nigeria receive less than 75 percent of their annual rainfall and this is particularly worrisome in the north (Hassan et al. 2019).

By virtue of Nigeria's location primarily within the low land humid tropics, the country is generally characterized by a high-temperature regime almost through the year. In the far south, the mean maximum temperature is between 30 and 32˚C while in the north it is between 36 and 38˚C (World Climate Guide 2019). However, the mean minimum temperature is between 20 and 22˚C in the southern while the northern part experiences a much higher annual range. The mean temperature for the country is between 27 and 29˚C (Britannica 2021). The diverse nature of the country's climate consequently gives rise to a high degree of biological diversity resulting mainly in six vegetation zones: the mangrove swamps, the saltwater and freshwater swamps, tropical lowland rainforests, Guinea savannah, Sudan savannah, and Sahel savannah (Table 1).

Table 1: Nigerian agroecological zone and the effects of climate change

Goepolitical zone	***Ecological zone***	***Practical effects***	***Projected effect by 2050***
South-south	Costal swamp	Sea rise, flooding	Sea level rise of 1m
South-east	Costal swamp	Sea rise, flooding	Sea level rise and flooding
South-west	Costal swamp/rainforest	Sea rise, erosion	Sea level rise of 1m
North central	Southern/northern guinea savannah	Gully erosion and flooding	Increase rainfall 0.4-04mm/day
North-east	Sudan sahel	Increased, temperature, drought and desertification	Increased, temperature, 2.0-2.2 ˚C and 3.5-4.5 ˚C by the end of 21st centuary
North-west	Sudan-savannah	Increased, temperature, drought and desertification	Increased, temperature, 2.0-2.2 ˚C by the end of 21st centuary

Adopted from Bosellof et al. (2018)

Salt and freshwater swamps area along the coast of Nigeria (World Climate Guide 2019). The salt-water swamps stretch inland for 1-2km in the Lagos area to over 30km in the Sapele area (Nigerian Embassy in Sweden 2018). Further inland, beyond the reach of tidal waters, mangroves give way to freshwater plants, the most important of which is the raffia palm. From a water balance perspective, the country experiences large spatial and temporal variations in rainfall, and less variation in evaporation and evapotranspiration. Consequently, rainfall is by far the most important element of climate in Nigeria and thereby becomes a critical index for assessing agricultural and water resources potential in the country. These led to the different effect of climate change across the country (Bosellof et al. 2018).

In general, the common effects of climate change in agriculture include extreme weather events such as thunderstorms, heavy winds, and floods that devastate farmlands and lead to crop failure; pests and crop diseases as a result of climate variations (Polley et al. 2013). High frequent of floods and drought hazards; the proliferation of pests and crop diseases that hinder storage because of the temperature increases; reduction in animal weight gain and diary production and modification of tree growth and development, reducing the availability of non-timber forest products such as spicy vegetables and mushrooms (Henry et al. 2012; Nardone et al. 2010). Based on the IPCC (2001) projection, the humid tropical zone of southern Nigeria which is already too hot and wet is expected to be characterized by increase in both precipitation (especially at the peak of the rainy season) and temperature. Already, temperature increases of about 0.2-0.3˚C per decade have been observed in the various ecological zones of the country, while drought persistence has characterized the Sudan-Sahel regions, particularly since the late 1960s (IPCC 2018).

The increase in temperature in these areas would also possibly increase evaporation, reducing the effectiveness of the increase in precipitation. Furthermore, the IPCC (2018) projections show that rainfall in the very humid regions of southern Nigeria is expected to increase. This may be accompanied by an increase in cloudiness and rainfall intensity, particularly during severe storms. It could also result in shifts in geographical patterns of precipitation and changes in the sustainability of the environment and management of resources. However, since the increase in temperature could increase evaporation and potential evapotranspiration, there would be a tendency toward “droughts” in parts of these humid areas of the country (Eze 2018). In fact, recent studies have shown that precipitation decreased in the humid regions of West Africa, including southern Nigeria, since the beginning of the century is an about 10-25 percent or about 2-5 percent per decade (IPCC 2018).

With increase in ocean temperatures, there could be increase in the frequency of storms in the coastal zone of the country. In contrast to the humid areas of southern Nigeria, the savannah areas of northern Nigeria would probably have less rainfall coupled with temperature increases, reducing moisture availability (Eze 2018). Recent studies have indicated that the Sudan-Sahel zone of Nigeria has suffered a decrease in rainfall in the range of about 30-40 percent or about 3-4 percent per decade since the beginning of the nineteenth century (Peter 2010). Already, these savanna and semi-arid areas suffer from seasonal and inter-annual climatic variability, there have been droughts and serious desertification processes, particularly, since the 1960s. This situation may be worsened by the expected decrease in rainfall with greater drought probabilities and more rainfall variability and unreliability (IPCC 2018). This was projected by the Part of the conclusions of IPCC’s (2001) Third Assessment Report is that during the twenty-first century, some extreme climatic events will increase in frequency and severity due to changes in the mean and variability of climate. All these climate risk events will have negative impacts on agricultural production.

2.1.6 Climate change policy and adaptation plan of Nigeria

In Nigeria, agriculture is the main source of food and the main employer of labour, employing about 60-70 percent of the population. Cereals (notably millet and sorghum), groundnuts and cowpeas dominate crop production in the northern part of the country, while the dominant crops in the south are maize, rice, cassava, and yam. Agriculture is a significant sector of the Nigeria economy and the source of a lot of raw materials used in the processing industries, as well as a source of foreign exchange earnings for the country (FAO 2019). Therefore, any change in climate is bound to impact on small-scale arable crop farmers being the main producer of food crops and their socio-economic activities in general. In response to the increasing importance of climate change issues in Nigeria, in 2012, the Federal Executive Council of the country adopted Climate Change Policy Response and Strategy. To ensure an effective national response to a significant and multi-dimentional impacts of climate change, Nigeria has adopted a comprehensive strategy, as well as a number of specific policies (UNFCCC 2015). in 2015, Nationally Determined Contribution was developed by the country, its NDC towards the ratification of the Paris Agreement on Climate Change. It intends to reduce its greenhouse gas (GHG) emissions intensity of GDP by 20% by 2030 relative to the emissions intensity of GDP in the base period of 2010 to 2014 on an unconditional basis as well as a further 45% on a conditional basis consequent upon receiving climate finance, technology transfer and capacity building from the developed countries (FME 2021).

The NDC is expected to improve the standards of living, promote clean energy access, food and water security for all and make the country more resilient to climate impacts, as well as enable the country to contribute to the goal of keeping the global temperature increase below 2℃ (UNFCCC 2015). The strategic goal of the Nigeria Climate Change Policy Response and Strategy is to foster low-carbon, high growth economic development and build a climate-resilient society through the attainment of the following adaptations:

Regarding *crop and livestock* aspect, the sector promote the adoption of improved agricultural systems for both crops and livestock (e.g., diversify livestock and improve range management, increase access to drought resistant crops and livestock feeds, adopt better soil management practices, and provide early warning/meteorological forecasts and related information); implement strategies for improved resource use management (e.g., increase use of irrigation systems that use low amounts of water, increase rainwater and sustainable groundwater harvesting for use in the agricultural sector, and intensify crop and livestock production in place of slash and burn); focus on agricultural impacts in the savanna zones, particularly the Sahel and the areas that are likely to be most affected by the impacts of climate change (UNFCCC 2015).

Regarding *freshwater resources and fisheries*, the country initiated a national plan of action to integrate water resource management at the watershed level; intensify programmes to survey water quality and quantity for both ground and surface water; implement programmes to extend and improve water supply and water management infrastructure sustainably; explore water efficiency and management of water demand, particularly in Sahel and Sudan savanna areas of the country; and enhance artisanal fisheries and encourage sustainable aquaculture (UNFCCC 2015).

Regarding *forest and biodiversity*, the country intended to implement the national Community-Based Forest Resources Management Programme (CBFRMP); supported a review and implementation of the National Forest Policy; developed and maintained a frequent forest inventory system to facilitate monitoring of forest status; and initiate a research programme on a range of climate change related topics, including long term impacts of climatic shifts on closed forests and provide extension services to Community Service Organizations (CSOs); involve the communities and the private sector to help establish and restore community and private natural forests, plantations and nurseries; improve management of forest reserves and enforce low impact logging practice (UNFCCC 2015; FME 2021). In addition, support and encourage the active implementation of the National Biodiversity Strategy and Action Plan (NBSAP); particularly those strategic actions that address climate change impacts; support recommended climate change adaptation policies and programmes in sectors that affect biodiversity conservation, including agriculture, forestry, energy and livelihoods; support and implement programmes for alternative livelihoods in order to reduce unsustainable resource use that contributes to loss of biodiversity (FME 2021).

Regarding *livelihood of the citizens*, is to develop a replicable approach that uses intermediate NGOs, community members and radio to diffuse climate change adaptation approaches and information and to gather feedback on adaptation actions focused on livelihoods; build a network of intermediate NGOs capable of working on climate change and livelihoods issues; animate communities with appropriate engagement methods to elicit and document valid climate change and livelihood-related needs; use or reinforce available endogenous community resources to reduce vulnerability and build livelihood-linked capacity to adapt to climate change; and encourage community participation and active roles by both genders in all livelihood development initiatives (UNFCCC 2015).

Regarding *vulnerable groups*, the country creates awareness among government staff, including disaster and emergency management personnel about climate change impacts and how these impacts affect vulnerable groups; provides basic training for government staff on gender awareness tools to enhance implementation capacities; adapts government programmes, including emergency response plans and programmes directed at vulnerable groups; adapt public service facilities, including school buildings, to withstand storms and excess heat; intensify immunization of children and youth to provide protection against diseases that are expected to become more prevalent with climate change; retrain health workers to appreciate emerging climate change challenges within the context of immunization delivery and other comprehensive healthcare delivery; encourage faith-based and civil society organizations to provide social welfare programmes and other support to address the climate change-induced needs of vulnerable groups; adapt to national, the World Meteorological Organization Global Framework for Climate Services (WMO-GFCS) to Nigeria's needs to reduce vulnerability of communities (UNFCCC 2015; FME 2021).

2.2 Concept of Food Security

The term food security, first emerged in 70th, at the World Food Conference (1974). During a conference food security that was defined as supply of food "ensuring the availability and price stability of basic foodstuffs at the international and national level" (FAO 2006). Since then (World Food Conference 1974), the concept of food security has evolved and change into what is now generally agreed as the standard definition which was adopted during the World Food Summit in 1996. The World Food Summit, 1996, agreed that food security "*exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*" (FAO 2008).

This definition depicted the basic four components of food security: availability, accessibility, utilization, and stability of food. Based on this, all the four components must be satisfied concurrently to meet before the term food security can be achieved. The four components in detail are as follows: i) *Availability*: There must be physical, social, and economic access to sufficient and nutritious food by all people and at all times. The food has to satisfy the nutritious and dietary needs and preferences of the people. This availability is relative as food availability can differ from global to regional, national, and community to household level. To a great extent, food availability depends on the level of local production, imports, stock levels and net trade in food items (Matemilola and Elegbede 2017). ii) *Access*: This refers to economic, social and physical access to food by all people at all times. That an adequate amount of food is available at the regional, national or international level does not imply it is accessible at household level. It must be locally accessible and affordable. iii) *Utilization:* Generally, utilization refers to the pattern in which the body makes use and benefits from the various food nutrients. Utilization is determine by food quality, nutritional values, preparation method and storage as well as feeding pattern. iv) *Stability:* this refers to the stability of food availability, accessibility and utilization over time. All three components must be present concurrently at all times. A person who has adequate access to quality food today is still considered food insecure if he has a irregular access to food which may cause nutritional deteriorate. Variation in weather conditions, political and economic instability, and price fluctuation are some factor that may impact on food security status (FAO 2008; Matemilola and Elegbede 2017).

2.2.1 Climate change and food security

Despite diversity of climate change scenarios, it is clear that climate change poses a significant threat to agricultural production throughout the cultivated areas of the world. Even so, some regions and crops are confronted by challenges more immediate and more severe than others (FAO 2015). There is strong agreement among simulations that tropical regions will experience substantial negative impacts on agricultural productivity from climate change, given current management practices. While small increases in global mean temperature may be beneficial in cooler regions, climate change impacts are likely to be negative at moderate or high levels of global warming. These findings are largely in agreement with previous site-scale assessments. Several studies indicate that the effect of climate change on food security is rely on climate-sensitive agroeconomic practices for livelihood (Kotir 2011; Tesfaye et al. 2015).

It is evident already experiencing episodes of climate change, manifested by seasonal changes in precipitation and temperature of varying severity and duration despite overreliance on rain-fed agriculture. Kogo et al. (2020) revealed that CC would continue to negatively affect crop production and food security to the already vulnerable communities in the arid and semi-arid areas. They projected that climate variability will likely alter cropping patterns, yields and food security in several regions. The influences of climate change such as temperature, precipitation, humidity, cloudiness, and sunshine on vegetation index, agriculture, and food production have already evident (Islam and Ma 2018). Due to changing climatic conditions, food production has been reduced, which is a significant concern in the coming years (Hossain et al. 2016). The CC and its impact on crop yield increasing attention worldwide over a decade. Islam et al. (2020) reviewed the comprehensive and multi-variant food security index of China and Bangladesh. The authours revealed that, both countries are alike on the highly vulnerable and risky situation in several manners, although their capacities and size difference in many aspects. They reported that the conceptual consequences of CC were mainly on food productions and diversities of food security of these two countries. They further recorded that per capita relative food surplus and food safety as one of the dimensional cause affect food security. Esham et al. (2018) studied the effect of CC on food security in Sri Lankan. The authours reported that CC will affect all the food system activities from production to consumption in several ways. Ranging from impacts on production, markets and food prices, to all other supply chain activities and infrastructure.

2.2.2 Status of food security in Nigeria

Agriculture is the major occupation in Nigeria, employing almost two-thirds of the active work force and contributing 40 percent of the national GDP (FAO 2014). However, based on date from U.S. Energy Information Administration (2015) Nigeria has the largest natural gas reserves in Africa and is the continent's biggest oil exporter. These wealth of resources have helped it maintain Nigeria's relatively steady economic growth even in the face of recent global financial meltdown. Nigeria leapfrogged South Africa as Africa's largest economy in 2013 with Nigeria's GDP growing from \$169.48 billion in 2010 to 522.64 billion in 2014 (Matemilola and Elegbede 2017). This development makes Nigeria's economy to be 24th largest in the world. It also means that Nigeria's GDP per capita substantially rose to \$2689, up from a previous year of \$1555 (Naisbitt and Naisbitt 2016).

Unfortunately, this increased GDP did not translate into the pockets of the common man in Nigeria, where about 70% still live below \$1.25/day (Naisbitt and Naisbitt 2016). The new figures according to the author only emphasis the level of marginalization in a country in which a generation of multimillionaires and billionaires has emerged (Naisbitt and Naisbitt 2016). However, national and international expert have severally mentioned that Nigeria's economic output is underperforming. Despite the huge resources the nation sit upon and the rapid economic progress, poverty have remained deeply rooted in the in Nigeria as about 70 percent of the population still live below the poverty line as earlier established (World Bank 2018).

In addition, the Global Human Development Index (HDI) of Nigeria is 0.539 (Figure 6) and ranked the country 161th out of 187 nations (UNDP 2020). This indicates that despite the increase in the GDP the country remains relatively low compare to other countries. The prevalence of poverty and hunger is more pronounced in the rural regions of Nigeria where up to 80% of the population survive on less than a US dollar per day (World Bank 2020). In the rural Nigeria, inadequate post-harvest technology and poor distribution of food have combined with poverty to form an almost a major challenge and especially with unpredictable variations in weather conditions (Akinyele 2009). Nigeria remains a food insecure nation and relies heavily on importation of grains, livestock products including fish in the recent years. As previously opined by

Omorogiuwa et al. (2014), Nigeria has about 75 percent of its land suitable for agriculture, but only 40 percent is actually cultivated. Over welming rural population engage on subsistent farming on small plots of land to feed their households and relying on seasonal rainfall. Lack of access to necessary infrastructures such as roads has further worsen the rural poverty situation by disconnecting the rural farmers from required inputs and the markets (IFAD 2012).

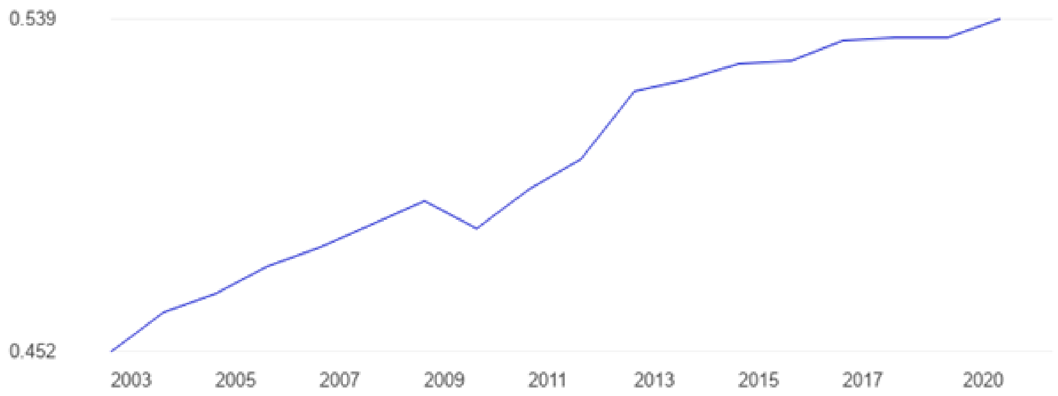

Figure 6: Nigerian human development index from 2003-2020

Source: UNDP 2020

Food insecurity is a multifaceted problem. It is quite tedious task discussing the driving factors for food insecurity in Nigeria. Nigerians lack enthusiasm for local products and often consider them inferior to imported food products (Naisbitt and Naisbitt 2016). The emergence of oil sector marked the imminent end of the agriculture sector as the huge revenue generated from the petroleum products shifted attention from agriculture. The government rely on importation of food and local production shrunk away, especially as wealth from oil has changed the status and tastes of many Nigeria in favor of foreign goods (Otaha 2013). This couple with socio-political instability which precluded the economic downturn, dwindling human resource base, gender inequality, education decadence, poor health facilities and the general loss of good governance have coexisted to further degenerate food accessibility (Naisbitt and Naisbitt 2016).

Climate change impacts food security, however food insecurity implies unavailability, inaccessibility and poor utilisation of food (Dutse and Ibrahim 2013). Food insecurity in the country results from increased crop failure and loss of livestock. In some areas diminishing returns are already setting in with a loss in the length of growing days of 20%. Growth rates of major staples like maize, guinea corn, millet and rice are suppressed by a rise in temperature (Olayide 2021). In addition, pest infestation and diseases is affected by variability in climate, thus deteroriate food storage.

Furthermore, climate change induced a migration of herdsmen and their animals to the southern part of the country in search for water and greener pastures has resulted in conflicts (Onyia et al. 2015). This situation has made cattle herders begin their annual migration every December to january of the year to the south earlier and the situation forces them to stay in the southern fields for longer periods in the hope that the fields in the north would have had enough time to be fully regenerated (Olayide 2021). Migration of rural youths to urban area has been said to be an another main cause of food insecurity in Nigeria as affect the farm labour availability. Drought, desertification and deforestation are recurrent and now occur at alarming rates in northern Nigeria as a result of water scarcity and pasture inadequacy that triggered migration (Nweke 2019).

2.3 Farmers Awareness of Climate Change

Studies reported different levels of climate change awareness among farmers, for example in Ghambia, Kutir et al. (2015) studied climate change awareness among farming households using Climate Change Awareness Index (CCAI) and reported that most (80.6%) households were aware about climate change in North Bank Region of Gambia. Oduniyi and Tekana (2019) investigated the relationship between climate change awareness and the adoption of agroforestry among farmers in the northwest province of South Africa. The author reported that 74.4% of the farmers were aware of climate change.

Keneilwe et al. (2018) studied the perceived climate change indicators and its effects over the past 10 years among agro-pastoralist farmers in Kweneng District, southeastern Botswana. The authour recorded that majority (97%) of the respondents in the study perceived increase in mean temperature while 91% of them perceived also increase in number of hot days in a year, on the issue of rainfall, 97% of them perceived decrease in mean annual rainfall. The 82% of them perceived decrease in number of annual rainfall days and the author further reported that 82% of them indicated increase in the occurrence of drought in the area while 74% reported no changes on the occurrence of flood. This may be attributed that Botswana is a landlock country with limited rivers and small mean rainfall of around 400mm and 70% of the country are predominantly desert. However, the author reported that 76% and 73% of the farmers interviewed perceived decrease in crop and livestock productivity respectively.

Abdallah et al. (2019) studied the intra-household farmers' perception and adaptation to climate change in Bangladesh and reported that 80% of the husbands in higher water scares areas perceived high changes in climate and further revealed that 89% of them indicated increase in temperature and 75% mentioned decrease in intensity and timing of rainfall, though 80% reported that they experienced drought (water stress) every year however they attributed it to natural disaster and only 5% of them attributed to anthropogenic activities.

Ibrahim et al. (2015) analized the crop famers' awareness of the causes and effects of climate change in south-western Nigeria using the climate change and environmental impact awareness index (CCEIAI) and noted that deforestation feature at the top of the list and followed by land clearing, bush burning, and fossil fuel use, while use of nitrogen fertilizer and burning waste appeared fourth position and finally reported that the result of CCEIAI revealed that almost half of the crop farmers were aware about the causes of climate change. On the effects of climate change, the authors reported that increased temperature rank first among others and followed by more frequent hot days and nights, increase in drought, reduced rainfall duration, intensity and increased evaporation while the result of CCEIAI shows that majority of crop farmers were aware of the effects of the climate change. This shows that farmers are more aware about climate change effects than the causes.

Bryan et al. (2013) assessed the climate change perception and adaptation among farmers across four agroecological zones of Kenya. The author reported that majority (94%) of them perceived an increase in mean temperature, 84% perceive a decrease in precipitation over 20 years, while only 2 and 6% observed a decrease in temperature and increase in rainfall and finally the author reported that 75% of them observed changes in rainfall variability. Mahamadou et al. (2019) recorded that 94.4% of the cereal farmers in Mali knew that floods course by climate change, affect crop production negatively while, 96.3% mentioned that they observed changes in rainfall patterns and only 15.6% perceived that increase in temperature has no negative effect on cereal production.

Few studies elicited information on climate change sources of information and channels used by farmers. Kutir et al. (2015) reported that farmers used variety of information for climate change awareness, the author reported that 45.91% were using radio, extension and farmers colleagues constituted 19% each, 13% from NGOs while only 1.7% received their climate change information from farmers association. Mahamadou et al. (2019) analysed the climate change information sources used by cereal farmers in Mali and reported that the most common source farmers get climate change information is through environmental NGOs with mean score of 0.93, then friends/colleagues (0.44) followed by radio (0.23), farmers association (0.18), television (0.06) and extension agent (0.03). this implies that the most important climate change source of information of farmers in Mali is NGOs, however, extension agent that are expected to be a bridge between farmers and research institutions is not important in terms of disseminating climate change information, which they are considered to provide scientifically based solution to farmers needs and problems. Oduniyi and Tekana (2019) investigated the relationship between climate change awareness and adoption of agroforestry among farmers in north-west province of South Africa and recorded that the majority (64.7%) of the farmers have climate change information from farmers association.

2.3.1 Determinants of climate change awareness among farmers

Factors that affect climate change awareness were identified according to the reviewed literature can be group into socio-demographic, farm, institutional and agro-ecological factors. Access to agricultural productive resources including information are varied between different socio-economic characteristic such as gender, in many society affect the climate change awareness farmers. *Gender*: Bryan et al. (2013) reported significant influence of gender on climate change perception among farmers in Kenya, the author revealed that female household head are more likelihood to perceive changes in average rainfall than their male household head counterpart. *Age:* Abdallah et al. (2019) studied the intra-household farmers' perception and adaptation to climate change in Bangladesh and reported that husband's age has negative significant influence on knowledge of climate change and perception, and he attributed that as a result of their involvement in non-agricultural and reluctant to engage in agricultural practices. While spouse age has significant influence on knowledge of climate change and perception. Ibrahim et al. (2015) used Tobit regression model to explain factors influencing the CCEIAI among crop farmers and found out that age of farmers has significant negative influence on both climate change causes and effects, this implies that increase in age of crop farmer will decrease the likelihood to be aware about climate change in the study area. Oduniyi and Tekana (2019) studied the relationship between climate change awareness and adoption of agroforestry among farmers in north west province of South Africa and reported the significant negative effect of farmers age on climate change awareness. *Education:* Abdullah et al. (2019) reported a significant negative effect of husband's years of education on knowledge of climate change and perception among farmers in Bangladesh and attributed that to their no participation fully in agricultural practices conversely, the author reported a significant positive influence of spouse age on knowledge of climate change and perception and attributed that with their fully participation in agricultural practices. Ibrahim et al. (2015) noted that years of formal education has positive association with the knowledge of climate change causes. The autor explained that the possible reason is that educated farmers may have more access to information sources that will make them more aware about the causes while on the other hand because of their level of education they may have access to white kola job which will make them to consider crop production as their secondary occupation that will make them not clarly feel the effect of climate change in compare to less educated farmers that fully engaged in farming. Oduniyi and Tekana (2019) analysed the relationship between climate change awareness and adoption of agroforestry among farmers in north west province of South Africa and reported the significant positive effect of level of education on climate change awareness. *Household size*: Abdullah et al. (2019) reported non-significant influence of household size on knowledge of climate change in Bangladesh. Ibrahim et al. (2015) recorded that number of household members has positive significant influence on climate change effect awareness among crop farmers of south western Nigeria. *Income*: Abdallah et al. (2019) recorded non-significant of both husband-and-wife total income on knowledge of climate change in Bangladesh. Ibrahim et al. (2015) recorded significant positive influence of non-agric income on both causes and effects of climate change in south western Nigeria. This is something strange that need more investigation for the validity and the reason for that. *Farm size*: Abdullah et al. (2019) reported non-significant influence of land under cultivation on knowledge of climate change among farmers in Bangladesh. Ibrahim et al. (2015) reported significant negative infuence of number of hectares of land owned by farmer on climate change causes awareness and negative but not significant on its effects among crop farmers of south western Nigeria. The possible reason for that is that farmers with large farmland may have some methods of copping with the effect of climate change by practicing crop rotation, fallowing etc. that will make them not to feel the effects unlike farmers with small size of farms. *Years of farming experience:* farming experience may influence the awareness of climate changes because change is a process that require time. Ibrahim et al. (2015) noted that farming experience has positive significant effect on awareness of climate change causes however negatively not significant on climate change effets awareness in south western Nigeria. Bryan et al. (2013) found out that farming experience has significant positive effect on climate change perception of farmers in regard to perceive changes in rain variability, decrease in rainfall and increase in temperature in kenya. This is very possible because the changes is process which require time. Oduniyi and Tekana (2019) investigated the relationship between climate change awareness and adoption of agroforestry among farmers in north west province of South Africa and documented a positive effect of farming experience on climate change awareness.

The institutional factors facilitate access, right and privilege to resources like extension services, land, market etc. *Extension contacts:* Abdallah et al. (2019) recorded negative association between frequency of extension contact of both husband and spouse on knowledge of climate change however it is not significant. Ibrahim et al. (2015) reported that increase contact with extension agent increases climate change causes awareness significantly in south western Nigeria. Bryan et al. (2013) noted a negative significant effect of extension field visit on perceive decrease in temperature among farmers in Kenya and attributed that to low extension contact may lead to the low level of farmers knowledge on current discussion of which increase in temperature is one of them. Oduniyi and Tekana (2019) analysed the relationship between climate change awareness and adoption of agroforestry among farmers in north-west province of South Africa and reported significant negative effect of extension visit on climate change awareness. *Organization membership*: Abdallah et al. (2019) reported that membership of organization of both husband and spouse has no significant effect on knowledge of climate change among farmers in Bangladesh, the possible reason for that, the author did not restricted membership with only agricultural organizations. *Access to credit:* Ibrahim et al. (2015) noted that farmers’ access to credit positive association with causes of climate change awareness but not significant and negative association with effect climate change awareness though the association is not significant among crop farmers in south western Nigeria. Abdallah et al. (2019) reported that husband access to credit has a positive significant effect on knowledge of climate change among farming households in Bangladesh.

Agroecological zone: Bryan et al. (2013) reported that farmers that are in humid zone are more likely to perceive decrease and less likely to perceive increase in rainfall compared to arid zone farmers and farming households in semi-arid zone are more likely to perceive decrease in rainfall compared to farmers of arid zone in Kenya. Abdallah et al. (2019) found out that farmers and spouses that are living in the medium water scarce area are more likely to know about climate change than low water scarce area spouses and also go further and reported those in high water scarce area are more likely to aware about climate change than those in low water scarce area in Bangladesh.

2.3.2 Theoretical framework for climate change awareness and knowledge

Experience demonstrates that small-scale farmers are not so much concerned with questions related to causes and effects but rely more on their own perception and awareness of changes, (FAO 2014). Farmers respond to climate change according to their perception of the causes of the environmental changes rather than scientific facts and evidence as conventional media trust is not guaranteed among farmers (Hyland et al. 2015; Arbuckle et al. 2015). The actions taken towards climate change mitigation and adaptation thus implies, that the farmers experience the negative effects of climate change on their farm operations. The awareness of climate change among farmers has been a focus of interest in recent scientific discussions (Bryan et al. 2013; Ibrahim et al. 2015; Kutir et al. 2015; Keneilwe et al. 2018; Oduniyi and Tekana 2019; Abdallah et al. 2019 and Mahamadou et al. 2019). However, studies that investigate how the knowledge of climate change is associated with the farmers' climate change perception are scanty despite its paramount importance, as it can be used to guide and shape the farmers' climate change for appropriate mitigation and adaptation decisions. This research gap served as motivation for our study.

Investigating not only farmer awareness but also knowledge of the causes of climate change in the context of the need for appropriate mitigations, is of the utmost relevance, but very few studies elicit such information (Madhuri and Sharma 2020). According to the knowledge gap theory, which hypothesized that when an information is disseminated to a social system increase, segments of the population with higher socioeconomic status tend to acquire this information at a faster rate than the lower status segments so that the gap in knowledge between these segments tends to increase rather than decrease (Tichenor et al. 1970). In this way, farmers with high social status will be likely to be more knowledgeable on climate change as they have access to a variety of information sources/channels that broadcast or publish governmental and non-governmental programs on climate change. This indicates the effect of socio-economic variables such as education, income, etc. as well as the role of information sources and channels on the knowledge of climate change of farmers (Figure 7).

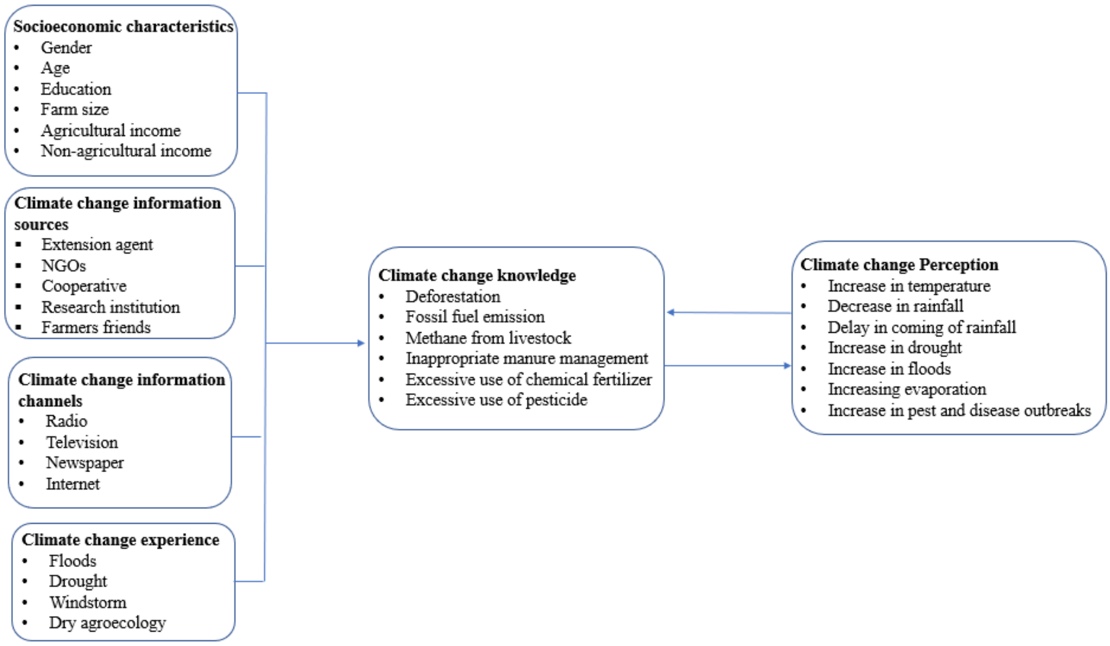

Figure 7: Theoretical framework of climate change awareness and knowledge

Source: Authour

However, some authors found out that people with low socioeconomic status are more knowledgeable about local issues that affect them directly than their counterparts (Hwang and Jeong 2009; Madhuri & Sharma 2020). In this way, farmers that experienced climate risk events are assumed to be more knowledgeable on climate change. This particularly applies to small-scale farmers with poor coping strategies and financial shock absorbers and this, depicts the effect of climate risk experience in climate risk-prone agroecological zones such as dry agroecology (arid, semi-arid, savannah zones, etc.).

2.4 Agricultural Insurance

Due to climate change farmers face a variety of risks that farm produce may be destroyed by drought, floods, or new pest and disease outbreaks (IFAD 2010). The adverse impacts of climate change are expected to continue leading to production losses in the sector, compromising the attainment of the Sustainable Development Goals, especially Goal 1 “Eradicate Extreme Poverty and Hunger” and Goal 7 “Ensure Environmental Stability” (BNRCC 2011). The types and severity of the risks confronting farmers vary by farming system, agroecological features, local policy, and institutional settings. Agricultural risks are particularly burdensome to small-scale farmers in the developing world, their livelihoods depend to a large extent on agricultural production (IFAD 2010; Omerkhil et al. 2020). Access to formal financial services is usually very limited to smallholder farmers that increasing their risks of climate and weather extreme vulnerability, slow economic development and poverty reduction (IFAD 2010).

To make the agricultural production systems resilient to drought, floods and other climate change risks a reasonable focus on adaptation in the agriculture sectors and advocates for better management are a prerequisite for attaining food security, eradicating extreme poverty and hunger (FAO 2017). Over time, those involved in the agriculture sector have developed a range of relevant risk-management practices. Rural households and communities, financial institutions, agricultural traders, relief agencies, and governments all use different methods of coping when losses occurred (IFAD 2010). In the modern days, different approaches were introduced to make the inherited methods more effective and introduce a new one where the need necessitates. Agricultural insurance is one of the modern risk management strategies to make the agricultural system resilient and help farmers adapt to climate risk to ensure food security (Skees et al. 2008; Skees and Barnett 2004).

Agricultural insurance could play a key role in protecting vulnerable households. It increases resilience, including the adaptive capacity, as it is designed to cover financial losses incurred due to a reduction in expected outputs, and also serves as security for banks for servicing loans that lead to food security (Nnadi et al. 2013). Cash payments from an insurer improve opportunities for farmers to make the capital investments needed to adapt with changing environment or to maintain their current production strategies and insurance can encourage adaptation by being bundled with new technologies that will improved farm productivity (Collier et al. 2009). Insurance positively affects the resilience of livestock herders, food security and risk management during climate risk (Thornton and Herrero 2014; Biglari et al. 2019). Agricultural insurance is expected to lead to an increase in the area planted and encourage investment in a profitable way (Elabed et al. 2013), and also, proved to increase household consumption (De Nicola 2015; De Nicola and Hill 2013).

These potential benefits of the agricultural insurance make it to be recommended and promoted as one of the climate change adaptation strategies to farmers for attaining food security by intergovernmental organizations (Nnadi et al. 2013; World Bank 2014; IPCC 2018; IPCC 2019). Training and technical assistance were given to climate change stakeholders of developing countries such as Ministries of environments and agriculture, banks, insurance companies and brokers, farmers group as well as policymakers that should enable them to design local policies that create a smooth-running and adoption of insurance (IFPRI 2014; IWMI 2021). Skees et al. (1999) theoretically proposed agricultural insurance for developing countries and tested it empirically in Morocco (Skees et al. 2001).

Strong statistical correlation between rainfall, and cereal revenues in seventeen provinces in the agro-climatic zones of Morrcco and proportional rainfall insurance contracts was observed (Skess et al. 2001; Hess et al. 2002). As agricultural insurance provides cover to agricultural production that makes it more resilient to weather and climate extreme risk, which is one of the pillars of climate-smart agriculture (FAO 2021; IPPC 2018). In this context, agricultural insurances are not simply covering the risk of failed harvest, however, may encourage the farmer to be a bit lesser risk-averse and go to apply riskier adaptation innovations that promise higher yields and income. In this regard, insurance may trigger innovation and development not only protection against failed harvests. Agriculture insurance is well-established as an effective tool for increasing farmers’ resilience in the face of various production risks (Hansen et al. 2017).

2.4.1 Agricultural insurance in Nigeria

Commercial agricultural insurance scheme was first introduced in 1987 by Niger Insurance, later Federal Government introduced the National Insurance Corporation of Nigeria (NICON) and the National Cooperative Insurance Society of Nigeria (NCISN) to operate agricultural insurance schemes (Nnadi et al. 2013). The objective is to offer protection to the farmer from the effects of natural disasters and to ensure payment of appropriate compensation sufficient to keep the farmer in business after suffering a loss (NAIC 2021; Nnadi et al. 2013; Olubiyo et al. 2009). In 2010 Nigeria formally included insurance among agricultural climate change adaptation strategies in its Nationally

Determined Contribution (UNFCCC 2015). With government support, the National Agricultural Insurance Corporation (NAIC) have offered insurance with up to 50% of premiums subsidy (World Bank 2011) with the intention to expand the insurance to Nigerians roughly 15 million smallholder farmers (NAIC 2021). Despite these supports given to the climate change stakeholders and potential benefits for farmers, low patronage and adoption of agricultural insurance prevailed in the country (Olajide-Adedamola and Akinbile 2019; Akinola 2014; Falola et al. 2013; Ibitoye 2013).

Later, the National Agricultural Resilience Framework (NARF), launched by the Federal Ministry of Agriculture and Rural Development in 2014 intended to cover 15 million smallholder farmers with agricultural insurance (Adegoke et al. 2014). NARF is a policy framework designed to ensure that Nigeria’s agricultural sector can cope with the shocks and stresses of changing climate. Nigeria joined the Global Alliance for Climate-Smart Agriculture (GACSA), to contribute to the goal of ensuring that 500 million smallholder farmers worldwide can adopt Climate Smart Agriculture (CSA) technologies and practices through agricultural insurance as well as other options (Hansen et al., 2017). As the smallholder farmers in Nigeria roughly estimated to be 57 million (Statista 2021; FAO 2020), the country’s insurance programme intended to cover 20% of them (Hansen et al. 2017). The Nigerian Federal Government indicated five key areas to increase farmers’ access to insurance: data systems, awareness and capacity building, facilitating international risk pooling, smart subsidies, and creating an enabling policy environment (World Bank 2011).

Insurance agents and brokers, banks and consultants are intermediaries to NAIC based on relevant laws, rules and regulations. They are charged for broadened the insurance market; prepared initial documentation, collect premiums, and supervise to ensure farmers meet conditions for good crop and livestock husbandry as laid down in guidelines (Olubiyo and Hillan 2005). Commercial and merchant banks are to avoid losing the money that had been advanced due to natural disasters; the Central bank has the legal obligation to link participating banks and NAIC and the financial contract between NAIC and the loan beneficiaries (Hansen et al. 2017; Olubiyo and Hillan 2005). Thus, the interest of the Central bank through the Agricultural Credit Guarantee Scheme Fund (ACGSF) in the insurance is to monitor bank compliance with government policies on farm finance and to safeguard against bogus claims for compensation arising from loan defaults not related to insured hazards (Olubiyo and

Hillan 2005). Farmers are expected to be registered for the insurance by paying their premium depending on the farm type, following the standard farming procedure and inputs as mentioned in the contract document and reporting the losses within the stipulated period (NAIC 2017).

2.4.2 Variables influencing the agricultural insurance awareness and adoption

Factors found to affect the awareness and the adoption of agricultural insurance can be grouped into socio-demographic, farm and institutional characteristics, and climate risk experiences based on the studies. We consider awareness as a step and pre-requisite for the adoption, studies show that *awareness* of crop insurance as a climate risk mechanism was found to be influenced by gender, Olila and Pambo (2014). Studied the determinants of farmers' awareness about crop insurance in Trans-Nzoia county, Kenya and reported a significant effect on the agricultural awareness of farmers. In the same way, Ghazanfar et al. (2015) investigated the farmers' perception, awareness and factors affecting awareness of farmers regarding crop insurance as risk coping mechanism evidence from Pakistan and reported a significant insurance awareness difference between the two *gender* and attributed that effect of different access to information sources and climate risk vulnerability levels. Level of *education* of farmers found to positively affect the awareness of agricultural insurance in Trans-Nzoia county, Kenya and Pakistan. As education help farmers to understand written information from insurance stakeholders such as government, banks and brokers. Hountondji et al. (2018) investigated the determinants of farmers awareness about crop insurance case of Ouesse District, Benin. The authors reported a positive significant effect of farmer's education on insurance awareness.

Farm characteristics may affect the awareness of agricultural insurance as they serve as proxy of wealth. For example, *farm size* was reported to affect the insurance awareness (Olila and Pambo 2014; Ghazanfar et al. 2015). The institutional factors that are found to affect the insurance include *access to credit*, for example, studies in Pakistan and Benin republic reported the positive effect of access to credit on insurance awareness (Ghazanfar et al. 2015; Hountondji et al. 2018). With regards to *cooperative association* Jatto (2019) assessed the farmer's awareness of agricultural insurance packages evidence from communities of Zamfara State, Nigeria, and reported a significant positive effect of farmers' cooperative society on insurance awareness.

With regards to the effect of socio-demographic characteristics on *adoption* of agricultural insurance, Chand et al. (2020) studied the status and determinants of livestock insurance in India at micro-level and reported the significant effect *gender* as female farmers were found to be more likely to adopt livestock insurance than their male counters. Age was found to affect index-based livestock insurance adoption in South Africa (Oduniyi et al. 2020). As education play a vital role in evaluation the benefits of innovation and taking right decision making. *Farmers' education* was found to influence the adoption of livestock insurance positively in India, South Africa and Ghana (Chand et al. 2016; Oduniyi et al. 2020; Abugri et al. 2017). Chand et al. (2016) and Oduniyi et al. (2020) revealed that *farming experience* in livestock rearing has a positive significant influence on the adoption of livestock-based index insurance in India. A number of *household dependents* influence the decision to use index-based livestock insurance positively in South Africa (Oduniyi et al. 2020).

With regards to farm characteristics, farm characteristics can serve as proxy of farmers wealth which can facilitates the adoption of agricultural insurance. For example, Chand et al. (2016) reported that *herd size* influences farmers' decisions to adopt livestock insurance positively in Haryana and Rajasthan, India. Budhathoki et al. (2019) analyzed farmers' interest and willingness to pay for index-based crop insurance in the lowlands of Nepal and reported that *farm size* influences the use of crop insurance in a positive way. With regards to institutional characteristics, as access to financial, information and other productive resources expected to affect the use agricultural innovations, weather index insurance adoption was found to affected by access to bank/credit positively in India, Ethiopia and Nepal (Gine et al. 2008; Bogale 2014; Amare et al. 2019; Budhathoki et al. 2019). Concerning the climate risk experience, *moisture stress* and the number of *flood experiences* were reported to significantly influence the use of crop insurance in Ethiopia and India (Bogale 2014; Budhathoki et al. 2019; Amare et al. 2019).

2.4.3 Theoretical framework of the insurance awareness and adoption

A number of studies investigated different aspects of agricultural insurance, such as appropriate agricultural financial management in a changing climate (Daron and Stainford 2014; Turvey et al. 2006; Woodard et al. 2016; Zhu et al. 2018). Other studies analyzed, how insurance contributes to social protection (Devereux 2016; Jensen et al. 2017), increases welfare of farmers (Chantarat et al. 2017), is used in providing subsidies to farmers (Ricome et al. 2017; Freudenreich and Musshoff 2018). Some studies investigated how the insurance help in rural poverty reduction (Hansen et al. 2018) and social equity (Fisher et al. 2018). Less attention was given to agricultural insurance awareness and adoption of farmers and the reasons for the low adoption (Carter et al. 2016; Jin et al. 2016; Ntukamazina et al. 2017).

There is a consensus that awareness of the innovation is prerequisite and the first stage for the adoption based on Awareness, Interest, Evaluation, Trial and Adoption [AIETA] processes (Daberkow and Mcbride 2003) which are influenced by the information channels as postulated by Diffusion of innovation theory (Rogers 2003). (see Figure 8). We grouped the variables potentially affect the awareness and adoption of agricultural insurance into i) Demographic characteristics, ii) Information channels, iii) Wealth and assets and iv) climate change extreme experience.

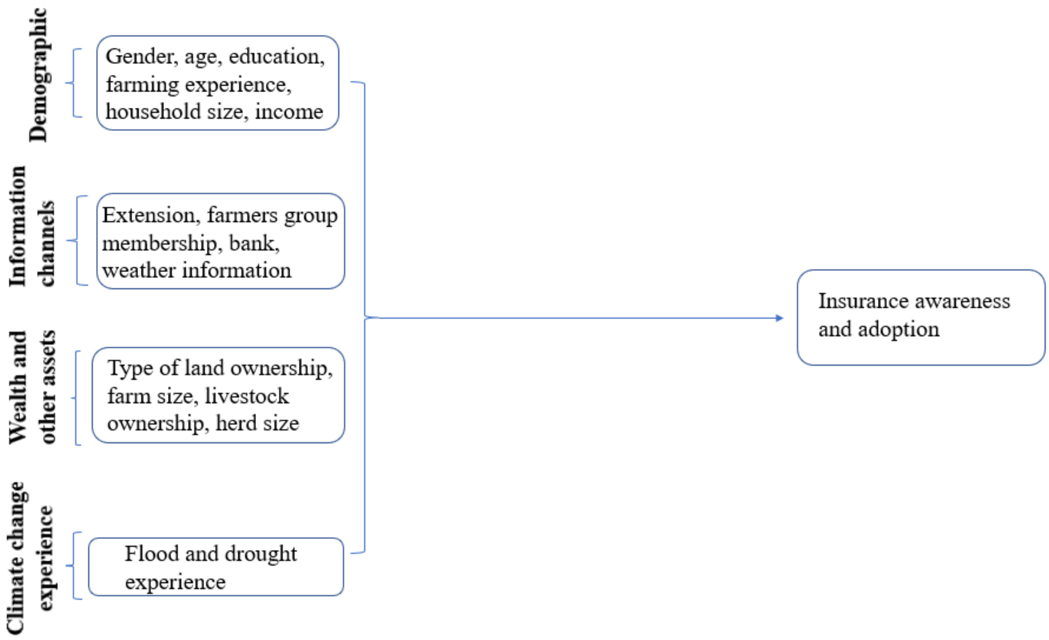

Figure 8: Theoretical framework of agricultural insurance awareness and adoption

Source: Authors

It is a paramount to investigate the insurance awareness of farmers before taking adoption into consideration. Financial capability of the farmer may also influence the adoption behaviour of farmers, this emphasized the role of wealth such as income, livestock ownership and other assets as depicted by Resource-based theory (Below et al. 2014). As the needs and necessity to upset the effect of emerging threats such as drought and flooding experience, that will make farmers to seek a new knowledge and techniques that will help them to overcome these constraints as highlighted by Protection motivation theory (Floyd et al. 2000). Based on this background, this study investigated the drivers of agricultural insurance awareness and adoption of farmers.

2.5 Livestock Vulnerability to Climate Risk

Livestock production contributes to the improvement of food security and some sustainable development goals such as no poverty, gender equality, zero hunger, and climate action (UNSTAT 2020). Livestock constitutes about 40% of agricultural output in developed countries and 20% in developing countries, supports the livelihood of 1.3 billion people worldwide, and supplies about 34% of the global protein (FAO 2021a). About 30% of global meat and 6% of milk production originate from grazing systems on land that is often poorly suited for cropping (Herrero et al. 2013). Further, livestock provides a range of other services: a source of draught power, a means of transportation, source of nutrients for poor soils, source of income generation and diversification, and a form of investment all of which contribute to the overall well-being of many communities (CIRAD 2016).

The sector is vulnerable to climate variability and risk, for example, due to changes in production and quality of feed crops and forage (Chapman et al. 2012; IFAD 2010; Polley et al. 2013; Thornton et al. 2009). Further, increasing temperatures affect animal growth and milk production negatively (Henry et al. 2012; Nardone et al. 2010) and induce drinking water scarcity for the animal (Thornton et al. 2009). Heat stress reduces feed intake, increases water intake, and alter physiological functions such as reproduction and respiration rate (Nardone et al. 2010) and has resulted in increased livestock morbidity and mortality in tropical agroecological zones (AEZs) around the world in the last decades (Renaudeau et al. 2012; Seo and Mendelsohn 2008). These impacts are primarily due to an increase in temperature, precipitation variation, and a combination of these metrological variables (Aydinalp and Cresser 2008; Henry et al. 2012; IFAD 2010; Nardone et al. 2010; Polley et al. 2013). The potential impacts of climate change on present livestock systems worldwide constitute a significant concern.

2.5.1 Livestock in Nigeria

Pastoral systems dominate 82% of the livestock system in the country, where farmers move animals particularly cattle from the north to the south in search of pastures and water. Cattle herd size in the country ranges from 100 to 300 heads of indigenous breeds, production is subsistence-oriented, and animals are kept on uncultivated pastures and rely on grazing mostly without any feed supplements (FAO 2019b)

Population growth in Nigeria, increasing urbanization, and incomes are resulting in increased demand for livestock products. Study estimates that, between 2010 and 2050, beef, poultry meat, and milk consumption will increase by 117, 253 and 577 percent, respectively (FAO 2018). As a result, the livestock sector will transform and grow, resulting in a new relationship between domestic animals, populations, natural resources, and wildlife (FAO 2018). The number of major animal species in Nigeria estimated in 2012 and projected to 2050, cattle from 20.7million in 2012 to 53.6 million in 2050, goat from 80.8 to 207.8 million, sheep from 42.5 to 78.2 million, poultry from 207.6 to 1,284.3 million, and pigs from 6.5 to 21.1 million (FAO 2019; Statista 2021a).

In terms of emission from the sector, poultry production systems in the country emit 24.4 9 kg CO_2eq./head/year, dairy production systems 5,974 kg CO_2eq./head/year, poultry water footprint is approximately 7,000 m^3 per ton of live animal where mixed systems, it reaches 9,169 m^3 per ton and in commercial systems about 5,000 m^3 per ton, cattle water footprint is approximately 5,100 m^3 per ton of live animal from agro-pastoral and intensive systems, it reaches 7,202 m^3 and 3,091 m^3 per ton, respectively, land use in the country dominated 33% by pasture and permanent meadows and free-range grazing by cattle, sheep, goats, donkeys and camels is a common practice in pasture areas, where the land is not privately owned (FAO 2018).

2.5.2 Livestock climate risk adaptations

There are different livestock adaptation strategies in literature, addressing varieties of climate risks such as feed deficit and rainfalls that make the livestock systems resilient to the changing environment to ensure food security. For example, *preserving crop straw and hay (PCSH)*, help farmers to supplement livestock feeding with dried straw-based and legume fodder feed in winter and feed deficit period that had very promising results, and seems likely to become popular in some areas (FAO 1996; Lee et al. 2013; Kalaugher et al. 2017). *Pasture irrigation* is an artificial supply of water to pasture and rangeland which found a significant effect on creating employment and adding value to forage crop production in southern Alberta's irrigated areas in Canada and recommended in Australia (Jones 2000; Connor et al. 2012; Lee et al. 2013). *Destocking* is selling out of a small or large number of the animal during the water, feed scarcity and other associate climate risks (Kalaugher et al. 2017; Mugari et al. 2020) usually at a low price (Morton and Barto 2002).

Supplementary irrigation using underground water is a process of taking water from well, borehole and other modern methods like sprinkler and drip irrigation to provide water for pasture and livestock drinking water during drought and water deficit as a coping and adaptation strategies (World Bank 2016), modern irrigation are one of the water scarcity and dry spell adaptation in agriculture (FAO 2016). *While the supplementary irrigation* using streams and rivers serves the same purpose but accessible to only farmers that are proximity with the run-off or standing water, farmers consider it as good adaptation (Gebru et al. 2020) and is recommended to be an adaptation to drought (Connor et al. 2012; Lee et al. 2013; Kalaugher et al. 2017). *Rainwater harvesting techniques* is a collection of in-field run-off rainwater from a surface, and its storage that allows for the rainwater to be used at a later time (Innovative water solution 2016; Gandure et al. 2013) and used by farmers during water scarcity for vegetables and livestock (Legesse et al. 2013; Gandure et al. 2013), farmers consider it as good adaptation (Gebru et al. 2020).

Switching to crop is an allocation of resources used for livestock production to crop production system and found to be one of the livestock adaptations among farmers (Hassan and Nhemachena 2008); farmers consider it as a good adaptation (Gebru et al. 2020). Farmers are rational producers that allocate resources to higher profitable venture or lower risk and uncertainty production; this nudge livestock farmers to change their farm production from livestock to crop production as recommended by a study (Seo 2013). *Livestock-crop integration* (mixed farming) makes agriculture more resilient by intra-mutual benefits, by contribution feeds to livestock production, and to crop production through the provision of traction and manure (Descheemaeker et al. 2018). Mixed farming systems, in which crops, and livestock are integrated on the same farm, were reported as climate adaptation strategies among farmers (Thornton and Herrero 2014). *Off-farm livelihood activities* are any income-generating source that is not directly from farmland, it found that livestock farmers of the midland agro-ecological zone adopted it as a climate risk adaptation strategy (Legesse et al. 2013).

2.5.3 Variables influence the adoption of livestock adaptation

Factors found to influence livestock adaptation in literature can be grouped into socio-demographic, farm, institutional characteristics and agroecological factors. For example, socio-economic factors that affect the adoption of rainwater harvesting. Destaw and Fenta (2021) analyzed climate change adaptation strategies and their predictors amongst rural farmers in Ambassel district, Northern Ethiopia and reported a significant effect of *gender*, *increasing age*, *farmers' education*, *family size*, and *agricultural income* on supplementary irrigation and feeding. Mango et al. (2017) assessed the awareness and adoption of land, soil and water conservation practices in the Chinyanja Triangle, Southern Africa and reported a significant positive effect of *age* and *education* on adoption of rainwater harvest. Also *age*, *farmers' education* and *non-agricultural income* were found to negatively influence the adoption of animal destocking significantly in Kenya and China (Silvestri et al. 2012; Yang et al. 2021). Obayelu et al. (2014) studied factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria and found that farmers' *age* and *non-agricultural income* have positive effects on the use of crop-livestock integrated farming. *Farming experience*, was found to positively affect pasture/forage cropping, integrating crops with livestock and destocking of animal significantly during climate risk in Ethiopia (Gebru et al. 2020). Households' *dependency ratio* was found to affect off-farm adoption among livestock farmers in China (Yang et al. 2021). Kgosikoma et al. (2017) studied agro-pastoralist adaptations, including supplementary irrigation and feeding management, and reported a positive significant effect of *household size*. Also, the *household size* and *off-farm activities* were found to positively affect the adoption of livestock-crop integrated (mixed farming) system (Legesse et al. 2013).

With regards to farm characteristics, Legesse et al. (2013) studied smallholder farmers' perceptions and adaptation to climate variability and climate change in Doba district, west hararghe, Ethiopia and reported that the livestock-crop integrated (mixed farming) system was found to positively affect by *herd size* and *farm size*. *Herd size* was also found to affect pasture/forage cropping and integrating crops with livestock positively in Ethiopia (Gebru et al. 2020). Kgosikoma et al. (2017) analyzed the agro-pastoralists' determinants of adaptation to climate change and reported a significant positive effect of *land ownership* and *farm size* on supplementary irrigation and feeding management.

With regards to institutional characteristics, access to *extension* advisory services and *weather information* were found to positively affect the adoption of water conservation of livestock farmers in particular rainwater harvesting technology in Ethiopia and South Africa (Mango et al. 2017; Destaw and Fenta 2021). Similarly, Legesse et al. (2013) studied smallholder farmers' perceptions and adaptation to climate variability and climate change in Doba district, west hararghe, Ethiopia and reported that the livestock-crop integrated (mixed farming) system was found to positively affect significantly the frequency of *extension contact* and *weather information* was found to affect the adoption of destocking in China (Yang et al. 2021). Farmers' *group membership* found to affect pasture/forage cropping, integrating crops with livestock (mixed farming), and destocking significantly in Ethiopia and South Africa in a positive way (Gebru et al. 2020; Mango et al. 2017). Also, Legesse et al. (2013) found that frequency of *extension* is positively affects rainwater harvest significantly in Ethiopia. *Access to weather information* was found to significantly affect supplementary irrigation and feeding management significantly (Kgosikoma et al. 2017).

Regarding agroecological factors, farmers of the *midland* and *highland* AEZs were more likely to adopt soil and water conservation strategies than those in the *lowland* AEZs amongst rural farmers in the Ambassel district Northern Ethiopia (Destaw and Fenta, 2021). Association between *dry tropical zone* and the likelihood of livestock farmers to adopt off-farm activities was reported (Gebru et al. 2020). Legesse et al. (2013) found that livestock farmers of the *midland* AEZs are more likely to adopt a rainwater harvesting strategy.

2.5.4 Theoretical framework and variables affect livestock adaptations

We expect that agroecological conditions would determine the choice of different types of livestock climate risk adaptation strategies according to the theory of induced innovation and protection motivation. The theory posits that when an agent (e.g. livestock farmer) experiences problems with changes in the environment in which they operate, such as water scarcity, drought, flooding or other climate risks, they are likely to seek new technologies and approaches that will help to overcome the emerging threats (Netra et al. 2004; Ndambiri et al. 2012). We also expected that despite AEZ conditions institutional factors may play a significant role in the adoption behaviour of farmers, as explained by institutional theory (North 1990). Institutional factors create an enabling environment for technology adoption as it regulates and modifies resource rights and access to services such as rights to land, irrigation water, weather forecast information, credit, and livestock information that may facilitate the adoption of climate risk adaptation strategies. Previous studies (Deressa et al. 2009; Hisali et al. 2011; Tambo and Abdoulaye 2012; Bryan et al. 2013; Comoé & Siegrist 2015; Asfaw et al. 2018) investigated the effect of AEZs and institutional factors on climate change adaptation behaviour of farmers, with a focus on the crop sector. The livestock sector needs the same scientific attention and priority to better understand the adoption of livestock climate-smart practices that will make the system resilient.

Further, we acknowledged the effect of farmers' demographic and farm characteristics on the climate risk adaptation strategies as explained by *resource-based* and *diffusion of innovation* theories (Figure 9); however, our study gave emphasis to the effect of AEZs and institutional factors on the adoption of livestock climate risk adaptation of farmers Regarding ecological conditions, an association between AEZs and adoption of supplementary feeding adaptation, destocking, irrigation adaptation strategies, switching to crop production, and off-farm activities were reported (Destaw and Fenta 2021; Gebru et al. 2020; Legesse et al. 2013; Shemdoe 2011). Institutional factors expected to affect the adoption of livestock climate risk adaptations based on the *institutional theory* are: access to extension advisory services, climate change/weather information, access to credit, and access to livestock-related information (Mango et al. 2017; Destaw and Fenta 2021; Legesse et al. 2013; Mabe et al. 2014; Naseer et al. 2014; Tiwari et al. 2014; Berhe et al. 2017; Kgosikoma et al. 2017; Nkuba et al. 2019; Kato et al. 2019; Shahbaz et al. 2020; Yang et al. 2021).

Other factors identified by *resource-based* and *diffusion of innovation* theories include farm head and household and farm characteristics (including gender, age, and education), and are used as control variables in our livestock adaptation models (Obayelu et al. 2014; Kgosikoma et al. 2017; Mango et al. 2017; Silvestri et al. 2012; Yang et al. 2021). Non-agricultural income affects the adoption of irrigation, as well as the frequency of switching to crop production livestock-crop integration and off-farm activities (Silvestri et al. 2012; Yang et al. 2021; Obayelu et al. 2014). Family size, dependency ratio, farming experience, and agricultural income were found to positively affect the adoption of supplementary feeding, destocking, irrigation technology adaptation, integrating crops with livestock, and off-farm activities (Kgosikoma et al. 2017; Gebru et al. 2020; Destaw and Fenta 2021; Yang et al. 2021). With regards to farm characteristics, the adoption of supplementary feeding, livestock-crop integrated (mixed farming) systems, and off-farm income generation activities are affected positively by farm size and total livestock units (Legesse et al. 2013; Gebru et al. 2020). Land ownership, farm size, and herd size were found to positively affect supplementary feeding and irrigation adaptation strategies (Kgosikoma et al. 2017; Destaw and Fenta 2021).

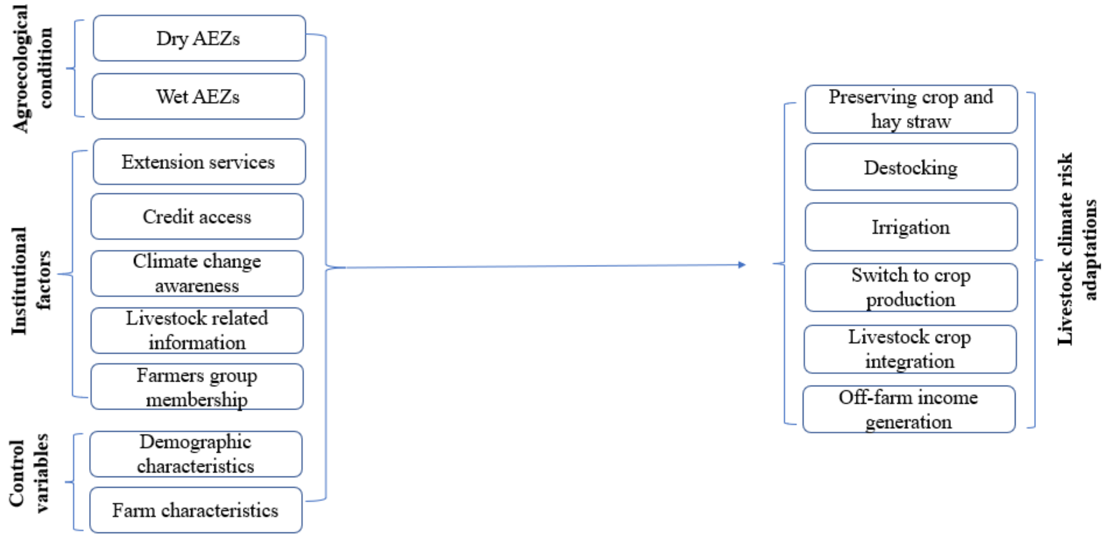

Figure 9: Theoretical framework of effect of AEZs and institutional factors on livestock adaptation. Source: Authour

2.6 Crop Adaptation Strategies and their Drivers

Adaptation is referred to as the adjustment and changes to the existing systems in response to expected and unexpected climate stimuli and their impacts (FAO 2001)**.** Farmers response to the climate change in different ways, for example Kutir et al. (2015) reported that majority (93.41%) of the farming household in North Bank Region of Gambia adopted one or more response strategy(ies) to reduce their vulnerability to climate change and increase their crop yields, however 6.59% did not adopt any response strategy despites its effect on their crop production. The author further revealed that 74.42% adopted strategy "A" (response strategy that involved the practiced of *crop diversification*, used different *planting dates*, use *drought resistant crops*, used *chemical fertilizers*, *prayer/ritual* offerings, *implemented soil and water conservation methods*, practiced *crop rotation*, *early maturing varieties*) while only 2.33% adopted strategy "B" (response strategy that involved the practiced *crop diversification*, *used different planting dates*, used *drought resistant crops*, practiced *crop rotation*, and *changed area/size* of farm land).

Keneilwe et al. (2018) studied the perceived climate change indicators and its effects over the past 10 years among agro-pastoralist farmers in Kweneng district, south eastern Botswana and recorded that majority (84%) of the respondent changed their *planting date*, 27% of them used *soil improvement techniques* (the author did not specify which one among them) and 23% *changed their crop variety* and 20% of them *changed to the use of chemical fertilizers* and *pesticides*, however, it will be good if the author try to find out clear what happing after the change: Are they change from one form of synthesized chemical to another one or to organic one?.

Abdallah et al. (2019) studied the intra-household farmers' perception and adaptation to climate change in Bangladesh and recorded that 28% of the farmers adopted *short time variety* and *drought tolerant* rice variety, 27% of them adopted *supplementary irrigation*, 21% adopted non-rice and *horticultural crops* as their adaptation strategy and only 11% each for adoption of *improved channel/water harvesting* and those that does not adopt any climate change adaptation. In this way, Bryan et al. (2013) recorded that the common adaptation strategies among farmers in Kenya were *changing crop varieties* (33%), *changing planting date* (20%), and *changing crop type* (18%). Other adaptation reported by the authour in Kenya include *planting of trees* and *water and soil management* practices constituted by 5%, finally the author reported that 19% of the study sample did not adopt any climate change adaptation. Hassan et al. (2019) recorded that farmers and ministry of environmental officials considered that supplies of *inorganic fertilizers*, improved *drought-resistant* crop seeds and *irrigation* would help decrease the impacts of drought in north-eastern Nigeria.

Mahamadou et al. (2019) analysed the climate change adaptation strategies adopted by cereal farmers in Mali and found that the most common among others are *timely planting* (1.93), planting of *short-time varieties* (1.12), *drought resistance* seed (0.83), *rotational of crop*ping (0.71) and use of *improve seed* (0.69). Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and reported that 85% of the farmers adopted at least one the strategies to the climate change. The author recorded that the common adaptation methods were *planting different crops* on single plot (intercropping) and *changing land* under cultivation, each comprising 64% of the respondents while the least employed adaptation methods by farmers were switching from farming to *non-farming livelihood activities* by 9% and increased use of *irrigation* by 8%. In regard to adaptation drivers, literature shows that factors influencing crop adaptation among farmers can be grouped into: demographic variables such as gender, age, etc., farm characteristics such as farm ownership and size, institutional variables such as access to credit, access to extension services etc. and climatic condition of the area such as land fertility, drought and underground water scarcity, occurrence of flood etc.

For the sociodemographic factors found to affect the crop adaption includes, *gender:* Keneilwe et al. (2018) reported that female house head farmers are more likely to adopt crop climate change adaptation than their male counterparts in Kweneng District, south eastern Botswana among agro-pastoralist farmers and attributed that to willingness of female to change their farming system in order to take care of their family, however this might not be the reason because male household head also share this responsibilities, it will be better if this is attributed to access to productive resources such as land, credit and climate information. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and reported that female farmers are more likely to adopt climate change adaptation strategies than male counterpart. And attributed that woman are usually a frontline worker in the farm that make them more sensitive and response to the environmental changes.

Age: age of farmer can affect the use of adaptation strategy as older farmers may experience the changes more than the younger ones, or in contrast they may be conservative to change. For example Keneilwe et al. (2018) revealed that *farmer's age* has significant negative influence on the adoption of climate change adaptation among agro-pastoralist farmers in kweneng district, south eastern Botswana and attributed this to old farmers are likely to be conservative and attached to the traditional farming practices of which is logical and in line with the *diffusion of innovation* theory, this is consistent with that of Abdallah et al. (2019) who reported significant negative influence of *husband age* on adoption of climate change adaptation while positive for their spouse in Bangladesh and attributed that male are not fully involved in agricultural activities compare to their wives in the country. Conversely, Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and found out a significant positive effect of *farmers age* on climate change adaption strategy. This indicate the effect of age on adaptation is context specific.

Household size: number of house members can influence the adoption of farming technologies and innovation as it may facilitate it when the active labour of the households is high or contrary if the dependent is dominants in some cases. Study of Keneilwe et al. (2018) recorded a significant negative effect of *household size* on adoption of climate change adaptation in one district of south-eastern Botswana and attributed that to income diversification of the large family. Abdallah et al. (2019) found out that *household size* has significant negative influence on adoption of climate change adaptation strategies and attributed it to non-agricultural endeavour involvement of large families. However, some may argue that high number of family members can serve as a free source of labour that can facilitates the adoption of labour intense climate adaptation such as local water channels and supplementary irrigation which is one of climate adaption considered in the study. Bryan et al. (2013) found out that farmers with large *family size* are more likely to adopt soil and water management than farmers with small households in Kenya. The author did not mention the possible reason for that as he did on other factors, however the possible reason for that is that soil and water management practices at small scale level are mostly labour intensive, which large household size might use it as a source of free labour as common practice in most of African rural areas. This enables them to adopt such practices while small household do not have this available labour. Mahamadou et al. (2019) reported a significant positive relationship between *number of household* and climate adaptation among cereal farmers in Mali and attributed that with the abundance of family labour. However, Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and reported a significant negative influence of *family size* on climate change adaptation strategies and attributed that availability of labour that can be diversify into off-farm livelihood activities to carter with the needs of the family.

Level of education: education may likely affect the adoption of climate change adaptation because knowledge is the most important tool of evaluation of innovation and decision making however, Keneilwe et al. (2018) reported no significant influence of *education* on climate change adaptation among farmers in Botswana. Abdallah et al. (2019) reported that *years of schooling* of both husband and spouse has no significant influence on adoption of climate change adaptation in Bangladesh thought it has positive regression coefficient. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and aver a positive effect of *education* on adoption of climate change adaptation strategies and attributed that to its effect on access and ability to understand information.

Farm and off-farm income: Bryan et al. (2013) found out that farmers with *non-farm income* livelihood are more likely to adopt planting trees and change of fertilizer than farmers without non-farm income livelihood in Kenya. This may attribute with the large capital required for agroforestry and the information needed which farmers with diversify sources of income have this advantage. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and reported a significant positive effect of *farm income* on climate change adaptation strategies. *Farming experience:* years of farming experience may influence the adoption of climate adaptation of the farmer as the gathered a farm managerial skill over time. Keneilwe et al. (2018) reported no significant negative influence of years of *farming experience* on adoption of climate change adaption among agro-pastoralist famers in Botswana. However, Bryan et al. (2013) reported a significant positive effect of *farming experience* on soil and water management as climate change adaptation among farmers in Kenya. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and recorded a significant positive influence *farming experience* on climate change adaptation strategies. The author attributed that the farmers with more years of farming experience realised the environmental changes that is taking place that nudged them to the adoption.

Regarding farm characteristics, *Land ownership and Farm size:* Bryan et al. (2013) found out that farmers with land title are more likely to adopt change in fertilizer than those without land title the author further reported that increase in cultivated hectares of farm under the farmer increase the likelihood adoption of change variety, planting trees and soil and water management in Kenya. Mahamadou et al. (2019) found out a significant positive association between *farm size* and adoption of climate change adaption strategies among cereal farmers in Mali.

Regarding the effect of institutional factors on crop adaptation, *extension contacts:* access to extension services may have a significant effect on behaviour of farmer as a reliable source of agricultural information very close to the farmer. Abdallah et al. (2019) recorded a positive association between *extension contact* and adoption of climate change adaptation among farmers of Bangladesh though is not significant. Bryan et al. (2013) classified different classes of extension, and found that farmers with access to *crops extension* (field visit, farmer field school, farmer-to-farmer, exchange farmer group, and common interest group) are more likely to adopt change of planting date, change of variety, planting trees, change fertilizer, soil and water conservation. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya reported a significant positive effect of receiving information from *extension agent* on adoption of climate change adaptation. *Access to credit*: access to credit may give financial capability to a farmer when the adoption of climate change adaptation requires purchasing of some new inputs e.g new crop varieties, irrigation facilities etc. For example, Keneilwe et al. (2018) reported that lack of *access to credit* has significant negative influence on climate change adaptation in Botswana which is in conformity with that of Abdallah et al. (2019) who reported a significant positive influence of *credit facilities* on adoption of climate adaptation strategies among farmers in Bangladesh and attributed that to access to credit make the adaptation more affordable for the farmer. Bryan et al. (2013) found out that *access to formal credit* has no significant effect on adaptation of any climate change adaptation in Kenya however the author found out that farmers with access to *informal credit* are more likely to use climate change adaptation. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya reported a significant negative effect of *access to credit* on adoption of climate change adaptation strategies. *Membership of organization:* Abdallah et al. (2019) recorded a significant negative effect of *organizational membership* on adoption of climate change adaptation strategies among farmers in Bangladesh and mentioned that the possible reason for that is that all forms organizations were considered in the study and these organizations received contradictory information on climate change adaption strategies. To understand the real effect of relevant organization only agricultural/environmental organization should be considered. Bryan et al. (2013) found that farmers with *association membership* are more likely to adopt planting trees and less likely to adopt change of variety than farmers without association membership in Kenya. The author attributed that engaging in agroforestry requires new knowledge and huge financial investment which can be facilitate with organizational membership. This is true because agroforestry can be easily practice by smallholder farmers collectively in form of group or community. Oduniyi and Tekana (2019) analysed the relationship between climate change awareness and adoption of agroforestry among farmers in north-west province of South Africa and reported a positive significant effect of farmers *group membership* on the adoption of agroforestry as climate change adaptation.

Access to climate change and adaptation information: Keneilwe et al. (2018) found out a significant positive influence of access to *climate change information* on climate change adaptation among farmers in south-eastern district of Botswana. Mahamadou et al. (2019) recorded a significant positive association between use of *information sources* and adoption of climate change adaptation strategies among cereal farmers in Mali, this implies that increase in access to information sources will increase the adoption of climate change adaptation strategies of farmers. Oduniyi and Tekana (2019) analysed the relationship between climate change awareness and adoption of agroforestry among farmers in north-west-province of South Africa and reported a significant positive effect of access to *climate change information* on adoption of agroforestry as climate change adaptation.

Agro-ecological features: Abdallah et al. (2019) found out that farmers that experienced severe *drought* (water stress) are more likely to adopt climate adaption significantly among farmers in Bangladesh. Bryan et al. (2013) studied climate change adaptation among famers across four agroecological zones of Kenya and reported that farmers in *humid* AEZs (Gem and Siaya districts) are more likely to adopt change of crop type as adaptation strategies than those in arid ecological zone (Garissa) this it may be because those in humid zone have more crop types that might adopt to the zone than water stressed zone of arid. Bryan et al. (2013) also reported that farmers in semi-arid zone (Mabeera south and Njoro) are more likely to adopt change of crop variety, change of crop type, and planting trees. The semi-arid farmers in the study shared change of crop adaptation with farmers of humid zone as climate change adaptation and differ with change of crop variety and planting of tress. The possible reasons for that is that farmers in semi-arid have narrow alternative of change the crop type completely rather than the maintain their type of crop and search for more drought resistant varieties within the same type of crop, and for planting of trees, semi-arid zones characterised dominantly by shrubs or grasses and receive rainfall less than its potential evaporation, therefore farmer may get agroforestry practice as one of the suitable solution to reduce such high evaporation and regulate their immediate environmental temperature. Bryan et al. (2013) finally recorded that farmers in temperate ecological zone (Mukurwe-ini and Othaya) are more likely to adopt change of crop type, change of crop variety and planting of trees. Farmers in this zone shared change of crop type with farmers of humid zone, change of crop variety and planting trees with farmers of semi-arid zone, the possible reason for that is farmers in temperate zone experience humid condition in some part of the year which can facilitate change of crop completely and also experience high evaporation and dryness in some part of the year which can make the agroforestry practices more attractive to them to regulate the environmental temperature.

In term of soil fertility Bryan et al. (2013) reported that farmers that are in area with high *soil fertility* are more likely to change their crop variety as climate change adaptation than those in area with low and moderate *soil fertility* in Kenya. The possible reason for that is, farmers of high soil fertility area have an advantage of meeting the nutrient requirement of newly improved and hybrid crop varieties than those in other low and moderate soil fertility. Ndambiri et al. (2012) assessed farmers adaptation to climate change in Kyuso district in Kenya and reported that farmer in *arid AEZs* are more likely to adopt climate change adaptation strategies than those in semi-arid AEZs.

2.6.1 Crop adaptation strategies considered in the study

Adaptation to climate change refers to farming systems adjusting to actual and anticipated climatic and non-climatic stimuli and conditions to avoid or alleviate related risks or realise potential opportunities (IPCC 2001). Following crop adaptations have been developed and promoted under Smart-Climate Agriculture to increase the resilience of the agricultural system and, in turn, higher productivity (FAO 2021):

i. *Adjusting planting dates*: postponement or shifting the planting and transplanting of seedlings to when the rainfall is well established based on the weather forecast. This strategy was found to be of importance in adaptation studies (Asrat and Simane 2017; Asrat and Simane 2018; Ali et al. 2021). ii. *Shifting to another crop or variety*, such as changing to new climate favour species, e.g., changing maize crop with sorghum in drought-prone areas (Tessema et al. 2019), or moving to iii. *Planting early mature variety*: an improved crop variety with a short life cycle to avoid or reduce the effects of drought and heat stress. Early maturing varieties are a key adaptive response to climate change in areas where rainfall is erratic (Asrat and Simane 2017). iv. *Choosing drought-tolerant varieties*: selected crop cultivars with reasonable yield and the agronomic trait to tolerate prolonged moisture stress (Tesfaye et al. 2018). v. *Supporting crop-livestock integration*: mixed farming systems forming a sustainable synergistic relationship between plant and animal systems and enable resilience to weather anomalies (Thornton and Herrero 2014; Peterson et al. 2020).

2.6.2 Theoretical framework and variables influencing the crop adaptation

Various theoretical and conceptual basics were used to study farmers' behaviour toward climate change adaptation strategies. This study used the *induced innovation* theory, *resource-based* theory and *diffusion of innovation* theory as theoretical background. The *induced innovation* theory highlights the important roles of risk and other environmental threats such as moisture stress and floods; *resource-based* theories relates adoption with income, assets, and other financial capabilities of farmers and *diffusion of innovation* theory links adoption to socio-demographic and access to institutional services (Netra et al. 2004; Ndambiri et al. 2012; Wescott et al. 2017; Adger 2003; Rogers 2003). The theories were used to identify and explain the factors influencing farmers' adoption behaviour. Following these theories, four groups of factors explain the choices to apply the crop adaptation strategies: i. farmers' demographical characteristics, ii. farm characteristics, iii. access to institutional services, as well as iv. agro-ecological characteristics.

Farmer's socio-demographic characteristics (e.g. gender, age, income and farming experience) affect the likelihood of shifting to a new crop (Jianjun et al. 2015; Mabe et al. 2014; Obayelu et al. 2014). Ali and Ereinstein (2017) reported that age, household size, education and agricultural income affect the adoption of shifting to another crop in a positive way. Age, education, and income increase the adjustment of the planting date (Destaw and Fenta 2020; Obayelu et al. 2014; Ali and Ereinstein 2017). Education and income positively affect the adoption of early mature varieties (Destaw and Fenta 2021). Drought-tolerant varieties adoption is positively influenced by age, education and agricultural income (Ali and Ereinstein 2017). Crop-livestock integration is positively affected by age and farming experience (Idrissou et al. 2020; Obayelu et al. 2014). Concerning *farm characteristics*, adjusting planting dates drought-tolerant varieties are found to be positively affected by land ownership, farm size and livestock ownership (Ali and Ereinstein 2017). Various studies (Tun et al. 2017; Ali and Ereinstein 2017; Nhemachena et al. 2014) reported the positive effect of livestock ownership on the adoption of early mature varieties, drought-tolerant varieties and crop and livestock integration adaptations.

Regarding access to *institutional services*, shifting to another crop and adjusting planting dates are positively influenced by access to weather information and extension services (Obayelu et al. 2014; Bryan et al. 2013). Ali and Ereinstein (2017) proved the positive influence of group membership and extension services on adjusting planting dates. In addition, access to extension services and group membership affects the adoption of drought-tolerant varieties and shifting to another crop in a positive way (Ali and Ereinstein 2017). The location of the farm in moisture stress AEZs is also important. Farmers in these areas are more likely to change the type of crop planted (Bryan et al. 2013). Ali and Ereinstein (2017) reported a similar result: farmers of a dry and irrigated agroecological zone are more likely to adopt drought-tolerant variety and shift to another crop.

2.7 How to Quantify Food Security

There are numerous indicators used in measuring food security at different level, dimension, and categories. However, this research focused on reviewing the prominent indicators that measure food security at household and individual level.

Experience-based indicators: this kind of indicators were first developed by Radimer and his team under the Community Childhood Hunger Identification Project as Household Food Security Survey Module (HFSSM) (Wehler et al. 1992). US Agency for International Development (USAID) sponsored Food and Nutrition Technical Assistance Project (FANTA) which developed a Household Food Insecurity Access Scale (HFIAS) to help development organizations in evaluating food security programs implemented in developing countries (Leroy et al. 2015). The construction of the HFIAS was built on a review examining commonalities in the experience and expression of food insecurity (defined as lack of access) across cultures. Another adaptation of the US HFSSM, also informed by scales used in Venezuela, Brazil, and Colombia, is the Latin American and Caribbean Food Security Scale (Escala Latino-americana Caribena de Seguridad Alimentaria ELCSA), in 2010, a workshop was held to harmonize the different versions of the ELCSA in use across Latin America and the Caribbean for use in Mexico and Central America.

The review identified four major domains and several subdomains of food insecurity that appear to be universal across different countries and cultures. The four domains (and subdomains) were: uncertainty (in the long term) and worry (in the short term) about food; inadequate quality (unhealthy foods and diets, limited variety); insufficient quantity (running out of food, not consuming enough, eating less, disrupted eating patterns); and social unacceptability (unacceptable means of acquiring food, eating foods that cause shame or embarrassment)" (Leroy et al. 2015).

The HFIAS includes nine items that measure both occurrence and frequency and represent the universal domains associated with household food insecurity access, using a recall period of 30 days (Coates et al. 2007). After some time, the HFIAS validated and a new scale, the Household Hunger Scale (HHS) was developed, which captures universal experiences of the quantity dimension of food access and uses the last three items of the HFIAS on the occurrence of severe experiences of food shortage and actual experiences with hunger (Leroy et al. 2015). The commonly used scales (HFSSM, ELCSA and HFIAS) are composed of similar sets of items that cover the same components of food insecurity. Evidence for validity and construct equivalence of these indicators in differentiating groups of households and separating households with varying levels of food insecurity is strong (Leroy et al. 2015).

The available evidence about these indicators suggests, however, that the responses to items depend on cultural and social contexts in ways that may not allow comparison of prevalence from these indicators across countries. The Household Hunger Scale (HHS), with three items indicating severe food insecurity (i.e., hunger), has been shown to generate equivalent comparisons of prevalence across countries, but this scale is limited because it measures only the most severe food insecurity experiences and focuses only on the quantity (and not the quality) of food access; it is appropriate for situations in which a large number of households are expected to be severely food insecure (Leroy et al. 2015).

Coping Strategies based indicator: coping strategies refer to the responses that people make when facing hardships such as household food insecurity and the measures they take to attenuate or mitigate their consequences (Leroy et al. 2015). The Coping Strategy Index (CSI) assesses the frequency of occurrence of increasingly severe coping strategies, i.e., the behaviours people engage in when they cannot access enough food. Leroy et al. (2015) reported that there is no universal CSI, but rather a methodology is proposed to derive locally relevant CSIs. The methodology involves identifying through focus group discussions a set of coping strategies (for a total of no more than 12 to15) that are used in a given context when households and individuals are faced with limited access to food as shown in Table 2. The coping strategies are organized in four basic categories: dietary change, short-term measures to increase household food availability, short-term measures to decrease the number of people to be fed and approaches to rationing or managing the shortfall.

Once the coping strategies have been identified, a new series of focus groups is held to assign a weight (1 to 4) to each strategy based on its severity. A continuous score is calculated by summing the frequency (number of days) each coping strategy is used multiplied by its severity weight. The higher the score, the more coping reported, and therefore the more food insecure is the household. A reduced CSI also has been developed using a smaller set of five pre-weighted strategies, the recall period for both indicators is 7 days. The CSI was primarily intended to be used in determining the causes and consequences of food insecurity, early warning (by identifying coping strategies that reflect early onset, rather than very severe forms of food insecurity), and identifying households with food insecurity.

Table 2: Food security coping strategies index (CSI)

List of coping strategies
1. Dietary Change
a. Rely on less preferred and less expensive foods
2. Increase Short-Term Household Food Availability
b. Borrow food from a friend or relative
c. Purchase food on credit
d. Gather wild food, hunt, or harvest immature crops
e. Consume seed stock held for next season
3. Decrease Numbers of People
f. Send children to eat with neighbors
g. Send household members to beg
4. Rationing Strategies
h. Limit portion size at mealtimes
i. Restrict consumption by adults in order for small children to eat
j. Feed working members of HH at the expense of non-working members
k. Reduce number of meals eaten in a day
i. Skip entire days without eating

Source: WFP 2008

Assessing coping strategies is useful for understanding behavioural responses when a household cannot access enough food, but not necessarily for assessing the access dimension of food insecurity and whether or not a household adopts certain coping strategies depends upon the availability of those strategies as well as the perceived need and/or desire to adopt them (Leroy et al. 2015). *Dietary diversity-based indicators*: Dietary diversity has long been recognized as a key element of diet quality, because eating a variety of foods helps ensure adequate intakes of essential nutrients and promotes good health. Dietary diversity scores are constructed using a simple count of foods or food groups consumed over a reference period, usually 24 hours (Leroy et al. 2015).

2.7.1 Impact of climate risk adaptation on food security

Previous studies (Tlhompho 2014; Ali and Erenstein 2017; Nkomoki et al. 2018; Samuel and Sylvia 2019) analyses the effect of the adoption of climate risk adaptation strategies on food security. For example, Ali and Erenstein (2017) assessed farmers' use of climate change adaptation practices and their impact on famers' food security and poverty in Pakistan. They found that farmers adopting more climate risk adaptation practices (drought-tolerant varieties, adjusting planting dates and shifting to another crop) had higher food security levels than those who did not. Similarly, Nkomoki et al. (2018) studied the adoption of sustainable agricultural practices and food security threats in Zambia. They reported that adopting crop diversification and agroforestry is associated with the food security status of small-holder households. Tlhompho (2014) studied African climate change adaptation in South Africa and reported that mixed farming and crop diversification are among the endogenous climate change adaptation that affects food security. Samuel and Sylvia (2019) established the nexus between climate change adaptation strategy and small-holder farmers' food security status in South Africa. They reported that adopting early varieties is related to household food security status.

Some studies (Islam et al. 2016; Di Falco et al. 2011; Rising and Devinen 2020; Oyinbo et al. 2019) investigated the effect of adaptation strategies on food security using crop yield as a proxy of food security. For example, Islam et al. (2016) reported higher crop yields among farmers who adopted drought-tolerant varieties than those who did not adopt them in more than 10 developing countries. Farming households who adopted (changing crop, soil and water conservation strategies or tree planting) tend to produce more than those who did not adopt (Di Falco et al. 2011). Switching to another crop avoids yield loss by half and takes advantage of yield increase (Rising and

Devinen 2020). Early mature variety increases the household farm-level productivity performance of the adopters (Oyinbo et al. 2019; Lemessa et al. 2019).

2.7.2 Measurement of causality effect

The gold standard approach for estimating the effect of exposure, treatment or intervention is Randomized Controlled Trials (RCTs) whereby the changes on the outcome indicator is reliably attributed to the treatment and intervention (Mathes et al. 2018). In a simple randomized trial, subjects in different treatment groups are comparable because all subjects have the same property in every aspect and probability of being assigned to a particular treatment condition (Morgan 2017; Monti et al. 2018). The critical aim of randomization is to balance treatment groups on any confounding factors (whether observed like gender and colour or unobserved such as traits, experience and inherent talent), eliminating treatment selection bias and ensuring that the groups are comparable (Burns et al. 2011; Wang 2020). At the end, the researcher is well assured that the only difference between the groups (treated and control) is the intervention, hence, any difference in outcomes between the two groups can be attributable to the effect of the treatment, this refers to "causal" effect of treatment in the study population (the average treatment effect).

However, homogeneous randomized selection may not always be feasible for reasons such as cost, time, ethical, and practical constraints. Over the years, several methodologies have been developed to control for confounding bias in observational studies. The propensity score matching (PSM) methods propounded by Rosenbaum and Rubin in 1983 (Rosenbaum and Rubin 1983) are among the popular analytical approaches in taking care of the compounding factors (Ali et al. 2015) and the changes on the outcome indicator(s) can be reliably attributed to the treatment (Adelson et al. 2018). In PSM, treated and untreated individuals with similar propensity scores have, on average, similar or comparable pretreatment characteristics, a mimic and similar situation to RCTs (Ali et al. 2019). Hence, balancing these pretreatment potential confounders through propensity scores enables researchers to obtain a "quasi-randomization" of treatment groups to reduce confounding and hence to get a better estimate of the treatment effect (Austin 2011).

Yet, despite counterfactual analytical approach of this method, PSM has a limitation of biased results of misspecification (Robins et al. 2007; Wooldridge 2010). To provide a remedy for such misspecification Inverse Probability Weighted Regression

Adjustment (IPWRA) that has the double-robust property was introduced to ensures consistent results that account for misspecification (Wooldridge 2009). Still, the issue of endogeneity bias is unobservable, such as farmers' inherent skills and talent, results based on matching techniques will be biased. This brought the Endogenous Switching Regression model that accounts for both observed and unobserved sources of bias (Lokshin and Sajaia 2004; Shiferaw et al. 2014; Ma and Abdulai 2016). The conceptual framework for the effect of crop adaptation strategies on farming households' food security is shown in Figure 10.

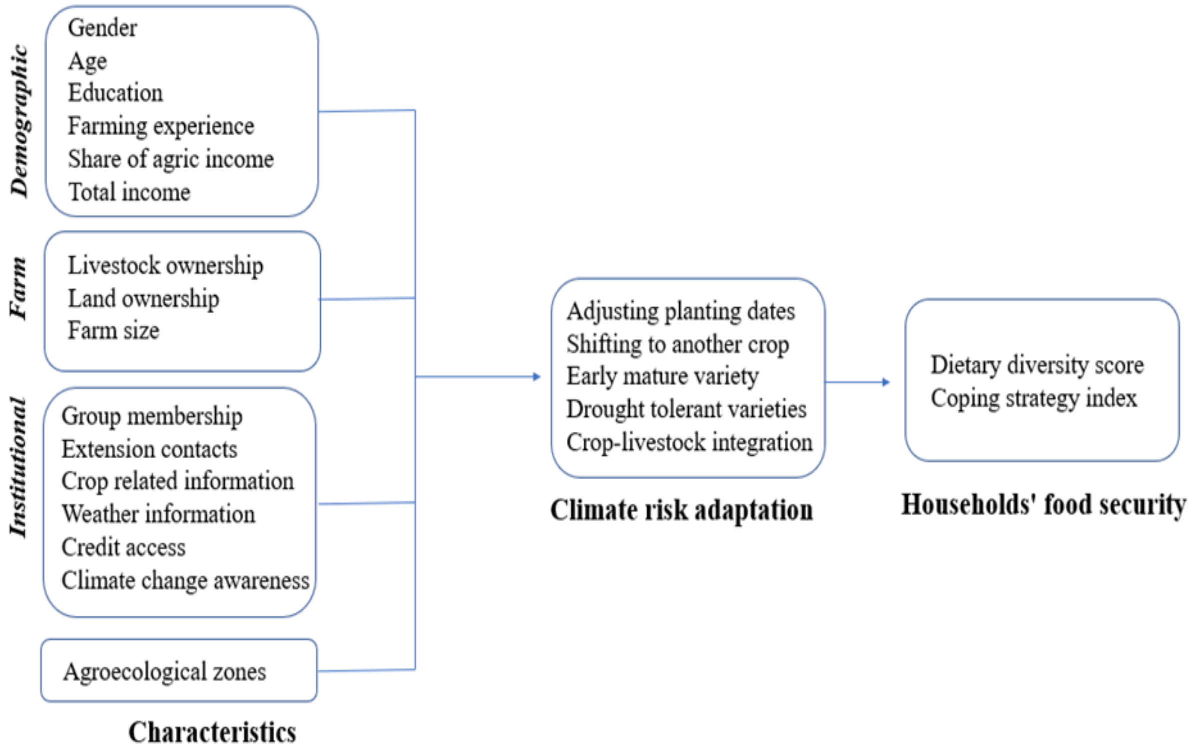

Figure 10: The conceptual framework of effect of crop adaptation on food security

Source: Authour

3 Aims of the Thesis

3.1 Research Objective

Climate risk is a major threat to the sustainable food production of many farmers who depend on rainfed agricultural systems. In response to this threat, climate-smart agricultural adaptation, such as drought-tolerant, early mature crop varieties and agricultural insurance have been developed and promoted. It is well-known that adopting innovations and improved technologies positively impact adopters' well-being. Therefore, the broad objective of this study was to assess the effect of agricultural climate change adaptations on farming households’ food security in Nigeria. The specific objectives of the study were:

i. Assess the climate change knowledge of farmers and its association with their climate change perception.

ii. Analyse the awareness and adoption of agricultural insurance as a climate risk adaptation strategy in Nigeria.

iii. Investigate the effect of agroecological and institutional factors on livestock climate risk adaptation strategies.

iv. Analyse the drivers of crop adaptations strategies to climate change and

v. Assess the effect of crop adaptation strategies on food security of farming households.

3.2 Research Questions

The research answered a number of questions which includes:

i. Is the climate change knowledge of farmers associated with their climate change perception and which factors affect the awareness of climate change and the farmers’ knowledge of the causes of climate change?

ii. What are the drivers of the awareness and adoption of agricultural insurance as climate risk adaptation strategies and what are the adoption impediments associated with strategy perceived by farmers as well as the difficulties faced by farmers that adopted the strategies?

iii. What is the effect of AEZs on the choice of livestock climate risk adaptation strategies and the influence of institutional factors on the adoption of livestock climate risk adaptation strategies?

iv. What are the drivers of crop adaptations and their impact on farming households' food security in Nigeria?

4 Methodology

This section provides description of the study area, its agroecological zones, land mass area, climatic information. It further, provides information on how the study sample was drawn from the study population as well as survey instrument development and data collection. The section also, provides information on data analysis, model operationalization and fitness.

4.1 Study Area

Nigeria has a total land area of 910,768km^2, a water area of 13,000km^2 (World Bank 2018). The country is characterized by a tropical climate, with six distinctive AEZs (Figure 11). These AEZs can be categorized into i. the Semi-arid zone, ii. the Sudan savanna, iii. the Guinea savanna, iv. the Swamp Forest, v. the Mangroves, and vi. the Rainforest ecological zones. Rainfall is bimodal in the humid/southern (freshwater swamp, Mangroves and Rainforest) part, while unimodal in dry/northern part (the Semi-arid zone, the Guinea and Sudan savannas) of the country (World Climate Guide 2019). Annual rainfall varies significantly from about 500mm/annum in the north (the Semi-arid zone) to 3,000mm/annum in the extreme south (the Mangrove and Rainforest ecological zones).

The mean maximum temperatures are high as 40°C during the hot months of April and May, although in the same season frosts may occur at night (Britannica, 2021). The humid climate in the country is a result of the proximity to the Gulf of Guinea. Seasonal temperature differences range from 40˚C in the extreme north (the Semi-arid zone) around April and May to only 12˚C in the central part of the country (the Mangrove/drive savannah agro-ecological zones) around December and January (World Climate Guide 2019). The mean temperature of the country keeps increasing over the last 30 years and the mean precipitation of the country decreases (World Bank 2020).

The drought occurrences are more pronounced in the dry AEZs (Eze 2018), and floods affect almost all parts of the country with a high extent in the dry AEZs of the country (Usigbe 2021). In Nigeria, there was an increase in temperatures of an average of 0.8°C between 1960-2006, with a steep rise since 1980, particularly in the northern region; and a decrease of 3.5 mm in precipitation per month per decade between 1960-2006 (USAID 2019). It was projected that temperatures will rise 1.1-2.5°C by 2060.

More extreme events are expected, including an increase in the number of extreme heat days to 260 days by the year 2100 (versus only ten days in 1990). A substantial decrease in the number of cold nights is forecasted and projected to be close to zero by 2090. High uncertainty exists around future rainfall amount and frequency, with variability likely to increase, as well as sea levels expected to rise from 0.4-1.0 m by 2100 (USAID 2019).

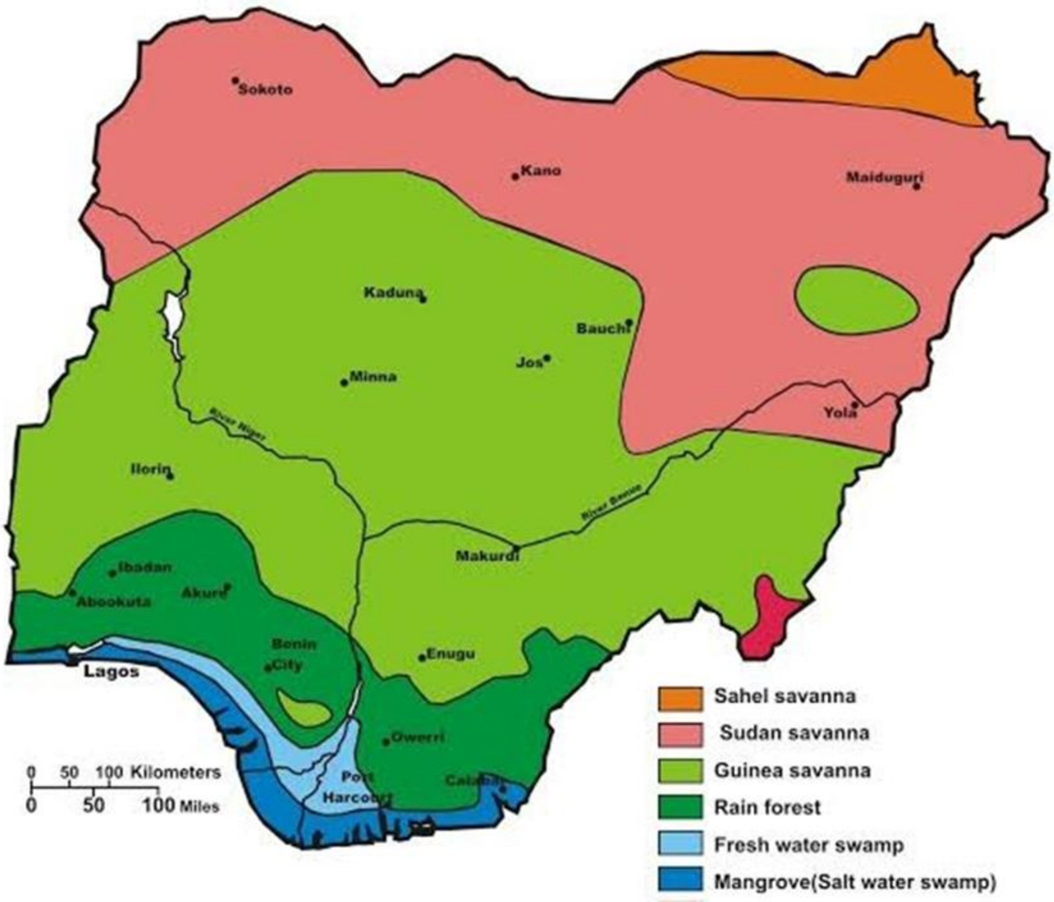

Figure 11: Map of Nigeria showing the agro-ecological zones

Source: Odebode and Eniola 2019

Commercial agricultural insurance scheme was first introduced to the country in 1987 by Niger Insurance, later federal government introduced the NICON and the NCISN to operate agricultural insurance schemes (Nnadi et al. 2013; Aina and Omonona 2012). The objective is to offer protection to the farmer from the effects of natural disasters and to ensure payment of appropriate compensation sufficient to keep the farmer in business after suffering a loss (NAIC 2021; Nnadi et al. 2013; Olubiyo et al. 2009). In 2010, the country formally included insurance-based risk adaptation options among agricultural climate change adaptation strategies in its Nationally

Determined Contribution (UNFCCC 2015) that offers insurance with up to 50% of premiums subsidized (World Bank 2011).

Pastoral systems dominate 82% of the livestock system in the country, where farmers move animals, particularly cattle from the north to the south in search of pastures and water. Herd size ranges from 100 to 300 heads of indigenous breeds, production is subsistence-oriented, and animals are kept on uncultivated pastures and rely on grazing mostly without any feed supplements (FAO 2019b). Nigeria continues drive into alarming levels of food insecurity and malnutrition from the exacerbating vulnerabilities of climate variability, shorter agricultural seasons, floods, dry spells, as well as pests and diseases (FAO 2022).

4.2 Sampling Process

Multi-stage sampling was used to select the respondents for this study. In the first stage, to cover the entire area of Nigeria, we applied a convenient sampling to select one state from each AEZ (Figure 12), followed by the random sampling method (a lottery), which was used to select a total of 12 local government areas (LGA), 2 LGAs from each selected state. Based on these specifications, two wards were selected randomly from each local government area making a total number of 24 wards. Lastly, 45 farming households were drawn randomly (again using a lottery) from each selected ward, reaching a total of 1,080 farming household for the study (Table 3 and appendix 1). In cases where random sampling was not possible because of missing lists of farmers (about 20% of wards), snowball sampling was used. From the entire study sample (1,080 farming households), by coincidence, 609 farming households were found to keep livestock that forms the study sample of objective iii (Investigate the effect of agroecological and institutional factors on livestock climate risk adaptation strategies.) appendix 2.

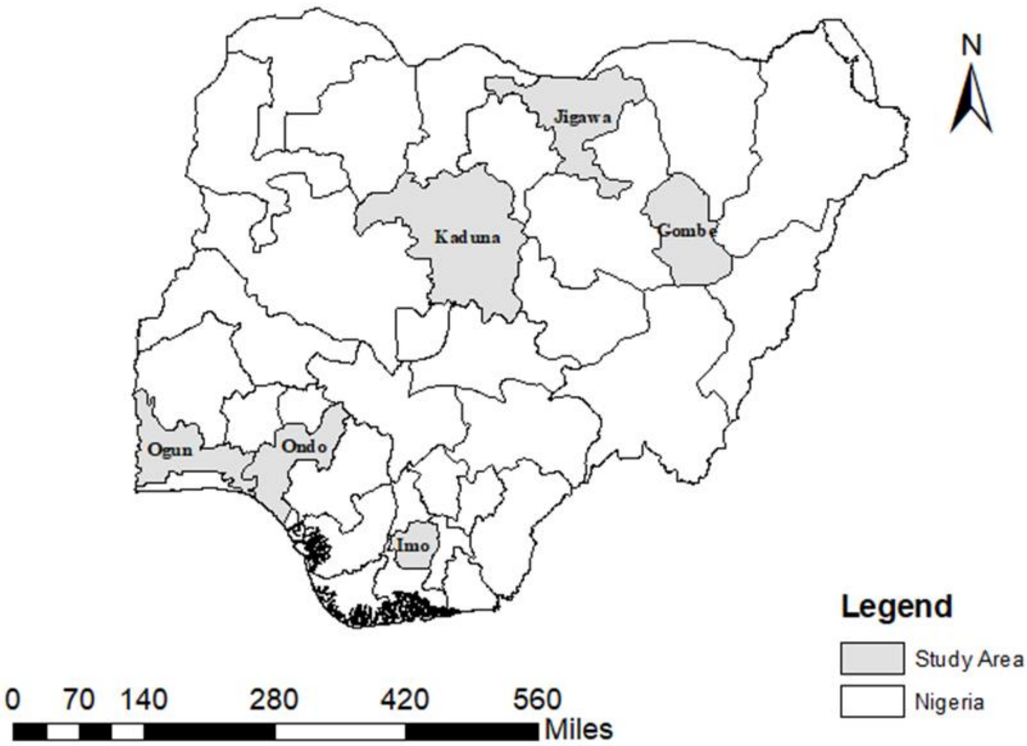

Figure 12: Map of the study area

Source: Authour

Table 3: Sampling and sample size

Area	*Agro-ecological zone*	*State*	*No. of farming households*
Dry part	Semi-arid	Jigawa	180
	Sudan savannah	Gombe	180
	Guinea savannah	Kaduna	180
Humid part	Mangrove	Ondo	180
	Freshwater swamp	Imo	180
	Rainforest	Ogun	180
		Total	**1,080**

4.3 Data Collection

4.3.1 Questionnaire design

The survey questionnaire consists of information on farmers' socio-demographic, farm, and institutional characteristics. In addition, climate change awareness, climate change information sources and channels, climate risks experience in the last 10 years as well as adopted climate risk adaptation strategies (agricultural insurance, livestock climate risk adaptations such as destocking, supplementary feeding, and crop adaptations such as adjusting planting date, shifting to another crop, early mature cultivars, drought resistance varieties, etc.). A separate part of the questionnaire was used to collect information on dietary intake as reported through food items consumed daily by the household in the last 7 days, the behaviour of the household in the reported week and the number of events when the household did not have enough food or money to buy food (appendix 3). Only the validated questions from the literature (Leroy et al. 2015; Di Falco et al. 2011; Ali and Erenstein 2017; Nkomki et al. 2018; Samuel and Sylvia 2019) were incorporated.

4.3.2 Survey implementation

The data were collected in face-to-face interviews by the author with the help of 12 trained enumerators (village extension workers) using a pen-and-paper semi-structured questionnaire survey between October 2020 and February 2021 (Appendix 4). Farming household heads were interviewed or their representatives in the absence of the household heads. The interviews were conducted in English or in the local languages (mainly Hausa, Igbo and Yoruba) and translated into English. The questionnaire was pre-tested on 40 farmers and amended accordingly, the pre-tested data were not included in the main analysis.

4.3.3 Sample description

Table 4 portrays the description of the sampled farming households, 78.33% of the household heads are male and 50.45% of them are within the age bracket of 41-60 years and 81.85% of them are married. Further, 74.40% of them had less than 11 years of farming experience and 82.40% have access to extension services and the majority (57.50%) have at least a distance of 3 kilometers between their home and food market.

4.4 Data Analysis and Operationalization

4.4.1 Association between climate change knowledge and climate change perception

Spearman correlation was used to assess the relationship between climate change knowledge and the climate change perception of farmers. The climate change knowledge score (ranging between 0 and 7) was correlated with the perception of climate change indicators in the study area, such as perceived increase in temperature, decline in the amount of annual rainfall, delay in rainfall start, etc. (measured on a five-point scale). The Spearman correlation equation is:

$$\boldsymbol{p = 1 - \frac{6\sum d^2}{n(n^2-1)}} \quad \textbf{... (Eq. 1)}$$

where $\boldsymbol{p}$ is the Spearman rank correlation coefficient, $\boldsymbol{d^2}$ is the difference between the rank value of the climate change knowledge score and the climate perception of farmers, and $\boldsymbol{n}$ is the number of observations.

Table 4: Sample description (N=1,080)

Variable	Items	%
Gender	Male	78.33
	Female	21.67
Age (years)	<40	41.20
	41-60	50.45
	>60	8.35
Marital status	Married	81.85
	Single	18.15
Farming experience (years)	<11	74.40
	11-20	21.20
	>20	4.40
Access to extension	Yes	82.40
	No	17.60
Distance to food market (km)	<1.5	15.60
	1.5-3	26.80
	>3	57.50

4.4.1.1 Climate change awareness determinants

To examine the factors influencing climate change awareness, a binary response (Probit) model was used. Following previous studies, we considered that a farming household head was aware of climate change if they heard the term climate change from information sources and channels or if the farmer experienced climate risk events, such as frequent drought and floods and other climatic variations as postulated by knowledge gap theory (table 5) as used by the previous studies (Oduniyi and Tekana 2019; Abdallah et al. 2019 and Mahamadou et al. 2019). The probit model after converted from sigmoid to linear is:

$$\boldsymbol{Ln(y_{i1}) = \alpha + \beta_1 X_1 + \beta_2 \beta_2 + \beta_3 X_3 \ldots + \beta_{20} X_{20} + \varepsilon} \quad \textbf{... (Eq. 2)}$$

Table 5: Description of variables imported into Eq. 2 and 3 (N=1,080)

Variable	*Description*	*Mean and standard deviation*
Dependent variables		
Climate change awareness	Yes= 1, otherwise= 0	0.72 (0.44)
Knowledge of climate change causes	Farmer's quiz score 0-7	2.62 (1.56)
Independent variables		
Socio-demographic characteristics		
Gender	Male= 1, female= 0	0.78 (0.41)
Age	Years	48.15 (13.30)
Years of education	Years of formal education	8.24 (5.59)
Farming experience	Years of being in farming	22.61 (12.18)
Farmers group membership	Yes= 1, no= 0	0.82 (0.37)
Farm size	In hectare	3.44 (3.45)
Credit	Access to credit (Yes= 1, No= 0)	0.32 (0.46)
Livestock ownership	Yes= 1, No=0	0.56 (0.49)
Agricultural income	Annual agricultural income (Naira)	7,563.60 (5,249.34)
Non-agricultural income	Annual non-agricultural income (Naira)	86.99 (96.78)
Dependency ratio	Number dependent/number of active labour	1.13 (1.70)
Climate change information sources		
Government extension agent (GEA)	Receiving weather information from GEA (Yes= 1, No=0)	0.69 (0.45)
Environmental NGOs	Receiving weather information from NGOs (Yes= 1, No=0)	0.22 (0.42)
Farmers' cooperatives	Receiving weather information from farmers' cooperatives (Yes= 1, No=0)	0.37 (0.48)
University and research institution (URI)	Receiving weather information from URI (Yes= 1, No=0)	0.10 (0.31)
Farmers' friends	Receiving weather information from farmers' friends (Yes= 1, No=0)	0.40 (0.49)
Climate change information channels		
Radio	Number of times receiving climate-related information via radio in a month	9.84 (9.37)
Television	Number of times receiving climate-related information via television in a month	1.63 (4.75)
Newspaper	Number of times receiving climate-related information via newspapers in a month	0.49 (2.37)
Internet	Number of times receiving climate-related information via the internet in a month	1.10 (4.46)
Climate change experience		
Extreme temperature	Number of extreme temperature experiences by farmer in the last 10 years	0.71 (0.45)
Flooding	Number of flood experiences by farmer in the last 10 years	0.73 (0.43)
Drought	Number of drought experiences by farmer in the last 10 years	2.15 (2.23)
Dry agroecological zones	If a farmer is from one of the three dry zones = 1 otherwise= 0	0.5 (0.50)

In equation 2, $\boldsymbol{Ln}(\boldsymbol{y_{i1}})$ is a probability that farming household head i will be aware of climate change by getting climate information or climate variability experience is greater than zero ($\boldsymbol{y_i}$> 0). $\boldsymbol{\alpha}$ is a constant, $\boldsymbol{\beta_1\beta_n}$ is the regression coefficients, X_i -X_n denotes the set of explanatory variables or factors that influence climate change awareness (Table 5), $\boldsymbol{\varepsilon}$ is the error term.

4.4.1.2 Climate change knowledge determinants

Poisson regression was used to analyze the factors affecting knowledge of agricultural practices contributing to climate change. Farmers were asked seven quiz questions on farming practices related to climate change mitigation to indicate their level of climate change knowledge. Each question answered correctly by a farmer received a score of 1, and a wrong answer or "I do not know" received 0. The scores for each farmer were summed up, with the final count score ranging from 0 to 7. Table 6 shows the score distribution of farmers in the following seven agricultural practices that are common in the study area:

i. Deforestation: this is the process of cutting down plants and crops. This breaks the carbon cycle by stopping the CO_2 absorption function of plants. Between 2015-2017, the global loss of tropical forests contributed to about 4.8 billion tonnes of CO_2 per year (or about 8-10% of annual human emissions of carbon dioxide) (Climate Council 2018).

ii. Land clearance by bush burning: this is a process where farmers clear their farmlands using fire to prepare for the rainy season. Bush burning can deplete top-soils nutrients, potentially causing crop yields to decrease (Hassan et al. 2019). Furthermore, it changes organic nitrogen into mobile nitrates which makes it very volatile and causes air pollution through the release of carbon stored in plant leaves, stems, and branches into the atmosphere (Sciencing 2017).

iii. Fossil fuel use: is the primary source of CO_2 that is emitted directly from human-induced impacts. The total CO_2 contribution from fossil fuel use and other industrial processes alone contributes 65% of the global greenhouse gas emissions (EPA 2018).

iv. Methane (CH_4) from livestock production: methane makes up the majority of emissions that come from farmed livestock, such as sheep and cattle; animals naturally produce methane as a by-product of their digestive processes and release it into the air (NIWA 2018). Between 1970 and 2010, emissions of CH_4 from enteric fermentation and rice cultivation increased by 20 % (IPCC 2014).

v. Inappropriate use of manure: inappropriate manure handling and application lead to the emission of CH_4 and Nitrous Oxide (N_2O), this agricultural activity contributes to climate change (EPA 2018).

vi and vii. Use of chemical fertilizer and other agrochemicals: agricultural activities contribute approximately 30% of total greenhouse gas emissions, mainly due to the

Table 6: Farmers' scores on quiz questions of causes of climate change (N=1,080)

Quiz mark	**Score distribution of farmers (%)**	**Cumulative frequency**
0	10.11	10.11
1	9.46	19.57
2	29.13	48.70
3	25.88	74.58
4	14.01	88.59
5	6.40	94.99
6	2.88	97.87
7	2.13	100.00

intensive use of chemical fertilizers and other agrochemicals (IAEA 2020). The regression model in it is specific form is;

$$\boldsymbol{y_{i2} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon} \quad \textbf{... (Eq. 3)}$$

In equation 3, $\boldsymbol{y_{i2}}$ is the number of questions a farmer answered correctly (Table 3) with answer options of yes and no. A correct answer attracted 1 point and a wrong answer attracted 0 points resulting in a total score ranging from 0 to 7 points, $\boldsymbol{\alpha}$ is a regression constant, $\boldsymbol{\beta_1 - \beta_n}$ is the regression coefficient, $\boldsymbol{X_i}$ -$\boldsymbol{X_n}$ represents the explanatory variables (Table 2), $\boldsymbol{\varepsilon}$ is the error term. The Logit and the Multiple linear models were tested for multicollinearity and homogeneity by using the Variation Inflation Factor (VIF) (Appendix 5) and normality of the residuals; no signs of homogeneity and multicollinearity were found, as no value exceeded the threshold of VIF>5, which would be a sign of multicollinearity among the explanatory variables (Akinwande et al. 2015).

4.4.2 Awareness and adoption of agricultural insurance

Two multivariate logistic regression models were used for analyzing the variables that influence the farmer's awareness and adoption of agricultural insurance. Multicollinearity was tested using correlation analysis, the variable "type of credit" is dropped because it is highly correlated with the variable "access to banks", "land ownership" variable was also dropped because is highly correlated with "type of land ownership". Further, we used the Variance Inflation Factor (VIF) to test the multicollinearity between the remaining variables (Appendix 6) and none of the coefficients is greater than the threshold (Akinwande et al., 2015).

4.4.2.1 Awareness of agricultural insurance

Agricultural insurance awareness may be influenced by the number of factors as explained by the theoretical framework of the study, thus,

$$\boldsymbol{y_3 = \alpha + \beta_1 X_1 + \beta_2 X_2 + . \ldots \qquad + \beta_n X_n + \varepsilon} \qquad \textbf{… (Eq. 4)}$$

Where: $\boldsymbol{y_3}$ indicates the likelihood of the farming household's head to be aware of agricultural insurance, α is constant, ε is the residual, $\beta_1 - \beta_n$ is the regression estimates, $X_1 - X_n$ denotes the set of explanatory variables or factors expected to influence the agricultural insurance awareness as climate change adaptation measures (Table 7).

4.4.2.2 Adoption of agricultural insurance

The household's decision of whether to insure their crop or livestock is considered under the general framework of utility or profit maximization. It is presumed that economic agents (farmers) adopt agricultural insurance only when the perceived utility or net benefit from using it is significantly higher than the cost. In this circumstance, the expected utility of the farmer is not observable, but the actions of the economic agent could be observed through their choice to insure their crop or not as used by several studies (Mendelsohn 2000; Greene and Hensher 2003; Di Falco et al. 2011; Bryan et al. 2013). The potential explanatory variables expected to influence the perceived benefit that leads to the decision to adopt the agricultural insurance are summarized in Table 7.

Farmer's expected benefits from adaptation are equal to y_i,

Thus, $$\boldsymbol{y_{i4} = \alpha + \beta_1 X_1 + \beta_2 X_2 + . \ldots \qquad + \beta_n X_n + \varepsilon} \qquad \textbf{… (Eq. 5)}$$

Where: $\boldsymbol{y_{i4}}$ is the unobserved, or latent variable, which indicates that household *i* will choose to adopt agricultural insurance if expected benefits are greater than zero ($\boldsymbol{y_{i4}}$> 0), α is constant, ε is the residual, $\boldsymbol{\beta_1 - \beta_n}$ is the regression estimates, $\boldsymbol{X_1 - X_n}$ denotes the set of explanatory variables or factors that influence the expected benefits**.**

Table 7: Description of explanatory variables of Eq. 4 and 5

Variables	*Description*	*Mean and std dev.*	*VIF*[1]
Dependent variables			
Awareness of agricultural insurance	Aware of agricultural insurance as climate risk measures=1, otherwise=0	0.48 (0.50)	
Adoption of agricultural insurance	Adopter of agricultural insurance=1, otherwise=0	0.08 (0.28)	
Independent variables			
Socio-demographic characteristics			
Gender	Dummy for sex of the household head: 1=male; 0, otherwise	0.78 (0.41)	1.19
Age	Age of household head in years	48.16 (13.31)	2.92
Years of education	Education of household head in years of schooling	8.23 (5.58)	1.31
Household size	Number of household members	8.89 (5.83)	1.65
Years of farming experience	How long a household spent in farming: in years	22.62 (12.19)	2.62
Farm characteristics			
Type of land ownership	Type land ownership right: Statutory=1; customary=0	0.14 (35)	1.18
Farm size	Total landholding in hectares	3.43 (3.43)	1.22
Livestock ownership	Farmer-owned livestock=1, otherwise= 0	0.56 (0.49)	1.46
Herds size	Number of animal heads owned by farmer	50.24 (341.06)	1.18
Institution characteristics			
Group membership	Social groups membership of the household: member= 1; 0, otherwise	0.82 (0.37)	1.14
Extension contact	Number of receiving extension services in the last farming season	6.84 (7.45)	1.59
Bank	Dummy for access to the bank: 1=Yes, 0=No	0.32 (0.46)	1.32
Weather information	Dummy for access to weather information: 1=yes, 0 otherwise	0.72 (0.44)	1.15
Climate risk experience			
Flood	Farmer experience floods in the last 10 years=1, otherwise=0	0.73 (0.43)	1.40
Drought	Farmer experience droughts in the last 10 years=1, otherwise=0	0.67 (0.46)	1.35

4.4.2.3 Description of insurance adopters Vs non-adopters' characteristics

Descriptive results show a significant difference of age between the adopters and non-adopters, as mean age of the adopters is 50.4 years against 47.9 years of non-adopters (Tables 8). With regards to years of formal education, and adopters had an average of 10.4 years of formal education significantly higher than non-adopters (8 years). Adopters of agricultural insurance have average farmland of 4.5 ha under cultivation which is significantly higher than 3.3 ha of the non-adopters. The average herds number of adopters is 234 against the 28 of the non-adopters and average annual non-farm income of $123.2 for adopters against $83.7 for non-adopters. All these may implication on adoption of agricultural insurance as postulated by the diffusion of innovation theory (Rogers, 2003).

Table 8: Comparison between adoption and non-adopters of agricultural insurance (N=1,080)

Variables	Adopter (mean and std.)	Non-adopter (mean and std.)	t-test	Sig.
Age	50.48 (12.79)	47.93 (13.34)	-1.797	0.072
Household size	9.04 (6.16)	8.87 (5.80)	-0.266	0.789
Dependency ratio	1.09 (1.52)	8.87 (1.72)	0.267	0.789
Years of formal education	10.47 (5.97)	8.01 (5.52)	-4.153	0.000
Years of farming experience	24.00 (5.79)	22.47 (12.11)	-1.150	0.250
Land size (ha)	4.57 (3.48)	3.31 (3.40)	-3.400	0.000
Number of livestock	234.09 (840.69)	28.86 (210.51)	-4.947	0.000
Agricultural income ($/year)[1]	2,292.63 (4,200.62)	1,812.60 (5,263.15)	1.034	0.301
Non-agricultural income ($/year)[1]	123.29 (109.27)	83.75 (95.17)	-3.793	0.000

[1]the original values were in local currency, 1$=380 Naira

Table 9 revealed no significant difference in gender between the adopters and non-adopters of agricultural insurance, as 82.29% of the adopters are male and 77.88% of non-adopters are female and 89.58% of adopters are members of the farmers group which is significantly higher than the group members non-adopter (82.06%). The 94.79% of the adopters owned farmland which was also significantly higher than 60.04% of the non-adopters that possessed farmland and 71.87% of them participated in off-farm livelihood activities. This may have an implication on the adoption of agricultural insurance as farmers cooperatives may facilitate the insurance information.

Table 9: Difference between the discrete characteristics of adoption and non-adopters of agricultural insurance (N=1,080)

Variable	***Category***	***Adopters (%)***	***Non-adopters (%)***	***Chi-square value***	***Sig.***
Gender	Male	82.29	77.88	1.000	0.317
	Female	17.71	22.12		
Farmers' group	Members	89.58	82.06	3.464	0.063
	Non-members	10.42	17.94		
Land ownership	Landowners	94.79	60.04	4.392	0.036
	Landless	5.21	39.96		
Off-farm activity	Participant	71.87	68.81	0.592	0.441
	Not participant	28.13	31.19		
Extension contacts	Access to extension services	76.04	83.08	2.992	0.084
	Not access to extension services	23.96	16.92		
Access to bank	Access to bank	65.62	28.60	55.161	0.000
	No access to bank	34.38	71.40		
Type of credit accessed[1]	Formal	66.67	41.03	13.707	0.000
	Non-formal	33.33	58.97		
Weather information	Access to weather information	88.42	69.75	13.332	0.000
	Not access to weather information	11.58	30.25		
Floods	Farmers who experience floods in the last 10 years	85.40	72.70	7.338	0.007
	Farmers who do not experience floods in the last 10 years	14.60	27.30		
Drought	Farmers who experience drought in the last 10 years	66.7	67.20	0.010	0.919
	Farmers who do not experience drought in the last 10 years	33.30	32.80		

[1]the total number of those that have access to credit is 353, *p<0.1, **p<0.05, ***p<0.01

Furthermore, the farmers differ in terms of access to agricultural extension services and credit as agricultural insurance adopters have less access to extension advisory services significantly as 76.04% of the adopters have access to extension against the and 83.08% of the non-adopters and conversely, with regards to access to credit, the 65.62% of the adopters have access to credit which significantly higher than only 28.60% of the non-adopters that have the access. In the same way, this significant difference was observed in the type of credit accessed as 66.67% of the adopters have access to formal credit against the 41.03% of the non-adopters that have access to formal credit. In addition, most (88.47%) of the agricultural insurance adopters are aware of climate change which is significantly higher than 69.75% of the non-adopters that are aware of climate change.

4.4.3 Effect of AEZs and institutional factors on livestock climate risk adaptation strategies.

Multivariate logistic regression models were used for analysing the effect of AEZs and institutional factors on the adoption of different livestock climate risk adaptation strategies. The results were compared with the constraints reported by the farmers. The household decision of whether to undertake adaptation is considered under the general framework of utility or profit maximization. Economic agents (like livestock farmers) used adaptation options only when the perceived utility or net benefit from using a particular adaptation is significantly greater than the cost of adoption, which can be induced by agro-ecological conditions and facilitated by the enabling environment created by institutional factors.

In this circumstance, the utility of the economic agents is not observable, but the actions of the economic agent could be observed through their decisions (Mendelsohn 2000; Greene and Hensher 2003; Di Falco et al. 2011; Bryan et al. 2013). These benefits may include increased net income from livestock production, supplementary feeding, or reduced production risk as in the case of destocking under climate risk (Kato et al. 2011). Also, farmers allocate their time and labour resources out of farm production when the expected return for off-farm activities is higher than farm production.

4.4.3.1 Livestock climate risk adaptations

Farmers are rational producers that allocate resources to more profitable ventures or lower risk and uncertainty production. Major livestock climate change adaptation strategies (dependent variables in our models) in the study area are:

i. *Preserving crop straw and hay* (PCSH). This helps farmers to supplement livestock feeding with dried straw-based and legume fodder feed in feed deficit periods (FAO 1996; Lee et al. 2013; Kalaugher et al. 2017; Napogbong et al. 2020).

ii. *Destocking* is selling out of a few or great number of the animals during times of water scarcity, feed scarcity, and other associate climate risks (Kalaugher et al. 2017; Mugari et al. 2020), usually at a low price (Morton and Barto 2002).

iii. *Supplementary irrigation* using different sources of water such as pumping underground water from a well or borehole, and other modern methods like sprinkler and drip irrigation to provide water for pasture and livestock drinking water during droughts and times of water deficit as coping and adaptation strategies (World Bank 2016).

iv. *Switching to crop* is a reallocation of resources used for livestock production to crop production systems, this has been found to be one of the livestock adaptations among farmers (Hassan and Nhemachena 2008; Gebru et al. 2020).

v. *Livestock-crop integration* (mixed farming) makes agriculture more resilient by inter-mutual benefits, contributing feed to livestock production and to crop production through the provision of traction and manure (Descheemaeker et al. 2018). It has been reported as one of the primary climate and environmental adaptation strategies among farmers (Akber et al. 2022; Thornton and Herrero 2014).

vi. *Off-farm livelihood activities* are any income-generating source that is not directly from farmland. It was found that livestock farmers of the midland AEZs adopted this as a climate risk adaptation strategy (Legesse et al. 2013).

A correlation test was used to check for the dependency and association between the livestock climate risk adaptation strategies, and no high correlation or statistical association was found (Appendix 7). Figure 13 revealed that the predominant type of livestock in the area is the goat, as 42.8% of livestock owners have a goat. This is in line with the FAO (2020) estimates, which indicate that the predominant ruminant animal in the country is the goat. The next most common is sheep with 27.07%, then 15.99% cattle, and finally poultry farmers constituted 14.76%.

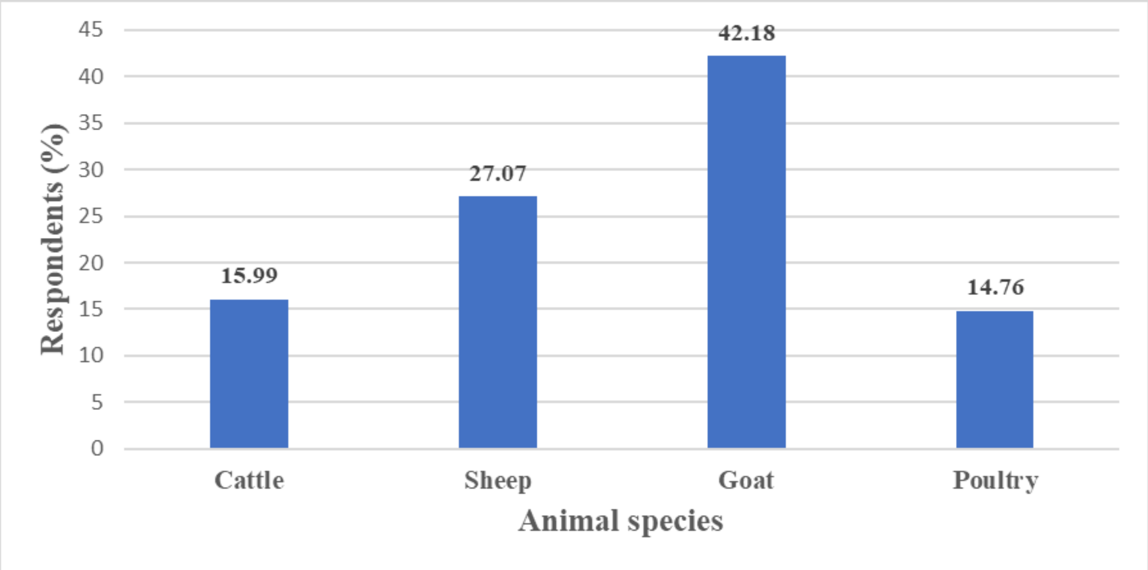

Figure 13: Share of farmers owning different livestock species (N= 569)

Source: Authour

4.4.3.2 Model operationalization of the effect of AEZ and institutional factor on livestock climate adaptation

Farmers' expected benefits from adaptation are equal to y_i, where:

$$\boldsymbol{y_5 = a x_1 + \varepsilon} \qquad \textbf{... (Eq. 6)}$$

In this equation, y_5 is the unobserved, or latent variable, which indicates that household *i* will choose to adopt a livestock climate change adaptation if expected benefits are greater than zero (y_i> 0). ε is the error term and x_1 denotes the set of explanatory variables or factors that influence the expected benefits of adaptation and α explains the magnitude of the explanatory variables. Therefore, the multivariate logistic regression in its implicit form is:

$$\boldsymbol{y_6 = \alpha + \beta_1 X_1 + \beta_2 X_2 + . \ldots \qquad + \beta_n X_n + \varepsilon} \qquad \textbf{... (Eq. 7)}$$

Where: $\boldsymbol{y_6}$ is the livestock climate risk adaptation strategy, α is constant, ε is the residual, $\beta_1 - \beta_n$ are the regression estimates, and $X_1 - X_n$ denotes the set of explanatory variables or factors that influence the expected benefits (Table 10). The explanatory variables were tested for possible multicollinearity (Appendix 8) using the Variance Inflation Factor (VIF). All explanatory variable VIF coefficients are below the threshold of 3 as recommended by Akinwande et al. (2015).

Table 10: Description of the variables imported into the models (N=569)

Variable	*Description*	*%*	*Min.*	*Max.*	*Mean*	*Stand. deviation*
Dependent variables						
Preserving crop straw and hay		41.12				
Destocking		31.99				
Irrigation (using underground, stream water and rainwater harvest)		29.88				
Switching to crop production		36.03				
Livestock-crop integration		77.86				
Off-farm income generation		18.10				
Independent variables						
Ecological features						
Dry AEZs	Dry AEZs= 1 otherwise= 0		0	1	0.65	0.47
Institutional factors						
Extension service	Number of contacts in a year		0	30	6.14	7.02
Access to credit	Yes= 1 and otherwise= 0		0	1	0.32	0.47
Climate change awareness information	Yes= 1 and otherwise= 0		0	1	0.69	0.46
Access to livestock related information	Yes= 1 and otherwise= 0		0	1	0.27	0.44
Farmers' group membership	Member= 1, and otherwise= 0		0	1	0.82	0.37
Control variables						
Household head characteristics						
Gender	Male=1 and female= 0		0	1	0.78	0.40
Age	Years of household head		17	82	47.69	12.66
Education	Years of formal education		0	25	7.84	5.84
Household characteristics						
Household size	Number of persons		0	41	9.90	5.95
Dependency ratio	Dependent/active labour		-9	13	1.37	1.94
Farming experience	In years		0	55	23.18	12.27
Agric income	$ in the recent year (2019)		12,105.26	605.263.15	3,138.68	30,000
Non-agric income	$ in the recent year (2019)		10.60	106,05	101.21	114,92
Farm characteristics						
Land ownership	Yes= 1 and otherwise= 0		0	1	0.96	0.19
Land ownership status	Statutory= 1 and customary= 0		0	1	0.14	0.35
Farm size	Hectares		0	30	3.83	3.70
Herd size	Number of animals owned		5	5000	60.43	373.21

4.4.4 Operationalization of determinants of crop adaptation and its effect on food security

Multivariate probit regression models were used to analyze the variables influencing farmers' adoption of agronomical climate risk adaptations. The potential explanatory variables expected to influence the decision to adopt based on the theories are summarized in Table 10. Five agronomic climate risk adaptation strategies were considered as dependent variables in probit models and treatment variables in the Propensity Score Matching (PSM), Inverse Probability Weighted Regression Adjustment (IPWRA) and Endogenous Switching Regression (ESR). The farmers' adoption is equal to $\boldsymbol{y_7}$,

thus, $$\boldsymbol{y_7 = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon} \quad \textbf{… (Eq. 8)}$$

Where y_7 is the latent variable of farmers' choice to adopt, which indicates that household i will choose to adopt a climate risk adaptation strategy ($\boldsymbol{y_7}$> 0). α is constant, ε is the residual, $\beta 1 - \beta n$ is the regression estimates, $X1 - Xn$ denotes the set of explanatory variables that influence the expected benefits (Table 11).

4.4.4.1 Food Security as outcome variables

For the outcome variable of food security, two food security indicators were used, i) Household Dietary Diversity Score (DDS) and ii) Household Coping Strategy Index (CSI).

i. The DDS was developed by Food and Nutritional Technical Assistance Project (FANTA), this has often been used as a proxy for capturing the nutritional quality of food consumed by households, household access to calories and diverse foods (INDDEX Project, 2018). It is assumed that daily diets with a greater variety of food groups are associated with greater energy and nutrient intakes (Kant 2004; Rose et al. 2002), and more adequate nutrient intakes (Hatloy et al. 1998; Steyn et al. 2006), and more positive anthropometric outcomes for adults, women and children (Arimond and Ruel 2004; Rah et al. 2010; Ruel 2003). DDS food security indicator includes 12 food groups that capture the consumption of macro and micronutrients within the recall period of 24 hours, which form a range scale of 0-12.

ii. The CSI refers to people's responses when a household faces food insecurity and the measures they take to attenuate or mitigate its consequences (INDDEX Project 2018). In addition, the CSI assesses the frequency of occurrence of increasingly severe coping strategies, i.e., the behaviours people engage in when they cannot access enough food. Leroy et al. (2015) reported that there is no universal CSI, but rather a methodology is proposed to derive locally relevant CSIs. Therefore, this study considers 12 coping strategies commonly used in Nigeria (Akerele et al. 2013; Olayemi 2012).

Table 11: Description of the variables imputed into Eq. 7 (N=1,080)

Variable	*Description*	*Mean*	*Std. Dev.*	*Min*	*Max*
Outcome variables					
Dietary Diversity Score	Number of food groups consumed in the last 24 hours by the farming household	6.84	2.51	1	12
Coping Strategy Index	Number of coping strategies employed in the last week by the farming household	8.44	6.44	0	19
Treatment/dependent variables					
Adjusting planting date	Adopter= 1; otherwise= 0	0.76	0.42	0	1
Shifting to another crop	Adopter= 1; otherwise= 0	0.71	0.45	0	1
Early mature varieties	Adopter= 1; otherwise= 0	0.56	0.47	0	1
Drought tolerant varieties	Adopter= 1; otherwise= 0	0.61	0.48	0	1
Crop and livestock integration	Adopter= 1; otherwise= 0	0.46	0.49	0	1
Independent variables					
Socio-demographic characteristics					
Household head gender	Male= 1; female= 0	0.78	0.41	0	1
Age	Years of household head	48.15	13.30	17	85
Education	Years of formal education of household head	8.24	5.59	0	25
Farming experience	Years in the farming of household head	22.61	12.18	0	55
Share of agricultural income	Percentage contribution to total income	79.59	29.82	30	100
Total household income (in 1000)	Estimated annual farm and non-farm income in Naira	2,927	2.0e+04	73,000	2.8e+05
Farm characteristics					
Livestock ownership	Livestock owner= 1; otherwise= 0	0.56	0.49	0	1
Land ownership	Landowner= 1; otherwise= 0	0.88	0.32	0	1
Farm size	Total farm size (ha)	3.44	3.45	0	30
Institutional characteristics					
Farmers group	Group member= 1; otherwise= 0	0.82	0.37	0	1
Extension contacts	Number of contacts in year	6.84	7.45	0	30

Crop related information	Access to crop information= 1; otherwise= 0	0.34	0.47	0	1
Weather information	Access to weather information=1; otherwise= 0	0.38	0.48	0	1
Access to credit	Access to credit= 1; otherwise= 0	0.32	0.46	0	1
Climate change awareness	Farmer that are aware=1; otherwise= 0	0.72	0.44	0	1
Agroecological features					
Dry AEZs	Farmer from dry AEZs=1 otherwise= 0	0.50	0.50	0	1

4.4.4.2 Food security description of the farming households

The results (Appendix 9) show the relative annual contribution of different food sources to the farming household food security. 62% of the farming households' food comes direct from their own farm production, which indicates the important role of farm productivity to household food security. Further, 31% of their foods come from food markets, which implies that, firstly, this might happen because farming households cannot produce what can sustain them a year-round or secondly, they emphasize cash crops due to their comparative advantages that sold out later and buy food from market to complement their annual food needs.

Table 12 portrays the food groups consumed (DDS) by the farming households in the last 24 hours recall period and the food security coping strategies (CSI) adopted in the last 7 days. With regards to DDS, 85.27% of the farming household consumed cereals, followed by oils and fats (78.92), vegetables (77.52%) and root and tubers (71.27%) in the last 24 hours of the data collection. This implies that farming households consumed less protein including animal (eggs, fish and meat) and plant sources (nut and seed) than carbohydrates sources.

Table 12: Food security of the farming household

Food group category	***% of the households eat***	***Copping strategy***	***% of households use it***
Cereals	85.27	Relay on less preferred and less expensive food	71.11
Root and tubers	71.27	Borrow food from a relative or friend	23.77
Vegetables	77.52	Purchase food on credit	55.55
Fruits	50.93	Consume seed stock for next season	16.96
Meat	54.01	Gather wild food, hunt, or harvest immature crops	15.10
Eggs	32.68	Send children to eat with neighbor/relative	10.90
Fish and seafood	46.83	Send members of the household to beg	9.04
Legumes	50.38	Reduce the portion size at mealtimes	46.13
Nut and seeds	42.44	Restrict consumption of adults for children to eat	31.50
Milk and dairy	43.28	Reduced the number of meals eaten in a day	41.60
Oils and fats	78.92	Skip a complete day without eating	12.97
Sweet, spices, condiments, and beverages	50.33	Sell of agricultural equipment/assets	19.23

On the other hand, the CSI, 71.11% of farmers rely on less preferred and less expensive food in the last 7 days to meet the food need of their farming households in terms of quantity by compromising quality, while 55.55% purchase foods on credit and 46.13 reduce the portion size at mealtimes in the last 7 days of the data collection.

4.4.4.3 Impact estimation of adaptation on food security

The impact of climate risk adaptation strategies on household food security was estimated by Treatment Effect approaches (Propensity Score Matching [PSM], Inverse Probability Weighted Regression Adjustment [IPWRA] and Endogeneity Switching Regression [ESR]). Firstly, Propensity Score Matching (PSM) was employed.

The average treatments effect on the treated (ATT) of the adoption of climate risk adaptation strategies is given as follows.

$$\boldsymbol{ATT = E\{Y(1) - Y(0)T - 1\}} \qquad \textbf{… (Eq. 9)}$$

Where Y(1) and Y(0) are outcome indicators (in our case, food security of adopter and non-adopter households of which DDS and CSI were used), T is a treatment indicator (adoption of climate risk adaptation). However, we can only observe $ATT = E\{Y(1)\}/T = 1$ in the data set, and $ATT = E\{Y(0)\}/T = 1$ is missing. In essence, the study cannot observe the food security of treated households if they have not adopted the adaptation strategy. Therefore, a simple comparison of adoption and food security level of farmers with and without adoption (treatment) status introduces bias in estimated impacts due to self-selection bias. The magnitude of self-selection bias is formally presented as:

$$\boldsymbol{E[Y(1) - Y(0)/T - 1] = ATT = E(Y(0)/T = 1 - Y(0)/T = 0]} \qquad \textbf{… (Eq. 10)}$$

By creating comparable counterfactual households for treated households, PSM reduces the bias due to observables. Furthermore, once households are matched with observables, PSM assumes that there are no systematic differences in unobservable characteristics between treated and untreated households. Given this assumption of conditional independence and the overlap conditions, ATT is computed as follows:

$$\boldsymbol{ATT = E(Y(0)T = 1, P(x) - E[Y(0)/T - 0/P(x)}} \qquad \textbf{… (Eq. 11)}$$

Where ATT is the average treatment effect on the treated, Y is the adoption likelihood, P is the matching, and x is the observed effect. However, ATT from PSM can still produce biased results in the presence of misspecification in the propensity score model (Robins et al. 2007; Wooldridge 2010). To provide a remedy for such misspecification bias, we used IPWRA. The IPWRA estimator has a double-robust property that ensures consistent results. It allows the outcome (DDS and CSI) and the treatment (climate risk adaptation) model to account for misspecification. According to Imbens and Wooldridge (2009), ATT in the IPWRA model is estimated in two steps.

$\boldsymbol{ATT = 1/Nw \sum\_i^{\wedge}Nw[(\gamma 1 - \gamma 0) - (\delta 1 - \delta 0)X1}$ **… (Eq. 12)**

Where:

Nw = total number of farmers who adopted climate risk adaptation strategy

(γ1-γ0) = estimated inverse probability-weighted parameters for treated household (adopters)

$(\delta 1 - \delta 0)$ = estimated inverse probability-weighted parameters for non-treated households (non-adopters). However, regardless of adjustments for misspecification bias, matching techniques can only overcome the selection bias caused by observables. Still, the issue of endogeneity bias is unobservable heterogeneity, such as farmers' inherent skills and talent, results based on matching techniques will be biased. This study, therefore, employed an Endogeneity Switching Regression (ESR) model that accounts for both observed and unobserved sources of bias as used in the literature (Lokshin and Sajaia 2004; Shiferaw et al. 2014; Ma and Abdulai 2016). The ESR approach addresses this endogeneity problem by simultaneously estimating the selection and outcome equations using the full information maximum likelihood (Lokshin and Sajaia 2004; Ma and Abdulai 2016). The ESR model estimates used to estimate ATT (DDS and CSI) and average adoption effect (treatment effect) on non-adopter households (untreated) as follows:

$\boldsymbol{ATT = E(y\_1i \backslash T\_i = 1) - E(y\_21 \backslash T\_1 = 1)}$ **… (Eq. 13)**

Where;

$(y\_1i \backslash T\_1 = 1)$= endogeneity of the farming household adopted the climate risk adaptation

$E(y\_21 \backslash T\_1 = 1)$= endogeneity of the non-adopting farming household. We adopted the empirical methodology to assess the intervention's impact on farmers' welfare (Wossen et al., 2017; Ma and Abdulai, 2016).

5 Results and Discussion

This chapter present the result of the study and discussed them thoroughly, the chapter is subdivided in descriptive and inferential sub-chapters. The descriptive subchapter displays a summarised and described the socio-demographic characteristics of the study sample, climate change perception and knowledge of farming practices that cause climate change based on the dry and humid agroecological zones. In addition, experiences of the farming households' heads with environment-induced events and a comparison between adopters and non-adopters of agricultural insurance, their awareness, and adoption of the insurance were described and discussed. Furthermore, livestock climate production risk and adaptation strategies adopted as well as crop adaptation strategies and perceived constraints were displayed and discussed. The inferential subchapter depicted the result of the study objectives, and the research questions were answered in line with the theoretical, conceptual, and empirical background that yielded the conclusion and the recommendation aspect of the research.

5.1 Descriptive Results

5.1.1 Socio-demography of farming households based on AEZ

Table 13 presents the Chi-square result of the discrete socio-demographic characteristics of the farmers. The majority (88.89%) of the farming households' head in dry and humid AEZs were male. There is a significant difference between the two AEZs as female households' head constituted 32.22% of respondents in humid AEZs, while in dry AEZs females represented only 11.11%. In general, farming households with secondary school education constituted 31.1% of the respondents while 29.6% had primary education. Furthermore, we identified a significant difference between the two zones in terms of education. Farming households with non-formal education in dry AEZs constituted 36.11% and only 7.59% in humid AEZs. This could partially be attributed to the fact that this type of modern education has been in the southern part of the country (humid AEZs) for over a hundred years before reaching the northern part (dry AEZs) as well as the political unrest and insurgency in the dry zones in northern Nigeria lead to the destruction of schools and displaced people from their hometowns (UNICEF 2021).

The majority (88.2%) of the farmers in this study possessed farmland. The differences between the AEZs are significant. Only 0.93% of farmers from dry AEZs had no farmland as opposed to 22.59% of farmers from humid AEZs. Most farming households (82.4%) had access to extension services with no significant difference between the AEZs. 82.68% of the farming households were members of farmers' groups/cooperatives with a significant difference between the two AEZs. 85.19% of farmers from the dry AEZ were members of farmers' groups as against 80.19% of farmers of humid AEZs. In addition, we identified a significant difference in livestock ownership between the dry and humid AEZs. 73.70% of farmers of dry AEZs reared animals while only 39.07% had livestock in humid AEZs.

Table 13: Socio-demographic characteristics of farmers (N=1,108) [categorical variables]

Variables	*Category*	*Dry part (%) N=540*	*Humid part (%) N=540*	*Sig[1]*	*Total sample (%)*
Sex	Female	11.11	32.22	**0.000**	21.7
	Male	88.89	67.78		78.3
Level education	Non-formal	36.11	7.59	**0.000**	21.9
	Primary	27.96	31.30		29.6
	Secondary	21.67	40.56		31.1
	NCE/Diploma	9.82	10.00		9.9
	Graduate	3.89	9.81		6.9
	Postgraduate	0.56	0.74		0.6
Land ownership	No	0.93	22.59	**0.000**	11.8
	Yes	99.07	77.41		88.2
Extension contacts	No	16.11	19.07	0.201	17.6
	Yes	83.89	80.93		82.4
Farmers' group membership	No	14.81	19.81	**0.030**	17.32
	Yes	85.19	80.19		82.68
Livestock ownership	No	26.30	60.93	**0.000**	43.69
	Yes	73.70	39.07		56.31

[1] Significant level of X^2 result

Table 14 presents the t-test result of the continuous socio-demographic characteristics of the farming households. There is a significant difference in the age of the household heads between the two AEZs. The mean age of farmers in the dry AEZs is 42.66 while the mean age in the humid AEZs is 53.63. Farmers in the dry AEZs have a larger family size compared to those in the humid AEZs. 11 members is the average household size of farmers in the dry AEZs while the average family size is 6 members in the humid AEZs. This may be attributed to the polygamous family setting of dry AEZs (northern part) of the country compared to the dominant monogamous family setting of the humid AEZs (southern part) of the country (Kramer 2020).

Table 14: Socio-economic characteristics (N=1,080) [continues variables]

Variable	*Dry part[1]*	*Humid part [1]*	*Sig*	*Total[1]*
Age	42.66 (11.85)	53.63 (12.38)	**0.000**	48.15 (0.40)
Household size	11.44 (6.97)	6.38 (2.64)	**0.000**	8.89 (0.17)
Farm size	3.93 (3.97)	2.87 (2.60)	**0.000**	3.44 (3.45)
Farming experience	23.98 (12.11)	22.61 (12.18)	**0.000**	22.61 (12.18)
Agric income ($)[2]	1,493.28(127.83)	1,350.90 (708.66)	**0.000**	7,563.60 (5,249.34)
Non-agric income ($)[2]	76.63 (61.80)	97.32 (5.24)	**0.000**	86.99 (96.78)

[1] Mean and standard deviation (in parenthesis) are reported. [2]original value was in Naira ($1=381 Naira)

The average farming experience of the households' heads in the dry AEZs was 24 years and was thus significantly higher than that of the humid AEZs of 22.61. This is because agricultural activities in the dry AEZs zones are more predominant as an occupation than in the humid AEZs. Farming households in the dry AEZs earn more than the farming households of the humid AEZs from agriculture. The agricultural income varies significantly with an average of $1,493 in dry AEZs in contrast to an average of $1,350 in humid AEZs. This may affect their ability to adapt to climate change as postulated by Resource-based theory. However, in terms of non-agricultural income, farmers in the humid AEZs earn more than the farmers of dry AEZs. The average non-agricultural earnings of farmers in the humid AEZs is $97.32 and $76.63 for the farmers in the dry AEZs. This result is not surprising, as agricultural activities are the main occupation in the dry AEZs, while business activities are more predominant in the humid AEZs of Nigeria. In addition, the level of investment is higher in the humid AEZs (southern part) of the country (World Bank 2016).

5.1.2 Climate change perception in dry and humid AEZs

Table 15 presents the farmers' climate change perceptions based on indicators of climate change and risk occurrences (five-point from strongly disagree to strongly agree (1-5) scale). Perceived increases in temperature have a mean of 4.03, indicating that most farmers perceived some temperature increases in the last 10 years. These findings agree with NiMet (2020) and BNRCC (2011). Farmers also perceived a decrease in rainfall and a delay in the onset of rainfall. The perception mean value of the dry AEZs farmers was 3.82 while the mean perception of the humid AEZs farmers was 3.72. Furthermore, farmers perceived an increase in drought, evaporation, and frequency of floods in the last 10 years. These perceptions are in conformity with BNRCC (2011) and Montcho et al. (2022) In addition to climatic conditions, farmers perceived an increase in crop pest and disease outbreaks in the last 10 years.

Table 15: Climate change perception of indicators and risk occurrences in last 10 years

Indicator[1]	*Dry AEZs*[2]	*Humid AEZs*[2]	*Sig*	*Mean and standard deviation*[1]
Climate change indicators perception				
Increase in temperature	4.02 (0.98)	4.04 (0.77)	0.647	4.03 (0.88)
Decrease in rainfall (amount)	3.9 (1.07)	3.85 (1.00)	0.241	3.77 (1.10)
Delay in coming of rainfall	3.81 (1.22)	3.72 (1.07)	**0.083**	3.88 (1.04)
Climate risk occurrence perception				
Increase in frequency of drought	3.83 (1.07)	3.88 (0.87)	0.780	3.85 (0.98)
Increase in frequency of flooding	3.84 (0.99)	3.87 (1.04)	0.715	3.86 (1.01)
Increase in evaporation/rapid dry of soil	3.82 (1.02)	3.89 (0.84)	0.857	3.86 (0.93)
Increase in crop pest and disease outbreak	4.18 (0.91)	3.95 (0.84)	**0.000**	4.07 (0.88)

[1] five-point from strongly disagree to strongly agree (1-5) scale. [2]Mean (Std Dev.)

A significant difference between the zones is observed, as 4.18 was the mean perception of increases in crop pest and disease outbreaks in the dry AEZs while 3.95 was the mean perception of increases in crop pest and disease outbreaks in the humid AEZs. Further results revealed no significant differences between the two AEZs on the climate change indicators perceptions except for the delay in coming rainfall. In general, within the climate risk occurrence perception, a significant difference was only observed on increase in crop pests and disease outbreaks. These findings clearly show that the farmers in this study are strongly perceiving negative climate change effects despite the varying climatic conditions in the selected AEZs of Nigeria.

5.1.3 Knowledge of farming practices causes climate change based on AEZs

Table 16 reports a chi-square test of farmers' knowledge of causes of climate change comparing dry and humid AEZs. Farmers in dry AEZs are more aware on deforestation being a cause of climate change than farmers of the humid AEZs. In the dry AEZs, 78.70% of farmers knew deforestation could cause climate change while 52.89% of farmers in humid

AEZs were aware of this. Although many of the farmers were aware, it did not stop them from engaging in deforestation because they also consider it as a drought coping strategy (Hassan et al. 2019; Asfaw et al. 2019).

Table 16: Farmers' knowledge of farming practices causes climate change (N=1,080)

Causes	*Item*	*Dry AEZs (%) N=540*	*Humid AEZs (%) N=540*	*Sig*	*Total % (of knew)*
Deforestation	No	21.30	47.11	**0.000**	69.67
	Yes	78.70	52.89		
Land clearance by bush burning	No	27.04	52.59	**0.000**	60.1
	Yes	72.96	47.41		
Fossil fuel emissions	No	56.48	65.37	**0.000**	39.0
	Yes	43.52	24.62		
Methane from livestock	No	79.26	89.44	**0.000**	15.57
	Yes	20.74	10.56		
Inappropriate manure management	No	78.15	87.04	**0.000**	17.41
	Yes	21.85	12.96		
Excessive use of chemical fertilizer	No	63.52	88.52	**0.000**	24.0
	Yes	36.48	11.48		
Use of chemical plant protection and pesticides	No	58.34	61.67	0.264	40.0
	Yes	41.66	38.33		

72.96% of the farmers in dry AEZs were aware of land clearance by bush burning causing climate change as opposed to 47.41% of the farmers in the humid AEZs. This corroborates with Hassan et al. (2019) who reported that farmers had no knowledge of the negative impacts of bush-burning. Also, they believe this traditionally used method is the most cost-effective way of land clearance (Hassan et al. 2019).

Simultaneously, 39% of all respondents were aware that fossil fuel emissions from agricultural machinery can cause climate change. However, there is a significant difference between the farmers of the two AEZs. In dry AEZs 43.52% of farmers knew fossil fuel emissions can cause climate change while in humid AEZs only 24.62% were aware of this. Farmers thus appear to have relatively low knowledge of this issue. Previous research in

Malaysia showed, that 85% of the public identified fossil fuel emission as a major cause of climate change and is converse with the knowledge in developed countries, where most farmers know about the effect of fossil fuel emissions on global warming (McCright et al. 2013).

Our results further indicate that farmers have low knowledge on methane emission from livestock production is contributing to climate change. On average, only 15% of the farmers knew about this, with 20.74% in dry AEZs and 10.56% in humid AEZs knew that methane emission from livestock production can cause climate change. This differs from developed countries, for example New Zealand, where many farmers were not only aware but also looking for feed management from different type of plants with low impacts on the amount of methane produced by an animal (NIWA 2018). Only 17% of farmers knew that inappropriate manure management can cause climate change because of methane and nitrous oxide emissions.

We identified a significant difference between the farmers in dry AEZs with 21.85% being aware while only 12.96% being aware in humid AEZs. 24% of farmers knew about the intensive and indiscriminate use of chemical fertilizer contributing to climate change. Again, we found a significant difference between the dry and humid AEZs. 36.48% of the dry AEZs farmers knew that excessive use of chemical fertilizer can cause climate change while only 11.48% of humid AEZs were aware of this issue. This is in line with finding of Environmental Protection (2017), in which most respondents were not aware that N_2O is one of the harmful GHGs. 40% of the farmers were aware that the use of chemical plant protection and pesticides contributed to climate change with no significant difference between the two AEZs.

In a related study, Bhandari (2014) reported that farmers generally tend to be unaware of the negative effect of agrochemicals on the environment. The result depicted the farmers having very low knowledge that Methane from livestock and inappropriate manure management contributed to climate change irrespective of their AEZs. Although the respondents in the dry AEZs had a lower level of education compared to their counterparts in the humid AEZs, we could uncover that the farmers in the dry AEZs had significantly more knowledge on climate change causes in almost all dimensions. This would also go in line with previous findings indicating that social status and education might not necessarily lead to more knowledge on a specific subject (Hwang and Jeong 2009).

5.1.4 Experience with environment-induced events of adopter Vs non-adopters

As we expect climate risk experience to affect the awareness and adoption of agricultural insurance as explained by the Protection motivation theory, Figure 14 presents the climate change events affecting the livelihood of farmers due to changing environment in the last 10 years. The majority (89.03%) of farmers in the study area experienced a decline in their crop yield, while 71% reported complete crop failure. This indicates that farmers perceived that their crop farms were affected by climate risk. In addition, 64% and 65% of the farmers reported that they experienced a shortage of livestock feeds and crop pest and disease outbreaks, respectively, in the last 10 years. Almost half (49% and 47%) of them experienced the death of livestock and livestock pest and disease outbreaks.

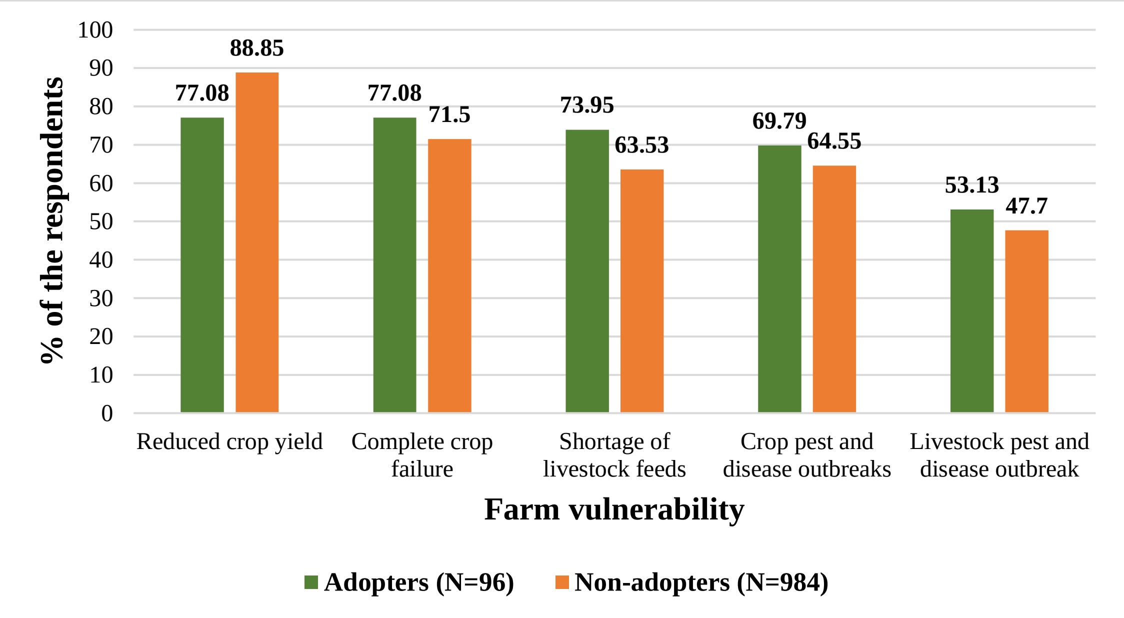

Figure 14: Experiences of farmers with environment-induced events in the last 10 years

Source: Authour

5.1.5 Farmers' awareness and adoption of agricultural insurance

The results in Table 17 show that 48.6% of the farmers are aware of agricultural insurance as a climate change adaptation strategy. This implies that more than half of the farmers are unaware of agricultural insurance as a climate risk measure. Olajide-Adedamola and Akinbile (2019) recorded that only 43% of Nigerian farmers are aware of agricultural insurance policy, which is quite similar to Ankrah et al. (2021), who reported that 64.4% of smallholder farmers are not aware of agricultural insurance in Ghana. Also consistent with

Elum et al. (2017), who reported that 40% of farmers are ignorant of insurance policies/products in South Africa. Furthermore, the result revealed that only 8.9% of the farmers adopted agricultural insurance. This corroborates with Elum et al. (2017) findings in South Africa, who reported that only 6.67% of cabbage farmers and 13.33% of potato farmers adopted agricultural insurance.

Table 17: Awareness and adoption of agricultural insurance (N=1,080)

Variables	***Category***	***%***
Awareness of agricultural insurance	No	51.39
	Yes	48.61
Adoption of agricultural insurance	No	91.09
	Yes	8.91

5.1.6 Livestock climate production risk and adaptation strategies adopted

Table 18 reveals a self-reported climate risk experienced of livestock farmers in the last ten years. 83.83% of the livestock farmers experienced a shortage of livestock feed, with not much difference between the two AEZs. 68.72% of the sample experienced livestock pest and disease outbreaks in the last 10 years, with the breakdown indicating that 78.93% of farmers are from dry AEZs and less than half (48.96%) of farmers from humid AEZs experienced livestock pest and disease outbreaks. The results furthermore show that 56.16% of livestock farmers experienced a decline in livestock productivity, and farmers of humid AEZs (61.34%) experienced the decline more than the farmers in dry AEZs (53.47%). Lastly, 29.70% of livestock farmers experienced the death of animals in the last ten years and most of them are from dry AEZs. This indicated that farmers of dry AEZ experienced livestock production risk in all the risks under the study except for decline in livestock productivity. And this may affect their response to climate change adaptation as explain by *Protection motivation theory*.

Table 18: Livestock production risk of farmers in the last 10 years (N= 569)

Risk	***Dry AEZs (%)***	***Humid AEZs (%)***	***Sample %***
Shortage in livestock feed	84.80	81.95	83.83
Livestock pest and disease outbreak	78.93	48.96	68.72
Decline in livestock productivity	53.47	61.34	56.16
Livestock mortality	33.06	23.19	29.70

The results in Figure 15 display the major livestock climate risk adaptation strategies adopted by farmers. The results show that each of the livestock climate risk adaptations under the study were adopted, and that livestock-crop integration (77.86% respondents adopted) was the most prominent adaptation strategy among them, followed by PCSH (41.12%). Irrigation was adopted by 29.88% and destocking by 31.99% of livestock farmers. 36.03% of farmers switched to crop production, while off-farm income generation is the least used climate risk adaptation adopted by just 18.10% of farmers.

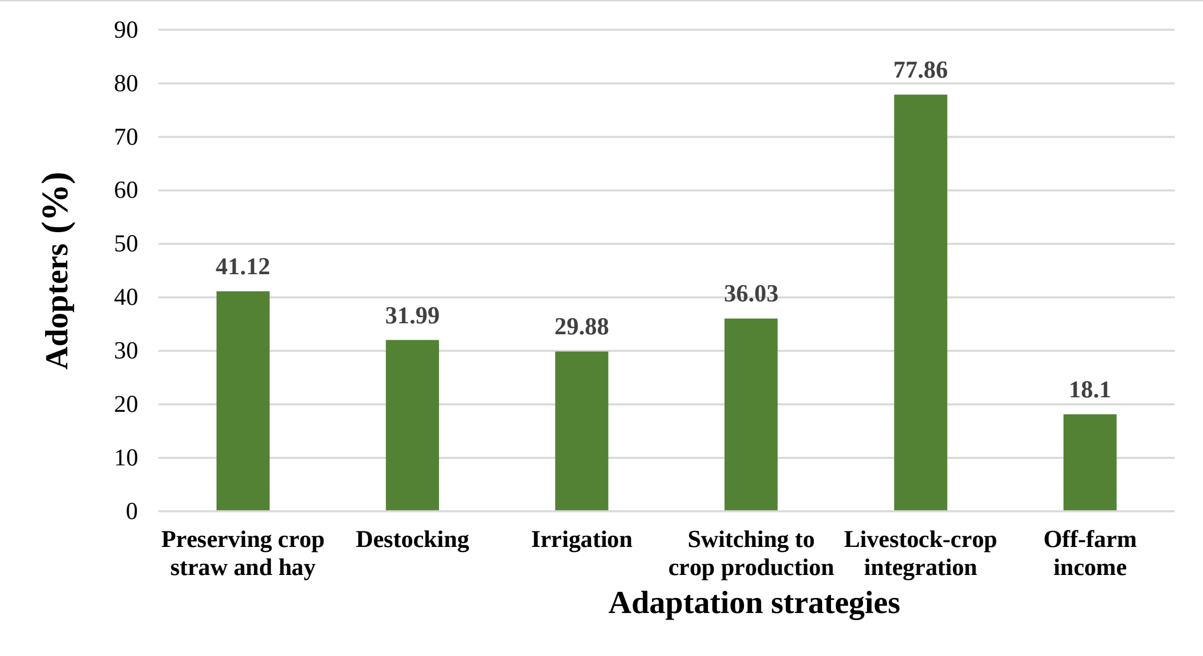

Figure 15: Livestock climate adaptation strategies adopted by farmers in last 10 years (N=569). Source: Authour

Figure 16 displays the comparison of the distribution of the livestock climate risk adaptation strategies of farmers between the dry and humid AEZs. Climate risk adaptation strategies adoption is more frequent in dry AEZs than humid AEZs. 90.93% of the farmers of dry AEZs adopted livestock-crop integration against the 54.57% of farmers in the humid AEZs. 61.84% of farmers of dry AEZs adopted PCSH against the 30.40% of farmers of humid AEZs this is probably due to the relative moisture stress levels of the dry zones. The destocking adaptation strategy was adopted by 40% of farmers of the dry AEZs compared with 28.25% of humid AEZs. In general farmers of dry AEZs already use the adaptation strategies higher than farmers of humid AEZs, which may be attributed to the vulnerability conditions of their area.

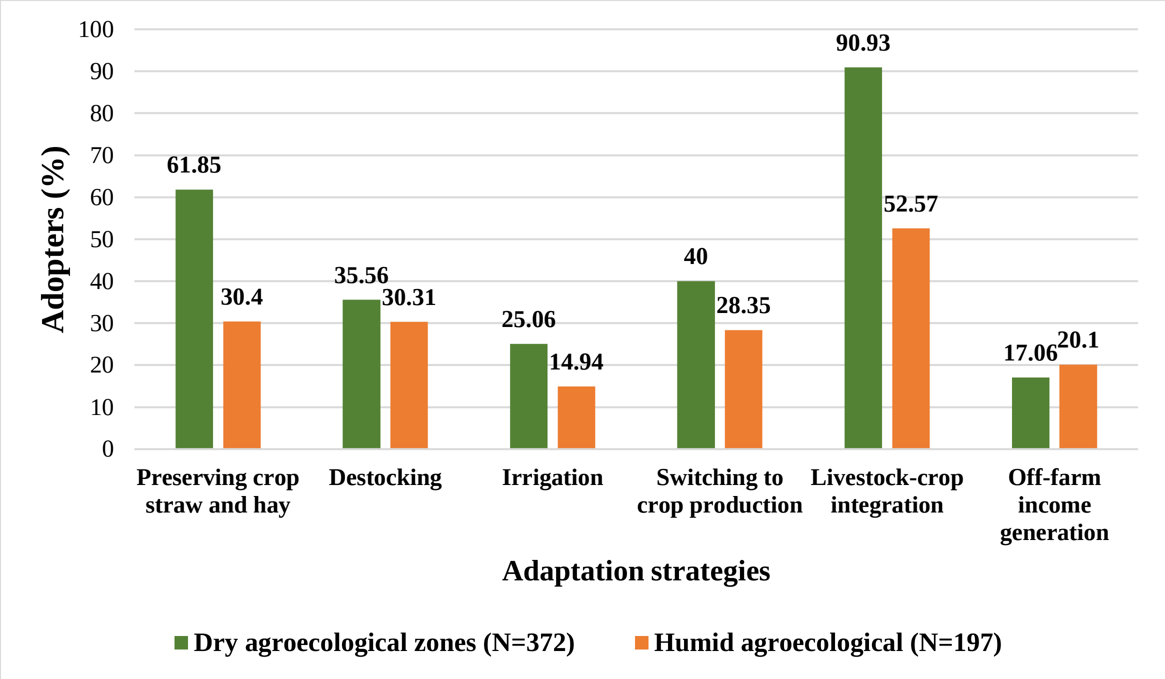

Figure 16: Adaptation strategies across the agroecological zones (N=569)

Source: Authour

5.1.7 Crop adaptation strategies and perceived constraints

Table 19 presents crop adaptation strategies adopted by the farming households in our sample. The primary adaptation strategy adopted by farmers is crop-livestock integration, adopted by 76.8%, followed by adjusting planting dates adopted by 71.2%, shifting to another crop was adopted by 65.4% of the farmers, and 61.6% of them adopted early mature varieties and the least adopted agronomical climate risk adaptation strategy by farmers is drought-tolerant varieties (46.5%). This implies that all the crop adaptations under the study were greatly adopted by the farmers except drought-tolerant varieties.

Table 19: Crop adaptation strategies adopted

Adaptation	*Percentage of adopters*
Adjusting planting dates	71.2
Shifting to another crop	65.4
Early mature variety	61.6
Drought-tolerant varieties	46.5
Crop-livestock integration	76.8

A number of climate risk adaptation strategies used at a time by farming households are presented in Figure 17. Almost 23% of farming households combined 3 and 4 climate risk adaptation strategies at a time, 20% of farming households combined 5 climate risk adaptation strategies, 19% used 2 climate risk adaptation strategies, only 12% adopted 1 climate risk adaptation strategy and 2% none. This depicted that almost all the farmers used more than one adaptation strategy at a time.

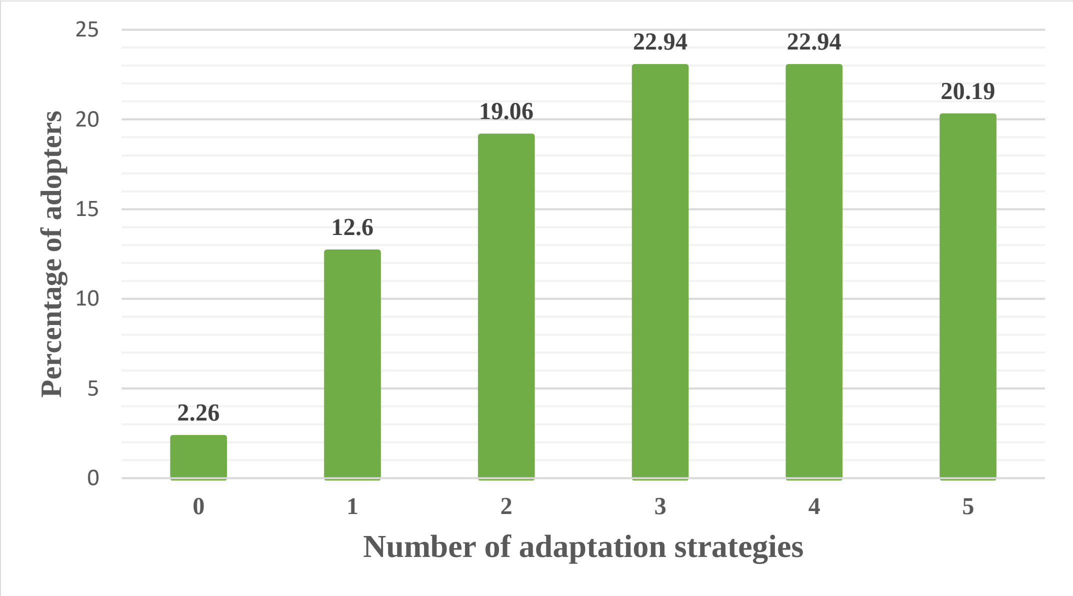

Figure 17: Number of crop adaptations adopted by farming household at a time

Source: Authour

Results in Table 20 display the perceived adoption constraints reported by farming households. 77.94% of the farming households reported inadequate knowledge of the potential climate risk as a constraint to their intended adoption, and 75.25% of them mentioned that limited knowledge of appropriate climate risk adaptation strategies hinders their adaptation. Furthermore, the result shows that 72.57% of the farming households mentioned that inadequate capital impeded their adaptation. The inadequate supply of drought-tolerant varieties in the market was reported by almost 70% of the farming households as a constraint. This might be one of the reasons for its low usage compare to other crop adaptation strategies (Table 15).

Table 20: Perceived constraints to the adoption crop adaptation strategies

Constraint	*Percentage of farmers reported*
Inadequate knowledge of the potential climate risk	77.94
Limited knowledge of appropriate adaptation measures	75.25
Inadequate drought-tolerant varieties in the market	69.97
Inadequate capital	72.57
Limited or lack of land	47.54
Labour shortage	57.65

5.2 Inferential Results and Discussion

5.2.1 Climate change knowledge and its relation to the perception of climate change

There is a relationship (Eq. 1) between farmers' knowledge of the causes of climate change and their perceptions of several climate indicators (Table 21). The perception of an increase in temperature, decrease in rainfall, delay in coming of the rains, frequency of drought, and increase in the frequency of floods are all positively associated with having higher climate change knowledge scores. Overall, these findings show that perception and knowledge of the causes of climate change are positively correlated with each other. However, it is not clear from this study whether climate change perception pushes the farmers to learn more about climate change causes or whether farmers with more knowledge tend to give more attention to the changes or possibly exaggerate the effects. This is a psychological phenomenon that deserves more attention in further studies.

Table 21: Relationship between the perception of climate indicators and knowledge of causes (N=1,080)

Climate change perception[1]	***Mean***	***Standard deviation***	***Climate change Knowledge Score[2]***
Perception indicators			Correlation Coefficient (r)
Increase in temperature	4.03	0.88	0.651**
Decrease in rainfall (amount)	3.79	1.02	0.820**
Delay in coming of rainfall	3.88	1.04	0.634**
Increase in frequency of drought	3.76	0.98	0.556**
Increase in frequency of floods	3.86	1.01	0.592**
Increase in evaporation	3.87	1.03	0.140
Increase in crop pest and disease outbreaks	4.07	0.89	0.671***

[1]measure in five Likert scale from lowest (1 = not perceived) to highest (5 = highly perceived). [2]Correlation coefficient and robust standard error are reported, ** $p < 0.05$, and *** $p < 0.01$.

5.2.1.1 Factors influencing awareness and climate change knowledge

The factors that influence the general climate change awareness and the knowledge of agricultural practices contributed to climate change (Eq. 2 and 3) are shown in Table 22. Members of farmers' groups are significantly more likely to be aware of climate change ($p<0.05$) and are more knowledgeable about the causes of climate change compared to farmers not members of such groups. This is attributed to the climate change related information received from such farmers' group. Similar observations of positive effect of farmers' group membership have been made by studies (Hasan and Kumar 2021; Huong et al.

2017; Mango et al. 2017 and Mudombi et al. 2014). A higher share of non-agricultural incomes of a farmer significantly increased the probability of climate change awareness and knowledge of climate change causes. This might be attributed to getting more access to information channel as a result of the increasing income as postulated by the *knowledge-gap theory*. In line with this, Ibrahim et al. (2015) recorded a significant positive influence of non-agricultural income on both the knowledge of the causes and effects of climate change in southwestern Nigeria.

Farmers who received weather information from government extension agents were more likely to be aware of climate change. While this is in line with some studies (Ali et al. 2021; Ibrahim et al. 2015) and supported by the knowledge-gap theory, it contrasts with findings of other literature (Bryan et al. 2013; Elum et al. 2017; Oduniyi and Tekana 2019) in which extension contact affected climate change awareness *negatively*. We thus see varying effects of extension service provision and how the quality of these facilities can have an influence on their effectiveness. Farmers receiving weather information from environmental NGOs are significantly more likely to be aware of climate change and have more knowledge of the causes of climate change. Similar results were reported in Mali and South Africa, where environmental NGOs were identified as the most important source of climate change information among farmers (Mahamadou et al. 2019; Mudombi et al. 2014). These findings indicate the need for closer collaboration between the public and private sector concerning the provision of information on climate change issues.

Farmers receiving weather information from farmers' cooperatives were significantly more likely to be aware of climate change and more knowledgeable of the causes of climate change. Other studies, such as those from Muench et al. (2021), De Sousa et al. (2018) and Menike and Arachchi (2016), uncovered the positive effects of agricultural cooperatives on information access and awareness of climate change among farmers. Cooperatives serve as a common communication platform to stimulates information exchange among farmers. Therefore, receiving weather information from fellow farmers significantly increased the likelihood for a farmer being aware of climate change, too. In addition, we observed an increase in knowledge of the causes of climate change due to access to information from other farmers. Farmer-to-farmer interaction was also identified as a highly important source of climate change information in Mali (Mahamadou et al. 2019) and Nepal (Muench et al. 2021).

Table 22: Determinants of climate change awareness and knowledge (N = 1080)

Variable	*Logistic regression[1] (Awareness)*	*Linear regression[2] (Knowledge)*
Socioeconomic		
Sex	0.0818 (0.128)	0.0957 (0.119)
Age	0.0050 (0.006)	0.0057 (0.005)
Years of education	0.0132 (0.009)	0.0137 (0.009)
Farming experience	0.0094 (0.006)	0.0069 (0.005)
Farmers group membership	0.3322 (0.136)**	0.2471 (0.125)**
Farm size	0.0113 (0.015)	0.0093 (0.0141)
Credit	-0.1516 (0.118)	-0.1373 (0.109)
Livestock ownership	0.0505 (0.111)	0.1055 (0.104)
Agricultural income	-0.0003 (0.00)	-0.0014 (0.007)
Non-agricultural income	0.0834 (0.028)***	0.0748 (0.026)***
Dependency ratio	0.0349 (0.028)	-0.009 (0.026)
Weather information sources		
Government extension agent	0.5744 (0.118)***	0.4713 (0.108)***
Environmental NGOs	0.2465 (0.124)**	0.2332 (0.115)**
Farmers' cooperatives	0.1913 (0.109)*	0.2464 (0.100)**
University and research institution	-0.0295 (0.171)	-0.0467 (0.157)
Farmers friends	0.6389 (0.108)***	0.6136 (0.100)***
Weather information channels		
Radio	0.0255 (0.005)***	0.0273 (0.005)***
Television	0.0091 (0.010)***	0.0054 (0.009)
Newspaper	-0.0030 (0.020)	-0.0098 (0.018)
Internet	0.01165 (0.011)**	0.0119 (0.010)
Climate risk experience in the last 10 years		
Extreme temperature	0.1679 (0.130)**	0.0517 (0.025)**
Flooding	0.0420 (0.123)	0.0499 (0.023)**
Drought	0.6640 (0.117)***	0.0802 (0.024)***
Windstorm	0.4384 (0.107)***	0.0656 (0.024)***
Dry agro-ecological zones	0.7535 (0.158)***	0.6309 (0.147)***
F-value	***0.000***	***0.000***
Pseudo R^2/R^2	***0.1915***	***0.5231***

[1]Marginal effect and standard error are reported. [2]Regression coefficient and std error is reported, *p<0.10, **p<0.05 and ***p<0.01.

We can thus derive a generally close peer interaction in smallholder farming systems. As local farmer cooperatives are encouraging peer exchange, farmers in the study area should be motivated to join cooperatives. The importance of cooperatives, informal farmer groups and peer exchange as information sources among Nigerian farmers is evident. This revelation is particularly important because the dissemination rate in agriculture is comparably low (Fichter and Clausen 2021).

An increase in receiving weather information via radio significantly increased the likelihood of a farmer's awareness of climate change and knowledge of the causes of climate change. Similar findings were reported in the US and South Africa (Dorothee et al. 2011; Mudombi et al. 2014). Using television to access weather information had a significant effect on the likelihood of farmers being aware of climate change. This corroborated the findings of Junsheng et al. (2019), who reported the substantial contribution of television to climate change awareness. Mass media, such as television and radio clearly have a smaller effect on climate change awareness than the institutional factors reported in this study. Nevertheless, they should not be neglected as information sources, particularly in the light of the need for access to weather information in rural areas and in communicating with farmers during emergencies such as pest and disease outbreaks, expected flooding, windstorms or wildfires. Receiving and searching for weather information primarily from the internet positively influenced the likelihood of farmers being aware of climate change. This effect of internet usage on climate change awareness agrees with the findings of Dorothee et al. (2011). Experiencing extreme temperatures more often increased both the perception and knowledge of the causes of climate change among our sample.

Regarding effect of climate risk experience, an increase in the number of flood experiences had by farmers enhanced their knowledge of the causes of climate change significantly. Experience of droughts made farmers more likely to be aware of climate change while it also increased the farmer’s knowledge of the causes of climate change. Experiencing windstorms made farmers significantly more likely to be aware of climate change and increased the farmer’s knowledge of the causes of climate change. This indicated that social status that grantee access to information is not the only reason but also climate risk experience play a significant role on climate change awareness and knowledge of farmer as agued by Hwang and Jeong (2009) and Madhuri and Sharma (2020).

An interesting revelation of this study was that farmers in the dry AEZs (the Semi-arid, Sudan savannah, and Guinea savannah zones) were more likely to be aware of climate change and have more knowledge on climate change compared to farmers in the humid AEZs (the Rainforest, Mangrove and Swamp Forest zones). This can be attributed to the fact that farmers living in vulnerable climate risk areas experience the effects of climate change more than those that are not living in climate risk areas, as depicted by the second argument of knowledge gap theory (Hwang and Jeong 2009; Madhuri and Sharma 2020). The location has been found to affect climate change knowledge, such as perceived changes in drought, flooding, temperature and rainfall patterns, as proxies (Huong et al. 2017). Similar findings, from Kenya and Bangladesh respectively, reported that farmers in arid and semi-arid areas perceived a decrease in rainfall and an increase in its variability, as well as an increase in temperature, more than their humid AEZs counterparts (Bryan et al. 2013; Ajuang et al. 2016; Abdallah et al. 2019). This result puts an emphasize on the importance of considering regional differences in the context of climate change awareness campaigns, policy formulation and mitigation efforts in agriculture. Climate change policies should thus not only be formulated on a national level but specified according to regional requirements.

5.2.2 Determinants of agricultural insurance awareness

The results in Table 23 show the explanatory variables of agricultural insurance awareness and adoption. Regarding the awareness model (Eq. 4), *socio-demographic characteristics* of the household heads were found to affect the awareness. Older farmers are more likely to be aware of agricultural insurance than younger farmers. This may be attributed to the changes observed over a period and the high vulnerability of older farmers that push them to search for available adaptation strategies. Year of schooling increase the agricultural insurance awareness significantly. Educated farmers are more likely to consult different agencies that promote agricultural insurance as an adaptation option (Ghazanfar et al. 2015; Hountondji et al. 2018).

Regarding *farm characteristics*, farmers with small farms and non-livestock owners are more likely to be aware of agricultural insurance significantly. This may be attributed to their vulnerability to climate risk, which makes them search for new knowledge that will help overcome these constraints, as indicated by the *Protection motivation theory*. This contradicted the finding of Olila and Pambo (2014) and Ghazanfar et al. (2015) which indicate the context specific of the effect of farm size on insurance awareness. An increase in herds size increases the likelihood of farmers being aware of agricultural insurance significantly. The possible reason is that farmers with a large number of animals may experience difficulties in handling their livestock due to climate risks that will push them to search for how to minimize the anticipating severe loss. Another plausible reason is that large herds can serve as a proxy of wealth which may give access to a variety of information sources for the farmer and the ability to pay for insurance. Furthermore, the loss due to illness/disaster may be much higher than for farmers with smaller herds.

For the effects of *institutional characteristics*, group member farmers, farmers with access to the banks and weather information are more likely to be aware of agricultural insurance. Most farmers get information on agricultural innovations, new government policies and programmes during group meetings. Ibotoye (2013) reported that 66% of farmers come to know about agricultural insurance during farmers' cooperative society meetings; in that way, Jatto (2019) reported the positive effect of cooperative membership on agricultural insurance awareness.

Table 23: Awareness and adoption of agricultural insurance (N=1,080)

Variables	***Awareness***		***Adoption***	
	Marginal effect	***Standard error***	***Marginal effect***	***Standard error***
Socio-demographic characteristics				
Sex	0.0812	0.0602	0.0150	0.0150
Age	0.0123	0.0026***	-0.0005	0.0007
Years of education	0.0161	0.0046***	0.0034	0.0013**
Household size	-0.0142	0.0049***	0.0020	0.0012
Years of farming experience	-0.0025	0.0028	0.0010	0.0008**
Farm characteristics				
Type of land ownership	0.0575	0.0648	0.0812	0.0329**
Farm size	-0.0167	0.0071**	0.0014	0.0016
Livestock ownership	-0.2247	0.0616***	0.0239	0.0146
Herd size	0.0023	0.0009***	0.0001	0.0000***
Institutional characteristics				
Group membership	0.2647	0.0643***	0.0165	0.0186
Extension contact	0.0045	0.0036	-0.0030	0.0011***
Access to bank	0.0998	0.0533*	0.0954	0.0285***
Weather information	0.1432	0.0564**	0.0383	0.0140***
Climate risk experience				
Flood	0.1703	0.0564***	0.0349	0.0157**
Drought	0.0709	0.0557	0.0311	0.0131**
Pro>chi^2	***0.000***		***0.000***	
Pseudo R^2	***0.2467***		***0.3160***	

***p<0.1, **p<0.05, ***p<0.01**

For access to banks, banks are intermediaries in the agricultural insurance market arrangement that brings farmers into an agreement with Nigerian Agricultural Insurance Corporation (Olubiyo and Hillan 2005). Therefore, the positive effect of access to weather information is that it helps farmers know the anticipated climate risk that will make the farmer search for proactive measures (Ghazanfar et al. 2015; Hountondji et al. 2018).

Concerning the effect of *climate risk experience* on the awareness of agricultural insurance, farmers who experience flood incidences were more likely to be aware of agricultural insurance. The flood incidence makes the farmers search for how to make their farming business more resilient and other ex-post management strategies that will keep them in the business.

5.2.2.1 Determinants of agricultural insurance adoption

For the insurance adoption model (Eq. 5), *socio-demographic characteristics* found to affect the adoption of agricultural insurance by farmers is education (Table 23). An increase in years of schooling increase the probability of adoption significantly. Education plays a role in reducing cognitive failure that can affect the willingness of individuals to spend their limited income to cover risks (Amare et al. 2019). The positive effect of education on the adoption of agricultural insurance is consistent with various studies (e.g., Oduniyi et al. 2020; Amare et al. 2019; Abugri et al. 2017; Chand et al. 2016; Bogele 2014).

Regarding *farm characteristics*, farmers with statutory land ownership type are more likely to adopt agricultural insurance than farmers with the customary type of land ownership significantly. This might be attributed to statutory land ownership being more secure than customary land ownership; this gives farmers the courage to make large investments that need security (Jianjun et al. 2015) or be used as collateral for credit access. Furthermore, farmers with a large number of livestock are more likely to adopt agricultural insurance. Livestock is a proxy of wealth that will make farmers financially capable, as explained by *resource-based theory*. On the other hand, a large number of livestock require enormous investment and running costs, which makes farmers secure the investment by adopting agricultural insurance. Farmers with small herds size might find it uneconomical to secure their livestock. Our finding on the positive effect of statutory type of land ownership and herd size is in line with the study of Chand et al. (2016).

Concerning *institutional characteristics*, an increase in extension services received by a farmer creates less likelihood of the farmer to adopt agricultural insurance. It is possible that farmers who had access to extension services were more likely to have knowledge of different climate risk management strategies and could, therefore, choose from a greater variety of different risk diversification and reduction options (Barrett et al. 2001; Bryan et al. 2009), in such situation, a negative relationship would have been expected (Arshad et al. 2016; Budhathoki et al. 2019). Another possible reason is that extension organizations and agents were not involved in promoting of agricultural insurance to farmers. Insurance agents and brokers, banks and consultants are intermediaries that charge to bring farmers into a business relationship with NAIC within the provision of the relevant laws, rules and regulations (Olubiyo and Hillan 2005). Therefore, farmers with access to banks are more likely to adopt agricultural insurance. In *resource-based theory*, adoption ability is dependent on one's wealth and assets; in other words, farmers demand to secure more of their investment with an increase in wealth (Marr et al. 2016). Another plausible reason is that access to credit helps farmers enhance their financial ability to pay insurance premiums (Amare et al. 2019). Furthermore, poor individuals have a lower capacity to build capital for climate risk management and risk transfer except through credit (Tadesse et al. 2015). The result of this study is consistent with the literature (e.g. Budhathoki et al. 2019; Arshad et al. 2015; Tadesse et al. 2015; Abugri et al. 2015; Bogale 2014). Farmers with access to weather information are more likely to adopt agricultural insurance. This is probably because knowledge of anticipated weather and climate extremes makes farmers prepare for the anticipated climate risk (Hill et al. 2013).

Regarding the effect of *climate risk experience*, farmers that experienced floods and drought are more likely to adopt agricultural insurance. This is explained by the *protection motivation theory* that when a farmer experiences threat in the environment they operate, they seek techniques to upset the threats (Floyd et al. 2000). This finding is in line with studies (Amare et al. 2019; Bogale 2014; Akinola 2014). Amare et al. (2019) explained that insurance adoption most likely comes from farming systems where livelihood strategies of households are widely exposed to weather-related risks. Bogale (2014) reported that farmers in conditions with moisture stress are more likely to adopt weather index insurance.

5.2.2.2 Reasons for not adopting agricultural insurance from those that are aware of it (N=524)

Figure 18 presents the impediments to adopting the agricultural insurance reported by farmers aware (48.61%) of it. The major impediment reported by 59% of farmers is not being sure of the effectiveness of the insurance. This is corroborated by Ankrah et al. (2021). Furthermore, 45% of farmers are unable to afford the insurance. This indicates the robustness of our inferential result that revealed the statistically significant effect of access to banks (credit) on insurance use, as is also postulated by the *resource-based theory*. This is in line with Cole et al. (2013), who reported that liquidity constraints are more important than education for agricultural insurance uptake and further explains the experimental result that insurance take-up increases if a high-cash reward before purchasing insurance is given. Our findings are also in line with Giné et al. (2010) and Budhathoki et al. (2019). The 32% of the farmers reported that the reason for not using the insurance is fear of failure to honour the agreement by insurance providers. This implies that the farmers’ trust in agricultural insurance companies makes farmers insure their farms.

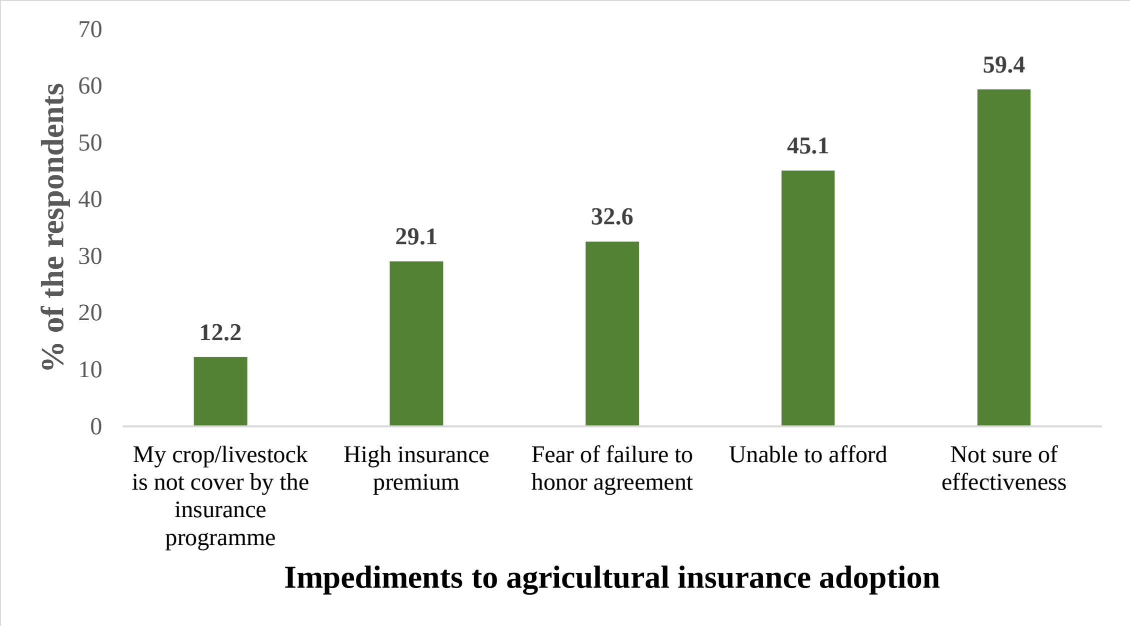

Figure 18: Reasons not to adopt reported by non-adopters of agricultural insurance (N=524)

Source: Authour

This is consistent with several studies (e.g. Cole et al. 2013; Ibitoye 2013; Marr et al. 2016). Futher, 29.10% of farmers mentioned that the high premium price constrains them from using agricultural insurance. This agrees with a number of studies (e.g. Ibitoye 2013; Kong et al. 2011; Ali et al. 2020; Ghazanfar et al. 2015).

5.2.2.3 Difficulties faced by adopters of agricultural insurance and their opinion on its performance

Table 24 displays how long the farmers have been using the agricultural insurance and their opinion on the performance of the strategy. The majority (75%) of the farmers adopted the agricultural insurance in the last 5 years, around 20% in the last 10 years and only 1% adopted it at the beginning of the last two decades; this may indicate that the strategy follows the normal process of diffusion of innovation in relation to time and society as postulated by Rogers (2003). Lastly, the result also reveals that 54.8% rate the performance of the agricultural insurance as good and very good based on their personal assessment and 27.9% rated the programme as poor.

Table 24: Farmers' opinion on the performance of agricultural insurance (N=96)

Variables	Categories	%
Years of adoption	<5	75.00
	5-10	19.60
	11-15	4.30
	>15	1.10
Rating of agricultural insurance	Poor	27.96
	Fair	17.20
	Good	35.48
	Very good	19.35

The result in Figure 19 displays the reported challenges associated with agricultural insurance as a climate change adaptation strategy from farmers that are using the product (N=96). The result shows that 47.8% and 38.9% of farmers experienced difficulties in accessing compensation and late payment of the compensation. Previous studies have highlighted the delay of compensation pay-outs as the main reason for the low uptake (e.g. Ajieh 2010; Ghimire et al. 2016; Johnson et al. 2018; Marr et al. 2016; Broberg 2019).

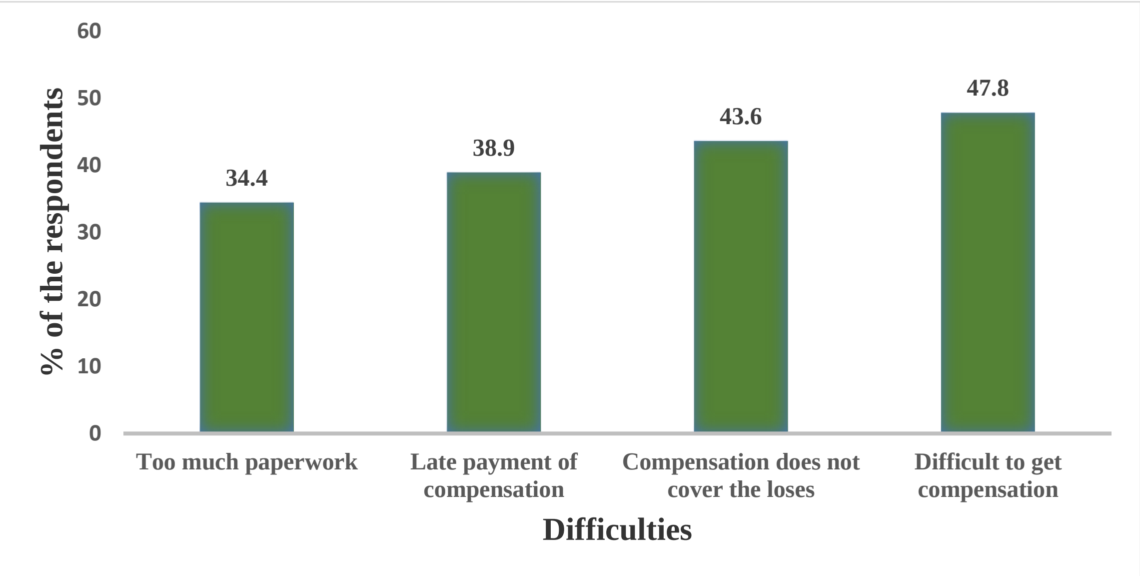

Figure 19: Difficulties encountered by the adopters of agricultural insurance (N=96)

Source: Authour

43.6% of the adopters reported that the compensation does not cover the farmers' losses. This implies that the aim of agricultural insurance to keep farmers in the venture in ex-post risk and disaster will be defeated if the compensation cannot cover the incurred loss (Nordlander et al. 2019; Ajieh 2010). 34.5% reported too much paperwork/administration hassle during the registration and compensation application process. This is corroborated with the findings of Budhathoki et al. (2019).

5.2.3 Effect of AEZ and institutional factors on the livestock climate risk adaptation strategies

The results (Table 25) show the effect of agroecological conditions on the adoption of major livestock adaptation strategies by farmers in order to adapt with climate variability and uncertainty (Eq. 7). As we expected, the results depict that the farmers of dry AEZs are more likely to adopt PCSH, destocking and irrigation adaptation strategies, and less likely to switch to crop production and integrating crop into livestock than farmers of humid AEZs. The reason for PCSH and irrigation may be attributed to the water and moisture stress of the dry AEZs, because the rainy period of dry AEZs are less than 4 months (85-115 days) unlike the humid AEZs where rainy days range from 5-9 months per year. The livestock farmers must provide feed and drinking water for their animals year-round, meaning the long dry period of dry AEZs nudge them to adopt PCSH and irrigation. This is consistent with literature (Destaw and Fenta 2021; Legesse et al. 2013).

The possible reason for the adoption of the destocking adaption is the fact that when the preserved feed is not sufficient to feed the animal for the remaining 8 months, then farmers have no other alternative than to destock their herds. This finding corresponds with Shemdoe (2011). The possible reason for the lower probability of dry AEZs farmers switching to crop production and integrating crops into livestock is the moisture stress of the area which gives them limited opportunity to try crop production compared to farmers of humid AEZs. Another plausible reason is that farmers of the dry AEZs might consider livestock production a less risky venture than crop production, as livestock can be moved from one place to another in search of pastures and water which is reported as a common practice in the area (FAO 2019b).

The results (Table 25) further show that an increase in extension contact increases the likelihood of adopting PCSH, destocking and irrigation, and off-farm income generation adaptation strategies. For PCSH and destocking, the possible reason is that extension workers encourage farmers to preserve animal feed in the time of surplus and abundance as proactive measures, but at times of climate risk when livestock farmers experience feed shortages they encourage farmers to adopt destocking as the only alternative measure at hand for minimizing or alleviation of losses.

Table 25: Effect of agroecological and institutional factors on adoption of livestock climate risk adaptation strategies (N= 569)

Variable	*Preservation of Crop Straw and Hay*	*Destocking*	*Irrigation*[1]	*Switch to Crop Production*	*Livestock Crop Integration*	*Off-farm Income Generation*
Ecological features						
Dry AEZs	0.4465 (0.090)***	0.3033 (0.102)***	0.1326 (0.064)**	-0.1895 (0.087)**	-0.1136 (0.064)*	0.0977 (0.080)
Institutional factors						
Extension contacts	0.2531 (0.058)***	0.1810 (0.047)***	0.1162 (0.049)**	-0.1259 (0.081)	-0.0271 (0.023)	0.0922 (0.045)**
Credit access	-0.0047 (0.070)	-0.1270 (0.0504)**	0.0313 (0.056)	-0.008 (0.069)	-0.0376 (0.029)	0.0651 (0.052)
Climate change awareness	0.1616 (0.056)***	-0.1604 (0.057)***	-0.0608 (0.049)	0.0532 (0.061)	0.0162 (0.025)	.0166 (0.042)
Livestock related information	0.2287 (0.066)***	-0.2446 (0.063)***	-0.0042 (0.048)	-0.0439 (0.063)	-0.0325 (0.029)	0.1403 (0.053)***
Farmers' group membership	-0.2416 (0.077)***	-0.0379 (0.066)	-0.0129 (0.060)	-0.0682 (0.076)	0.0228 (0.033)	-0.1469 (0.069)**
Other influential factors						
Demographic characteristics						
Gender	0.0181 (0.079)	0.1236 (0.048)**	-0.1544 (0.075)**	-0.0290 (0.078)	0.0155 (0.029)	-0.1106 (0.064)*
Age	-0.0092 (0.003)**	-0.0033 (0.002)	-0.0031 (0.002)	0.0021 (0.003)	-0.0003 (0.001)	-0.0039 (0.002)
Education	0.0003 (0.005)	-0.0111 (0.004)**	0.0014 (0.003)	0.0049 (0.005)	0.0022 (0.002)	-0.0085 (0.003)**
Household size	0.0013 (0.005)	0.0032 (0.004)	0.0104 (0.003)***	-0.0071 (0.005)	0.0058 (0.003)*	0.0030 (0.003)
Dependency ratio	-0.0177 (0.016)	0.0277 (0.013)**	0.0078 (0.011)	0.0466 (0.016)***	-0.0000 (0.005)	0.0297 (0.010)***
Farming experience	0.0046 (0.003)	0.0017 (0.002)	0.0017 (0.002)	0.0030 (0.003)	-8.69e-06 (0.001)	-0.0013 (0.002)
Agric income	-4.81e-09 (0.000)	-1.19e-07 (0.000)***	-2.70e-10 (0.000)	3.41e-08 (0.000)	8.92e-08 (0.000)***	-4.31e-09 (0.000)
Non-agric income	8.56e-10 (0.000)	2.28e-06 (0.000)***	-2.21e-07 (0.000)	3.53e-06 (0.000)***	-7.51e-07 (0.000)**	-4.28e-07 (0.000)
Farm characteristics						
Land ownership	0.0166 (0.041)	0.1353 (0.140)	-0.1183 (0.298)	0.1118 (0.2794)	-0.0648 (0.023)***	0.1338 (0.065)**
Land ownership status	0.0341 (0.080)	-0.1229 (0.049)**	0.1126 (0.072)	0.1067 (0.081)	-0.0172 (0.029)	0.0944 (0.061)
Farm size	-0.0079 (0.008)	0.0024 (0.006)	0.0074 (0.005)	-0.0142 (0.008)*	0.0017 (0.003)	0.0015 (0.005)
Herd size	-0.0013 (0.000)**	0.0004 (0.000)*	0.0001 (0.000)	0.0000 (0.000)	-0.0003 (0.000)***	0.0003 (0.000)**
Prob>chi^2	***0.000***	***0.000***	***0.006***	***0.000***	***0.000***	***0.000***
Pseudo R^2	***0.1915***	***0.2349***	***0.0885***	***0.1322***	***0.3155***	***0.1107***

Marginal effects were reported, the numbers in parenthesis are standard deviation, ***=p<0.01, **=p<0.05 and *p<0.10. [1]encompass all the three sources of water: Rainwater harvest, underground and streams/river

This result is in line with Shahbaz et al. (2020) and Nkuba et al. (2019). The positive effect of extension services on irrigation can be attributed to the fact that extension services provide knowledge of water conservation techniques that may give livestock farmers a managerial skill for exploring different water sources in their environment for irrigation. Our finding is consistent with the literature (Mango et al. 2017; Destaw and Fenta 2021). Livestock farmers with access to credit are less likely to adopt the destocking adaptation strategy. This can be attributed to the fact that credit can be used to provide necessary adaptation measures, such as supplementary feeding, to avoid untimely destocking as a result of a feed deficit. This is in line with Zewdu (2020).

Livestock farmers that are aware of climate change are more likely to adopt the PCSH adaptation strategy and less likely to adopt destocking. The possible reason can be attributed to the fact that farmers' awareness of potential climate change and the associated weather risk makes them more likely to adopt PCSH as a proactive measure to prevent selling their animals most times at low prices. This agrees with the findings by Kato et al. (2011). Another plausible reason for the positive effect of climate change awareness on PCSH adaptation is that climate forecasting information services guide farmers to plan their livestock production and other farm management decisions based on the projected rainfall distribution patterns and temperature variations (Berhe et al. 2017).

The results (Table 25) furthermore show that farmers with access to livestock-related information are more likely to adopt PCSH and off-farm income generation adaptation strategies and less likely to adopt destocking adaptation strategies. Farmers with knowledge of animal handling will have alternative strategies to manage their animals during climate extremes, as PCSH provides supplementary feeds during times of drought and other feed-deficit conditions. Off-farm income serves as an external and secure funding source that can be used for purchasing feed to avoid destocking during times of climate risk. This finding confirms the results of previous studies (Mabe et al. 2014; Naseer et al. 2014; Tiwari et al. 2014) and illustrates the importance of disseminating and facilitating livestock-related information to farmers which includes adaptation strategies. The results show that livestock farmers who are members of farmers' groups are less likely to adopt PCSH and OIG. The possible reason for this is that group members may have access to financial support from groups and cooperatives, which makes them less reliant on off-farm income.

5.2.3.1 Perceived livestock adaptation constraints

Table 26 presents the constraints that livestock farmers considered as an impediment to the adoption of climate risk adaptation. 83.13% of the sampled livestock farmers considered inadequate knowledge of potential climate risk as a constraint to the adoption of adaptation strategies, with no clear difference between the farmers of dry and humid AEZs. Furthermore, 80.14% of them reported limited knowledge of appropriate adaptation measures, with most farmers of both AEZs reporting this as the main constraint. With regards to lack of capital (funds), 71% of respondents reported inadequate capital (75% of farmers from humid AEZs and 68.27% of farmers from dry AEZs) as a constraint to adoption. Most climate risk adaptations, such as pasture and hay preservation and irrigation, require capital investment. More than half (52.20%) of farmers reported inadequate irrigation facilities as a climate adaptation constraint. Lack of land ownership is a constraint for 33.07% of farmers in dry AEZs and 44.33% of farmers in humid AEZs.

Table 26: Perceived livestock climate adaptation constraints (N= 569)

Constraint	*Dry AEZs (%)*	*Humid AEZs (%)*	*Sample (%)*	*Rank*
Inadequate knowledge about potential climate change/risk	81.67	84.02	83.13	1
Limited knowledge of appropriate adaptation measures	81.60	77.32	80.14	2
Inadequate capital/funds	68.27	75.25	71.00	3
Limited or lack of land ownership	33.07	44.33	36.91	5
Inadequate irrigation facilities	44.27	67.53	52.20	4

5.2.4 Determinants of crop adaptation strategies

Table 27 presents the maximum likelihood estimates of the probit model (Eq. 8). Regarding *socio-demographic characteristics* of the farming households, female household heads are significantly more likely to adopt drought-tolerant varieties than their male farmers counterparts. This is attributed to female household heads being more vulnerable to climate risk (FAO 2016; Glazebrook et al. 2020). This result is consistent with recent studies (Lunduka et al. 2019; Martey et al. 2020).

Age also appears as an important factor; a one-year increase in the age of the farming household head increases the adoption likelihood of early mature varieties.

Table 27: Explanatory variables of crop adaptation strategies (N=1,080)

Variable	Adjusting planting date	Shifting to another crop	Early mature varieties	Drought-tolerant varieties	Crop and livestock integration
Demographic characteristics					
Gender of the household head	-0. 0134 (0.037)	-0.0018 (0.042)	-0.0391 (0.044)	-0.0932 (0.046)**	0.0257 (0.048)
Age	-0.0027 (0.001)	-0.0026 (0.003)	0.0090 (0.002)***	-0.0032 (0.002)	0.0009 (0.002)
Education	-0.0039 (0.003)	-0.0036 (0.003)	0.0062 (0.003)*	-0.0036 (0.003)	0.0022 (0.003)
Farming experience	0.0028 (0.001)	-0.009 (0.002)	-0.0086 (0.002)***	-0.0004 (0.002)	-0.0001 (0.002)
Share of agricultural income	0.0041 (0.000)***	0.0021 (0.000)***	0.0013 (0.000)**	0.0006 (0.000)	0.0010 (0.000)
Total income	3.42e-08 (0.000)	-1.91e-10 (0.000)	2.75e-09 (0.000)	-7.80e-10 (0.000)	3.51e-08 (0.000)
Farm characteristics					
Livestock ownership	-0.2358 (0.031)***	-0.1670 (0.035)***	0.1261 (0.038)***	0.1086 (0.038)***	0.8035 (0.043)***
Land ownership	0.0168 (0.066)	0.0417 (0.107)	-0.0166 (0.111)	-0.0670 (0.114)	0.0775 (0.153)
Farm size	0.0105 (0.005)*	0.0025 (0.005)	0.0220 (0.005)***	0.0250 (0.005)***	0.0010 (0.006)
Institutional characteristics					
Farmers group	0.0315 (0.042)	-0.0030 (0.049)	-0.1173 (0.046)**	0.0537 (0.052)	0.0529 (0.055)
Extension contacts	0.0078 (0.002)***	-0.0013 (0.002)	0.0150 (0.002)***	0.0145 (0.002)***	-0.0085 (0.002)***
Crop related information	-0.1011 (0.037)***	-0.0928 (0.039)**	0.1529 (0.038)***	0.0902 (0.040)**	0.0345 (0.043)
Weather information	0.0737 (0.027)***	0.0899 (0.037)**	0.1440 (0.037)***	0.0705 (0.039)*	0.0521 (0.040)
Access to credit	0.1291 (0.032)***	0.1063 (0.036)***	-0.0208 (0.040)	-0.0983 (0.040)**	-0.0901 (0.043)**
Climate change awareness	0.1219 (0.040)***	0.0399 (0.041)	0.0595 (0.042)	0.0767 (0.042)*	0.0034 (0.041)
Agro-ecological feature					
Dry AEZs	0.2566 (0.040)***	0.2577 (0.049)***	0.2066 (0.052)***	0.1186 (0.054)**	0.3305 (0.060)***
Prob > chi^2	***0.000***	***0.000***	***0.000***	***0.000***	***0.000***
Pseudo R^2	***0.2716***	***0.1241***	***0.1161***	***0.0799***	***0.2751***

***** , ** and *significant at p< 0.01, p<0.05 and p<0.1 respectively**

This is because older farmers have acquired a longer observation-based knowledge and therefore are more aware of the need to implement adaptation strategies (Oyinbo et al. 2018).

As expected, education is a key determinant of climate change adoption strategies, including the adoption of early mature varieties. By default, farmers with higher education should have more profound knowledge and ability to understand and respond to anticipated changes, have a better level of planning, as well as able to forecast future scenarios, and largely have relatively better access to information and opportunities (Opiyo et al. 2015; Kumasi et al. 2017). In line with this, the adoption likelihood of early mature variety is increasing due to the increase of one year of formal education. This positive effect of education on adoption of early mature variety is consistent with the recent literature (Destaw and Fenta 2021; Oyinbo et al. 2019).

An increase in the farming experience of farming household heads decreases the likelihood of adopting early mature varieties. As expected, the share of the agricultural income of farming households is found to affect the adjusting planting dates, shifting to other crops, and adopting early mature varieties. This implies that farming households with high dependence on agriculture are more vulnerable to climate risk that nudge them to adopt the climate risk adaptation because the higher the share of agricultural income, the higher the dependence on agriculture. This is in line with the findings by Ali and Ereinstein (2017) in Pakistan.

Regarding *farm characteristics* of the farming households, the result suggests that farmers that owned livestock are more likely to adopt early mature varieties, drought-tolerant varieties and crop-livestock integration adaptation strategies. This is because livestock serves as a proxy of wealth and capital that can facilitate the adaptation as explained by *resource-based theory*. This is consistent with the literature (Tun et al. 2017; Ali and Ereinstein 2017; Nhemachena et al. 2014). Conversely, livestock ownership affects the adjusting planting dates and shifting to another crop negatively. Farm size also appears as an important factor; an increase of one hectare of farmland significantly increases the likelihood of adjusting planting dates, use of early mature varieties and drought-tolerant varieties. This is supported by the finding of Ali and Ereinstein (2017).

Concerning the effect of access to *institutional services*, having access to extension services is expected to affect the adaptation as it provides vital information on agricultural production and management practices (Asnake and Mammo 2016). Our result revealed that group member farmers are less likely to adopt early mature variety than non-group members. An increase of one extension contact in a year increases the adoption likelihood of adjusting planting dates, adopting early mature varieties, and drought-tolerant varieties significantly, which is in line with the findings by Martey et al. (2020) and Ali and Ereinstein (2017). However, it decreases the likelihood of adopting crop-livestock integration. Furthermore, access to crop-related information is expected to provide farmers with different crop management options for adapting to the changing environment. As expected, farmers with access to crop-related information are more likely to use early mature and drought-tolerant varieties ($p<0.01$). This agrees with the previous studies (Bryan et al. 2013; Nhemachena et al. 2014; Ali and Ereinstein 2017). On the other hand, it reduces the adoption likelihood of adjusting planting dates and shifting to other crops ($p<0.01$).

Farmers with access to weather information are more likely to adjust their planting dates, shift to other crops, and use early mature and drought-tolerant varieties. This may be attributed to noticing the change in the average rainfall and temperature that make farmers adapt to the changing environment. This is supported by previous studies (Atinkut and Mebrat 2016; Nhemachena et al. 2014). Furthermore, weather information provides farmers with the onset of rains, cessation, quantity and pattern of the rainfall and possibility of dry spells that make farmers to be proactive towards the possible climate risk. The positive effect of weather information on climate change adaptation was also reported by Obayelu et al. (2014). Similarly, access to information on temperature and rainfall was shown to increase the probability of shifting to a new crop as an adaptive measure (Deressa et al. 2009).

It was expected that the availability of credit services would increase the farmers' capability to meet costs associated with various adaptation options and allows farmers to purchase necessary inputs (Taruvinga et al. 2016). Credit accessibility increases the likelihood of adjusting planting dates and shifting to another crop which is in line with previous studies (Deressa et al. 2009; Nhemachena et al. 2014); conversely, it decreases the likelihood of using drought-tolerant varieties and crop-livestock integration. Farmers that are aware of climate change are more likely to adjust planting dates and use the drought-tolerant varieties than those that are unaware.

Farming households that are more vulnerable to climate risk are expected to adapt more to the changing environment as explained by *induce protection theory*. Farmers of dry agroecological zones are found to be more likely to adopt all five adaptation strategies (adjusting planting dates, shifting to another crop, early mature variety, drought-tolerant varieties and crop-livestock integration). This is consistent with studies that reported that farmers of moisture stress agro-ecological zones are more likely to change their type of crop planted, adopt drought-tolerant varieties and shift to another crop (Ali and Ereinstein 2017; Tessema et al. 2019; Martey et al. 2020).

5.2.5 Effect of crop adaptation strategies on DDS and CSI of farming households

Table 28 portrays the treatment effect estimates for adopting climate risk adaptation strategies on household dietary diversity scores using alternative estimation techniques (PSM, IPWAR and ESR). In general, the reported effects of adjusting planting dates are robust across all estimation methods, showing the important role of adjusting planting dates on DDS outcome indicators. We found that adjusting planting dates increases the food security of farming households by eating an additional 1.54 food groups using PSM, 1.25 using the IPWRA and 2.80 using ESR specifications. This is attributed to the fact that adjusting planting dates with the onset of rains decrease yield loss, increases crop yield, minimises the pest and disease pressure, and is ideal for pollination (Meisner 2018; Ahmed et al. 2015). Our result is consistent with the literature (Ali and Ereinstein 2017; DI-Falco et al. 2011; Rising and Devinen 2020).

Shifting to another crop significantly affects the food security of farming households across all the alternative estimation techniques. Farming households that shifted to another crop have an additional DDS of 0.8 using PSM, 0.92 using IPWAR and 4.66 using ESR. Less effect on food security was observed from using an early mature variety with only the ESR depicted its effect. The ESR estimation techniques indicate that farming household that adopted early mature variety has 0.12 DDS additional against non-adopter households. The possible reason is that early mature varieties help adapt to the short growing periods to avoid the incidence of precipitation shortage and drought (Oyinbo et al. 2019). The potential positive effect of early mature varieties on food security was projected by Thornton and Herrero (2014). Our positive impact result of adopting early mature variety on farming household food security is consistent with Oyinbo et al. (2019); Thornton and Herrero (2014); DI-Falco et al. (2011) and Lemessa et al. (2019).

Reported results also suggest that adopting drought-tolerant varieties positively and significantly affects farming household food security. Farming households that adopted the drought-tolerant varieties had an additional 5.30 DDS (ESR) against the non-adopting households. This is consistent with Ali and Ereinstein (2017) and Tofa et al. (2021) as the use of such varieties increases farm productivity (Lemessa et al. 2019; DI-Falco et al. 2011) and farm income (Lunduka et al. 2019) which all could result into food security. Farming households that adopted crop-livestock integration had an additional DDS of 0.48 using PSM and 1.22 IPWAR daily.

Table 28: Effect of climate change adaptation on household DDS (N=1,080)

Adaptation	*Treated*	*Propensity score matching*		*Inverse probability weighted regression*		*Endogeneity switching regression*	
		ATT	***Std. Err.***	***ATT***	***Std. Err.***	***ATT***	***Std. Err.***
Adjusting planting dates	642	1.54	0.336***	1.25	0.167***	2.80	0.066***
Shifting to another crop	595	0.83	0.238***	0.92	0.160***	4.66	0.067***
Early mature variety	553	-0.11	0.236	0.15	0.187	0.12	0.057**
Drought-tolerant varieties	430	0.08	0.226	-0.16	0.163	5.30	0.065***
Crop and livestock integration	427	0.48	0.356***	1.22	0.221***	0.10	0.091

***** and **significant at p< 0.01 and p<0.05 respectively, DDS= dietary diversity score, ATT= Average treatment effect on the treated**

The results in Table 29 reveal the counterfactual treatment effect estimates for adopting crop adaptation strategies on the household food security coping strategy index (CSI) using alternative estimation techniques (PSM, IPWAR and ESR). We expect that farming households that adopt crop adaptation will employ less food security coping strategies than non-adopting farming households due to the impact of the adaptation strategies on their food security. The farming households that adjusted their planting dates are less likely to employ 1.19 CSI using PSM and 3.19 using ESR weekly than the non-adopting farming household. The positive effect of adjusting planting dates on food security was reported in the studies (Meisner 2018; Ahmed et al. 2019; Rising and Devinen 2020). Shifting to another crop adaptation strategy makes the adopting farming households less likely to employ 3.63 CSI using ESR weekly than non-adopting farming households. This may be attributed to the adaptive nature of the newly cultivated crop.

Table 29: Effect of climate change adaptation on food security CSI (N=1,080)

Adaptation	***Treated***	***Propensity score matching***		***Inverse probability weighted regression***		***Endogeneity switching regression***	
		ATT	***Std. Err.***	***ATT***	***Std. Err.***	***ATT***	***Std. Err.***
Adjusting planting date	642	-1.19	1.044**	-0.21	0.527	-3.19	0.153***
Shifting to another crop	595	0.34	0.727	0.29	0.484	-3.63	0.145***
Early mature variety	553	0.67	0.597	-1.06	0 .464**	0.21	0.152
Drought-tolerant varieties	430	0.27	0.60	-1.72	0.396***	-1.44	0.149***
Crop and livestock integration	427	-3.37	1.187***	-3.06	1.005***	-1.72	0.205***

***** and **significant at p< 0.01 and p<0.05 respectively, CSI= coping strategy index, ATT= Average treatment effect on the treated**

Farming households adopting an early mature variety are less likely to employ 1.06 CSI weekly using IPWAR. The possible reason is that early mature varieties help adapt to the short growing periods to avoid the incidence of precipitation shortage and drought. (Oyinbo et al. 2019). The potential positive effect of early mature varieties on food security was predicted by Thornton and Herrero (2014) in their simulation result. Our positive impact result of adopting early mature variety on farming households' food security is consistent with Oyinbo et al. (2019); DI-Falco et al. (2011) and Lemessa et al. (2019).

Those using drought-tolerant varieties are less likely to employ 1.72 CSI using IPWAR and 1.44 CSI using ESR. This is consistent with Ali and Ereinstein (2017) and Tofa et al. (2021) as the use of such varieties increases farm productivity (Lemessa et al. 2019; DI-Falco et al. 2011) and farm income (Lunduka et al. 2019) which all could result into the farming household's food security. Crop-livestock integration by a farming household make it less to utilise 3.37 CSI using PSM, 3.06 CSI using IPWAR and 1.72 using ESR. The possible reason is the mutual benefit between crops and animals in the production system. This bolsters the production of crops (including feeds) through improved soil nourishment from animal manure, serves as a pest and disease aversion method, and increases farm resilience to climate risk. This finding is in line with previous research (Thornton and Herrero 2014; Peterson et al. 2020).

6. Conclusion, Recommendations and Policy implications

This chapter draws a conclusion from the result and discussion chapter, answered the research questions and suggested a number of policy implications. The chapter is divided into four subchapters in line with the specific objectives of the study.

6.1 Climate Change Knowledge and Perception

This subchapter draws on a primary data survey using a structured questionnaire to; assess the knowledge of farmers on farming practices that are related to climate change and how it's associated with climate change perception of farmers and the factors influencing awareness and knowledge of climate change.

With respect to the causes of climate change attributed to agriculture, we were able to uncover varying degrees of knowledge in our sample. Most farming households know that deforestation and land clearance by bush burning contributes to climate change. However, many farmers did not know that methane emissions from livestock (enteric fermentation) can cause climate change, despite it being a major GHG contributor within the agricultural sector. This also holds for inappropriate use of manure, fossil fuel emissions from agricultural machinery and the excessive and indiscriminate use of agrochemicals.

The climate knowledge of farmers was found to be positively associated with the climate perception of farmers. This finding serves as evidence that wrong or missing information can lead to distorted perception. Critical gaps in knowledge consequently lower the mitigation preparedness of farmers towards climate change as intended by the country. Given the mixed results in the level of knowledge about the agricultural causes of climate change among the respondents, we recommend policymakers to focus on educating farmers more about the effects of farm practices on the environment. A well-planned process of knowledge transfer would positively influence the degree of understanding of the subject matter.

Regarding the factors positively influencing the awareness of climate change and knowledge of its causes, contrary to the first aspect of *knowledge-gap theory* the socio-economic factors do not show much effect on farmers' climate change awareness and knowledge of farm practices that mitigate climate change. This may happen because the smallholder farmers seem to be socio-economically homogenous. However, weather information sources, channels and climate risk experience of farmers show much significant influence on the farmers' climate change awareness and knowledge of farm practices mitigate climate change.

As cooperative membership, government extension agents, environmental NGOs and farmer-farmer climate change information sources influence the farmers' climate change awareness and knowledge of farming practices that mitigate climate change. This indicates the importance of using subject information sources in teaching farmers the effect of farming practices, such as the effect of methane from livestock and inappropriate manure management, can have on the climate and environment. As radio affects both the farmers' climate change awareness and knowledge of farming practices that mitigate climate change, this highlighted the vital of using radio in climate change awareness creation, guiding climate change perception of farmers toward scientific facts and findings for appropriate actions.

Furthermore, as experiencing extreme temperatures, drought, flooding and windstorms were identified as positive drivers of climate change awareness and knowledge, we found farmers of humid AEZs were less knowledgeable about the farm practices that mitigate climate change than their peers in dry AEZs. Living in areas prone to a higher climate risk thus also increases the level of climate change knowledge. This holds particularly when there is not a large difference in income or education and access to the information sources and channels among the study population as depicted by the *knowledge gap theory*. Therefore, we identified the *location* as an important factor framing the perception and knowledge of climate change. These findings indicate that farmers of climate risk-prone areas are already ahead of their counterparts in terms of climate change perception and knowledge of farming practices that mitigate climate change that will ease the adaptation process, what they need is to be guided according to the scientific findings.

In general, climate change awareness and education schemes should be made available through farmers' cooperatives, radio, television, and the internet. The better the farmers understand climate change issues and how they affect them, the more they will be ready to adapt to them accordingly. An increase in organizational involvement with farm-related associations and encouragement of farmers to participate in farmer-to-farmer extension and knowledge-sharing networks could strengthen their climate change knowledge and shape their perceptions.

6.2 Awareness and Adoption of Agricultural Insurance

This subchapter provided a conclusion on the drivers of agricultural insurance awareness and adoption of farmers, the reasons for not adopting the strategy and the difficulties experienced by the farmers that adopted the insurance in Nigeria.

More than half of the farmers are unaware of agricultural insurance as a climate risk management strategy. As awareness of agricultural insurance is a prerequisite to its adoption, this indicates the need for awareness creation. Very few farmers adopted agricultural insurance and the trends in insurance adoption since the introduction revealed that the adoption of the insurance has increased in the last five years. However, there is a significant number of farmers remained not adopting despite they are aware of it. The low rate of adoption highlighted how big a challenge for the government to meet their target as the percentage number of adopters (8.91%) found in the study compared with the 20% (15 million) smallholder farmers intended to cover by the programme.

Concerning the drivers of agricultural insurance *awarenes*s, young farmers, farmers with a low level of education, landless farmers, and those without access to banks should be given a priority in the design and campaign of agricultural insurance awareness and facilitating weather information also has a long way to contribute to get farmers aware of the insurance. Farmers with a small number of household members, small farm size and farmers without livestock should also give concerned for promoting agricultural insurance that may lead to the adoption. As this study found the significant effect of farmers' group membership, access to banks and weather information, this implies the vital role of using cooperatives and other farmers' groups, increasing bank accessibility and weather information for agricultural insurance awareness creation.

Education was found to affect the *adoption* of agricultural insurance, as it helps farmers to anticipate the consequences of climate change and understand the potential benefit of agricultural insurance. Agricultural insurance products can be difficult to understand especially for populations with low literacy rates, this indicates the need of simplifying the information of the insurance product for the absorption of farmers with a low level of education as this will boost their patronage to the product. As the statutory type of land ownership promotes the adoption, the government should make a policy that farmers with the customary type of land ownership can apply and get a certificate of ownership easily which will make the land more secured and can be used as credit collateral which will increase the financial capability toward the agricultural insurance.

Farmers with small size of herds should be encouraged to form a group to apply for the insurance for the economics of scale, this may help them to adopt since farmers can insure their farms in form of a group. As the bank serves as a major agricultural insurance information source and credit source, increasing banks' accessibility to farmers will increase their financial capability for the insurance. As the extension organizations and agents are the farmer's closest and most reliable source of agricultural information in developing countries, they should be involved in promoting agricultural insurance and the insurance should be included in the list of climate risk adaptation options promoted. As the access to weather information affects the adoption of agricultural insurance, this highlighted the need for making weather information accessible to farmers vital in the promotion of agricultural insurance.

To cope with prejudices of non-adopters and hurdles faced by adopters, firstly, as the farmers are not sure about the effectiveness of the strategy; unable to afford; fear of failure from insurance providers; and the high price of insurance premiums. Sensitizations and workshops to develop confidence and building of trust in farmers toward the insurance will help in the adoption of the insurance. Thus, this can only be solved by developing confidence and trust in farmers, as subsidy is already part of the programme, we suggested different modes of payments should be introduced such as paying in-kind, and installments.

The problems associated with the insurance reported by the adopters are difficult to get compensation, and insufficient and late pay-out. The government should offer or facilitate the accessibility of reliable weather data and crop risks model to assess risks exposures that will give a good picture of farmers' losses. A unit should be created that will monitor the prompt pay-out of losses and sanctioning should be developed and enforced where necessary on insurance companies for keeping rigorously to contractual arrangements and to get the trust of adopters and allay the fears of non-adopters.

Finally, the agricultural insurance awareness creation programmes and making farmers aware of the potential benefits of the agricultural insurance may increase the adoption rate. We proposed that the government and agricultural insurance companies should work towards i) eliminating or reducing the reported adoption impediments by non-adopter farmers; ii) reducing the challenges faced by the insurance users by meeting the contractual obligations to farmers who adopted the insurance iii) the government has to bear in mind that they have a decisive role to play in supervision and monitoring the activities of the insurance companies to check the prompt of justifiable compensation. This will boost the trust of farmers and result in increased adoption of agricultural insurance in the country as well as other developing countries and help to increase farmers' resilience to changing and unstable environments.

6.3 Effect of AEZs and Institutional Factors on Livestock Adaptation Strategies

This subchapter provides a conclusion on the effect of agroecological and institutional factors on livestock climate risk adaptation in Nigeria and answered the research questions.

The major climate risk adaptation strategies adopted by farmers are PCSH, destocking, irrigation, integrating crop and livestock production, and switching to crop production. As expected, the farmers of dry AEZs adopted almost all livestock climate risk adaptation strategies at a higher rate than farmers of humid AEZs. This supports the theory of *protection motivation* and illustrates the effect of agroecological features on the choice to adopt climate risk adaptation strategies. Also, it unveiled the vulnerability of farmers of dry AEZs attributed to the moisture stress of the area. This finding highlights the need for promoting and facilitating livestock climate-smart agriculture in the dry zones in particular water-efficient irrigation methods (e.g. drip and sprinkler) and improved PCHS preservation (such as silage), which will help farmers to adapt and cope with animal feed and drinking water shortages and improve the resilience of the livestock sector.

Our results show that institutional factors such as access to extension advisory services, climate change awareness and livestock-related information, and to credit plays a vital role in the creation of an enabling environment for adaptation as postulated by the *institutional theory*. These factors also help farmers to adopt PCSH and irrigation, which allows them to avoid destocking. This indicates that livestock-climate smart practices can be promoted by i. Dissemination of improved and qualitative extension services that will teach, demonstrate and encourage farmers regarding current and proactive climate risk adaptation measures; ii. Policy formulation that facilitates and links farmers with financial institutions for credit resources that will help them to adopt capital-demanding adaptations such as PCSH and irrigation, as well as laws that will allow access to water resources; iii. Provision of accurate and reliable weather forecasting/information provided by local internet service providers and meteorological institutions, in particular temperature, the expected date for rainfall onset, duration, intensity, variability, cessation dates, dry spells, and other expected extreme weather events. This will help farmers to prepare and make the provisions necessary to cope with the expected departure of any metrological variable from the normal; and iv. Public and private sector support for the design and construction of irrigation infrastructure which may also help farmers in areas with sufficient water access to adapt.

Comparison of perceived adaptation constraints reported by farmers extends the results of our inferential model (Eq. 7). Farmers perceive a lack of knowledge about the potential climate risks, which is in line with the effect of climate change awareness in our models. Climate change awareness campaigns and dissemination of weather forecasts can mitigate this constraint. Limited knowledge of appropriate adaptation measures is another perceived constraint, which is in line with the effect of extension services in the models which can be reduced by improved livestock climate-smart adaptation information provision from extension staff. Inadequate capital access is also perceived as an adaptation barrier and linked with the effect of credit in the models. Lack of capital can be overcome by facilitating credit provision to farmers through policy measures such as subsidization of interest rates or collateral provision, which will help with the adoption of capital-demanding and long-term risk adaptation strategies such as irrigation.

In general, the subchapter revealed that livestock farmers are aware of the effect of a changing environment on their production, especially farmers of dry AEZs as they have already adopted some climate risk adaptation measures to cope with the situation. Awareness and willingness to adapt are promising prerequisites to support farmers by applying corresponding institutional support from governmental and non-governmental actors via site-specific support and creating an enabling environment for the use of livestock climate risk adaptations. Understanding the unique challenges faced by organizations providing extension and climate information would bring valuable insights. Further study should consider the relevance of the introduction of drought-tolerant grasses and heat stress-tolerant breeds of livestock in dry AEZs.

6.4 Drivers of Crop Adaptation Strategies

This subsection provides the conclusion for the factors influencing the adoption of crop adaptation strategies and associated impacts on farming household food security. The major crop adaptation strategies adopted by farming households are crop-livestock integration, adjusting planting dates, shifting to another crop and early mature variety. The major perceived adoption constraints are: inadequate knowledge of the potential likely climate risk; limited knowledge of appropriate climate risk adaptation strategies; inadequate capital and inadequate drought-tolerant varieties in the market.

Less effect of *socio-demographical* characteristics was observed contrary to *diffusion and adoption theory*. However, the share of agricultural income of the farming household influences the adoption of climate risk adaption strategies positively. *Farm characteristics* that were found to increase adoption of the climate risk adaption strategies are livestock ownership and farm size. On the *institutional factors,* access to extension services, crop-related and weather information, access to credit and climate change awareness increase the adoption likelihood of adaptation strategies. Lastly, farmers of the dry AEZs are more likely to adopt the crop adaptation strategies which indicates their vulnerability and adaptation needs.

6.5 Effect of Crop Adaptation on Food Security of Farming Households

Our main results of the alternative estimation technique approach are summarized as follows: First, we found consistently positive and statistically significant impact of climate risk adoption on farming household DDS. Given that climate risk adaptation strategies have a positive impact on DDS and a negative impact on CSI of the farming households, there is scope for policy to further promote the adoption of crop adaptation strategies covered by the study. Firstly, the results highlight the importance of awareness and knowledge about the potential climate risk, appropriate adaptation strategies, access to credit and making the drought-tolerant varieties available to the farmers. Secondly, the result pointed out the importance of wealth on the ability of the farming households to invest in climate risk adaptation strategies to cope with the changing environment. Hence, policy should focus on: i) increasing awareness of climate change risk adaptation strategies, access to crop-related and weather (temperature and rainfall forecast) information; ii) improving the purchasing capability of farming households by augmenting the farming household income with access to credit and lowering the cost of the adaptation strategies; and iii) Policy on increasing the awareness should focus on increasing access to education and agricultural extension services; iv) enhancing the accessibility of the climate risk adaptation strategies should focus on increasing the endowments for instance through access to services to the farming households that will turn to improve their food security.

6.6 Limitations

We gave a strong consideration in our data collection and analysis however, as the climate change knowledge questions consist of "Yes" and "No", no provision for "I do not know" therefore this may affect the farmers respond because some may choose the correct answer by guessing because no provision was given to those that unaware, therefore this may affect the precision of the climate change knowledge result. Regarding the result of agricultural insurance awareness and adoption, there are different type of insurance in agriculture such as weather index insurance, livestock index insurance etc., which their adoption drivers may differ of which this study did not differentiate. Because many farmers can not differentiate the type of agricultural insurance, they are aware of or used.

As the study considered more than one species of animal, and it's evident that climate change risks affect species of animal differently, based on the level of susceptibility and vulnerability the specie. And this study did not include animal species in the analytical models. Furthermore, the result reflects the food security status of farming households as a unit, not an individual household's member, and the result reflects the food security of the farming households at period during the data collection as it is cross-sectional. Based on this, the result is not an annual food security picture of the farming households. Therefore, the findings should be interpreted as such. Another limitation the study did not include the real environmental factors such as soil fertility, relief and rainfall pattern and quantity in the analytical model instead though we used agroecological zones of farmers as proxy in the analysis to capture location fixed effects. The sample considered all farming households irrespective of the crop produce by the households which may influence the result. Because climate change affect crop differently dependent on the susceptibility of the crop to the environmental change.

6.7 Direction for further studies

Lastly, we recommend the future studies to consider answer option “I do not know” should be included in climate change knowledge research, this can improve the result precision. Further studies on agricultural awareness and adoption should try differentiating the awareness and adoption of different type insurance among farmers. Regarding livestock climate risk adaption by considering different species of livestock in the models. Finally, intra household food security and assess the impact on individual bases to explore the intra-family inequality also, use of panel data to come up with more robust findings as food security is a year-round issue. Future studies should consider environmental feature such as soil fertility conditions when estimating the effect of climate change adaptation on farming household’s food security for policy formulation. Follow-up studies using replicated cross-sectional and panel data may evaluate the effect of climate change adaptation on farming household’s food security for robust result for policy formulation.

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8 List of Authour's Scientific Contributions

Published articles

Madaki MY, Harald K, Miroslava B. 2023. Agricultural insurance as climate change adaptation strategy for developing countries: A case of Nigeria. Climate Policy https://doi.org/10.1080/14693062.2023.2220672

Madaki MY, Lehberger M, Bavorova M, et al. 2023. Effectiveness of pesticide stakeholders' information on pesticide handling knowledge and behaviour of smallholder farmers in Ogun State, Nigeria. Environ Dev Sustain (2023). https://doi.org/10.1007/s10668-023-03332-8

Madaki MY, Muench S, Kaechele H, Bavorova M. 2023. Climate Change Knowledge and Perception among Farming Households in Nigeria. Climate, 11, 115. https://doi.org/10.3390/cli11060115

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Madaki MY. 2021. Measurement of variables and questionnaire design. Chapter four in the book Survey Design edited by M. Bavorova. Published by Faculty of Tropical AgriSciences, the Czech University of Life Sciences Prague Kamycka 129, 165 00 Prague-Suchdol, Czech Republic. https://www.ftz,czu.cz/en

Submitted manuscripts

Madaki MY, Bavorova M, Zhllima E, Imami D. 2023. Effect of Climate Risk Adaptation on Food Security Among Farming Households: The Case of Nigeria. Climate risk Management article number: CLRM-D-22-00226. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4200275

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Bulus B, **Madaki MY**, Bavorova M. 2023. Effect of school feeding program on pupils' enrolment, attendance, and performance in Northeaster Nigeria. Studies in Education and Evaluation, article number: SEE-D-23-00439.

Ullah A, Bavorova M, **Madaki MY**. 2023. Livelihood impact of community-based forest landscape restoration in the Hindu Kush Himalaya, Pakistan. Population and Environment, article number: POEN-D-23-00164.

Conference contributions

Bulus B, Bavorova M, **Madaki MY**. 2022. Relationship between heat stress and adaptation strategies of poultry farmers in Bauchi state, Nigeria. Tropentag, September 14-16, 2022 at Czech University of Life Sciences Prague.

Madaki MY, Bavorova M. 2021. Relationship between farmers' climate risk vulnerability and food security. Tropentag 2021, September 15-17 hybrid conference in Germany. https://www.tropentag.de/2021/abstracts/links/Madaki_hs6wU5or.pdf

Bulus B, **Madaki MY**, Bavorova M. 2023. Examining the linking school feeding program on smallholder farmer income and household food security. Tropentag 2021, September 15-17 hybrid conference in Germany. https://www.tropentag.de/2021/abstracts/posters/170.pdf

Mbouwe IF, Jiofack TRB, Bavorova M. **Madaki MY**, Bulus B. 2020. Stakeholders and Marketing Analysis of African Nutmeg (Monodora myristica) in Cameroon. Tropentag 2020, September 9-11, virtual conference, Germany. https://www.tropentag.de/2020/abstracts/links/Irene_Franceline_a0NPPsRH.php

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Madaki MY, Miroslava B. 2020. Determinants of food safety behaviour among food vendors: the case of Nigeria. XVI EAAE Virtual congress: Raising the impact of agricultural economics; Multidisciplinary, stakeholder engagement and novel approaches 20-23 July, Prague, Czech Republic.

Participated Projects

1. Effect of agricultural credit on deforestation funded by the Czech University of Life Sciences Prague in collaboration with Abubakar Tafawa Balewa University Bauchi, Nigeria (2021-2022).

2. Climate change adaptation and mitigation strategy priorities in Azerbaijan funded by FAO and the research conducted by Czech University of Life Sciences Prague in collaboration with Azerbaijan Ministry of Agriculture and Natural Resources (2020-2022)

3. Silvicultural management of Ricinodendron heudelotii ‘Djangsang tree’ and market value in Cameroon funded by University Grant Competition CZU (2020-2021).

Research Proposals

Wiliness to pay for and impact of Takaful (mutual) weather index insurance on climate change resilience and welfare of crop farmers in Nigeria (a short proposal) ready for submission.

Re-cultivating abandoned farmland and welfare effects of social support: the case of Boko Haram victims in Nigeria (short proposal) ready for submission.

Awards

Czech University of Life Sciences Rector’s Award for Outstanding Master’s Thesis 2019.

Czech University of Life Sciences Rector’s Award for Ph.D. students with outstanding research and publication results in the academic year 2018-2019.

Appendices

Appendix 1: Sample size and sapling procedure

Agroecological zone	State	LGA	Ward	Sample size
Sahel savanna	Jigawa	Maigatari	Sakwaya	45
			Kachi	45
		Hadeja	Katanga	45
			Fake	45
Sudan savanna	Gombe	Kwami	Gadam	45
			Kompolata	45
		Akko	Kumo west	45
			Gadam	45
Guinea savanna	Kaduna	Kudan	Kauran wali	45
			Kudan	45
		Soba	Yakasai	45
			Soba	45
Derived savannah	Ondo	Akure north	A	45
			B	45
		Akure south	A	45
			B	45
Mangrove	Ogun	Ifo	Ilepa	45
			Pakoto	45
		Odeda	Osiele	45
			Olodo	45
Rainforest	Imo	Aguta	Ejemekwuru	45
			Akabor	45
		Okigwe	Umulolo	45
			Urban	45
Total	**6 States**	**12 LGA**	**24 wards**	**1080 farming households**

Appendix 2: Distribution of livestock farmers across agro-ecological zones (N=569)

Cluster	*Agroecological zones*	*% in the sample*
Dry AEZs	Semi-arid	28.13
	Sudan savannah	26.48
	Guinea savannah	10.86
Humid AEZs	Tropical rainforest	12.17
	Mangrove	6.09
	Swamp forest	16.28

Appendix 3: Survey Questionnaire

EFFECT OF CLIMATE CHANGE ON FARMING HOUSEHOLD FOOD SECURITY IN NIGERIA

Dear Sir/Madam,

I would like to ask you to fill in the following questionnaire. I am a student at the Czech University of Life Science Prague, Czech Republic, and I am conducting this study to learn more about the "***Effect of climate change on farming household food security in Nigeria*** ". All the data are collected anonymously. The filling would only take a few minutes. I would appreciate very much if you would fill in and help me to conduct this research. Thank You!

Identification

Name of the respondent (optional)…………………………………………………………….
Phone number (if available)…………………………………………………………………
Ward ……………………………………………………………………………………..
Local government area ………………………………………………………………..
State ………………………………………………………………………………………...
Agroecological zone…………………………………………………………………...
Date of the interview ………………………………………………………………….

Section A: Socio-economic

1. Sex of the household head	Male Female
2. What is the age of the household head (in years)?	
3. What is your years of education?	
4. What is your highest education level?	Nonformal, Primary, Secondary, NCE/Diploma, Graduate, Postgraduate
5. What is your marital status?	Single, Married, Separated, Divorced, Widowed
6. What is your household size (in persons)?	
7. Number of children ≤15 years	
8. Number of old persons >60 years	
9. What is your years of farming experience?	
10. Do you have access to extension services?	Yes ☐ No☐
11. If yes, how frequent in a year (in number)?	
12. Are you a farmers' group member?	Yes ☐ No☐
13. If yes, which type of group? (multiple choice is allowed)	Producer, Processors, Marketing, Multipurpose, Others ……………………………
14. What type of information/services received from the group (multiple choice is allowed)?	Weather, Climate change adaptation Crop related, Livestock, Market, Others (specify) ………………………………….
15. Do you own a land?	Yes No
16. If yes, what type of land ownership?	Customary Statutory
17. And what is the size of land owned (ha)?	

18. What is the size of land under cultivation (ha)?	
19. What is the major crop cultivated?	
20. What is the size of land allocated to the major crop (ha)?	
21. Do you have access to credit?	Yes ☐ No☐
22. If yes, which type of credit?	Formal Informal
23. Do you have an off-farm occupation?	Yes ☐ No☐
24. If yes, what is your major off-farm?	
25. What is your distance to main market (km)	

Section B: Climate change awareness

1. Are you aware about climate change?			Yes ☐		No☐
2. What is your perception on the following events on your farm in the last 10 years?					
Event[1]	**SD**	**D**	**UD**	**A**	**SA**
Increase in temperature					
Delay in coming of rainfall					
Decrease in rainfall duration (days)					
Increase in frequency of drought					
Increase in frequent flooding					
Sea level increase					
Increase in evaporation/drying of soil					
Increase of pest and disease outbreak					

[1] **SD= Strongly disagree, D=Disagree, UD=Undecided, A=Agree and SA=Strongly agree**

3. What is the source of your climate change information? (multiple choice is allowed)	Government extension agent, Environmental NGOs, Farmers cooperative, Research institution/University, Farmers friends , Others (specify)……………………………
4. From which of the following channels you receive climate change information? (multiple choice is allowed)	
Channel	**How frequent/month**
Radio	
Television	
Newspaper	
Farmers group/cooperative	
Internet	
Farmers colleagues	
Government extension agent	
NGOs	
5. Which of the following causes climate change in your opinion (multiple choice is allowed)?	Deforestation, Land clearing by bush burning, Fossil fuel use, Livestock production Use of Manure Use of inorganic fertilizer, Use of agrochemicals, Others (specify) ………………………………

Climate change vulnerability

6. What are the major climate risk event(s) you experienced at your farm?	**Yes**	**Number in the last 10 years**
a. Extreme temperature		

b. Flooding		
c. Drought		
d. Windstorm		
e. Crop pest and disease outbreak		
f. Livestock pest/disease outbreak		
g. Bushfire		
h. Others (specify)		
i. Others (specify)		

7. What are the effects caused by the climate risk events in the last 10 years?	Yes
a. Reduce crop yield	
b. Complete crop farm failure	
c. Shortage of livestock feeds	
d. Dead of livestock	
e. Crop pest and disease outbreak	
f. Livestock pest and disease outbreak	
g. Destruction of farm produce store	
h. Destruction of home	
i. Cause of physical injury to me/families	
j. Dead of family member	
k. Others (specify)	

Section C: Climate change adaptation strategies

1. Which of the following strategy/ies you adopted	Size (ha) where applicable	For how long you are using the strategies? (years)
Changing of planting date		
Changing of crop planted		
Early matured varieties		
Drought tolerant/resistant varieties		
Supplementary irrigation (using underground water)		
Supplementary irrigation (using streams and rivers)		
Rainwater harvesting		
Pest and disease tolerant varieties		
Optimum fertilizer application		
Off-farm income generation		
Temporary migration		
Zero tillage		
Minimal tillage		
Mulching		
Others (specify)		

Livestock

2. Do you have a livestock?	Yes	No
3. If yes, what is your major livestock?		
4. What is the approximate number of the		

major livestock?	
5. What is the major climate event (s) effect you have experienced in the last 10 years (multiple choice is allowed)?	Shortage of livestock feeds, Livestock pest and disease outbreak , Decrease in livestock productivity, Livestock dead, Others ………………..
6. What is the adaptation strategy /ies adopted to your livestock farming (multiple choice is allowed)?	Mixed farming, Switching to crop production, preserving crop straw and hay, Pasture irrigation, Destocking, Others (specify) ………………………………………..

7. Are you aware about agricultural insurance?	Yes No
8. Are you aware about agricultural insurance as climate change adaptation?	
9. Did you adopt crop/livestock insurance?	Yes No
10. If yes, for how long? (in years)	
11. How can you rate the insurance programme (your opinion)	Poor, Fair, Good, Very good
12. What are the problems associated with the insurance scheme you observed (multiple choice is allowed)?	Too much paperwork Difficult to get compensation Late payment of compensation Compensation paid does not cover the loses Others (specify)
13. If you did not use the insurance, what is the reason (multiple choice is allowed)?	Not aware of it Unable to afford Not sure of its effectiveness Against my religion/belief No reason, High insurance premium, My crop/livestock is not cover by the insurance, Fear of failure to honour agreement, Other (specify) …………………………..

Constraint to the adoption of climate change adaptation

14. What affect your climate adaptation strategies?		
a. Inadequate knowledge about potential climate change/risk	Yes	No
b. Limited knowledge of appropriate adaptation measures	Yes	No
c. Inadequate knowledge about drought resistance varieties	Yes	No
d. Inadequate capital	Yes	No
e. Limited or lack of land ownership	Yes	No
f. Inadequate irrigation facilities	Yes	No
g. Labour shortage during peak agricultural operation	Yes	No

Section D: Food security section

1. What is the source of your household foods in a year?

Source	**Yes**	**Percentage contribution (100%)**
a. Own production		
b. Purchase in the market		

c. Exchange for labour		
d. Exchange for items		
e. Gift from friends and relatives		
f. Food aids programme		
g. Others, specify ( )		

2. How frequent your household ate the below food items in the last 7 days

Food group	**Times eaten in the last 7 days**
a. Staple (maize, rice, sorghum etc.)	
b. Pulse (beans, soybeans, Bambara nut etc.)	
c. Vegetable (Amaranth, bitter leaf, okra etc.)	
d. Fruit (mango, orange, pineapple, guava etc.)	
e. Meat, fish, or egg	
f. Milk and dairy products	
g. Sugar (potato, cassava, yam etc.)	
h. Oil (palm oil, groundnut oil etc)	

Behaviors: In the past 7 days, if there have been times when you did not have enough food or money to buy food, how many days has your household had to:	**Frequency: Number of days out of the past seven: (Use numbers 0 – 7 to answer number of days; Use NA for not applicable**
a. Relay on less preferred and less expensive food	
b. Borrow food from a relative or friend	
c. Purchase food on credit	
d. Consume seed stock for next season	
e. Gather wild food, hunt, or harvest immature crops	
f. Send children to eat with neighbor/relative	
g. Send members of the household to beg	
h. Reduce the portion size at mealtimes	
i. Restrict consumption of adult for children to eat	
j. Reduced the number of meals eaten in a day	
k. Skip a complete day without eaten	
l. Sell of agricultural equipment/assets	

3. Please kindly indicate the food items your household consumed in the last 24 hours

Food items	**Yes**
a. Cereals	
b. Root and tubers	
c. Vegetable	
d. Fruits	
e. Meat	
f. Eggs	
g. Fish and seafood	

h. Legumes	
i. Nut and seed	
j. Milk and dairy	
k. Oils and fats	
l. Sweet, spices, condiment, and beverages	

Section F: Household farm income in the recent year

Crops/livestock	Estimated quantity	Farm gate price (100kg bag/animal)
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Non-farm income

8. Please kindly indicate your source of non-farm income and approximate monthly contribution to the household		
Source	**Yes**	**Estimate amount in Naira/ month**
a. Remittance from family member (cash and kind)		
b. Remittance from non-family		
c. Regular employment		
d. Casual employment		
e. Craft work		
f. Services (e.g teaching, banking)		
g. Running own business		
h. Firewood/charcoal		
i. Non-timber forest product		
j. Others (specify)		
k. Others (specify)		

Appendix 4: Data collection pictures

Appendix 5: Multicollinearity test of independent variables of Eq. 2 and 3

Variable	*VIF[1] coefficient*	*1/VIF*
Socio-demographic characteristic		
Sex	1.15	0.867
Age	2.94	0.340
Years of education	1.46	0.686
Farming experience	2.55	0.392
Farmers group membership	1.16	0.865
Farm size	1.23	0.813
Credit	1.38	0.726
Livestock ownership	1.33	0.750
Agricultural income	1.05	0.953
Non-agricultural income	1.16	0.864
Dependency ratio	1.10	0.908
Climate information sources		
Government extension agent	1.26	0.794
Environmental NGOs	1.20	0.834
Farmers' cooperatives	1.25	0.799
University and research institution	1.21	0.824
Farmers friends	1.22	0.820
Climate change information channel		
Radio	1.36	0.736
Television	1.22	0.823
Newspaper	1.15	0.867
Internet	1.22	0.817
Climate change experience		
Extreme temperature	1.58	0.633
Flooding	1.25	0.801
Drought	1.37	0.727
Windstorm	1.24	0.804
Dry agro-ecological zones	2.69	0.371

[1]VIF= variance inflation factors

Appendix 6: Multicollinearity test of independent variable in Eq. 4 and 5

Variables	***Description***	***Mean and std dev.***	***VIF***[1]
Socio-demographic characteristics			
Gender	Dummy for sex of the household head: 1=male; 0, otherwise	0.78 (0.41)	1.19
Age	Age of household head in years	48.16 (13.31)	2.92
Years of education	Education of household head in years of schooling	8.23 (5.58)	1.31
Household size	Number of household members	8.89 (5.83)	1.65
Years of farming experience	How long a household spent in farming: in years	22.62 (12.19)	2.62
Agricultural income	Approximate annual faming income in $	2,886.21 (2,631.57)	1.14
Non-agricultural income	Approximate annual non-farm income in $	87.24 (97.10)	1.17
Farm characteristics			
Type of land ownership	Type land ownership right: Statutory=1; customary=0	0.14 (35)	1.18
Farm size	Total landholding in hectares	3.43 (3.43)	1.22
Livestock ownership	Farmer-owned livestock=1, otherwise= 0	0.56 (0.49)	1.46
Herds size	Number of animal heads owned by farmer	50.24 (341.06)	1.18
Institution characteristics			
Group membership	Social groups membership of the household: member= 1; 0, otherwise	0.82 (0.37)	1.14
Extension contact	Number of receiving extension services in the last farming season	6.84 (7.45)	1.59
Bank	Dummy for access to the bank: 1=Yes, 0=No	0.32 (0.46)	1.32
Weather information	Dummy for access to weather information: 1=yes, 0 otherwise	0.72 (0.44)	1.15
Climate risk experience			
Flood	Farmer experience floods in the last 10 years=1, otherwise=0	0.73 (0.43)	1.40
Drought	Farmer experience droughts in the last 10 years=1, otherwise=0	0.67 (0.46)	1.35

[1]Variance Inflation Factor

Appendix 7: Correlation between the climate change adaptation strategies

Adaptation Strategy	Destocking	Livestock-crop integration	Switching to crop production	Preservation of crop straw and hay	Off-farm income generation	Irrigation
Destocking	1					
Livestock-crop integration	-0.1062	1				
Switching to crop Production	-0.1222	-0.0494	1			
Preservation of crop straw and hay	-0.0218	-0.2424	-0.0469	1		
Off-farm income generation	0.0299	-0.0241	0.075	0.006	1	
Irrigation	-0.0966	0.0797	-0.0424	0.0377	0.0814	1

Appendix 8: Multicollinearity test result of the livestock adaptation models (Eq. 7)

Variable	**VIF**	**1/VIF**
Dry AEZs	2.91	0.34
Age	2.64	0.38
Years of farming experience	2.57	0.39
Cattle farmer	2.21	0.45
Goat farmer	2.17	0.46
Sheep farmer	2.14	0.47
Household size	1.62	0.62
Extension service	1.49	0.67
Credit	1.48	0.68
Herd size	1.47	0.68
Years of education	1.39	0.72
Non-agricultural income	1.24	0.80
Farm size	1.24	0.81
Type land ownership status	1.21	0.83
Gender	1.2	0.83
Livestock related information	1.15	0.87
Dependency ratio	1.14	0.88
Climate change awareness	1.14	0.88
Land ownership	1.12	0.89
Farmers’ group membership	1.11	0.90
Agricultural income	1.05	0.95
Mean VIF	**1.6**	

Appendix 9: Sources of food contributions to the farming household