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Climate risk and climate services perception, and the efficacy of adaptation and mitigation strategies in agriculture, The Gambia

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Formation Doctorale: Economie et Changement Climatique

Présenté par: Sheriff CEESAY

Perception du risque climatique et des services climatiques, et efficacité des stratégies d'adaptation et d'atténuation dans l'agriculture en Gambie

Soutenue le 28/04/2025

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DECLARATION

I, CEESAY Sheriff, declare that this thesis, titled *“Climate risk and climate services perception, and the efficacy of adaptation and mitigation strategies in agriculture”* submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in Economic Sciences (Speciality: Climate Change Economics) at Université Cheikh Anta Diop (UCAD), Dakar, Senegal, is entirely my original work. It has not been submitted before, wholly or in parts, at any other university for the award of a degree or diploma.

Parts of this thesis have been presented at the following conferences:

- **Tropentag 2023**, Berlin, Germany: https://www.tropentag.de/2023/proceedings/proceedings.pdf
- **ICAE 2024**, New Delhi, India https://iaae.confex.com/iaae/icae32/meetingapp.cgi/Home/0
- **Tropentag 2024**, Vienna (BOKU), Austria www.tropentag.de/2024/proceedings/proceedings.pdf
- **AgriGHG-2024 Symposium**, Berlin, Germany. **The book of Abstracts** has been published and can be downloaded here
- Two of the essays of this thesis have also been published online as research articles in *Discov Sustain* **5**, 506 (2024). https://doi.org/10.1007/s43621-024-00616-5 and

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All materials and references used in this work have been duly acknowledged both in the text and in the reference section. I accept full responsibility for any errors that may exist in this dissertation.

CEESAY Sheriff
2025

DEDICATION

I thank Allah for making this possible. To my mother, Hoja Jarbo, my wife, Fatou Lowe and my children, Muhammed, Yafatou and Aisha. Thank you all for the support, prayer and understanding.

In memory of my late father, Alhagie Mot Ceesay.

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ACRONYMS

AfDB	African Development Bank
AGN	Assistance from government /NGOs
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
CCL	Change crop to livestock
CCT	Change crop type
CCV	Change crop variety
CD	Crop diversification
CDN	Country Diagnostic Note
CFSVA	Comprehensive Food Security and Vulnerability Analysis
CLC	Change livestock to crop
COP	Conference of Parties
CPD	Change planting date
CR	Crop rotation
CRED	Centre for Research on the Epidemiology of Disaster
CRR	Central River Region
CSQ	Change seed quality
FAO	Food and Agriculture Organisation
GBoS	Gambia Bureau of Statistics
GCA	Global Centre on Adaptation
GCMs	Global Circulation Models
GCRI	Global Climate Risk Index
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Green House Gas
GNCCP	Gambia National Climate Change Policy

GoTG	Government of The Gambia
GSP	Global Support Programme
HDI	Human Development Index
IHS	Integrated Household Survey
ICTs	Information Communication Technologies
IPCC	Intergovernmental Panel on Climate Change
Ir	Irrigation
LDCs	Least-developed Countries
Mg	Migration
MNL	Multinomial Logistic
MVP	Multivariate probit
NAPA	National Adaptation Programme of Action
NBR	North Bank Region
NCoTG	National Contribution of The Gambia
NDC	Nationally Determined Contributions
NDMA	National Disaster Management Agency
NEP	New Ecological Paradigm
NPV	Net Present Value
NWP	Numerical Weather Prediction
PA	Pesticide application
PB	Petty business
Pr	Praying
PST	Planting shaded trees
RCMs	Regional Climate Models
RPT	Risk Perception Theory
SC	Soil conservation
SCT	Stop cutting trees
UI	Use Insurance

UIF	Use of inorganic fertilizers
UN	United Nations
UNDESA	United Nations Department of Economics and Social Affairs
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
URR	Upper River Region
W	Wage
WBG	World Bank Group
WMO	World Meteorological Organisation

Abstract

Climate variability and extreme weather events present growing challenges to agricultural systems globally, particularly for smallholder farmers in The Gambia who depend on rain-fed farming. Rising temperatures and erratic weather patterns have worsened food insecurity, reduced harvests, and strained local adaptation efforts. This research aims to examine farmers' perceptions of climate risks, assess the factors influencing their access to and use of climate information, and evaluate the effectiveness of adaptation and mitigation strategies. The study was structured around three empirical essays based on data collected from 420 farm households across three agricultural regions in The Gambia in 2023. A combination of econometric and qualitative techniques including binary logistic regression, multinomial and multivariate probit models, and a perception index—was applied to analyse the data. Key findings reveal that age (35–55), access to markets, extension services, training on climate risks, and trust in media significantly enhance the use of climate information, which in turn is positively associated with adopting adaptation strategies. Results further show that land tenure, government support, and past weather shocks influence on-farm adaptation, while off-farm strategies are more common among middle-aged and female farmers. Gender disparities were evident, with women less likely to adopt formal adaptation measures. A perception index of 0.66 indicates a moderate level of confidence in the effectiveness of current adaptation and mitigation strategies, with farmers showing a strong preference for crop diversification and irrigation methods. The research underscores the importance of integrating farmers' perceptions and local realities into national climate policies. Strengthening extension services, improving access to credit, and providing gender-sensitive support are critical for building resilient farming systems and advancing sustainable agricultural development in The Gambia.

Keywords: **Keywords:** climate services, perception index, adaptation, mitigation, The Gambia

Résumé

La variabilité climatique et les phénomènes météorologiques extrêmes représentent des défis croissants pour les systèmes agricoles à l'échelle mondiale, en particulier pour les petits exploitants agricoles de Gambie qui dépendent de l'agriculture pluviale. La hausse des températures et les phénomènes météorologiques irréguliers ont aggravé l'insécurité alimentaire, réduit les récoltes et mis à mal les efforts d'adaptation locaux. Cette étude vise à examiner la perception des risques climatiques par les agriculteurs, les facteurs qui influencent leur accès aux informations climatiques et leur utilisation de celles-ci, et à évaluer l'efficacité des stratégies d'adaptation et d'atténuation. L'étude s'articule autour de trois essais empiriques basés sur des données recueillies auprès de 420 ménages agricoles dans trois régions agricoles de la Gambie en 2023. Une combinaison de techniques économétriques et qualitatives - y compris la régression logistique binaire, les modèles probit multinomiaux et multivariés, et un indice de perception - a été appliquée pour analyser les données. Les principaux résultats révèlent que l'âge (35-55 ans), l'accès aux marchés, les services de vulgarisation, la formation sur les risques climatiques et la confiance dans les médias favorisent considérablement l'utilisation des informations climatiques, qui à son tour est positivement associée à l'adoption de stratégies d'adaptation. Les résultats montrent également que le régime foncier, l'aide gouvernementale et les chocs météorologiques passés influencent l'adaptation au niveau de l'exploitation, tandis que les stratégies hors exploitation sont plus courantes chez les agriculteurs d'âge moyen et les agricultrices. Les disparités entre les sexes sont évidentes, les femmes étant moins susceptibles d'adopter des mesures d'adaptation formelles. Un indice de perception de 0,66 indique un niveau de confiance modéré dans l'efficacité des stratégies actuelles d'adaptation et d'atténuation, les agriculteurs montrant une forte préférence pour la diversification des cultures et les méthodes d'irrigation. La recherche souligne l'importance d'intégrer les perceptions des agriculteurs et les réalités locales dans les politiques climatiques nationales. Le renforcement des services de vulgarisation, l'amélioration de l'accès au crédit et l'apport d'un soutien tenant compte de la dimension genre sont essentiels à la mise en place de systèmes agricoles résilients et à la promotion d'un développement agricole durable en Gambie.

Mots-clés: services climatiques, indice de perception, adaptation, atténuation, Gambie

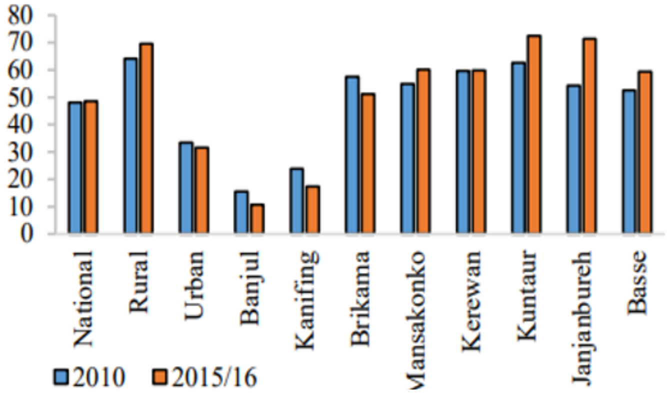
General Introduction

Background Climate change poses a major global threat, affecting many industries, especially agriculture, by causing production and food supply disruptions due to extreme weather variations. Numerous species' survival is endangered by temperature shifts, causing biodiversity loss and alteration in the ecosystem dynamics. Moreover, climate variations increase the risk of food and waterborne diseases, as well as the emergence of antimicrobial resistance, presenting further risks to human health (Abbass *et al.*, 2022). Climate change poses a substantial risk to the global viability of agriculture, especially in developing nations where agriculture plays a vital role in the economy. The world's highest temperatures and most natural disasters have been recorded in the last two decades (FAO, 2021). Adverse weather phenomena, including water scarcity, storms, heatwaves, floods, erratic rainfall, and pest outbreaks, are disrupting agricultural output and impacting the socioeconomic well-being of farmers (Verma *et al*., 2024). The climate change phenomenon significantly disrupts food production in various parts of the world. The occurrence of extreme weather events such as droughts, heat waves, and cold spells presents significant risks to crops, while the atmospheric concentration of carbon dioxide continues to rise (Kopeć, 2024). Research by Akhtar & Masud (2022) reveals that higher temperatures and increased energy consumption have a detrimental effect on rice and vegetable output, while CO2 emissions notably impact coffee production. Soil drought presents a major risk to agriculture due to its uncertain range, length, and effects, which are worsened by climate change, resulting in the desertification of agricultural lands (Akhtar & Masud, 2022).

Climate change is a big predicament for the African continent, especially the countries of West Africa. Given the threat of climate change, adaptation and mitigation strategies must address the accessibility dimension of climate information. According to (Mbaye and Atta, 2019) to deal with issues of information dissemination, it is essential to respond to the following questions: *Who needs what information and for what purpose? Who can provide this information? What are the most appropriate channels and media to respond to user needs?* In the Sahelian countries, the written press, radio and television have always played an enormous role in disseminating climate information. However, with the advent of information communication technologies (ICTs), interventions have been advanced to improve the dissemination of climate information, thus increasing their consideration of agricultural risk management strategies for global climate change.

The Gambia, with a population of 2.5 million people, is the smallest country in mainland Africa, ranked 172nd out of 189 on the 2020 Human Development Index (HDI), and is plagued by poverty and underdevelopment (UNDP, 2020). The population growth rate is about 3% and is projected to reach 3.1 million by 2030, stimulated by a high fertility rate and a decline in infant mortality rates (UNDESA, 2015). Arguably, poverty and food insecurity challenge almost all developing countries. Poverty is a major development challenge in The Gambia, with at least 48% of the population living on less than $1.25 per day (United Nations Economic Commission for Africa., 2017) (Figure 1).

Figure 1: The Gambia's poverty



Source**:** GBoS 2017

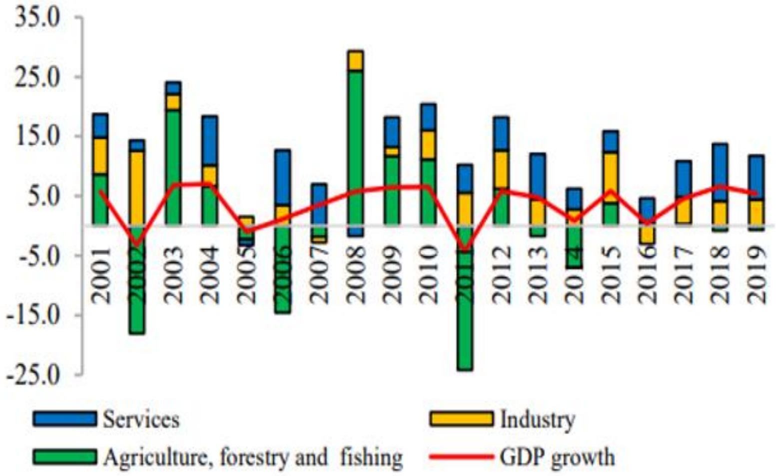
Located in the Sahel region, the Gambia has severe food insecurity and high susceptibility to climate change impacts such as floods, droughts and storms. The pandemic of COVID-19 has had a major impact on Gambia's socioeconomic situation. The Comprehensive Food Security and Vulnerability Analysis (CFSVA, 2021) found that 13.4% of the country's population is food insecure. Overall, 1.8% are severely food insecure and 11.6% are moderately food insecure. The food crisis increased from 8% in 2016 to 13.4% in 2021. The current flash floods are aggravating the already severe food insecurity for a large portion of The Gambia's population. It exacerbates existing challenges caused by poor harvest, the devastating 2021 windstorms, the crises in Russia and Ukraine, rising fuel and transportation costs, and more. Women, children and the elderly are at higher risk of food insecurity, with potentially disastrous consequences.

As global temperatures rise, extreme climatic conditions will become more frequent and severe (WMO, 2019a). About 20-80% of the annual crop yield variation is related to weather events, and

5-10% of national agricultural production losses are connected to climate change (FAO, 2019). Moreover, due to climate-related disasters, agriculture suffers 26% of damage and loss in third-world countries. Without ambitious climate action, the global demand for food will rise by 50%, and the yield will fall by up to 30% by 2050 (GCA, 2019). Within The Gambia, as in other West African countries and elsewhere in Africa, these phenomena are reflected in a significant drop in harvest, water shortage, and worsening of health crises, resulting in growing food insecurity and threatening the progress made in the fight against poverty in the last decades. Many farmers living in rural areas are characterised by low rainfall, salinity, degraded soils, and limited access to the market.

In The Gambia, 80% of the rural population relies on agriculture for their livelihood. About 91% of the extremely poor and 72% of poor households were reported in The Gambia 2015/16 Integrated Household Survey (IHS). Recurrent droughts, desertification, and floods make it harder to support subsistence agricultural practices, while extreme weather events can lead to extensive crop failure (Day & Caus, 2020; Tato, 2019). Agriculture has been the primary source of income and livelihood in rural Gambia. Despite the sector's 25% GDP contribution and its employment of more than 70% of the labour force (Harvey *et al*., 2014; Josephine *et al*., 2020) and the most vulnerable sector to climate change. The sector is faced with many challenges, such as institutional, biophysical, and technological, thereby hampering its share of economic development (Figure 2). The detrimental effects of climate change make this issue worse, undermining domestic efforts and making the nation one of the most vulnerable to climate change (Segnon & Zougmoré, 2021). The agrarian sector is the primary contributor to economic development (Tinta, 2017), but mostly characterised by small-scale subsistence rainfed farming, traditional cattle operations, horticultural production, and fishing (Josephine *et al*., 2020).

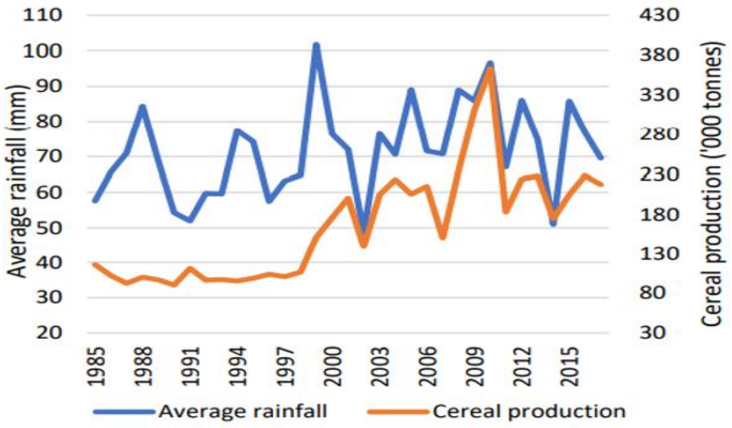
Figure 2: GDP growth and contribution by sector (%) in The Gambia



Source: AfDB Statistics Department 2020

Figure 3 shows that regular and irregular distribution of rainfall in the country can lead to low production and yields, leading to food shortages in the country (Jatta, 2016). Climate-related risks in The Gambia include droughts, torrential rains, storms, cold seasons, heatwaves and extreme rainfall (NAPA, 2007), with adverse impacts on communities. The effects of drought, floods and sea level rise since 2001 have resulted in crop failures. There was a drought in 2001-2002, followed by severe droughts in 2004-2005, 2010-2011 and 2013-2014.

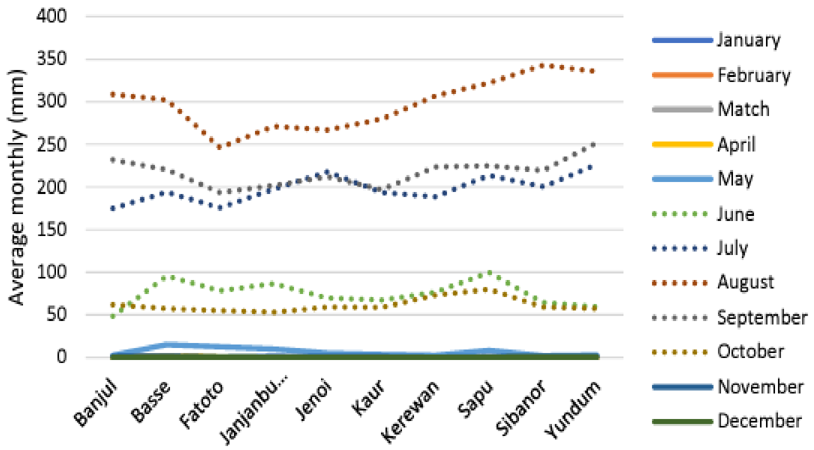
Figure 3: Cereal production and average rainfall



Source**:** Department of Water Resources and FAOSTAT

The Gambia's climate is characterised by a rainy season, with 98% of precipitation falling between June and October, which happens to be the rice planting season (figure 4). With spatial and temporal disparity, almost 37% of the rainfall occurs in August. A lengthy dry season is followed that is characterised by the harmattan winds. Yields are largely dependent on the climate, with average temperatures between 18°C and 36°C.

Figure 4: The rainfall pattern

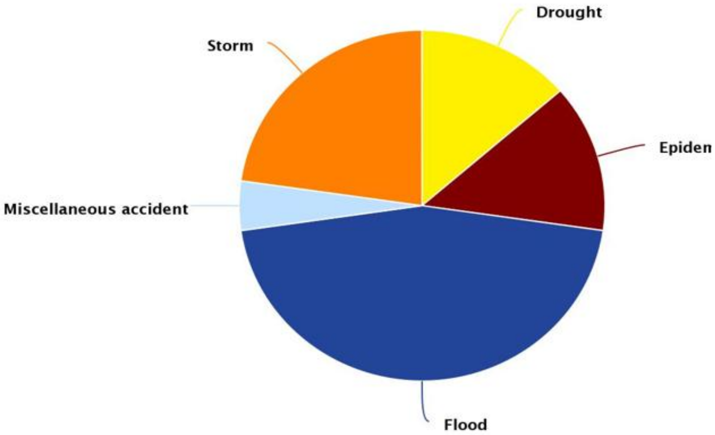


Source: Department of Water Resources (2019)

Agricultural productivity is heavily reliant on rainfall. The rainfall amount and distribution have been erratic, seriously affecting agricultural production. Almost all agricultural land in The Gambia receives about 98% of its rainfall, so reduced rainfall and rising temperatures are expected to limit crop yields. Long-term analyses of climate data show that total precipitation and rainy season length have decreased over the past 50 years. Due to irregular rainfall, farmers must employ adaptation tactics such as drought-tolerant crops, fertilisers, and other inputs to boost production.

Other than temperature and precipitation anomalies, climate change is also characterised by natural disasters (Figure 5). Natural disasters have escalated in Sub-Saharan Africa over the last four decades. Natural catastrophes vary in severity, yet they occur in all countries in the region. Drought affected most of the countries in the South, Horn, and Sahel parts of Africa; floods mostly affected countries in West and Central Africa, and those in South-eastern Africa experienced cyclones (Zeufack *et al*., 2021). Flood level is high across the country, at about 45.5%, storms are at 22.7%, and drought is at 13.6%. Heavy rainfall hit several regions of The Gambia in July 2022, flooding many regions of the country. Many buildings have been severely affected, and the occupants had to be moved to public buildings such as schools and Mosques for temporary safety. Almost all the regions were affected, but Banjul, Kanifing Municipality, West Coast, and North Bank were mostly affected. The flooding resulted in the deaths of five children in the North Bank Region and one in the West Coast Region. It also caused some roads to be inaccessible due to the overflow of rainwater. Approximately 1,961 households were affected (NDMA, 2022).

Figure 5: Average Annual Natural Hazard Occurrence 1980-2020



Source: https://climateknowledgeportal.worldbank.org/

Rising sea levels and rivers, heavy rains, and the low-lying areas that make up much of the capital, Banjul, are major concerns, especially for susceptible populations. The *United Nations Office for Disaster Risk Reduction* (UNDRR) estimates that the mean yearly loss from flooding is around 0.2% of GDP. This is primarily due to damage to manufacturing facilities, housing and transportation systems. Furthermore, coastal flooding due to a rise in sea level can lead to permanent damage to land and urban infrastructure, as well as the loss of seaside resorts, which are key to the tourism industry. Some years have no damage from floods, while others have severe damage. More than 50,000 people were affected by storms, floods and fires in September 2020. The floods have affected both non-agricultural and agricultural sectors, damaging buildings and flooding the Banjul Port (NDMA, 2020).

Access to climatic information remains a key challenge in the Sahel region due to the technical and physical limitations of dissemination channels and the inadequate capacity development of journalists in the field of climate science (Mbaye and Atta, 2019). Countries around the globe are facing adverse consequences of climate change, which will accelerate by 2030 (Zeufack *et al.*, 2021). Risks related to climate change are severely impacting countries in sub-Saharan Africa. One of the policy targets of The Gambia's National Climate Change Policy (GNCCP) is to provide sufficient climate change research for informed decision-making and to provide access to climate risk services for early warning, it is about facilitating quick access (Urquhart, 2016). There is a need to enhance the country's weather forecasting services and their application to address variations in climate change (Gibba *et al*., 2020). Applying contemporary information risk management strategies, such as early warning systems, will enable farmers and households to adjust their production plans and take measures to account for expected weather events. Climate services can improve farmers' ability to make tactical decisions, increase adaptability and build resilience to weather shocks. This will require consciousness of climate risks and effective management of these risks. A shift towards more proactive responses to anticipated risks, such as early action and participation of smallholder farmers, is paramount for climate resilience (Agbehadji *et al*., 2023). Linking early warning to early action is particularly vital in the agriculture sector. For farmers, heeding early warning signals can make a difference between a crisis and a catastrophe.

The Gambia has experienced increasing climate variability over the past four decades, with more frequent droughts, floods, and erratic rainfall patterns severely impacting its rain-fed agricultural sector and making smallholder farmers highly vulnerable to climate shocks (Jaiteh, 2011). Farmers employ adaptation strategies such as crop diversification, soil conservation, irrigation, and agroforestry, yet adoption remains low due to financial constraints, limited access to climate information, and institutional barriers, particularly for female farmers facing land tenure and credit challenges (Segnon & Zougmoré, 2021). Mitigation efforts, including conservation tillage and organic farming, have been promoted to reduce greenhouse gas emissions, but smallholder farmers often prioritise short-term survival over long-term sustainability, and implementation gaps persist despite government policies and international support (Araya *et al*., 2024). Access to reliable climate information is crucial for adaptation and mitigation, yet many farmers lack timely data, and dissemination through extension services and cooperatives varies in effectiveness, with trust in indigenous knowledge often outweighing institutional forecasts (Nyadzi *et al*., 2021). Additionally, national climate adaptation policies face execution challenges due to resource constraints and weak institutional coordination, while market failures, such as limited access to agricultural inputs and credit, further hinder effective adaptation. Understanding these stylised facts frames the study's research questions and objectives, contributing to policy recommendations that strengthen agricultural resilience in The Gambia.

The structure of climate services supply in The Gambia is crucial for supporting climate adaptation and mitigation, particularly in agriculture. Key institutions involved include the Department of Water Resources (DWR), which oversees weather forecasting and early warning systems, the National Disaster Management Agency (NDMA) for disaster risk management, and the Gambia Meteorological Services (GMS) for seasonal climate predictions (Urquhart, 2016). The Ministry of Agriculture (MoA) integrates climate services into extension programs, while international organisations such as the WMO, WASCAL, and ACMAD provide technical support and funding. Climate services are disseminated through traditional media (radio, TV, print), digital platforms (mobile apps, SMS, social media), agricultural extension services, and community-based systems that incorporate indigenous knowledge(European Commission: Joint Research Centre, 2025. The services provided include weather forecasts, early warning systems for extreme events, agricultural climate advisories, climate change projections, and insurance schemes for risk management (Gilruth *et al*., 2021). Despite their importance, challenges such as limited infrastructure, weak institutional coordination, and low digital literacy among farmers hinder effective dissemination. However, opportunities exist in expanding mobile-based climate services, fostering international collaborations, and integrating indigenous knowledge into formal climate systems. Strengthening these services through improved coordination, technological advancements, and policy reforms is essential for enhancing farmers' adaptive capacity and resilience to climate change.

Problem statement

Climate change threatens global agriculture, particularly for smallholder farmers dependent on rain-fed agriculture, as extreme weather events increasingly disrupt productivity and food security. The Gambia has become a highly fragile country that is extremely vulnerable to climate change. The country has had numerous severe floods, droughts, and hurricanes in recent decades. Droughts and floods severely affect food production and expose farmers to food shortages (Sonko *et al*., 2020). Few studies have been conducted on coping strategies in the Gambia in response to climate risk (Jallow *et al*., 1996; Bagagnan *et al*., 2019; Josephine *et al*., 2020; Yaffa, 2013). If urban farmers' perceptions of climate change remain ambiguous (Olumba et al., 2024), rural farmers may encounter greater ambiguity owing to possible constraints in access to information, education, and other resources essential for comprehending and adapting to its effects.

Little research has been done into farmers' perceptions of climate risk, susceptibility, and adaptation mechanisms at farm and off-farm levels in The Gambia. Although global adaptation efforts are increasing, there is limited evidence that climate risks are being reduced (Ford & Berrang-Ford, 2016; UNEP, 2021), and with the escalating impacts described in the IPCC Sixth Assessment Report, current adaptation implementation rates may not keep pace with increasing levels of climate change (UNEP, 2021; Schleussner *et al.*, 2021). Theoretically, the Diffusion innovation theory explains smallholder farmers' low adoption of climate services due to a perceived lack of immediate benefits, misalignment with traditional practices, complex information, risks, and invisible long-term gains. These barriers highlight the need for accessible, relevant and actionable climate services to support farmers effectively (Rogers, 2003). The empirical literature reveals that despite the availability of climate services, a critical gap remains in understanding how farmers perceive climate risk, access climate services, and implement adaptation and mitigation strategies (Hansen *et al*., 2019; Ouedraogo *et al*., 2022; Sanogo *et al.*, 2017; Siyao & Sanga, 2023). Farmers' perceptions do not always align with scientific projections, leading to discrepancies in adaptation responses. While some studies suggest that awareness and training improve risk perception, others indicate that cognitive biases and traditional beliefs hinder effective decision-making (Galford *et al.*, 2016; Hornsey & Lewandowsky, 2022; Salas Reyes *et al*., 2021; Zhang *et al*., 2025).

The efficacy of adaptation and mitigation strategies is debated, with some advocating for climate-smart agriculture and carbon sequestration practices, while others argue that smallholder farmers prioritise immediate livelihood concerns over long-term environmental benefits. The empirical evidence on the success of adaptation and mitigation strategies remains inconclusive, particularly in low-income rural settings where institutional support is weak (Bogale & Bekele, 2023; Jat *et al*., 2022; McGuire *et al*., 2022; Owombo *et al*., 2018; Teklu *et al*., 2022). This study addresses these gaps by examining farmers' access to climate-to-climate service, their perception of its usefulness, elements affecting their capacity to use it, factors that influence their decisions to adopt and determinants of on-farm and off-farm strategies, and the perceived efficacy of adaptation and mitigation strategies.

Research questions

The study's main research question is: How do smallholder farmers perceive climate risks, access climate services, and evaluate the efficacy of adaptation and mitigation strategies?

1. What is the perception of, access and use of climate services by smallholder farmers?
2. What is the effect of the use of climate services on the adoption of adaptation by smallholder farmers?
3. What are farmers' perceptions of climate risks, and what factors drive their adoption of on-farm and off-farm adaptation strategies?
4. How do farmers perceive the efficacy of climate risk adaptation and mitigation strategies in reducing the impact of climate risk in The Gambia?

Research objectives

The study's general objective is to evaluate smallholder farmers' perceptions of climate risks, access to climate services, and the effectiveness of adaptation and mitigation strategies.

1. To assess smallholder farmers' perception of, access and use of climate services
2. To analyse the effect of the use of climate services on the adoption of adaptation strategies
3. To examine farmers' perceptions of climate risk and the factors influencing their adoption of on-farm and off-farm adaptation strategies.
4. To evaluate farmers' perceptions of the efficacy of climate risk adaptation and mitigation strategies and develop an index to quantify these perceptions.

Hypothesis

1. Farmers who use climate information services are more likely to adopt adaptation strategies.
2. Farmers who perceive climate risk are more likely to adopt both on-farm and off-farm adaptation strategies.
3. Farmers perceive adaptation and mitigation strategies as highly effective in mitigating the impact of climate risk.

Significance of the study

According to the World Meteorological Organisation (WMO), about 85% of countries have established climate services as an integral part of their agricultural decision-making process (WMO *et al.*, 2019). Climate services can improve farmers' ability to make tactical decisions, increase adaptability and build resilience to weather shocks. This will require consciousness of climate risks and effective management of these risks. A shift towards more proactive responses to anticipated risks, such as early action and participation of smallholder farmers, is paramount for climate resilience (Agbehadji *et al*., 2023). Countries are facing adverse consequences of climate change, which severely impact countries in sub-Saharan Africa due to geography, poverty, and weak ability to adapt to weather shocks (Zeufack *et al*., 2021).

In The Gambia, over 60% of the population depends on agriculture for their livelihood (FAO 2012; ECOWAS, 2019). Climate risks in The Gambia encompass droughts, intense precipitation, storms, cold spells, heatwaves, and excessive rainfall (NAPA, 2007), with adverse impacts on communities. One of the policy targets of the GNCCP is to provide sufficient climate change research for informed decision-making and to provide access to climate risk services for early warning and forecasting, facilitating quick access (Urquhart, 2016). There is a need to enhance the country's weather forecasting services and their application to address variations in climate change (Gibba *et al.*, 2020). Applying contemporary information risk management strategies, such as seasonal weather forecasts and early warning systems, will enable farmers and households to adjust their production plans and take measures to account for unexpected weather events. Linking early warning to early action is particularly vital in the agriculture sector, as heeding early warning signals can make the difference between a crisis and a catastrophe.

Timely and accurate availability of information on climate risk management through early warning is a useful tool in policy decision-making processes. Hallegatte *et al*. (2018), A. J. Kull *et al*. (2016) and WMO *et al*. (2019) found positive benefits to investing in weather prediction and early warning systems. Accurate and timely early warning information provides farmers with crucial information, enabling them to make informed decisions regarding their farming operations and plan for and respond to extreme weather situations. With the rising effects of climate change, these technologies are critical for strengthening The Gambia's agricultural industry's resilience and sustainability. The Gambia is prone to weather-related risks such as floods, wind storms, and drought. Effective early warning systems can significantly reduce natural disasters and climate change risks.

This PhD research work contributes to the literature in many ways. First, the study contributes to the body of knowledge about climate change perception, access to climate services, and the use of climate information on early warning for the adoption of climate risk adaptation measures. Access to information is the key to using climate services, but access alone does not necessarily mean that information is useful (Sen *et al.*, 2021). This study, therefore, investigates differences in access to and use of climate services for early warning among smallholder farmers in rural Gambia. It also contributes to disaggregating access and use of climate services. To date, the researcher has not found any study that examines the perception of the usefulness and reliability of climate services on early warning by farmers. Accessing and using climate information are two distinct processes in the decision-making process that can be influenced by several factors. This study seeks to contribute to policy and practice by strengthening the resilience of Gambia’s agricultural sector, ultimately promoting sustainable development. It investigates factors influencing farmers’ access to and use of climate information, their perception of early warning information, and the relationship between climate information use and adaptation strategies. The findings are relevant to policy decisions because they show farmers used climate information in agricultural decision-making regarding adaptation strategies.

Due to climate change, The Gambia faces considerable development challenges in both the near and distant future. Short-term severe climatic phenomena include strong winds, droughts, and dust storms. In the long run, land loss, sea level rise, and coastal erosion will become significant issues (Jaiteh, 2011). According to the IPCC (2023), climate change has a substantial influence on The Gambia, which is ranked among the top 100 countries impacted by climate change, and the population is the world's most vulnerable to the consequences of increasing sea levels and coastline erosion (Gomez *et al*., 2020). The Gambia has recently seen an increase in the frequency and severity of floods, droughts, coastline erosion, storms, severe temperatures, and unpredictable rainfall. Such weather events, particularly droughts, impede efforts toward sustainable development and poverty alleviation (Gambia LTS, 2022). Climate data analysis reveals expected temperature and precipitation patterns for The Gambia in recent years. A second national report on the nationally determined contribution (NDC, 2022) reveals a 0.50 °C per decade increase in temperature since the 1940s. Rainfall patterns in The Gambia have changed throughout time, according to historical climate records.

This study's significance lies in addressing the gap in research on Gambian smallholder farmers' perception of climate risk and the factors influencing their adaptation strategies. It provides a data-driven analysis of these factors, which is crucial for creating effective adaptation policies. The study highlights the need for gender-disaggregated support and targeted policies to encourage the adoption of adaptation strategies among female farmers and the importance of considering both on-farm and off-farm adaptation strategies. The use of binary and multivariate logistic models allows for a more in-depth analysis of the various adaptation strategies employed by smallholder farmers. By addressing these gaps, the study offers significant insights into how smallholder farmers perceive climate risks and the factors that shape their adaptation decisions. This will contribute to better-informed policy interventions that bolster climate resilience in The Gambia’s agriculture sector, ultimately augmenting the capacity of smallholder farmers to cope with the impacts of climate change.

Climate risk adaptation and mitigation strategies are vital for enhancing the resilience and sustainability of agricultural systems, particularly in vulnerable regions such as sub-Saharan Africa (SSA). These strategies aim to mitigate the negative effects of climate change on agriculture by boosting productivity, building resilience, and reducing GHG emissions. Individuals aim to adopt protective measures and lessen the likelihood of maladaptation if they feel new measures will be effective at mitigating the effects of climate change (Dang *et al*., 2014). There is limited evidence on the effectiveness of specific adaptation strategies for climate risks. According to the *Intergovernmental Panel on Climate Change*, no studies have systematically evaluated the adequacy and effectiveness of adaptation to climate risks globally, across countries and sectors, or for different levels of warming (IPPC, 2022). The study of Yaffa (2013) identified that coping measures of households affected by drought in the Gambia's North Bank region were not sufficient. However, his study was limited to only one climate risk and one region of the country.

It's crucial to determine which of these variables has a big impact on how effective an adaptation is thought to be. There is limited information on how adaptation affects farmers' livelihoods across a variety of components (such as social, economic, and environmental). The development of a comprehensive set of flexible indicators that can be utilised in various situations and capture these elements of adaptation outcomes is a significant undertaking that has to be completed (Etana *et al*., 2022). Systematic risk assessment of climate risk, including adaptation limits, has remained scarce (Watts *et al*., 2018). There is documented information on how to assess, define, or investigate adaptation in certain settings (Morecroft *et al*., 2019; Patt & Schröter, 2008; Tubi & Williams, 2021) but little is known about the effectiveness of adaptation strategies. Successful and effective adaptation reduces climate impacts, vulnerabilities, and risks (Eriksen *et al*., 2015; Juhola *et al*., 2016).

This study provides valuable insights into the efficacy of adaptation and mitigation strategies in The Gambia, emphasising the crucial role of farmer engagement in enhancing adaptation efforts in agriculture. The research highlights the importance of integrating farmers' perceptions into climate adaptation and mitigation strategies to better meet the needs of local agricultural communities. By acknowledging and addressing farmers' realities, policymakers can better tailor interventions for improved effectiveness and sustainability in the face of global climate change. By assessing the perceived efficacy of various strategies, the research highlights the barriers to their adoption and implementation. The development of a perception index further quantifies farmers’ views, offering a robust framework to evaluate adaptation and mitigation efforts. The study also contributes to the global discourse on climate-smart agriculture by providing empirical data from one of the world's most vulnerable regions to climate change, helping bridge the knowledge gap in adaptation planning for sub-Saharan Africa.

Study area

The Gambia, the smallest country in mainland Africa, encompasses a total land area of 11,300 km^{2,} of which 1,300 km^{2} consists of aquatic bodies, which account for 11.5% of the total land area (Ampomah *et al*., 2012). The country is situated on the western coast of Africa, bordered by Senegal to the north, east, and south and the Atlantic Ocean to the West. Geographically, it lies between 13° and 14° north latitude and 13° and 17° west longitude. The Gambia has a population of 2.4 million people, with an annual growth rate of 2.5%. More than 70% of the population works in the agriculture sector, with around 90% of rural people directly or indirectly dependent on farming activities for their livelihood. Agriculture is practised by 47.2% of households, with crop farming being the most common activity, involving 28.8% of these households (GBoS, 2024).

Poverty is more pronounced among the rural population and those with less education than among the urban or educated populations.

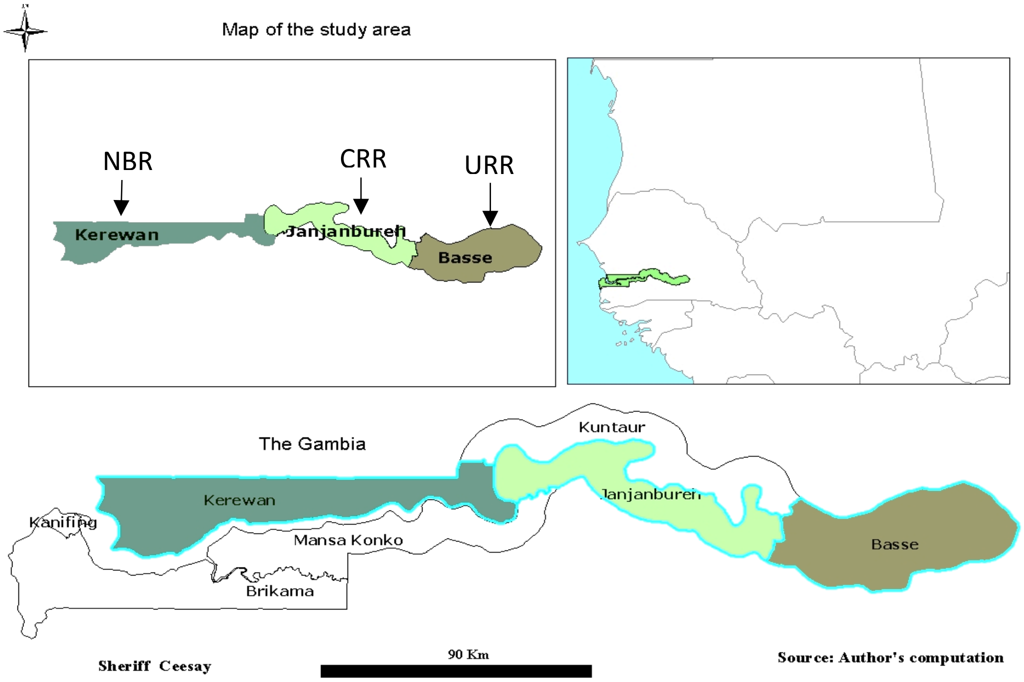
The Gambian economy comprises three main sectors: agriculture, forestry, and fishing; services; and industry. With a GDP annual growth rate of 4.8%, agriculture, forestry, and fishing contribute 24.8%; services account for 57.4%; and industry makes up 17.8% (GBoS 2023). Rural households rely on agriculture for income and subsistence farming, ensuring socio-economic stability. However, climate-induced hazards like soil degradation, water scarcity, and pest outbreaks have reduced agricultural productivity, necessitating urgent adaptation and mitigation strategies to sustain rural communities.

The Gambia has a tropical climate characterised by distinct dry and wet seasons. The dry season, lasting from mid-October to mid-June, features warm, dry weather with temperatures between 70°F (21°C) and 80°F (27°C) and humidity ranging from 30% to 60%. The rainy season commences from mid-June and ends in mid-October, with August being the wettest month. During this period, temperatures are generally hot, reaching up to 105°F (41°C) (Ali Bah, 2019). A 27% decline in annual rainfall has been reported since 1951, accompanied by a shorter rainy season and increased variability in year-to-year rainfall patterns. The primary crops cultivated within this agroecology encompass a variety of crops. These include early millet (*Panicum miliaceum*), groundnut (*Arachis hypogaea)*, maize (*Zea mays*), sorghum (*Sorghum bicolour*), rice (*Oryza sativa*) and several other types of rice, such as rain-fed upland and lowland, irrigated lowland, mangrove, and salt-tolerant mangrove varieties. Additionally, maize, vegetables, sesame, and cowpea are among the principal crops cultivated within this agroecological context (GNAIP, 2015).

This study was carried out in the North Bank Regions (NBR), Central River Regions (CRR), and Upper River Region (URR) of The Gambia (Figure 6). These three regions were purposely selected owing to their vulnerability, flooding damage, and agricultural importance. It is a rain-fed contextual setting in rural Gambia. Based on the integrated household survey 2015/16, the rural population stood at 865,483 people, and the selected regions comprised 596,640 people. The target population for the investigation consisted of smallholder farmers from three regions of rural Gambia.

Figure 6:

Map of the study area



Source: Author's computation

Research Design

A mixed-method approach integrates qualitative and quantitative data to help the researcher understand the topic more comprehensively. The mixed methodology is a relatively new research approach in the social sciences and humanities. Through the collection and analysis of quantitative and qualitative data, we can explore both the breadth and depth of the research topic and improve our understanding of the research (Creswell, 2013; Creswell & Creswell, 2007).

Data and data sources

This study used both primary and secondary data sources. The primary data collection took place in June 2023. Farmer representatives (most often household heads) were interviewed using a structured questionnaire to explore the study's research goals. The farm household surveys include questions about household demographics and socioeconomic characteristics. Perception of climate change, access to information on early warning and weather forecasting, and the perceived usefulness and reliability of early warning and weather forecasting information. Institutional support, including access to finance, extension services, input supply, livelihood assets, farm-level climate-related risk perception, farm-level adaptation strategies, constraints to adaptation, and perception of the efficacy of adaptation strategies. The questionnaire was written in English and was subsequently administered in the local language for the understanding of the respondents. Secondary data on rainfall and temperature were collected from the Climate Change Knowledge Portal of the World Bank database, retrieved 1st August 2023, https://climateknowledgeportal.worldbank.org/country/gambia/climate-data-historical.

Sampling techniques and sample size

The sample size for this study was determined using the Raosoft online sample size calculator, ensuring statistical representativeness. With a total population of 38,614 farming households in the target regions, a 5% margin of error and a 95% confidence level were used to calculate an optimal sample size. A multi-stage sampling technique was employed to select the study area and 420 smallholder farmers (Figure 7). Multi-stage sampling techniques are efficient for resource optimisation and managing logistics in a large and diverse population (Lambarraa-Lehnhardt *et al*., 2022). Initially, three main agricultural production regions were chosen: NBR, URR, and CRS. The regions are predominantly characterised by cereal crop farming. The selected regions also experience extreme climatic events such as floods, windstorms, droughts, poverty, and food insecurity (NDMA, 2022). In the second stage, 5 districts from the NBR, 4 districts from the URR, and 3 districts from the CRR were randomly selected.

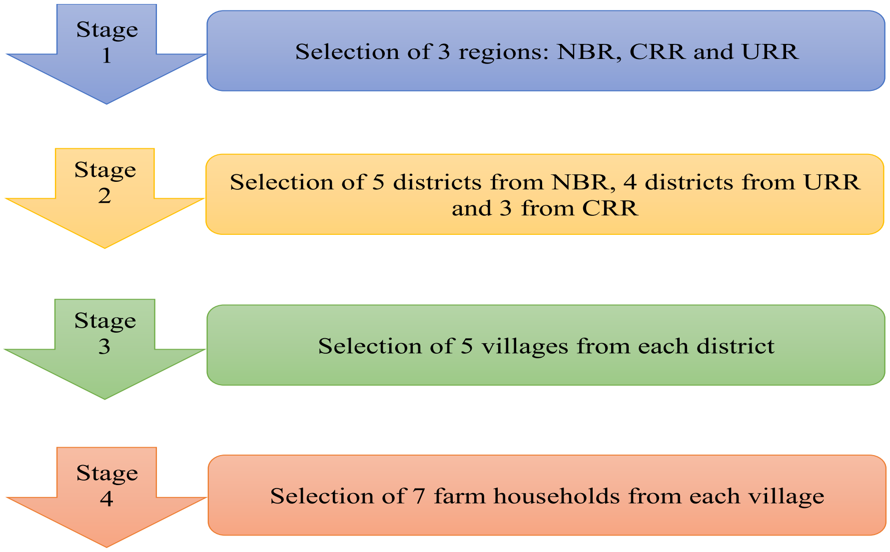


Figure 7: Multistage sampling approach

Source: Author's illustration, 2023

This was informed by the difference in population size of the regions. In the third stage, 5 villages were randomly chosen from each district, and in the fourth and final stage, 7 smallholder farmers were randomly chosen from the village registry. The selection criteria in the communities were that the primary source of income for a household should be farming. Therefore, a total of 420 agricultural households were incorporated into the investigation, and the survey was conducted in the year 2023.

Methods of Data Collection

The Data were collected by trained enumerators using the Kobo Collect toolbox. The Kobo toolbox application will serve as an interface for data collection, where questions are input for a structured interview. The app was also used to collect geo-coordinates of the communities in the districts, which provided additional insights into the study. A structured survey was conducted among smallholder farmers' household heads to meet the research objectives. The questionnaires were administered by trained enumerators whose selection was based on their proficiency in administering questionnaires and fluency in English and local dialects. The enumerators underwent a one-week training program to acquaint themselves with the topics of climate change, farm-level adaptation to climate change, the importance of research on climate change adaptation, and the fundamental principles of sampling, interviewing, and data processing. Aside from administering individual questionnaires. On-site pre-testing of the developed structured questionnaire was carried out not only for on-site training of interviewers but also to improve survey quality and prevent oversight of relevant information. Interviews were conducted according to common principles and ethics (Bogner *et al.*, 2009). Informed consent was obtained before the initiation of interviews with farmers, setting out the intent and objectives of the study. Households that refused to be interviewed during the consent stage were replaced. Overall, 420 farm households were interviewed.

Thesis structure

This PhD thesis comprises three interconnected essays with an opening general introduction. The essays centred on climate risk and climate services perception, adaptation and mitigation strategies among smallholder farmers in The Gambia, providing a comprehensive analysis from information access to implementation and impact. The general introduction outlines the research questions, objectives, and hypotheses and highlights the significance of the study and its relevance to addressing climate change and agricultural challenges in the Gambia. It also introduces the study area and the research design. The first essay examines farmers' access to climate information, their perception of its usefulness, and the socioeconomic and institutional elements affecting their capacity to use it effectively. Building on this, the second essay analyses factors that influence farmers' decisions to adopt climate risk adaptation strategies and determinants of farmers' adaptation of on-farm and off-farm strategies. The third essay evaluates the perceived efficacy of adaptation and mitigation strategies, assessing their impact on agricultural sustainability. The connection among these essays adheres to a coherent progression: the first delineates the significance of climate information as a basis for adaptation, the second analyses how climate risk perception drives adaptation, and the third assesses the effectiveness of these strategies. Together, they form a holistic narrative on climate risk adaptation, supporting a policy-oriented dialogue on improving agricultural resilience in The Gambia. Finally, the general conclusion summarises the main finding and their practical implications. It provides evidence-based policy recommendations and suggests areas for future research.

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1. Essay 1: Farmers' Perception of, Access and Use of Climate Services on Early Warning and Adaptation in The Gambia[1]

Abstract

Climate variability and extreme weather significantly contribute to global food insecurity, with rising global temperatures intensifying these conditions. Seasonal weather forecasts and early warning systems are crucial for enabling farmers to adjust their production plans and take pre-emptive measures against unexpected weather events. In the Gambia, such climatic phenomena have been reflected in substantial harvest decline, water shortages, and worsening health crises, exacerbating food insecurity and poverty reduction efforts. Despite the availability of climate information, its value is diminished if it fails to facilitate adaptation strategies among farmers. This study investigates the factors influencing farmers' access to and use of climate information, understands farmers' perceptions of the usefulness and reliability of early warning information, and examines the relationship between the use of climate information and the implementation of adaptation strategies. Using a multi-stage sampling method, the study selected 420 farm households across three primary agricultural regions in The Gambia. The logit results show that age (35-55 years), access to marketing information, training on climate risk adaptation, trust in the media, access to extension services and witnessed unexpected weather events positively shape farmers' access to and use of climate information. The Multinomial logistic result shows factors influencing farmers' perception of the usefulness and reliability of early warning information. The findings of the recursive bivariate probit indicate a statistically significant relationship between farmers' use of climatic information and the implementation of an adaptation strategy. The study seeks to contribute to policy and practice by strengthening the resilience of Gambia's agricultural sector, ultimately enhancing food security and promoting sustainable development. Policymakers should improve extension systems to deliver timely, accessible, and inclusive climate information, especially for women and vulnerable farmers.

Keywords: Access, adaptation, climate services, early warning, perception

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1.1 Introduction

Between 1970 and 2019, climate and weather-related disasters occurred on average every day, claiming many lives and causing US$202 million in losses daily (WMO, 2021). Early warning and flood forecasting are proficient and cost-efficient instruments for reducing the adverse consequences of floods and maximising potential benefits. Local-level alert delivery tools for proper preparedness and rapid response are non-existent or weak. In many countries, the flood warning system is not fully operational. For flood warnings to be effective, they must provide a sufficient lead time for vulnerable agencies and communities to take preparedness and mitigation actions. According to FAO (2019), an estimated 5-10% of domestic agricultural losses are due to weather changes. Studies in various countries show that obtaining and using weather forecasts can reduce the impact of weather shocks by 10-30% (Cabot Venton *et al*., 2012; Laudien *et al*., 2020; Meza *et al*., 2008; Rathore *et al*., 2016; Tarchiani *et al*., 2021).

Timely and accurate availability of information on climate risk management through weather forecasts and early warnings is a useful tool in policy decision-making processes. The studies of Hallegatte *et al*. (2018), A. J. Kull *et al*. (2016), and WMO (2015) found positive benefits to investing in weather prediction and early warning. Due to constraints in the current exercise, there is a need to enhance the accuracy and lucidity of forecasts released and build good communication between the forecasting agents and the forecast user on the conditions of the atmosphere (Gibba, 2020). Early warning mechanisms and their effectiveness can reduce the risks posed by these hazards, but studies evaluating their efficacy are limited (Lumbroso, 2018). The Gambia is prone to weather-related risks such as floods, wind storms, and drought. Effective early warning systems can significantly reduce risks posed by natural disasters and climate change. According to the *United Nations Framework Convention on Climate Change (UNFCCC)* report (Frizen, 2016), average temperatures are projected to increase by 1.1-3.1 °C by 2060 and 1.8-5.0 °C by 2090. The world's coastal regions are projected to stay within 20% of the global mean sea level rise of 26 cm to 98 cm by 2100. It projects Gambia's sea level rise to be from 19cm to 43cm by 2050. A one-meter rise in sea level would effectively submerge up to 8% of the country's land area, mainly around mangroves. Improved weather and forecasts could increase global productivity by up to $30 billion annually and reduce asset losses by up to $2 billion annually. The cost-benefit ratio is estimated on the order of 10: 1 (WBG; GFDRR; WMO *et al*., 2019).

Scaling up to deploy efficient climate services that reach the most vulnerable is critical to protecting the livelihoods of millions. Inadequate availability of quality data and access for agricultural users are major bottlenecks in developing climate services in Africa. As reported by Abdulla *et al*. (2020); FAO (2019), there is a gap among users regarding the availability and accessibility of information for making agricultural or livelihood management decisions. If climate services are available but not used effectively, they are lost. Most weather information services do not reach smallholder farmers due to poor communication channels, and the information is not adequately tailored to the needs of the communities or has not been translated properly into the local languages.

Early warnings are valuable sources of information for local growers' decision-making. Beal *et al*., (2021) highlights lacking information about local climate and forecast categories can lead to design errors, uncertainty, and ambiguity in forecast accuracy. In The Gambia, understanding the perception of and access to climate services, particularly those related to early warning and adaptation, among Gambian farmers is crucial for building climate resilience and facilitating informed decision-making in the agricultural sector. If climate information on early warning is available but does not enable households to adopt climate risk adaptation strategies, its value will be lost (B. B. Hansen *et al*., 2019). This study is set to assess how access to information on climate services on early warning enables households to adopt climate risk adaptation strategies. Specifically, the research seeks to analyse the perceptions of the usefulness and reliability of early warning and how the use of climate information on early warning influences farmers' adoption decisions.

Research question

The main research question for this essay is to assess smallholder farmers' perception of and access to climate services for early warning and adaptation. Specifically;

- what is the level of climate information access among smallholder farmers across different regions?
- what factors influence smallholder farmers' access to and use of climate information?

- how does the use of climate information influence smallholder farmers’ adaptation strategies?

Objective

To assess smallholder farmers’ perception of and access to climate services for early warning and adaptation. Specifically;

- to determine the level of climate information access among smallholder farmers across different regions.
- to examine the factors influencing smallholder farmers’ access to and use of climate information.
- to analyse the effect of the use of climate information on smallholder farmers’ adaptation strategies.

Hypothesis (Ho)

The use of climate information services has a positive effect on the adaptation strategies.

The essay enhances the literature on climate services access and the use of early warning information for climate risk adaptation (Sen *et al*., 2021a). It addresses a critical gap in scientific evidence on climate risk management information, particularly regarding weather forecasting and early warning (Lumbroso, 2018). A key contribution of this research is the distinction between access to climate information and its actual use in decision-making. While a growing volume of climate data is available, a significant gap remains in its accessibility and perceived reliability among farmers (Beal *et al*., 2021). This study examines how farmers perceive early warning information, the factors influencing its utilisation, and the relationship between climate information use and adaptation strategies (Agbehadji *et al*., 2023). By disaggregating access and use, it provides novel insights into the role of climate services in agricultural resilience. The findings have policy implications for enhancing climate information dissemination, strengthening adaptive capacity, and promoting sustainable agricultural development in The Gambia. Understanding farmers' perceptions of and access to climate services, particularly those related to early warning and adaptation, is crucial for building climate resilience and facilitating informed decision-making in the agricultural sector. While access to information is key to utilising climate services, access alone does not necessarily guarantee its usefulness (Sen *et al*., 2021a). To date, the researcher has not found any study that examines the perception of the usefulness and reliability of climate services on early warning by farmers. Accessing and using climate information are two distinct processes in the decision-making process that can be influenced by several factors. Two logit models were employed in the study to examine household access to information and the usefulness of information for decision-making.

This essay is structured into six main sections. Following the introduction, Section 2 provides a comprehensive literature review, covering both theoretical and empirical perspectives on climate services and adaptation. Section 3 outlines the research methodology, including sampling techniques, data collection tools, and analytical models employed. Section 4 presents the findings and results, highlighting the factors that influence farmers' access to and perception of early warning information. Section 5 offers a discussion and interpretation of the results in the context of existing literature. Finally, Section 6 concludes the essay with key recommendations for improving access to and use of climate services among smallholder farmers in The Gambia.

1.2 Background

1.2.1 Early warning

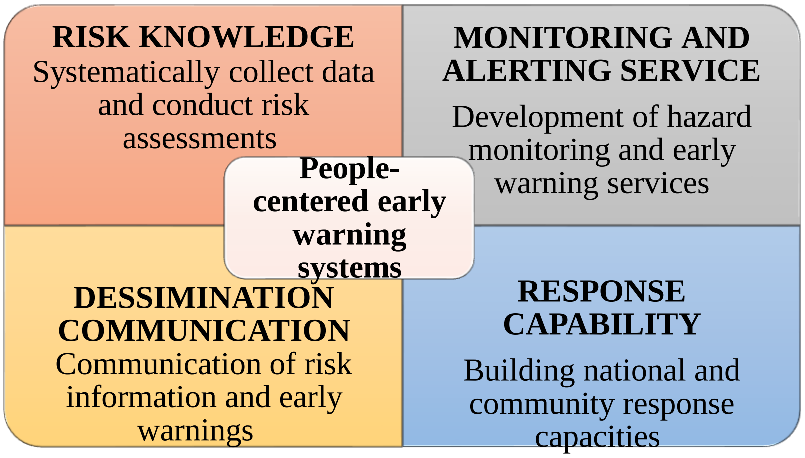
Early warning systems have existed for a long time. It has been used by different people around the world. Ancient Pacific tribes observed tsunami harbingers at sea, while in Africa and America, they watched the skies warn about potential destructive weather. As our understanding of natural hazards grows, advances in early warning systems and monitoring require the use of improved sensors and communication methods to disseminate data to national observatories. Climate services include the production, interpretation, communication and use of climate information in planning climate policy decisions. (GSP, 2021). UNDRR defines an early warning system as "*an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities, systems and processes that enable individuals, communities, governments, businesses, and others to take timely action to reduce disaster risks in advance of hazardous events*". Early warning is an integrated system for floods, droughts and storms that informs people when dangerous weather is approaching and how governments, communities and individuals can act to minimise adverse effects.

At the 2003 International Early Warning Conference, four concepts were presented for efficient or human-centred early warning systems based on four components (Figure 8).

1. Disaster hazard expertise, primarily on systematic data collection and disaster risk assessment.
2. Recording, monitoring, analysing and predicting hazards and possible consequences.
3. Disseminate and communicate relevant, timely, accurate and actionable alerts and relevant likelihood and impact information through official sources.
4. Preparedness at all levels to act on warnings received.

Floods and hydrological droughts are mainly based on observations and weather forecasts, not on hydrological and or hydraulic modelling. Investing in hydromet services should be considered with priority in climate risk adaptation and risk abatement strategies. Techniques to access the economic gains of these investments are still unfolding. As suggested in the literature, such activities are highly beneficial. Investing in early warning systems can help avoid damage from climate disasters and improve productivity in climate-dependent sectors. The significance of early warning systems has been recognised globally, in alignment with the *Sendai Framework for Disaster Risk Reduction 2015-2030, Priority 4* and Article 7 of the Paris Climate Agreement.

Figure 8: Concepts for efficient or human-centred early warning systems



Source: UNDDR, 2003

Weather forecasting can yield important socioeconomic benefits that can be harnessed through improved accuracy and lead times, weather monitoring, modelling, and computation. Forecasts rely on Numerical Weather Prediction (NWP), which is highly influenced by the availability of meteorological and space-based observations, but for Antarctica, Africa, South America, the Pacific, and parts of Asia, surface-based observations in the region are inadequate (D. Kull *et al.*, 2021b). Project design on disaster risk management and early warning services should focus on an effective value chain that connects monitoring and forecasting with solid services to various sectors of the economy and societies. Barley developing forecasts through better technologies will not fundamentally generate economic value unless the whole chain process works to promote impact and the end-user decision-making process. Weather forecasting is one of the most important applications of science in our daily activities and has played an integral role in mankind for many years.

1.2.2 Climate information services production initiatives across the world and in Sub-Saharan Africa and The Gambia

Climate information services (CIS) are vital instruments that provide climate data to support decision-making across various sectors, especially agriculture. Globally, many initiatives have been established to improve CIS production and transmission. In Sub-Saharan Africa and The Gambia in particular, targeted programs have been developed to meet regional and local climate information needs.

Globally, initiatives to improve CIS have concentrated on enhancing the collection, analysis and dissemination of climate data to support resilience and adaptation strategies (Warner *et al*., 2022). These efforts aim to provide accurate and timely climate information to all relevant stakeholders, facilitating informed decision-making in sectors vulnerable to climate variability. Programs such as the Global Framework for Climate Services (GFCS) by the World Meteorological Organisation (WMO) have facilitated access to dependable climate information, ensuring informed decision-making (WMO, 2021). The Consultative Group for International Agriculture Research (CGIAR) is also committed to advancing scientific innovations to revolutionise food, land, and water systems in response to the climate crisis. It has broadened its focus to address specific agricultural challenges and opportunities through various initiatives and platforms. CGIAR aims to improve global forecasting and decision-making processes by utilising contemporary technologies such as artificial intelligence and satellite systems (Ngaiwi *et al*., 2024).

In Sub-Saharan Africa, the Program on Climate Information for Resilient Development in Africa (CIRDA) is a notable initiative. CIRDA seeks to enhance climate information systems in vulnerable African countries, including Benin, Burkina Faso, Liberia, Sierra Leone, Sao Tome and Principe, Ethiopia, The Gambia, Uganda, Tanzania, Malawi, and Zambia. By promoting regional coordination and knowledge-sharing, CIRDA aims to strengthen national capabilities in climate information management. However, limited access to reliable climate data and insufficient transmission mechanisms remain significant obstacles, hindering adaptation initiatives at both governmental and local community levels (UNDP, 2025). CIRDA is instrumental in advancing CIS and early warning systems via technology transfer and capacity-building initiatives. These efforts seek to produce customised, practical climate data for key stakeholders, such as farmers and policymakers (Biagini B. 2015). Additionally, CIRDA supports the preservation of historical climate records and improves the proficiency of national meteorological agencies to deliver accurate forecasts. Empirical research indicates that improved access to climate information can reduce agricultural losses by 10-30% and significantly enhance the adaptive capacity of smallholder farmers (Cabot Venton *et al*., 2012; Tarchiani *et al*., 2021). The Global Environment Facility (GEF) supports CIS initiatives in countries such as The Gambia and Sierra Leone by financing the installation of weather stations, improving data collection systems, and training programs. These initiatives aim to enhance resilience to climate variability by improving the availability and accessibility of accurate climate data (UNEP, 2022)

In The Gambia, strengthening climate services and early warning systems project is a collaborative initiative between the government of the Gambia, the Global Environment Facility (GEF), and the United Nations Environment Program (UNEP). The project, with a total funding of $26.51 million, seeks to bolster climate resilience through the enhancement of climate monitoring capabilities and early warning systems. The primary objectives include the development of modern meteorological infrastructure, capacity building for local stakeholders, and the dissemination of tailored climate information to farmers and vulnerable communities (UNEP, 2022). By improving the availability and reliability of climate information, the project contributes to resilience-building and adaptive capacity in the face of climate variability and change.

1.2.3 Early warning information in the agricultural sector

Since 1968, The Gambia has experienced a significant decrease in rainfall, resulting in more interannual variability and decreased agricultural production. Climate forecasts and agrometeorological warnings are useful instruments for policy and decision-making, but they can only be realised in close and constant collaboration with "data users" (Gibba, 2002). The Gambia, like other Sahelian countries, has a rain-fed agriculture-based economy that is vulnerable to climate variability and extremes, particularly drought (Gomez *et al*., 2001). The weather has an impact on crops at all phases of their growth cycle and, hence, is an important component in production. Furthermore, weather-related changes in farm product supply are mirrored by oscillations in commodity prices and, thus, in farm revenue. Extreme meteorological disasters (such as droughts and floods) cause widespread economic damage. Thus, it is apparent that improved knowledge of major rainy season variables, in the form of climate forecasts and agrometeorological warnings, is critical for boosting production in an agricultural production system. However, in the Gambia, such information is not commonly used in agricultural productivity (Gibba, 2002).

Lastly, early warning information is critical for The Gambia's agricultural economy. Accurate and timely weather predictions can help farmers make informed decisions, and early warning information can help them plan for and respond to extreme weather events. With the increasing effects of climate change, these technologies are critical for strengthening the resilience and sustainability of The Gambia's agricultural industry

1.2.4 Farmers' perception of climate change

Climate change perception is a complex process involving understanding, beliefs, perspectives, and concerns about whether and how the climate is shifting (Whitmarsh & Capstick, 2018). Individual qualities, experience, information received, and societal and geographical location all have an impact on and form perception (Van der Linden *et al*., 2015; Whitmarsh & Capstick, 2018). As a result, evaluating climate change perceptions and attempting to identify the factors that influence them is a challenging task. One of the numerous obstacles that an individual encounters when attempting to differentiate between ordinary short-run changes and climate change manifestations is the fluctuation that local weather might have from one day to the next, season to season, and year to year (Hansen *et al.*, 2019). Local short-term changes are more obvious than longer-term patterns and can thus have significant effects on the establishment of climate change beliefs (Lehner & Stocker, 2015). However, individuals who rely on the weather for at least a portion of their income, such as farmers, have a more accurate perception than their rivals. They may still have difficulty correctly interpreting changes as significant enough to feel concerned and compelled to act (Weber & Wong, 2010; Whitmarsh & Capstick, 2018). Those who have been personally impacted by catastrophic weather events report that the likelihood of similar disasters recurring is relatively high (de Matos Carlos *et al.*, 2020; Patt & Schröter, 2008a). Furthermore, the information received by a person might alter or adjust her perception of climate change (Weber & Wong, 2010). Finally, because perception is a subjective process, persons in the same location may have different perceptions of climate change even though they encounter identical weather conditions (Simelton *et al.*, 2013).

Various studies have revealed varying results on farmers' attitudes towards climate change. According to the findings of Kargbo *et al.*, (2023); Mavhura *et al.*, (2021); Sanogo *et al.*, (2015) socio-demographic variables influence farmers' perceptions. However, these findings contradict the findings of (Odewumi, 2013; Sanogo *et al.*, 2015), who found no effect of any demographic characteristic on farmers' perceptions of climate change and variation. Farmers' perceptions are important in the adoption of new technologies (Meijer *et al.*, 2015). Perceptions of climate variable evolution differ throughout Africa's climatic zones (Deressa *et al.*, 2011a; Ochieng *et al.*, 2017).

A study done in southwestern Burkina Faso discovered that farmers recognised ongoing climate and environmental change as dependent on their previous weather and climatic experiences (Sanfo *et al.*, 2017). The majority of farmers in Senegal and Kenya, for instance, noticed fluctuations in the frequency of drought occurrences (D. Maddison, 2007). Farmers in Senegal's savanna zone relate the consequences of climate variability to the incidence of high winds and storms (Mertz *et al.*, 2012). Farmers on Burkina Faso's Central plateau reported a drop in average annual rainfall and the number of heavy showers (Mertz *et al.*, 2012). Farmers' impressions in Ghana and Niger are consistent with meteorological data (D. Maddison, 2007). Farmers' perceptions and adaptability to climate change are influenced by a variety of factors, including those that have nothing to do with weather or the environment but are dependent on local social dynamics and sense-making (Deressa *et al.*, 2011a). Farmer’s perspectives may be influenced by farm size, access to training, household size, and membership in farmer-based organisations (Ehiakpor *et al*., 2016). Flood occurrences, for example, have been proven to influence people's perceptions of climate change (Spence *et al*., 2011). Farmers' perceptions in some research corroborate observed meteorological data (Ayanlade *et al*., 2017; Habtemariam *et al*., 2016), whilst in others (Mertz *et al*., 2012).

Most studies on farmers' perceptions of climatic variability relate their conclusions to real meteorological data and, in some cases, link them to farmers' adaptation practices (Dolisca *et al*., 2006; Ndambiri *et al*., 2013). Little thought has been paid to how farmers view their exposure (vulnerability) to anticipated climate changes and the potential losses that may occur (severity). Adapting the agricultural sector to the negative consequences of climate change is critical for protecting the lives of the population that is directly dependent on agriculture (Asfaw & Lipper, 2016). In a world with perfect information, complete markets, and enough incentives, deciding whether or not to accept or implement a specific adaptation strategy would simply be a matter of weighing the net benefits of the said measure. That is most emphatically not the case for small and subsistence farmers in underdeveloped countries (Castells-Quintana *et al*., 2018).

As a result, implementing adaptation measures is far from automated or easy. According to the data, problems such as insufficient access to insurance or credit, limited information on adaptation possibilities, and imperfect property rights are impediments to technology adoption faced by small and subsistence farmers (Asfaw & Lipper, 2016). Farmers' perceptions of climate change are important in understanding their adaptation decisions (Clarke *et al*., 2012). Adaptation necessitates not only that individuals perceive that something is changing or may change, but also that they place enough weight on this view to be willing to act and try to change it (Eriksen *et al*., 2015).

Perceiving climate change might thus be viewed as a prerequisite for the implementation of agricultural adaptation methods (Makuvaro *et al*., 2018; Simelton *et al*., 2013). Furthermore, the successful implementation of public policies aimed at promoting adaptation necessitates, among other things, the cooperation and participation of those who will benefit from them. If their perspective of the implications or immediacy of climate change differs from that of policymakers, policy implementation is likely to fail (Patt & Schröter, 2008b).

1.2.5 Agricultural sector's vulnerability to climate change

The Gambia is predominantly an agricultural country in West Africa; it contributes significantly to the nation's GDP and employs a large number of people. However, the sector confronts numerous obstacles, including the effects of climate change, such as the increased frequency and intensity of extreme weather events. Reduced yields, crop and infrastructural damage, and food shortages can all result from this. Agriculture is the principal source of food production and subsistence for the majority of rural communities in Sub-Saharan Africa, including The Gambia (Cooper *et al*., 2008). This emphasises the significance of this industry in terms of food security and poverty alleviation in the region. Smallholder farmers play an important role in the agricultural sector of Sub-Saharan Africa, producing food for local consumption and creating cash for rural communities.

This emphasises the significance of this industry in terms of food security and poverty alleviation in the region. Smallholder farmers play an important role in the agricultural sector of Sub-Saharan Africa, producing food for local consumption and creating cash for rural communities. Despite its importance, the region's agricultural sector has some obstacles, including restricted access to capital and markets, infrastructure constraints, and the effects of climate change. Low precipitation and frequent droughts are examples.

Agriculture is one of The Gambia's most important economic activities, employing a sizable portion of the population. However, the industry is vulnerable to climate change, which will reduce yields and productivity. Furthermore, temperature increases and changes in precipitation patterns can affect pest and disease patterns as well as promote soil erosion, further lowering agricultural yields. The agricultural industry is vulnerable to climate change because it relies on rainfall, lacks efficient irrigation systems, and lacks access to credit, markets, and essential amenities such as education and health care.

Mitigating The Gambia's agricultural sector's vulnerability to the effects of climate change entails encouraging the adoption of climate-resilient agricultural practices, assisting in the development of sustainable water management practices, and addressing the sector's various challenges. These practices can assist in lessening the impact of climate change on agriculture, reduce the sector's dependency on rainfall, and increase farmer yields and profitability. To cope with it, a multipronged approach is required. Poverty, limited access to essential amenities, the effects of climate change, and so on. The Gambia can reduce poverty, increase food security, and provide livelihoods for its people by tackling these concerns and strengthening the agricultural industry. To address the agricultural sector's vulnerability to the effects of climate change, governments and international organisations are encouraging the adoption of climate-resilient agricultural practices and assisting in the development of sustainable water management practices. This involves encouraging the use of modern irrigation systems, enhancing water-saving practices, and encouraging the use of improved seed varieties.

Agriculture is anticipated to employ a sizable proportion of the Gambia's labour force. It accounts for around 25% of GDP and employs 40.3% of the labour force (World Bank, 2020). This highlights the importance of agriculture in providing livelihoods and employment possibilities for the inhabitants. It should be emphasised, however, that quantifying the real number of persons working in farming may be problematic, as many individuals in rural areas engage in agricultural operations as part of their livelihood alongside other economic pursuits. Furthermore, the majority of Gambia's agricultural labour force is made up of smallholder farmers who are not counted in official employment figures. Despite these issues, the agricultural sector provides income and employment for the majority of the Gambian people, making it a critical contributor to the country's economy and growth. The Gambia's poverty rate has climbed to 53.4%, according to The Gambia Poverty and Gender Assessment 2022 report.

Poverty is more prevalent in rural areas, with 7 out of 10 rural residents living in poverty compared to 3 out of 10 urban residents (World Bank, 2022). Poor households in The Gambia have low earnings, and poverty remains a serious concern for the country. According to the World Bank, over 40% of the Gambian population lives in poverty. In The Gambia, poor households frequently participate in subsistence farming, small trade, or the informal economy. Many have limited access to credit, markets, and basic services such as education and health care, which can limit their ability to improve their economic situation.

In The Gambia, poor households rely significantly on agriculture as a substantial source of income, and enhancing agricultural productivity and resilience will help reduce poverty and improve livelihoods. Governments and international organisations should enhance not only credit and market access but also agricultural practices and infrastructure, as well as support farmers affected by climate change, to ensure that the agricultural industry continues to offer income and employment. Over-reliance on rainfall and a lack of efficient irrigation systems are important issues for The Gambia's agriculture sector. The Gambia's agricultural industry is mostly dependent on rainfall rather than irrigation, rendering it sensitive to the effects of climate change, such as low precipitation and frequent droughts. This can result in decreased yields, poorer farmer revenue, and increased food insecurity. Yields and production quality are low, as evidenced by a drop in agricultural value added per worker from US$2,049 in 2015 to US$1,884 in 2019, the second lowest in West Africa (FAO, 2019b). Excessive reliance on rainfall and limited access to modern irrigation systems (only 6% of total agricultural land), difficult credit access, and a lack of essential inputs and processing facilities have all contributed to the development of the value chain, impeding green growth and poverty alleviation. To overcome this challenge, governments should encourage the use of modern irrigation systems and assist in the development of sustainable water management practices. This involves the installation of new irrigation systems, the rehabilitation of existing systems, and the promotion of water-saving practices. Efforts should also be made to assist farmers in adopting climate-resilient agricultural strategies such as crop diversification, intercropping, and conservation agriculture. These practices will assist in limiting the consequences of climate change on agriculture, lessen the sector's reliance on rainfall, and increase farmers' yields and income. Climate variability is expected to reduce local food output by 50 kg per person in West Africa by 2050, according to a study by Defrance *et al*. (2020). The upshot of this projection is predicted to be a decrease in domestic crop production and an increase in the need for imports.

According to File & Derbile (2020), Janssens *et al*. (2020), Menghistu *et al*. (2020), and Sultan *et al*. (2019), the effects of climate change, combined with high population expansion in the western Sahel region, are anticipated to contribute to a decline in crop yields by 2050. The anticipated fall in domestic output is expected to result in severe hunger, starvation, and malnutrition among the region's inhabitants. (Rhodes *et al*., 2017; Rosenzweig *et al*., 2001; Saxena *et al*., 2018; Zougmoré *et al*., 2014) have documented significant crop production losses due to climate change in the same region between 2000 and 2009. The average regional yield losses for millet and sorghum in the region were between US$2.33-4.02 billion and US$0.73-2.17 billion, respectively. These losses equate to a 10%-20 % and 5%-15% decline in crop output, respectively.

Crop production in The Gambia is being impacted by climate change, resulting in lower yields and lower-quality goods. Because The Gambia relies on rain-fed agriculture, the country is especially vulnerable to the effects of climate change and the country's limited usage of modern irrigation systems. Climate change may result in less rainfall, higher temperatures, and more frequent and severe droughts, lowering crop yields and impacting crop growth and development. Climate change can alter precipitation patterns, resulting in droughts, floods, and other severe weather events. These alterations have the potential to gravely harm crops, reducing production and quality. Crops can be stressed by high temperatures, resulting in lower yields. This is especially true for temperature-sensitive crops, such as maize and rice. Climate change can degrade soil, diminishing fertility and agricultural productivity. Changes in temperature and rainfall patterns may increase the number of pests and diseases affecting crops, lowering production and quality even further. Other constraints, such as low soil fertility, restricted access to credit and markets, and limited infrastructure, will worsen the impact of climate change on Gambia's crop production. These issues contribute to farmers' low yields and incomes, worsening poverty and food insecurity in the country. Climate change effects on crop output in The Gambia could have far-reaching consequences for food security and rural livelihoods. Crop growth and yield in rainfed farming systems are projected to be considerably hampered by the combined stress of heat and soil moisture as the climate becomes increasingly drier. Numerous research and analyses, such as (Blanc, 2012; Knox *et al*., 2012; Schlenker & Lobell, 2010; Yaffa, 2013), imply that climate change is severely impacting main crops farmed in The Gambia, resulting in lower yields. However, horticultural crops are less likely to be harmed by climate change if competing water supply objectives do not exist.

It is unclear how CO_2 concentrations in the atmosphere affect yields (Abebe *et al*., 2016; Long *et al*., 2006). Lowland rice production in The Gambia is especially vulnerable to excessive temperatures caused by climate change (Bojang *et al*., 2020). It is predicted that grassland agriculture in Africa will decline by 40% by 2050, negatively impacting rangeland output. This decrease in cultivation is expected to reduce animal production by 7.5% to 9.6%, resulting in a $9.7 billion to $12.6 billion economic loss. Smaller ruminants with restricted water and food consumption, on the other hand, can flourish in the Sahel due to its hotter and drier climate (Zougmoré *et al*., 2016). Grassland agriculture in Africa is expected to fall by 40% by 2050, posing a threat to rangeland production. The above leads to a 7.5% to 9.6% decrease in animal production and a $9.7 billion to $12.6 billion economic loss. Negative outcomes have a multiplier impact, resulting in higher livestock prices, decreased productivity, and poorer earnings for individuals who rely on livestock for a living and nutrition (Menghistu *et al*., 2020; Simpkin *et al*., 2020). The cattle sector in The Gambia is similarly vulnerable to the effects of climate change. Climate change-related temperature increases can cause heat stress in livestock, impacting growth, productivity, and fertility. This has the potential to have a significant impact on farmers' livelihoods as well as the country's economy as a whole.

Climate change will create changes in precipitation patterns, which may result in water scarcity in some areas, particularly dry areas where water supplies are already scarce. This can obstruct livestock access to water, limiting output and raising disease risk. Climate change is affecting the growth and quality of fodder, The Gambia's primary food source for animals. This can result in livestock malnutrition and decreased output. Climate change can also raise disease risk in livestock, particularly through the introduction of novel illnesses and the advent of new vectors such as ticks and mosquitoes. Addressing the impact of climate change on crop production in The Gambia will necessitate improved agricultural practices and infrastructure, as well as assistance for farmers affected by climate change. Access to loans and markets, improved irrigation systems, encouraging the use of improved seed varieties, and promoting sustainable farming practices are all examples. This is critical for ensuring food security, reducing poverty, and improving rural communities' livelihoods. Improving agricultural practices and infrastructure to assist farmers impacted by climate change is crucial to meeting these targets. The development of livestock production in a sustainable and climate-resilient manner can help to lessen the impact of climate change on livestock. Investing in R&D to improve animal health and productivity, supporting sustainable land use practices, investing in water management, and other steps to mitigate the impact of climate change on the livestock sector are all part of this strategy.

This information, as proposed by (Sultan *et al*., 2019) emphasises the significant cost that climate change will impose on West African subregions. Climate change will harm cattle, resulting in increased animal disease, decreased fertility, decreased milk output, shortened life spans, and higher animal mortality (Desmidt *et al*., 2021).

1.2.6 Farm-level vulnerability

It is widely accepted that vulnerability differs across communities, regions, and countries, as well as over time. When it comes to climate change, food security, and the field of political ecology, there are various ways in which vulnerability can be understood. The research identifies two categories of vulnerability: biophysical vulnerability and social vulnerability. Biophysical vulnerability primarily addresses the likelihood of natural disaster impacts, with an emphasis on the extent and severity (Ii *et al*., 2003; Smithers & Smit, 1997). Social vulnerability often considers the condition of the human system, which is influenced by elements such as political, social, and economic aspects that might put people at risk while also reducing their adaptive capacity to such risks (Belliveau *et al*., 2006; Ii *et al*., 2003). Concerning climate change. Vulnerability encompasses both biophysical and social variables. (IPCC, 2023) defines vulnerability as "the propensity or predisposition to be adversely affected." It includes several concepts and components, such as sensitivity to injury and the inability to effectively cope and adapt. Until the fourth IPCC Assessment Report (Pachauri *et al*., 2007), a vulnerability was thought to consist of three components: exposure, sensitivity, and adaptive capability. According to the (IPCC, 2023) study, vulnerability is a component of risk; these risks arise from the combination of hazards, vulnerability, and exposure.

If a system is highly exposed to climate-related risks, with low resilience and adaptive capacity, it may be referred to as fragile. In contrast, a system is more robust if it shows low sensitivity or has high resilience (Young et. al, 2012). The system’s level of sensitivity depends on its ability to be inversely influenced or even act against the external stimulus and resist adverse consequences (Smit & Pilifosova, 2003). Adaptive ability is often described as a critical characteristic of risk reduction for the system (Engle, 2011). People’s business and agricultural activities are impacted by various climate-related risks, such as floods, droughts, and extreme temperatures that lead to low crop yields or water shortages. However, farmers can reduce their exposure to these risks by learning how to adapt appropriately. As Lebel *et al*. (2015) note that farmers are ultimately the owners and primary decision-makers in this area. How they understand climate uncertainties and risks can influence not only short-term farm management techniques but also adaptation choices as well. Farmers who understand these risks accurately make reasonable choices about crops, seasons, and inputs. Other facets that could affect a farmer’s ability to adjust include the availability of technological, financial, and information resources or the social structure and local exchanges (Bryan *et al*., 2013a; Gorst *et al*., 2015).

1.3 Literature review

1.3.1 Theoretical literature

Theoretical studies that underpin climate services are incorporated into the theoretical literature; the most influential theories are reviewed.

1.3.1.1 Theory of planned behaviour and risk perception

Ajzen (1991) assert that behaviour is influenced by attitudes, subjective norms, and perceived behavioural controls. A farmer's decision to implement climate information services and adaptation strategies can be influenced by their risk perceptions, potential benefits, and normative pressures from their communities or institutions. Similarly, the risk perception framework suggests that farmers' previous experience with extreme weather events, such as floods and droughts, intensifies their urgency to adapt (Patt & Schröter, 2008b).

1.3.1.2 The adaptation decision framework

The adaptation decision-making model elucidates that farmers assess the costs, benefits and risks associated with climate risk management strategies before their adoption. It emphasises the economic trade-offs, including the immediate cost of implementing irrigation or drought-resistant crops compared to the long-term benefits of enhanced resilience (IPCC, 2023).

1.3.1.3 Human capital theory

The human capital theory (Becker, 1964) supports the idea that education and training enhance individuals' productivity and decision-making abilities. In this context, farmers' access to extension services and climate training can improve their ability to interpret and use climate information effectively. For instance, female farmers possessing secondary education demonstrated a more efficient use of early warning information (Sen *et al*., 2021a).

1.3.1.4 Public goods theory

Climate information services (CIS) can be viewed as public goods, given their non-excludable and non-rivalrous characteristics. However, obstacles such as underfunding and underutilisation arise due to their features as a public good (Stiglitz, 2000). Governments and international organisations often intervene to offer CIS, emphasising the need for subsidised or free access to vulnerable populations such as rural farmers.

1.3.1.5 Rational choice theory

This theory assumes that individuals make decisions by weighing the costs and benefits to optimise utility. Farmers adopt CIS when the perceived benefits, such as improved crop yield or minimised losses, outweigh the associated costs, such as time or money investment in training (W. H. Greene, 2007).

1.3.1.6 Innovation diffusion theory

The adoption of climate services aligns with the diffusion of innovation theory (Rogers, 2003), which explains how novel ideas, practices or technologies spread within a social framework. It delineates adopter categories such as innovators, early adopters, early majority, late majority and laggards. Elements like perceived relative advantage, compatibility, complexity, trialability, and observability influence the adoption rate. In the context of climate services, this theory elucidates why some farmers are early adopters of weather information for decision-making in climate services, while others are resistant (Rogers, 2003).

The direct support provided by CIS—through timely warnings, seasonal advice, localized recommendations, and enhanced communication—plays a crucial role in enabling farmers in The Gambia to mitigate risks, improve resource management, and adapt their farming practices in the face of climate variability (Nyong *et al*., 2007; Speranza *et al*., 2018; Tambo, 2016). However, empirical studies reveal discrepancies in farmers' behaviour. For instance, whereas climate information services (CIS)are meant to guide decision-making, research in The Gambia indicates that only 74% of farmers who access CIS implement climate risk adaptation strategies (Lambarraa-Lehnhardt *et al*., 2024). These inconsistencies underscore how factors such as risk aversion and lack of trust in scientific forecasts influence decision-making, deviating from the rational behaviour assumed in traditional utility models (Carmen Lemos *et al*., 2012). Farmers may prioritise short-term stability over long-term benefits, especially in a resource-constrained environment (Bryan *et al*., 2013a).

The expected utility theory posits that farmers make decisions under uncertainty by evaluating the expected utility of potential adaptation strategies. According to the expected utility hypothesis, individuals assess the prospective outcome of an action by assessing the probabilities and possible payoffs to optimise their satisfaction (Teugels & Sundt, 2004). For instance, a farmer might evaluate the cost of transitioning to drought-resistant crops against the expected benefits of higher yield amid erratic rainfall patterns. However, despite the availability of climate information, many farmers fail to use it effectively, indicating market failures in the distribution of climate information. The notion of information asymmetry, as articulated by Akerlof (1970), applies to climate services when the information provider (e.g., meteorological agencies) and the user (e.g., farmers) do not share a common understanding or access. Although CIS is available in the Gambia, gaps in dissemination channels and relevance to the local context create barriers. Only 65% of surveyed farmers in the Gambia reported access to extension services, a key channel for CIS, hence, limiting their ability to fully utilise climate data for agricultural planning (Lambarraa-Lehnhardt *et al*., 2024). Furthermore, the use of CIS often requires educational or technical skills that many farmers do not possess, contributing to ineffective adoption. As a result, market failures arise, leading to information being underutilised, diminishing its potential impact (Hallegatte *et al*., 2018b). Addressing these asymmetries through tailored dissemination and farmer training programs is critical. The perception of climate hazards can lead to either over-reliance on traditional knowledge or complete disregard for scientific forecasts, challenging the rationality assumed in neoclassical models. Behavioural economics contests the presumption of rationality posited in traditional economic models by considering how cognitive biases and emotions affect decision-making. (Hallegatte *et al*., 2018b).

The prospect theory of Kahneman & Tversky (1979) posits that individuals assess outcomes with a reference point and are more sensitive to losses than gains. In the context of climate services, farmers may exhibit loss aversion, prioritising established but potentially suboptimal practices over unfamiliar scientific forecasts (Patt & Schröter, 2008c). Some farmers in The Gambia relying on indigenous knowledge might avoid adopting CIS due to fear of potential inaccuracies in forecasts, despite the scientific data offering superior accuracy. Over-reliance on traditional methods can create a false sense of security, leaving farmers vulnerable to unforeseen climate events (Lemos *et al*., 2012). This behavioural mismatch underscores the need for participatory approaches in CIS development to bridge the gap between traditional and scientific knowledge.

Climate change poses substantial hazards to agriculture, and farmers must implement adaptive techniques to avoid negative consequences. Farmers can anticipate and prepare for bad weather conditions by using early warnings and weather forecasting information. The purpose of this theoretical framework is to investigate the relationship between the usage of early warning and weather forecasting information and the implementation of climate risk adaptation measures in agriculture. The Diffusion of Innovation Theory is a social science theory that describes how new ideas, products, or practices spread and are embraced by individuals within a social system. Everett Rogers, a sociologist, originated the theory in the 1960s, and it has subsequently been applied to a variety of subjects (Dooley, 1999; Stuart, 2002) identified several fields, including political science, public health, communications, history, economics, technology, and education, and described Rogers' theory as a commonly used theoretical framework in the domain of technology dissemination and adoption.

Researchers have studied the process of accepting new inventions for more than 30 years, and one of the most well-known models for adoption is given in Rogers' book, "Diffusion of Innovations" (Sherry & Gibson, 2002). Rogers, (2003) defined adoption as the decision to fully utilise an invention as the most advantageous course of action, whereas rejection refers to the decision not to fully utilise an innovation.

Rogers defines diffusion as "*the process by which an innovation is communicated through specific channels among members of a social system over time*." According to this hypothesis, a variety of factors influence the acceptance of new ideas and practices, such as climate risk adaptation measures. These include characteristics of the innovation itself, communication methods used to distribute knowledge about the innovation, and adopter characteristics. Early warning and weather forecasting information can be viewed as an innovation in the context of this paradigm, with the potential to influence the adoption of climate risk adaptation methods. The hypothesis is founded on the premise that adopting new technologies is a social process involving the interaction of various elements. The qualities of the innovation itself, the characteristics of the adopters, and the communication methods via which the innovation is distributed are among these elements.

The four essential aspects in the diffusion and innovation theory, according to Rogers, (2003) are innovation, communication channels, time, and the social system. According to the hypothesis, the adoption process is divided into five stages (Figure 9):

Awareness: Individuals become aware of innovation during the initial stage. This can occur through a variety of means, such as media, social networks, or personal experience.

Interest: Individuals become interested in the innovation and seek out more information about it during the second stage. This frequently entails seeking additional information, speaking with friends and family, or attending events or demonstrations.

Evaluation: Individuals examine the innovation at the third stage, weighing its potential benefits and costs. They may seek professional advice, read reviews, or even try the invention for themselves before deciding whether to adopt it.

Trial: In the fourth stage, individuals test the innovation's effectiveness and significance on a small scale. This frequently entails purchasing or employing the innovation in a limited capacity, such as using a new software programme for a certain task or experimenting with a new fitness regimen.

Adoption: In the last stage, people decide whether or not to embrace the invention and incorporate it into their daily lives or jobs. At this point, the invention has become a part of the social structure and may even influence others' adoption decisions.

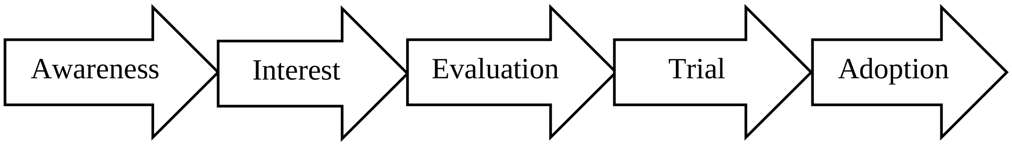


Figure 9: A five-stage model of the adoption decision-making process.

Source: Adapted from Everett M. Rogers (2003)

The theory also highlights various aspects that can have an impact on the adoption process, such as:

Relative advantage: The degree to which the invention is judged to be superior to current alternatives.

Relative advantage: How well the invention fits with the values, experiences, and needs of potential users.

Complexity: The degree to which the innovation is seen as simple to grasp and apply.

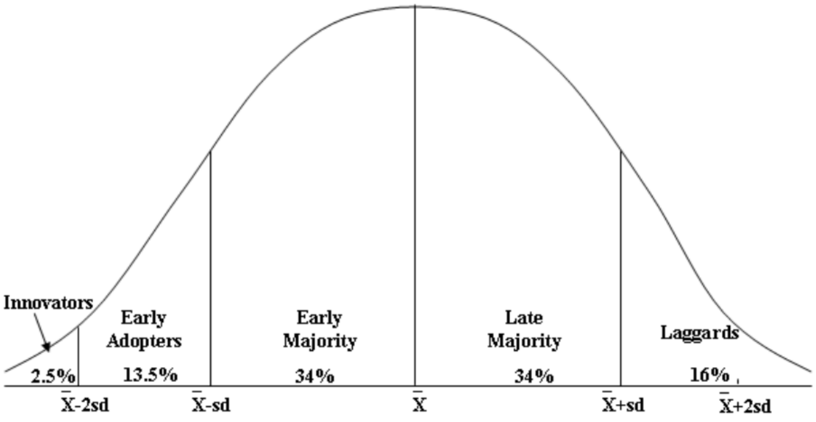
Trialability: The ability of an idea to be tested on a small scale before adoption.
Observability: The ease with which the benefits and outcomes of the invention may be seen and conveyed to others.

Adopter categories

Rogers, (2003) developed adopter categories to organise individuals in a social system based on their willingness to try new things, which he refers to as "innovativeness." Innovators, early adopters, early majority, late majority, and laggards are the classifications. Innovativeness is defined as an individual's proclivity to adopt new ideas before others in their social system (Rogers, 2003). Van Braak, (2001) described innovativeness as a stable feature indicating a person's willingness to change their familiar practices, which is dependent on innovation and social construction. Rogers believed that innovativeness was critical to understanding behaviour in the innovation-decision process, thus, he used it to categorise adopters. The graphic below depicts the adoption distribution as a normal distribution.

The adopter classification, according to (Rogers, 2003)is only applicable to individuals who have fully adopted a successful invention; those who have partially adopted or have not adopted at all are not included in this classification (Figure 10). The adoption distribution is a normal curve, with each category specified by a certain percentage of persons in the system.

Figure 10: Adopter classification
Source: Everett M. Rogers (2003)



i. Innovators

Rogers (2003) defined innovators as those who are open to new ideas and are willing to deal with the uncertainties and probable failures that come with them. The innovator group, for example, is made up of the first 2.5% of people who accept an innovation, as depicted by the area to the left of the curve and two standard deviations below the mean. Rogers believes that innovators are critical in introducing new ideas into a social structure from the outside. Other members of the social system, on the other hand, may not regard them favourably because of their willingness to take risks and their connections outside of the system. Because the innovations they attempt to implement are so complicated, innovators are expected to have sophisticated technical knowledge. Extension workers and other experts in agriculture may fall into this category. In agriculture, innovators come from a wide range of backgrounds and disciplines. Here are a couple of such examples:

Researchers and scientists: Agricultural researchers and scientists can help create new technology and procedures to increase agricultural yields, cut inputs, and solve environmental concerns. They could be employed by universities, government agencies, or private research firms.

Entrepreneurs and new businesses: In recent years, there has been an increase in the number of agricultural entrepreneurs and start-ups. These pioneers frequently bring a new viewpoint to old farming practices and may develop new technologies or business models to help enhance efficiency and sustainability.

Policymakers and regulators: Governments and regulatory organisations can also be key agricultural innovators. They may set rules or regulations to encourage the use of sustainable farming practices, or they may support research and development.

Farmers and ranchers: Farmers and ranchers are frequently the ones who recognise problems and obstacles in the field, and they can be good problem solvers. They may, for example, create new crop types or breeding procedures or devise novel pest and disease management strategies.

ii. The Early Adopters

Early adopters, as opposed to innovators, are more confined by the constraints of the social system (Rogers, 2003). Because early adopters are frequently in positions of leadership within the system, other members look to them for guidance and information about the innovation. Early adopters' attitudes towards innovation are especially important as role models since their subjective judgments are conveyed to other members of the social system via interpersonal networks. Early adopters provide a stamp of approval for the innovation, reducing ambiguity about it and encouraging its proliferation. Farmers' groups and other community leaders may be early adopters. Early adopters in agriculture are people who are open to experimenting with new ideas, technology and practices before they become widely embraced. People who might be early adopters in agriculture include:

Progressive farmers: Progressive farmers are those who are willing to take risks and experiment with new ideas on their farms. They are frequently leaders in their communities and can have an impact on the dissemination of new ideas and practices to other farmers.

Agricultural extension agents: These individuals work with farmers to assist them in adopting new technology and practices. They can be early adopters, putting new ideas and procedures to the test on their farms before promoting them to others.

Agribusinesses: Agribusinesses can be early adopters of new technology and practises, particularly if they see the potential for better efficiency, cost savings, or higher quality.

Researchers: Researchers who create new technology and practices might be early adopters themselves, testing new ideas on their own farms or study plots before sharing them with the larger agricultural community.

Educators: Agriculture educators can be early adopters, demonstrating the potential benefits of new technologies and practices in their classrooms and on demonstration farms. They can aid in the dissemination of new ideas and practices to the next generation of farmers.

iii. The Early Majority

The early majority, according to Rogers (2003), have significant links with other members of the social system, but they lack the leadership positions that early adopters have. Nonetheless, their interpersonal networks continue to play an important role in the diffusion of innovation. As shown in the graph above, the early majority adopts the innovation just before the other half of their peers, and they do so after careful thought. They are not the first or last to adopt the innovation, unlike innovators and early adopters. As a result, their decision to accept an innovation takes longer than the preceding adopter categories. The early majority in agriculture are individuals who are often hesitant to adopt new ideas but are willing to give them a try once others have proven them. People who potentially form the early majority in agriculture include:

Traditional farmers: Traditional farmers are frequently wary of new technologies and practices, but they may be persuaded to try them if they see other farmers utilising them effectively. Large-scale farmers: Large-scale farmers make larger investments in their operations and may be more risk-averse than smaller-scale farmers. However, if they discover that a new technique or practice has been adopted effectively by others, they are more willing to attempt it themselves.

Cooperatives in agriculture: Cooperatives in agriculture can be a major force in spreading innovative technologies and practices. Cooperatives can urge other members to adopt a new idea after a few members have successfully implemented it.

Government agencies: Government agencies can help promote the adoption of new technologies and practices by providing incentives or subsidies for their use. Once a new technology or practice has been demonstrated to be effective, government authorities can assist in spreading the word and encouraging wider use.

Industry groups: Industry associations can also play a role in encouraging the adoption of innovative technology and practices. It can provide instruction and training to its members, as well as assist in the formation of networks of farmers eager to share their experiences with new technology and practices.

iv. The Late Majority

The late majority, like the early majority, represents roughly one-third of the social system's members who tend to defer acceptance of the innovation until most of their peers have already embraced it. They frequently have qualms about the invention and its potential repercussions, but economic necessity or peer pressure can convince them to adopt it. Close peers in their interpersonal networks must encourage them to adopt the innovation to reduce their uncertainty about it. According to (Rogers, 2003), only when the late majority is convinced that the innovation is safe will it be adopted. In agriculture, the late majority is cautious of new ideas and may be slow to adopt them until they have been broadly adopted by others. People who may constitute the late majority in agriculture include:

Small-scale farmers: Because they have fewer resources to spend on their businesses, small-scale farmers may be more risk-averse than large-scale farmers. They may be more likely to accept new technologies or practices if they see others in their community using them successfully. Farmers over the age of 50 years: Farmers over the age of 50 may be set in their ways and less willing to try new ideas. They may be more likely to accept new technologies or practices if they see others in their community using them successfully.

Rural communities: Rural communities might be more secluded than urban regions, making it more difficult for new ideas to propagate. They may be more cautious of new technologies or practices until they realise that other farmers in their area have broadly adopted them.

Traditionalists: Some farmers may be resistant to change and prefer to use conventional practices. They are more willing to adopt new technology or practices if they see that they are generally accepted and have a track record of success.

v. The laggards

Individuals in the "laggard" group, according to Rogers (2003), have a more conventional perspective and are more resistant to new ideas and change than those in the "late majority" group. Because they are the most spatially localised sector of the social system, they mostly engage with other members of the same group. They also do not have any roles of leadership. They prefer to study the success of innovation before implementing it due to limited resources and a lack of understanding about it. As a result, laggards tend to make decisions after determining whether the invention has been successfully accepted by others in the social system. As a result of these characteristics, the trailing group has a longer period for making innovative judgements. Agriculture laggards are individuals who are slow to adopt new ideas and technologies and may be averse to change. Individuals who may be agricultural laggards include:

Traditionalists: Traditionalists may be averse to change and prefer to remain with old methods, even if they are less efficient or successful than new technologies or practices.

Subsistence and small-scale farmers: Small-scale and subsistence farmers may have fewer resources and are less prepared to take risks, making them more likely to be late adopters of new technology or practices.

Farmers in remote areas: Farmers in distant places may have limited access to knowledge and resources, making new technology or practices more difficult to implement.

Conservative farmers: Farmers who are conservative in their approach to agriculture may be unwilling to try new technologies or practices unless they are widely accepted and demonstrated to be effective.

In addition to these five categories of adopters, Rogers (2003) divided them into two major groups: earlier adopters and later adopters. The innovators, early adopters, and early majority are among the early adopters, whereas the late majority and laggards are among the later adopters. Rogers also emphasised the contrasts between these two groups in terms of socioeconomic position, personality traits, and communication practices, all of which are frequently associated with innovativeness. (Rogers, 2003) observed that those with less education and lower socioeconomic levels are the last to accept an invention, although they stand to benefit the most from it. However, age was not discovered to have a significant effect on adopting behaviour.

The Diffusion of Innovation Theory offers a valuable framework for comprehending how new ideas and practices spread and are embraced within a social system. The theory can help organisations and policymakers create and implement effective strategies for increasing the adoption of innovations by recognising the stages of the adoption process and the factors that influence it.

1.3.2 Empirical review

Naab *et al*. (2019) investigated the role of climate services in agricultural productivity in Ghana using quantitative research methods, including focus group discussions (FGDs), key informant interviews (KFIs) and secondary data analysis. The FGDs provided insights from smallholder farmers on climate change adaptation strategies, while the KFIs involved policymakers and institutions to evaluate the dissemination of climate services. The finding reveals that climate services are essential for improving productivity, but language barriers, insufficient dissemination channels, and poor institutional coordination impede their efficiency. Farmers continue to depend on traditional weather prediction methods, which are becoming less reliable due to escalating climate variability. The study underscored the need for a national framework for climate services to improve accessibility and integration into agricultural policy.

The research conducted by Vaughan *et al*. (2018) examines 101 climate service initiatives collected by the Climate Services Partnership (CSP) and the World Meteorological Organisation (WMO) in 2012 through a case study approach. The data obtained from self-reported descriptions were analysed using descriptive statistics and qualitative thematic analysis. The findings indicate that the majority of climate services were national initiatives, primarily providing agricultural seasonal forecasts and disseminated via internet platforms. While many initiatives focused on capacity building, challenges included restricted user interaction, sustainability of funding, and formal evaluations. The study highlights the need for stronger user-provider collaboration, sustainable funding and rigorous evaluation frameworks to enhance climate service effectiveness.

Wiréhn & Strandberg, (2025) employs the four-pillar framework to assess the climate service process and identify challenges in its implementation. The study identifies ten barriers, such as model uncertainty, institutional limitations, and discrepancies between providers and users, through an examination of scientific literature, stakeholder dialogues and Sweden’s climate services. Despite the progress in climate data production, the usability gap continues to pose a significant challenge. The study recommends the enhancement of climate data generation, fostering co-creation, enhancing user engagement and securing long-term finances to institutionalise climate services. Although the framework provides a holistic and pragmatic approach, its dependence on context-specific studies and qualitative analysis may limit its broader applicability.

Ogundeji *et al*. (2022) investigates how access to climate information affects smallholder farmers’ ability to adapt to climate change, employing the Multivariate Probit and Endogenous Poisson Treatment Effect models to analyse information pathways and adaptation strategies. The finding reveals that farmers rely on multiple channels- radio, TV, extension agents, and peer networks, which substantially influence their adaptive capacity. Socioeconomic factors such as income levels and education play a crucial role in determining access to climate information and adaptation outcomes. However, the broader generalisation of the study is limited by data constraints, model intricacy and geographical limits.

Toreti *et al*. (2022) assess the effectiveness of tailored climate services in supporting durum wheat production in the Euro-Mediterranean region through the integration of crop simulation modelling and climate forecasts. Climate change could reduce yield by 5.8% to 7.7%, with increased variability and dynamic cultivar selection; using seasonal climate forecasts could offset losses by up to 5.3%. However, adaptation strategies may double interannual yield variability, increasing price volatility unless prediction accuracy exceeds 70%. The study provides precise insights and highlights the potential of digital tools in agriculture, but it assumes unrestricted access to cultivars and idealised climate services, which may not reflect real-world constraints. Ultimately, advanced climate prediction tools are essential for balancing yield improvements and variability in future adaptation strategies.

Using three services: WaterApps, Buienradar and WaterSIS (Di Fant *et al*., 2024) examines user engagement in climate information services using a qualitative case study. Utilising Vedeld *et al*., (2019) framework, the study found that providers inconsistently conceptualise engagement levels within CIS stages, highlighting the complexity of implementation. While the cross-case analysis provides interdisciplinary insights, limitations include a provider-centric focus and framework bias toward agrometeorological services.

Sen *et al*., (2021) examines barriers to accessing and using climate information among farmers in the mountainous region of Thừa Thiên Huế province, Vietnam, using a logistic regression model. Survey data from 302 farming households revealed key barriers such as trust in formal climate services, low climate risk perception, and language barriers among ethnic minority farmers. While trust in formal information sources and ownership of communication devices notably influenced access and utilisation, many farmers used these devices for entertainment rather than climate information.

Onyeneke *et al*. (2023) investigate the determinants of access to and utilisation of climate information services among 405 farmers in Ebonyi State, Nigeria, and assess the impact of CIS on agricultural productivity. The study employs the Heckman probit and endogenous treatment effect models to address selection and endogeneity issues. The finding indicated that 89% of farmers accessed CIS and that CIS use significantly increased crop yield. While the methodology provided strong causal inference and addressed selection bias, its limitations included cross-sectional constraints and potential omitted variables. Fikadu *et al*. (2024) did similar work in Bereh Woreda, Ethiopia, with the same methodology but found 50% of farmers accessed CIS and less than half utilised it, hindered by high cost, lack of trust, and convoluted terminologies.

Ngigi & Muange (2022) reveal gender specific disparities in access to climate information services in Kenya. Their study used a recursive bivariate probit model, which controls for selection bias and unobserved factors affecting CIS access and adoption. (Alidu *et al*., 2022) did a similar study in the Northern Ghana region using a bivariate probit model, access to climate information and adoption of adaptation strategies were influenced by age, household income, access to extension services, and ownership of an asset. However, barriers such as large household sizes, low education, and financial constraints hinder adoption. The methodology is effective in controlling for selection bias but is limited by reliance on cross-sectional data and omission of information about knowledge sharing networks.

Terrado *et al*., (2024) employs a transdisciplinary co-production framework to examine how seasonal and sub-seasonal climate forecasts can assist Arctic reindeer herders in Finland, integrating scientific and traditional knowledge through a participatory approach. Findings reveal that those seasonal predictions for May and June assist in planning early harvests, while sub-seasonal forecasts for April and May aid in managing back winter occurrence, such as postponing reindeer release to safeguard claves. The methodology strengthens stakeholder engagement and trust, it is resource-intensive, context-specific and reliant on subjective inputs.

Lamptey *et al*., (2024) utilise a qualitative analytical framework to explore sustainability challenges and propose solutions for weather and climate services across the African continent. By integrating case studies, literature reviews and expert consultations, the research identifies key barriers, including scientific gaps in tropical meteorology, limited data access, poor forecasting models and inadequate capacity building. The holistic and collaborative approach strengthens its relevance, limitations include the lack of quantitative impact assessment. Baldissera Pacchetti *et al*. (2024) employ a multi-disciplinary qualitative analysis framework that integrates philosophical, social and physical climate services perspectives to assess the quality of climate information. The interdisciplinary methodology enhances depth, challenges include conceptual complexity and fragmentation within the climate service community.

Vogel *et al*., (2017) utilises a logic model framework to assess the Caribbean Agrotechnological Initiatives (CAMI), methodologically analysing key components of climate services such as prediction accuracy, information dissemination, and farmer adoption. This approach provides an extensive examination by incorporating social and process dimensions, ensuring practical applicability and flexibility across various sectors. However, it may oversimplify complex systems and focus more on intermediate rather than long-term outcomes. Their study identifies significant gaps in the dissemination and adoption of climate services.

Nesheim *et al*. (2017) investigate how agro-met information services influence farmers' decisions in Maharashtra, India, using a multi-method approach that includes interviews, focus groups, and observations. It found that these services are mostly valued for facilitating preventative measures, such as pest control and harvest protection; nonetheless, their use is limited due to factors like credibility and accessibility. Farmers often rely on personal competence and social connections rather than official agrometeorological data, underscoring the importance of platforms for dialogue and contextualization. In the same area Vedeld *et al.*, (2019) employs a governance and comparative case study approach to examine four agro-met services in Maharashtra, India, focusing on institutional design, engagement strategies, and co-creation of knowledge. The key finding reveals that most services operate at a basic level of one-way information provision, with only one provider exhibiting elements of co-production. The method encompasses its perspective and multi-level insights from various stakeholders, allowing for practical recommendations. Nonetheless, its contextual specificity, qualitative bias and time-consuming nature restrict broader applicability and generalisation. Obstacles to effectiveness include poor tailoring of advisories, limited accuracy and lack of localised information.

Suckall & Soares (2022) employ a quasi-experimental design, cost-benefit analysis and qualitative assessment to synthesise academic and grey literature on operational weather and climate services in the region, assessing their scale, evaluation methods and socio-economic benefits. It includes comprehensive insight into existing evaluations, integration of diverse data sources, and a systemic framework ensuring rigour and replicability. Despite this, its limitations include a scarcity of empirical evaluation (only 13 documents found), an emphasis on short-term economic advantages, and regional deficiency, especially in Afghanistan, Bhutan, the Maldives, and Sri Lanka. Key findings underscore the inadequate documentation of weather and climate services' socioeconomic benefits, with most evidence concentrated in India and Bangladesh. The evaluations predominantly focus on immediate economic advantage, whereas social and environmental benefits remain underexplored.

Carr & Onzere (2018) evaluate Mali’s Agrometeorological Advisory Program through a mixed-method approach that combines qualitative ethnographic research with the Livelihoods as Intimate Government (LIG) framework to examine the social, economic, and cultural determinants affecting the utilisation of advisory services in southern Mali. This method can elucidate intricate socio-cultural aspects of agricultural decision-making; however, it does not fully account for informal knowledge sharing systems or structural agricultural barriers. The study finds low advisory use rates, with senior men who have access to farming assets as principal benefactors, whereas junior men and women experience exclusion due to social hierarchies and resource constraints. Barriers to adoption include restricted access to essential farming equipment and entrenched dependency on senior male decision-makers.

Dilling & Lemos (2011) conducts a literature review of empirical evidence to analyse previous studies on the production and utilisation of climate science, with a focus on seasonal climate forecasting. Their study provides a thorough evidence foundation and highlights the interactive relationships between knowledge producers and users. And offers practical recommendations for enhancing science policy connections. However, it depends on previous studies that may exhibit regional or context biases, there is a lack of quantitative metrics for assessing the usefulness and concentrating exclusively on seasonal climate forecasts instead of addressing broader climate research challenges. The research found that usability depends on both the context of use and the knowledge production process, with iterative engagement being essential for practical outcomes.

Brasseur & Gallardo (2016) employ a perspective review approach to examine the development, challenges, and prospective trajectories of climate services. It underscores key weaknesses, including insufficient user awareness, ineffective design, poor information accessibility, and a flawed business model. The techniques offer a comprehensive, interdisciplinary, policy-relevant overview, but they lack empirical data, which can lead to subjective bias. The finding indicates that successful climate services require interdisciplinary collaboration among climate scientists, economists, engineers, policymakers, and communication specialists. Additionally, it emphasises the need for user-driven, co-designed services that connect climate information development with actual implementation.

Ricart *et al*. (2022) use a systematic literature review and bibliometric analyses to examine research trends, thematic clusters, and gaps in farmers' perception of climate change versus meteorological data. This methodology provides a comprehensive and replicable synthesis of current studies, yielding objective insight into research impact and thematic structure. The primary finding reveals a divergence between farmers' perceptions and observed climate data, influenced by socio-economic factors and adaptive capacity.

Dilleen *et al*. (2023) employ a two-stage qualitative methodology to explore smart farming technology adoption. This approach provides in-depth insights into farmers' trust networks, captures real-world digital engagement, and offers a holistic perspective by integrating online and offline data. The results reveal that peer farmers are the most trusted sources of information, while social media remains underutilised for smart farming technology knowledge dissemination. The finding lacks quantitative validation and has limited generalisability. Farmers tend to distrust technology vendors due to perceived commercial motives.

Fay Buckland & Campbell (2021) evaluates the factors influencing the use of agro-climate services by farmers in Clarendon, Jamaica, using regression analysis of survey data from 356 farmers and qualitative case studies. It identifies eight critical factors affecting awareness, access and use of these agro-climate services, including gender, age, access to extension workers, group participation, climate change perception, off-farm income, farm size, and agronomic conditions. It shows that younger, more educated farmers are primary users, highlighting socio-spatial aspects in agro-climate services adoption.

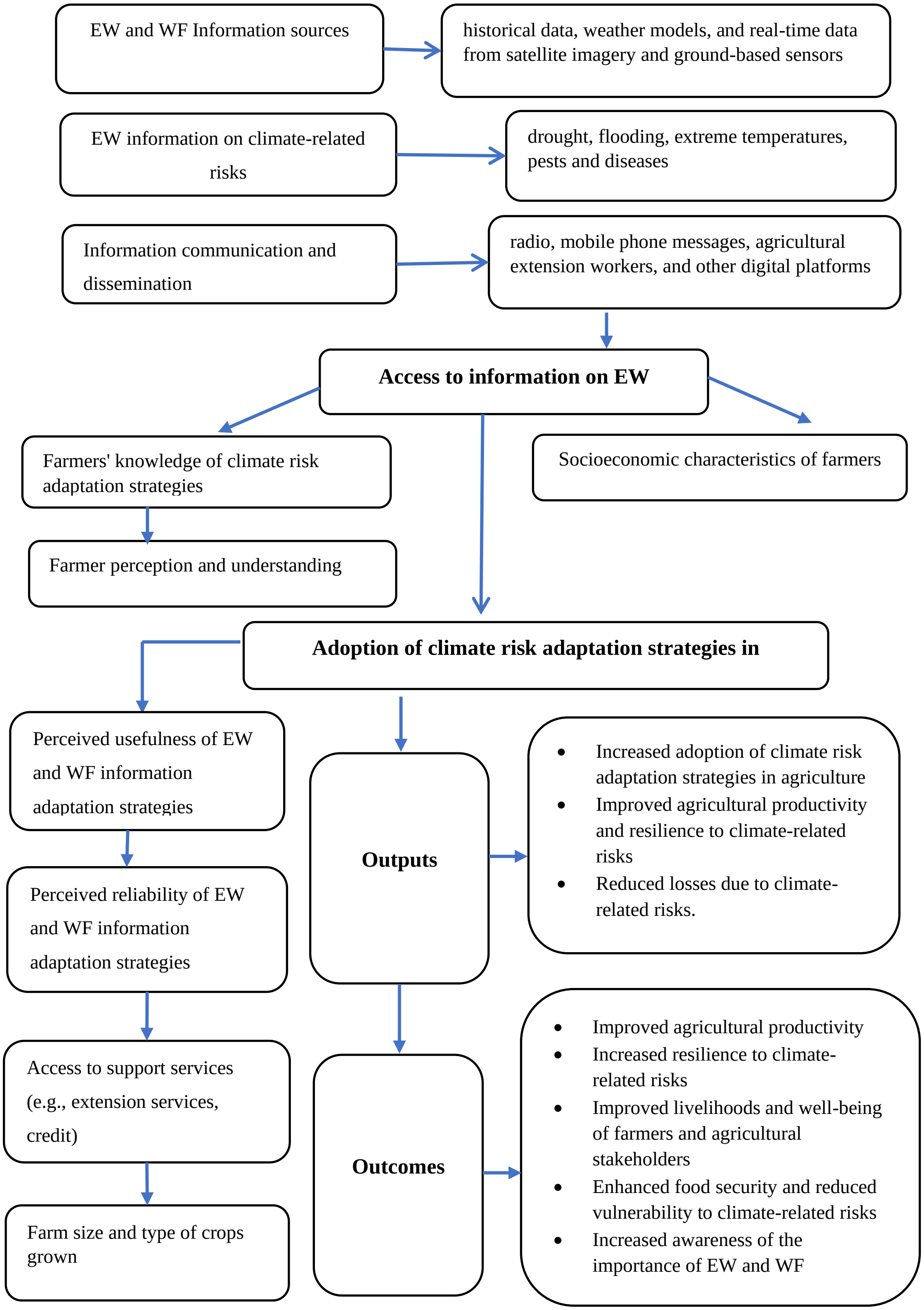
1.3.3 Conceptual framework of access to early warning systems and adaptation

The framework (Figure 11) illustrates how access to climate services, such as early warning (EW) and weather forecast (WF) information, influences farmers' adoption of climate risk adaptation strategies in agriculture. The arrows in the framework represent directional relationships or influence, showing how different variables and processes are connected and how one leads to or affects another.

The framework explains how EW and WF information sourced from satellite images, historical data, and models is communicated to farmers via different platforms. Once disseminated, farmers get access to this information, which enables their knowledge of climate risk adaptation strategies. Their perception and understanding of the information determine its relevance and usefulness, influencing whether they will adopt strategies in their agricultural practice. This results in output such as increased adoption, improved productivity and enhanced resilience. Ultimately, the outcomes include better food security, reduced vulnerability, improved livelihoods and greater understanding of climate risks.

Figure 11: Conceptual framework

Source: Author’s illustration, 2024



The diffusion innovation theory by Everett Rogers supports the framework by explaining how EW/WF information enables knowledge, influences farmers' attitudes, and promotes the adoption of new adaptation strategies through various communication channels and social systems. It provides a foundation for understanding how access to climate information can lead to farmers' adaptation of climate risk strategies.

Adaptation strategies represent the innovations, while communication channels facilitate their dissemination. The framework mirrors Rogers’s five-stage adoption process: farmers acquire knowledge via early warning and weather forecast information, evaluate its relevance, decide to adopt, implement it in practice and continue using it if deemed beneficial. Farmers' characteristics and broader social system, including community norms and institutional support, also influence the adoption process, which is consistent with Rogers's focus on the importance of adopter categories and social context.

Providing timely and accurate information regarding climate-related risks, weather patterns, and pertinent adaptation approaches to agricultural stakeholders has the potential to enhance farmers' decision-making capabilities and enable them to mitigate the adverse effects of climate-related risks on their livelihoods and communities. This approach yields several outcomes, including enhanced agricultural productivity, increased capacity to withstand climate-related risks, and improved food security and well-being for farmers and their communities.

The framework can be used as a guide for researchers or practitioners who want to investigate the relationship between the use of early warning and weather forecasting information and the adoption of climate risk adaptation strategies in agriculture, as well as the factors that may influence this relationship. The provision of timely and accurate information regarding climate-related risks, weather patterns, and pertinent adaptation approaches to agricultural stakeholders has the potential to enhance farmers' decision-making capabilities and enable them to mitigate the adverse effects of climate-related risks on their livelihoods and communities. This approach yields several outcomes, including enhanced agricultural productivity, increased capacity to withstand climate-related risks, and improved food security and well-being for farmers and their communities.

1.4 Methods of data analysis

The essay employed a stringent analytical methodology, integrating descriptive statistics and advanced econometric techniques to examine smallholder farmers' perception and adoption of climate risk adaptation and mitigation strategies in The Gambia. Binary Logistics regression was utilised to identify factors influencing farmers' access to and use of climate information and the adoption of climate risk adaptation strategies. Multinomial logistic regression (MNL) was used to analyse farmers’ perceptions of the usefulness and reliability of climate services. The recursive bivariate probit (RBP) was applied to jointly estimate the factors influencing the use of climate information and its impact on the adoption of adaptation strategies. The multivariate probit model was employed to analyse the interdependence and concurrent adoption of multiple adaptation techniques.

1.5 Empirical Model

1.5.1 Econometric specifications of perception, access to climate services and adaptation

Previous studies have analysed access and usage of climate change information using descriptive methods (Carr *et al*., 2016; Nwabueze Chukwuji *et al*., 2019), utilising regression models to determine and analyse variables likely to influence access and use of climate information. The utilisation of probit and logit models is highly pertinent for this particular investigation, owing to the binary characteristic of the dependent variable (Oyekale, 2015; Kallas et al, 2011; Muema *et al*., 2018). When compared with other models, the logistic regression model was chosen due to its notable advantage in mathematical simplicity to yield meaningful outcomes. One benefit of this approach is its lack of assumptions regarding multivariate normality and equal covariance matrices, which are typically required in discriminant analysis (Press & Wilson, 1978).

Logistic regression is best suited for problems when the explanatory variables are binary or have multiple categorical levels or multiple independent variables (Greene, 2007; Maddala, 1983). Since the independent variable in this study is a mixture of categorical and continuous, the logistic regression is the most appropriate due to its being statistically robust when compared to discriminant analysis (William *et al*., 1971). Furthermore, the binary logistic regression methodology is appropriate for estimating the discrete result of dichotomous dependent variables using multiple explanatory factors that might be dichotomous, continuous, or discrete. In this analysis, the output variable is a binary variable taking the value of 1 for 'households who have access to information on weather forecasting and early warning' and otherwise 0 for 'households who do not have access to information on weather forecasting and early warning'. The logit model was employed and specified in the following manner:

$$P(Y_i) = 1|X_i = F(X_i\beta) = F(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_k X_k)}} \qquad (1)$$

Where the dependent variable $P(Y_i)$ is the probability of household i access to or use of information on early warning and weather forecasts. X_i represents the predictor variables. And β is an unknown parameter coefficient. $F(.)$ is the logistic model distribution density function. The association between $P(Y_i)$ and X_i in this particular form might give rise to certain challenges in estimation. These challenges render the ordinal least square (OLS) technique unsuitable for estimating the parameters (Yabi, 2004). Therefore, it is proposed to utilise the aforementioned form by applying the natural logarithm to the probability ratio.

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = X_i = \beta_0 + \beta_n X_{in} \qquad (2)$$

Where β_0 and β_n are parameters to be estimated. X_{in} is an explanatory variable nth of the ith farm household. X_i the log odd ratio

According to Sen *et al*. (2021a), individuals look for or utilise information services for reasons other than their intended use, such as learning or understanding but not making a decision. Under different conditions, individuals may exhibit a lack of trust in the information provided or face difficulties in analysing it, leading them to refrain from utilising easily available information for decision-making purposes. Instead, they may rely on their prior experiences as a basis for making decisions. On the other hand, certain individuals possess the ability to utilise easily accessible information as a crucial factor in the process of making informed decisions. (Lemos *et al*., 2012; Muema *et al*., 2018). The act of obtaining and utilising information constitutes distinct stages within the decision-making process, hence rendering them susceptible to varying influences. Consequently, the analysis of household access to information and the utilisation of information for decision-making necessitated the implementation of two distinct logit models. Therefore, in this study, we considered households that accessed the climate information as accessing households and households that did not access the climate information as non-accessing households. Agricultural households with access to climate information were coded 1, and those without were coded 0. Similarly, farm households that used climate information for decision-making were coded 1, otherwise, they were coded 0.

The multinomial logit (MNL) model will be used to analyse the perceptions of the usefulness and reliability of early warning and weather forecasting information. For example, a perception of useful, not useful and indeterminate. The literature study revealed that researchers commonly employ the multinomial logit (MNL) model in surveys when respondents are constrained to choosing a single option from a predetermined adaptation set (Bogner *et al*., 2009; Deressa *et al*., 2009; Hisali *et al*., 2011). The Multinomial Logit (MNL) model necessitates that the dependent variables exhibit reciprocal exclusivity so that if farmer *i* perceives that early warning and weather forecasting information is useful, s/he would not also perceive that early warning and weather forecasting information is not useful. This model allows for the analysis of multiple responses across a basic category. This allows for the examination of numerous responses within a base category.

The MNL model can be specified as follows:

$$\log\left(\frac{P(Y=j}{P(Y=0)}\right) = \beta_{oj} + \beta_{1j}X_1 + \beta_{2j}X_2 + \cdots + \beta_{kj}X_k \qquad (3)$$

Where:

$P(Y = j)$ is the probability of the outcome being in the category j.

$P(Y = 0)$ is the probability of the outcome being in the base category.

β_{oj} is the intercept for the category j.

β_{ij} are the coefficients for the predictor variable X_i.

The probability that a household i with characteristics X has climate sensitivity Pj is specified as:

$$P_{ij} = x_i\alpha_j + \varepsilon_{ij,j} j = 0,1 \dots j \qquad (4)$$

To estimate the MNL model, we use the maximum likelihood estimation (MLE) approach. The log-likelihood function for the MNL model is:

$$\log L(\beta) = \Sigma_{i=1}^{N} = \Sigma_{j=1}^{J} \delta_{ij} \log P\ (Y_i = j) \qquad (5)$$

Where:

N is the number of observations

J is the number of outcome categories

$\delta_{ij}$is an indicator variable that equals 1 if observation i is in category j and 0 otherwise.

($P(Y_i = j)$ is the probability that observation i is in category j.

The probabilities $P(Y_i = j)$ are given by the logistic function:

$$P(Y_i = j) = \frac{\exp(x_i\, \beta_j)}{1 + \sum_{k=1}^{J-1} \exp(x_i \beta_k)} \qquad (6)$$

Where:

X_i is the vector of the predictor variable for observation i.

β_j is the vector of coefficients for category j.

To analyse how the use of information on weather forecasting and early warning influences households' adoption decisions. It is assumed that based on the utilisation of information on weather forecasting and early warning, a household head is to optimise the predicted utility by implementing techniques for climate change adaptation. Given the rationality of individuals, it can be inferred that people would make use of weather forecasts and early warning information as a means to adjust to climate change. This adaptation would be pursued if the anticipated advantages resulting from such actions (U^A) surpass the expected benefits of not adapting (U^N), denoted as $U^* = U^A - U^N > 0$. U^* While subjectivity cannot be directly observed, it can be represented as a latent variable function, as demonstrated below:

$$Y_i^* = \theta X_i + \alpha Z_i + u_{i,} \qquad Y_i = \begin{cases} 1 \; if \; U^* > 0 \\ 0 \; if U^* \leq \; 0 \end{cases} \qquad (7)$$

Where Y_i represents a binary outcome, where it takes the value of 1 if the household head adapts and 0 if not. The vector Xi represents a set of explanatory variables that exert an influence on the household's decision regarding whether or not to engage in adaptation. The vector θ denotes the parameter that is to be estimated, while Zi represents the utilisation of climatic information by households. The parameter α is associated with Zi the corresponding parameter to be estimated, and is also subject to estimation. Additionally, the error term and u_i is present in the model.

Let's denote the two binary dependent variables as Y_1 and Y_2 where:

Y_1 represents the use of climate information (treatment variable).

Y_2 represents the adoption of adaptation strategies (outcome variable).

Equation for Y_1 (use of climate information)

$$Y_1^* = X_1\beta_1 + \epsilon_1 \qquad (8)$$

$$Y_1 = 1 \; if \; Y_1^* > 0, and \; Y_1 = 0 \; otherwise \qquad (9)$$

Equation for Y_2 (use of climate information)

$$Y_2^* = \gamma X_1 + X_2\beta_2 + \epsilon_2 \qquad (10)$$

$$Y_2 = 1 \; if \; Y_2^* > 0, and \; Y_2 = 0 \; otherwise \qquad (11)$$

Where:

X_1 and X_2 are vectors of explanatory variables.

β_1 and β_2 are vectors of coefficients

γ is the coefficient measuring the effect of Y_1 and Y_2

ϵ_1 and ϵ_2 are error terms, assumed to be bivariate and normally distributed with a mean of zero and covariance matrix allowing for correlation.

In this study, we run descriptive statistics of variables and employ the recursive bivariate probit (RBP) model proposed by (Chiburis *et al.*, 2012) to analyse the impact of the use of climate information on the adoption of climate risk adaptation measures.

The recursive Bivariate Probit regression approach involves two probit equations with correlated errors, where one binary dependent variable serves as an endogenous regressor for the other dependent variable.

Consider we have two latent (unobserved) variables:

$$y_1^* = x'\beta + \alpha y_2 + \mu_1 , \qquad y_1 = 1[y_1^* > 0] \qquad (12)$$

$$y_2^* = z'\gamma + \mu_2 , \qquad y_2 = 1[y_2^* > 0] \qquad (13)$$

The error terms:

$$\binom{\mu_1}{\mu_2} \sim \mathcal{N}[\binom{0}{0}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}]$$

This means the $\mu_1$and μ_2 follow a bivariate normal distribution with correlation ρ. Greene, (2018) suggested that the endogenous nature of y_2 ignoring it, many still give similar results. Han & Lee, (2019) point out that identification is weak if the instrument used for y_2 are the same as those used for y_1i.e. when $x = z$.

The average treatment effect (ATE)

$$ATE = \emptyset\ (x'\beta + \alpha) - \emptyset(x'\beta) \qquad (14)$$

$\emptyset(:)$: represents the cumulative distribution function (CDF) of a standard normal distribution.

$x'\beta$: linear combination of covariates (x) with their corresponding coefficients (β), represent the baseline prediction.

α: treatment effect.

$\emptyset\ (x'\beta + \alpha) - \emptyset(x'\beta)$: captures the change in predicted probability of the outcome due to treatment, holding other factors constant.

The ATE is the average change in the probability of an outcome caused by the treatment, as determined by a probit model, averaged across the entire sample while controlling for all other variables.

The average treatment effect on conditional probability of outcome

$$ATEC = \frac{\emptyset_2(x'\beta+\alpha_1 z'\gamma,\rho)}{\emptyset(z'\gamma)} - \frac{\emptyset_2(x'\beta,-z'\gamma,\rho)}{\emptyset(-z'\gamma)} \qquad (15)$$

$\emptyset_2(;.;\rho)$: bivariate CDF with correlation ρ

$x'\beta$: linear prediction for the outcome equation

$z'\gamma$: linear predictor for the selection equation

ρ: correlation between the unobserved factors in the selection and outcome equations.

Owusu *et al*., (2021) outline three key benefits of employing the RBP model. Firstly, it allows for the estimation of the effect of a binary treatment variable on a binary outcome variable. Secondly, it jointly estimates the factors that influence the use of climate information and the factors that influence adaptation strategies. Thirdly, in addition to accounting for both observed and unobserved traits, the model corrects for possible self-selection biases. Factors that can influence the perception of climate change, such as household and institutional characteristics, are used as dependent variables. The Variance Inflation Factor (VIF) values show that multicollinearity is not a significant problem in the model, as all the VIF values are well below 5. Therefore, the variables included in the model can be considered relatively independent, allowing for reliable estimation of their individual effects.

1.5.2 Dependent and independent variables

Information on climate change boosts the probability of utilising adaptation strategies against the impact of climate change and variability. Bryan *et al*. (2013b); Danso-Abbeam *et al*. (2020; Danso-Abbeam & Baiyegunhi (2017); Mulwa *et al*. (2017a) find statistically significant positive impacts on access to climate change information, advisory services, and farming organisations' adoption of adaptation strategies. Better climate information assists farmers in selecting strategies that empower them in coping with climate risk and extreme weather (Baethgen *et al*., 2004; Ogutu *et al*., 2014). Access to information on climate risks and extreme weather has proven positive for adopting climate risk adaptation strategies (Ojo, Ogundeji, *et al*., 2021). Implicitly, the more farmers have access to information on early warnings and weather forecasts, the more likely they are to adopt more climate risk adaptation strategies. Information communication technologies (ICTs) are very important in providing the needed information for the rural poor agrarian to make more prudent decisions to improve their likelihood (Chapman & Slaymaker, 2002).

Research shows that farmers' perceptions of climate change and their adaptation strategies are influenced by education (Ogundari & Abdulai, 2014; Ojo *et al*., 2021b; Ojo & Baiyegunhi, 2020a; Roco *et al*., 2015). Better education creates awareness of potential benefits and a willingness to adapt to new risk management strategies. This could mean that as household heads become more educated, they are also more likely to be aware of climate change. Farmers' ability to receive and process information and their sense of propensity improved with increasing education and training (Asrat & Simane, 2018; Gaurav & Singh, 2012), ultimately leading to increased cognitive performance.

Proximity to markets is an important factor in adapting to climate risks, and markets probably serve as an opportunity to exchange information with other farmers. Distance to nearby markets increases adaptability to drought (W. P. Maddison, 2006; Nyangena, 2008; Ojo & Baiyegunhi, 2021) and found that long distances to the market reduced the likelihood of technology adoption in agriculture.

Farmers who belong to farm-based organisations and social networks can better share information on climate change and new technologies (Abdulai & Huffman, 2014; Baiyegunhi *et al*., 2022; Baiyegunhi & Hassan, 2018; Ojo & Baiyegunhi, 2021; Thinda *et al*., 2020). Farmers acquire much of their information about innovations using social networks and farm-based organisations, by increases the likelihood of adoption. Membership in farmers' organisations increased the chances of being aware of the impacts of climate change. ASFAW, (2019); Kibue *et al*., (2016); Ojo & Baiyegunhi, 2020b) found that farm-based organisations and extension services had a positive impact on farmers' propensity to adopt different adaptation strategies

Limited access to inputs and precarious property rights are the main challenges farmers face in adapting to climate change (Boyce *et al*., 2013; de-Graft Acquah & Onumah, 2011a; Thinda *et al*., 2020). Smallholder agriculture is practised primarily by women at the local level, has limited access to essential agricultural resources, and faces stigma related to access to information and inputs (M. Kassie *et al*., 2013). As pointed out by Ojo & Baiyegunhi (2020a), farmer gender hurts the adoption of climate change adaptation strategies.

Access to information and credit enhanced awareness among farmers (Chilot Yirga Tizale & Mekki Hassan, 2007; Ojo, Ogundeji, *et al*., 2021; Ojo & Baiyegunhi, 2020b; Thinda *et al*., 2020). Access to support services and credits gives farmers the information they need to make decisions and take adaptation measures. For example, funds enable farmers to purchase new crop varieties, irrigation techniques, and other essential inputs. The availability of credit lines increased farmers' financial resources and their ability to cover the operating costs associated with multiple adaptation options.

Several studies have shown that household characteristics significantly influence the adoption of adaptive strategies (Ali & Erenstein, 2017a; Denkyirah *et al*., 2016; Mulwa *et al*., 2017a; Ali & Erenstein, 2017a; Denkyirah *et al*., 2016; Mulwa *et al*., 2017a). However, Ojo, Ogundeji, *et al*., (2021), reveal that age has had a negative effect on some adaptation strategies adopted by farmers. This means that farmers' adaptability declines with age. This relates to the fact that older farmers become more risk-averse and less likely to adopt climate risk strategies, while younger farmers are expected to take risks. This has been recognised by (Denkyirah *et al*., 2016; M. S. Rahman *et al*., 2021) that young farmers are more energetic, risk-taking and innovative and adapt differently to climate change as they age. While elderly farmers prefer traditional farming methods.

1.6 Results and Discussion

1.6.1 Results

1.6.1.1 Description of variables

The descriptive statistics of the surveyed smallholder farmers are presented in Table 1. This section reports both the dependent and explanatory variables used in the models. The findings indicate that a significant proportion of farmers, specifically 87%, have implemented at least one climate risk adaptation strategy to address the impacts of changing climatic circumstances. Out of the 420 respondents, about 71% were males, while 29% were females. The average age and farming experience of the farmers were 49 and 29 years, respectively. This suggests that the majority of the farmers are in the productive age bracket. About 65% of the respondents had contact with extension agents.

Table 1: Descriptive Statistics of Key Variables (N =420)

Variable	**Description**	**Mean**	**Std. Dev.**	**Min**	**Max**
Age	In years	48.783	13.689	18	85
Household size	In numbers	19.686	14.344	2	103
Farming experience	In years	29.031	13.821	2	80
Farm size	Number of hectares	5.064	3.665	1	27
log annual income	Amount in '000 GMD	10.089	1.012	6.908	13.122
Distance to the main market	In km	8.405	7.703	1	35

	Category	**Freq.**	**%**
Access to climate information	No	80	19.05
	Yes	340	80.95
Use of climate services in farming	No Use	108	25.71
	Use	312	74.29
Usefulness of climate information	Not useful	95	22.62
	Useful	184	43.81
	Very useful	141	33.57
Reliability of climate information	Not reliable	97	23.1
	Reliable	179	42.62
	Very reliable	144	34.29
Adoption of adaptation strategies	Non-Adapt	56	13.33
	Adapt	364	86.67
Gender	Male	299	71.19
	Female	121	28.81
Education level	None/No formal	338	80.48
	Primary	35	8.33
	Secondary	37	8.81
	Tertiary	10	2.38
Age category	Young farmers	80	19.05
	Middle-aged farmers	209	49.76
	Old age farmers	131	31.19
Access to government support	No	344	81.9
	Yes	76	18.1
Access to marketing information	No	46	10.95
	Yes	374	89.05
Access to extension services	No	146	34.76
	Yes	274	65.24
Access to credit	No	383	91.19
	Yes	37	8.81
Access to irrigation	No	268	63.81
	Yes	152	36.19
Access to fertiliser	No	143	34.05
	Yes	277	65.95
Training on climate adaptation	No	334	79.52
	Yes	86	20.48
Membership in a social/farm group	Not a member	43	10.24
	Member	377	89.76
Witnessed unexpected weather	No	34	8.1
	Yes	386	91.9

Source: Author's analysis based on survey data (2023)

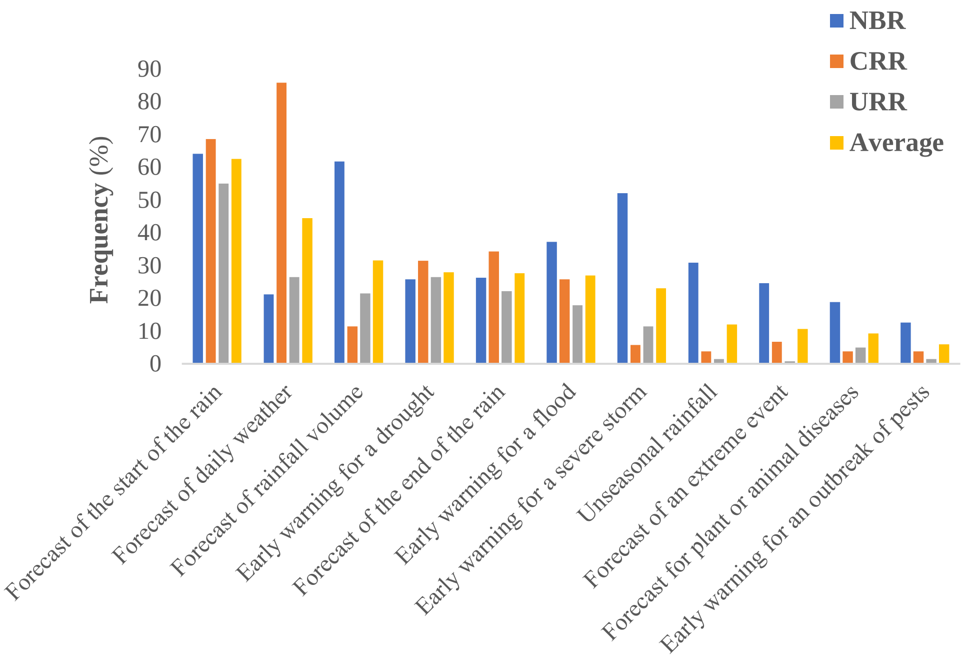
A small number of the farmers had access to credit and government support, 9% and 18% respectively, which is a major determinant in the adoption of adaptation strategies. 66% had access to fertiliser, and 21% had received training on climate risk adaptation strategies. 86% and 88% witnessed an unexpected event and perceived a change in the climate, respectively. Nevertheless, there existed a discrepancy of approximately 7% in terms of the disparity in accessing and utilising climate information. A significant number (about 81%) of the farmers had no formal education.

1.6.1.2 Level of climate information access by smallholder farmers in various regions

Figure 12 presents the different types and levels of access to climate information. The most prevalent climatic information available to farmers in The Gambia is the forecast for the start of the rainy season. This is most likely because the rainy season is the most significant season for agriculture in the Gambia. The graph demonstrates that many farmers also have access to information regarding extreme events like droughts and floods. This is significant because these occurrences can have a severe impact on their livelihoods.

Figure 12:[2] Types and level of access to climate information

1



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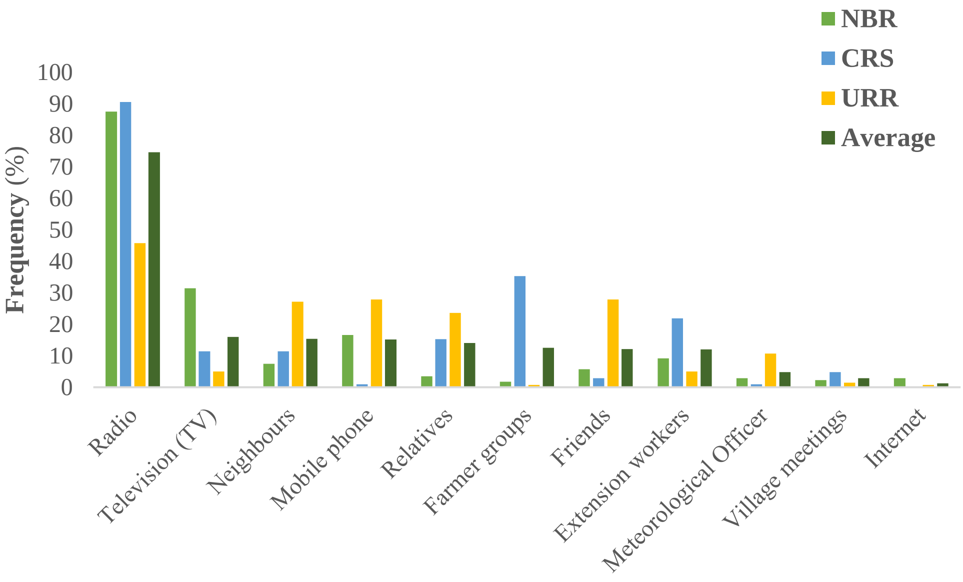
[2] NBR=North Bank Region
CRR=Central Reiver Region
URR=Upper River region

There is a considerable knowledge gap among users about what type of information is accessible, where it can be discovered, and how it may be used in agricultural management decisions. The value of climate and weather information is lost if it is not used to adjust crop management. Small-scale farmers often face challenges in accessing weather and agrometeorological information, which can be attributed to inadequate communication channels, despite the significant advancements in technology, a lack of adaptation to the farming scale, or a lack of translation into the local language (FAO, 2019a).

In Figure 13, Radio is the most common source of early warning climate information for farmers in The Gambia. This finding is different from (Sen *et al*., 2021a) who found that Television is the most common source of climate information in Vietnam. This is most likely since radio is an easily accessible medium that may reach a vast number of people in The Gambia. Mobile phones are also becoming more popular as a source of weather data because mobile phones are becoming more affordable and accessible, as well as the fact that they can be used to access a range of climate information apps.

Figure 13: Sources of climate information

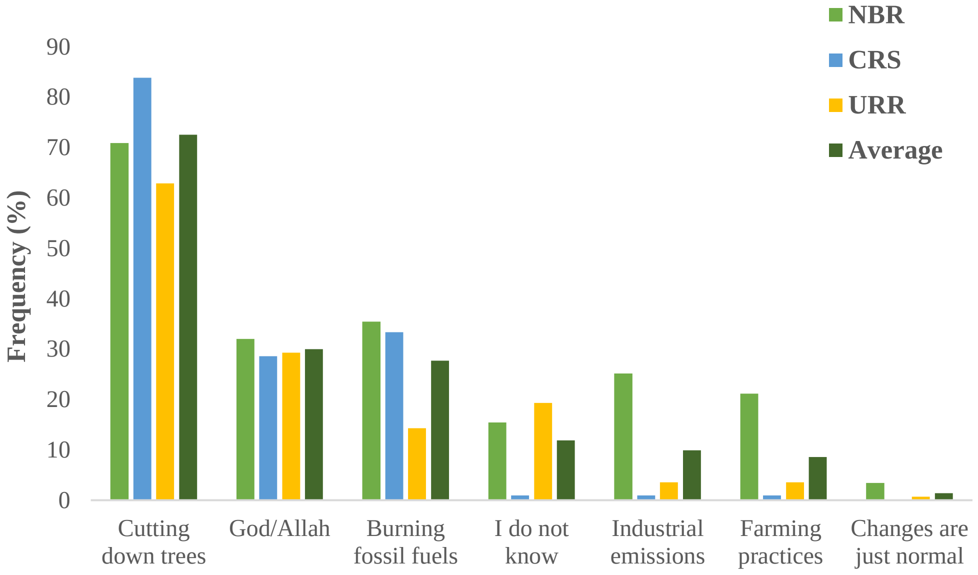


However, not many farmers receive information from government extension workers due to an inadequate number of extension workers available. The Internet is the least-used source of climate information for farmers. According to Business Insider Africa (2023), it is one of the countries with expensive data charges, with an average of $5.86 per gigabyte. The finding revealed that farmers in all three regions used climate information on agronomic adaptation strategies such as sowing and fertiliser application times. Given that farmers use climate information in their agricultural decision-making regarding adaptation measures, the findings can be relevant to policy decisions.

1.6.1.3 Perceived causes of climate change and types of adaptation strategies

Figure 14 depicts farmers' understanding of the causes of climate change. Farmers recognised numerous reasons for climate change. Farmers believed that the main causes of climate change are cutting down trees (73%), God/Allah (30%), burning fossil fuels (28%), industrial emissions (10%), and farming practices (9%). A good number of farmers (30%) still believe that God/Allah caused climate change, whereas 1% were unsure.

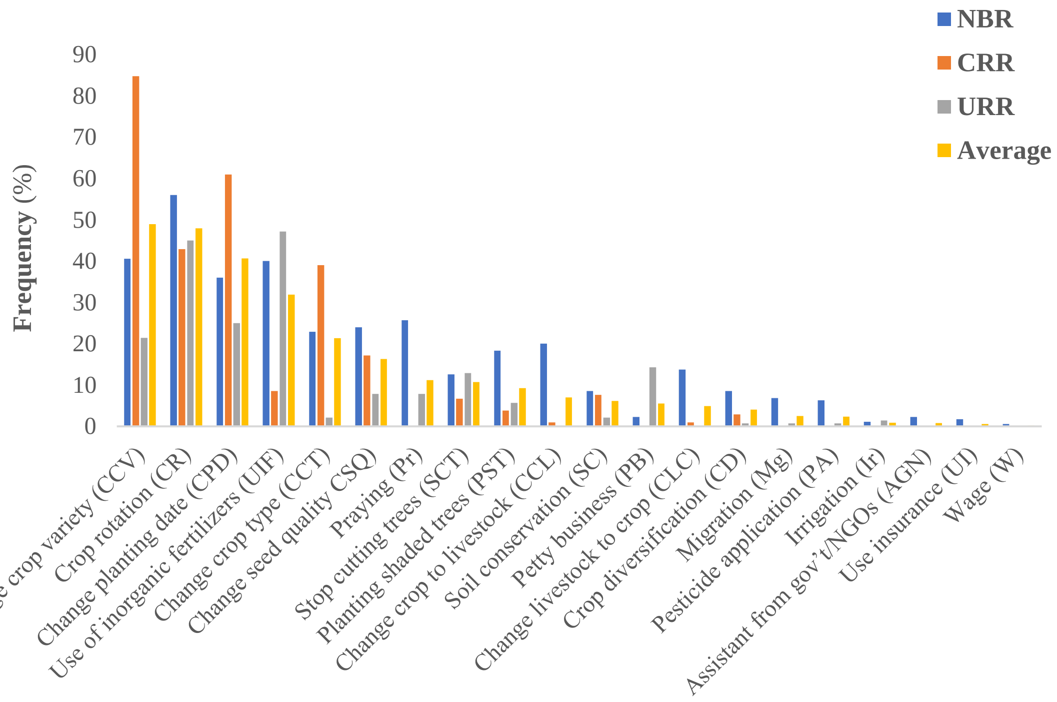
Figure 14: Farmers' perceived causes of climate change



Several studies have highlighted deforestation as the principal source of climate change (Nana *et al*., 2013; Ngigi *et al*., 2016; Tesfahunegn *et al*., 2016; Ugwoke Agbo *et al*., 2015). The causes of climate change can have an impact on the earth's capacity to absorb or reflect thermal and radiant energy. (Deressa *et al*., 2011b). According to the findings of Farauta & African Technology Policy Studies Network (2011), it has been determined that agriculture has a significant role in climate change, predominantly due to the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. However, it was observed that farmers in the research area could not recognise the impact of these agricultural practices on climate change. This highlights the importance of enhancing farmers' comprehension of this matter. Based on the 2023 assessment conducted by the Intergovernmental Panel on Climate Change (IPCC), the combustion of fossil fuels over more than one hundred years, along with inequitable and unsustainable practices in energy and land utilisation, has led to a global warming of 1.1°C above pre-industrial levels. Consequently, there has been a notable escalation in the frequency and intensity of extreme weather phenomena, presenting a mounting peril to both the natural environment and human populations across the globe (Reisinger *et al*., 2022).

The farm household survey results indicate 20 different livelihood adaptation techniques, with the majority of farmers participating in more than one (Figure 15).

Figure 15: Adaptation strategies used by farmers



Drought-resistant crops, short-maturing crops, soil conservation, modifying crop calendars, planting trees, water-gathering practices, and irrigation were among the most popular practices in both regions. The most popular livelihood adaptation techniques were changing crop variety (49%), crop rotation (48%), changing planting date (41%), and use of inorganic fertilisers (32%). These findings are consistent with previous research on climate change adaptation techniques and crop selection in Ethiopia and Africa (Ahmed *et al*., 2021; Bryan *et al*., 2013a; Demeke *et al*., 2011; Kosoe & Ahmed, 2022). Planting shaded trees (9%) was not a particularly common adaptation strategy adopted by farmers, contrary to studies (Adamseged & Kebede, 2023a; Bryan *et al*., 2013a; Kosoe & Ahmed, 2022) found growing trees to be a fairly common approach utilised by rural families.

1.6.1.4 Determinants of access and use of climate information

Table 2 shows the results of access and use of climate information. The probability of the chi-square is statistically significant at 1%, indicating that both models are appropriate and the results of the model are statistically significant.

Table 2: Logistic regression analysis of factors influencing access to and use of climate information

	Access to climate information		Use of climate information	
	Coef.	Std. Err.	Coef.	Std. Err.
Gender (Base: Male)				
Female	**-0.783****	0.383	**-0.672***	0.362
Education level (Base: No formal)				
Primary	0.087	0.695	**-0.894***	0.576
Secondary	-0.251	0.719	0.233	0.699
Tertiary	-0.43	1.042	0.20	1.106
Female#Primary	1.344	1.184	**3.161****	1.223
Female#Secondary	**3.241****	1.578	**2.340***	1.597
Female#Tertiary	0	-	0	-
Agecat (Base: Less than 35 (young farmers))				
35-55 years (Middle age)	**0.996****	0.433	**0.919****	0.397
Above 55 years (Old age farmers)	0.258	0.458	0.306	0.422
Access government support	-0.262	0.4	-0.145	0.398
Access to marketing information	**1.803****	0.425	**1.550****	0.437
Access to extension services	**0.711****	0.333	0.438	0.317
Training on climate risk adaptation	**1.712****	0.776	**1.278****	0.545
Member of asocial/farm group	**-0.890***	0.573	-0.546	0.526
Trust in the media	**2.343*****	0.401	**3.260*****	0.49
Witness an unexpected weather event	**1.133*****	0.397	**2.077*****	0.46
Constant	**-2.796****	0.77	**-5.127****	0.852
N	420		420	
Log-likelihood	-132.350		-147.029	
LR chi2(17)	144.310		202.880	
Prob>chi2	0.000		0.000	
Pseudo R2	0.353		0.408	

Source: Author's analysis based on survey data (2023)

The logit results show that farmers aged 35-55 years have access to marketing information, attend training on climate risk adaptation, trust in the media, have access to extension services and witness unexpected weather events; this positively shapes farmers' access to and use of climate information. This finding shows that middle-aged farmers have more access to and use climate information than young and old farmers. This is in line with the findings of (Sen *et al*., 2021a). Elderly farmers exhibit a greater propensity to depend on their accumulated experience and traditional wisdom for their livelihood pursuits, as opposed to embracing novel ways or absorbing external recommendations. With access to information about marketing, they may pick and improve the products they sell, select better marketing and delivery methods, promote things more effectively, and in some instances even influence prices. As farmers demonstrate a higher level of trust in the channels via which information is disseminated, this will result in increased attentiveness, support, and motivation to obtain and utilise the information. This outcome is consistent with the discoveries reported in previous studies conducted by (Lemos *et al*., 2012; Muema *et al*., 2018; Sen *et al*., 2021a).

Access to extension services only positively influences access to climate information, but does not influence farmers' use of the information. Being female has a negative influence on the access and utilisation of climate information. This result indicates that female farmers are less likely to access and use climate information than male farmers. This is because women are less likely to have access to digital devices and the internet, (Ministry of Gender Children and Social Welfare, 2024) compared to men. Secondary education does not show a significant influence on farmers’ access to and application of climate information. Still, when interacting with females, it has a significant positive impact on access to and use of climate information. This means educating women will increase their access to and use of climate information.

The marginal effect estimates, as presented in Table 3, provide key insights into factors influencing farmers’ likelihood to access and use climate information. Farmers with primary and secondary education have marginally higher probabilities of accessing and using climate information, but these effects were not statistically significant. Age emerged as a significant determinant, with middle-aged farmers being 9.7% more likely to access and significantly likely to utilise climate information compared to younger farmers. However, older farmers did not significantly differ from younger farmers.

Access to marketing information stood out as a robust predictor of both access and use of climate information, increasing it by 17% and 16%, respectively, reinforcing the critical role of market engagement in climate decision-making processes. Likewise, training on climate risk adaptation had a significant and positive effect on increasing access (16%) and use (13%) of climate information, emphasising the role of capacity-building initiatives for enhancing adaptive behaviours of farmers. Trust in the media was the most powerful determinant of access and use, increasing the probability by 22% and 34%, highlighting the pivotal role of credible communication channels in facilitating climate-responsive actions. Smallholder farmers who had exposure to unexpected or extreme weather events were also more likely to engage with climate information. This highlights the transformative impact of experiential awareness on climate responsiveness. While extension services also demonstrated a positive and statistically significant effect in only access.

Table 3: Marginal effect of the estimates

	Access to climate information	Use of climate information
Variable	Marginal effect dy/dx	
Female (base: Male)	–	
Education Level (vs Tertiary)		
Primary (base: Tertiary)	0.0463	-0.0131
Secondary	0.0509	0.0825
Tertiary (base)	–	
Age Category (vs Young)		
Middle-aged farmers (base: Young)	0.097*	0.1014*
Old-aged farmers	0.0286	0.0378
Access Variables		
Access to government support	-0.0249	-0.0153
Access to marketing information	0.1718***	0.1634***
Access to extension services	0.0678*	0.0461
Training on climate risk adaptation	0.1631*	0.1347**
Social Variables		
Member of a social farm group	-0.0848	-0.0575
Trust in the media	0.2233***	0.3437***
Witnessed unexpected weather event	0.108**	0.219***

NB: *$p < 0.05$, **$p < 0.01$, **$p < 0.001$

Source: Author's analysis based on survey data (2023)

Other factors, such as access to government support and membership in social groups, did not show a statistically significant effect. This finding highlights the critical role of market access, capacity building initiatives, trust in media, personal climate experience and middle age as key determinants of farmers’ engagement with climate information.

The result from Table 4 shows that gender (base: male) has a statistically significant impact on farmers' views of the reliability and usefulness of early warning climate information. Female farmers perceive climate information as less accurate and valuable compared to their male counterparts. This is because female farmers have fewer resources, and there is a gender norm around climate change that makes it difficult for women to adapt to climate change.

Table 4: Multinomial Logistic (MNL) regression analysis of factors influencing farmers' perception of climate information service

	Perceive a change in the average reliability of climate information (base: not reliable)		Perceive a change in the average usefulness of climate information (base: not useful)	
	Reliable		Useful	
	Coef.	Std. Err.	Coef.	Std. Err.
Gender (Base: Male)				
Female	**-0.969*****	0.381	**-0.872****	0.366
Agecat (Base: Less than 35 (young farmers))				
35-55 years (Middle age)	0.294	0.458	0.44	0.438
Above 55 years (Old age farmers)	0.487	0.507	0.417	0.488
Education level (Base: No formal education)				
Primary	-0.182	0.596	0.388	0.595
Secondary	-0.096	0.680	0.072	0.650
Tertiary	-0.359	1.135	-0.133	1.080
Access government support	-0.059	0.430	-0.009	0.416
Access to marketing information	**1.839*****	0.478	**1.489*****	0.439
Access to extension services	0.254	0.352	0.277	0.339
Training	1.009	0.755	1.072	0.719
Member of a social/farm group	0.026	0.580	-0.305	0.563
Trust in the media	**3.141*****	0.490	**2.679*****	0.447
Witness an unexpected weather event	-0.061	0.649	0.295	0.607
Climate change perception	**1.618****	0.705	**1.299****	0.647
Constant	**-4.850*****	0.915	**-3.969*****	0.843
N	420		420	
Log-likelihood	-324.39875		-334.37965	
LR chi2(28)	249.13		225.17	
Prob>chi2	0.000		0.000	
Pseudo R2	0.2775		0.2519	

Source: Author's analysis based on survey data (2023)

In the Gambia, women are expected to take on the burden of childcare, which will prevent them from finding time to learn about climate change. Female farmers are often less educated than male farmers (Sonko *et al.*, 2020). Middle-aged and older farmers show no significant difference in perception compared to the base category (young farmers). Access to marketing information, trust in the media, and witnessing unexpected events (such as extreme weather events, crop failures, or other unforeseen circumstances) place higher trust and value in climate information as a useful tool to anticipate and prepare for future events. Farmers who possess a perception of climate change exhibit an elevated level of adaptive capacity. These empirical findings provide support for the studies that posit that farmers' perceptions of climate change tend to enhance their perceived dependability and utility of climate information.

The empirical findings derived from Table 5, the recursive bivariate probit model, are divided into two aspects: factors influencing farmers' use of climate information services (selection equation) and the effect of using climate information on the adoption of climate adaptation strategies (outcome equation).

Table 5: Recursive bivariate probit estimation of factors influencing the use of climate information and adaptation strategy

	Use of climate information (Treatment Variable)		Adaptation strategy (Outcome Variable)	
	Coef.	Robust Std. Err.	Coef.	Robust Std. Err.
Use of climate information services			**1.009****	0.514
Gender (Base: Male)				
Female	-0.133	0.242	**-0.513*****	0.192
Education level (Base: No formal education)				
Primary Education	0.237	0.347	-0.202	0.278
Secondary Education	0.065	0.37	0.475	0.331
Tertiary Education	**6.083*****	0.324	-0.061	0.506
Household size	**-0.016****	0.007	-0.005	0.006
Age	0.051	0.038	0.041	0.034
Agesqu	-0.001	0.000	0.000	0.000
log Average annual	**0.380*****	0.121	-0.033	0.095
Membership of a farm/social group	0.086	0.288	-0.044	0.277
Access to extension services	0.117	0.199	0.182	0.164
Trust in the media	**0.627***	0.414	**2.501*****	0.252
Access government support	**0.671****	0.286	-0.137	0.191
Constant	**-4.713*****	1.727	**-1.967***	1.263
Treatment effects				
ATE	**0.1876***	0.111		
ATT	**0.2377****	0.1031		
/atanrho	0.3138	0.2304		
Rho	0.3038	0.2091		

N = 420

Wald chi2(25) = 705.00

Log pseudolikelihood = -259.09111

Prob > chi2=0.000

Wald test of rho=0: chi2(1) = 1.85434
Prob > chi2 = 0.1733

Source: Author's analysis based on survey data (2023)

The findings indicate that the use of climate information is positive and statistically significant, indicating that access to and use of climate information significantly increase the likelihood of adopting an adaptation strategy. This implies that farmers who use climate information are more likely to adopt strategies to respond to climate variability. Although the study conducted by Owusu *et al*. (2021) did not yield statistically significant results, it revealed that the use of climatic information did not have a substantial effect on the adoption of adaptation strategies in the Upper West Region of Ghana. The selection equation revealed several significant factors influencing farmers' use of climate information services. Notably, tertiary education shows a strong positive and statistically significant effect, indicating that farmers with higher educational attainment are considerably more likely to use climate information compared to those without formal education. The log of average annual income demonstrated a positive and statistically significant relationship, showing that affluent households are more inclined to obtain such pieces of information, potentially due to better connectivity or institutional linkages. Additionally, trust in media was also positively associated with the use of climate information, implying that farmers with faith in media sources are more receptive to information disseminated through these channels.

Furthermore, access to government support had a positive and statistically significant impact, emphasising the role of public interventions such as subsidies, training, and outreach programs in promoting the adoption of climate information services. The size of the household was found to have a negative effect, larger households may be slightly less inclined to access climate information due to competing demands on limited resources. Access to extension service variable is positive but not statistically significant. This is different from the studies of (Antwi-Agyei *et al*., 2014; Owusu *et al*., 2021), who found extension service to be statistically significant.

The treatment effects derived from the recursive bivariate probit model, which corrects for potential endogeneity, provide important insights into the impact of climate information use on the adoption of adaptation strategies. The Average Treatment Effect (ATE) was found to be statistically significant, indicating that, on average, the use of climate information increases the likelihood of Gambian farmers adopting adaptation strategies by 18.76%. More notably, the Average Treatment Effect on the Treated (ATT) increased the probability of adopting such strategies by 23.77%.

1.6.1.5 Hypothesis testing between the users and non-users of climate information

Table 6 shows the relationship between farmers who use or do not use climate information and those who take or do not take adaptation strategies.

Table 6: Pearson's chi-square test for the relation between the use of climate information and adaptation

	Adaptation		
Use of climate information	Non-Adapt	Adapt	Total
Use	11	292	303
	3.63	96.37	100
	19.64	80.22	72.14
No use	45	72	117
	38.46	61.54	100
	80.36	19.78	27.86
Total	56	364	420
	13.33	86.67	100
	100	100	100
Pearson chi2(1)	88.6185		
Pr	0.000		
Cramér's V =	-0.4593		

Source: Author's analysis based on survey data (2023)

The Cramer's V gives us the effect size. The probability of the chi-square is significant at 1%, and this means that the relationship between farmers who use climate information and take or do not take adaptation strategies is significant. The result of the proportion test calculator shows a significant difference between farmers who use or do not use climate information and those who adapt or do not adopt any adaptation strategy.

The result from Table 7 shows a significant difference between those who use and those who do not use climate information in adopting a climate risk adaptation strategy. This means that farmers who use climate information tend to adopt climate risk adaptation strategies than those who do not use climate information.

Table 7: Testing the significant difference between those who use and those who do not use climate information to adapt

Two-sample test of proportions				Adapt:	Number of obs = 292	
				Adapt:	Number of obs = 72	
	Mean	Std. Err.	z	P>z	[95% Conf. Interval]	
Use	0.802	0.023			0.757	0.848
No use	0.198	0.047			0.106	0.290
Diff	0.604	0.052			0.502	0.707
	under Ho:	0.061	9.870	0.000		
diff=pr p(use)-prop (no use)					z =	9.869
		Ho: diff=0				
	Ha: diff<0		Ha: diff! = 0		Ha: diff> 0	
	Pr (Z <z) =1.000		Pr (Z >z) =0.000		Pr (Z > z) =0.000	

Source: Author's analysis based on survey data (2023)

The hypothesis tested in this essay posits that farmers with greater access to climate information services are more likely to adopt effective adaptation strategies. The results from both the chi-square test and the two-sample test of proportion provide compelling evidence that validates it. Table 5 illustrates that the Pearson chi-squared statistic is highly significant association between the use of climate information and the adoption of adaptation strategies. Moreover, Table 6 reveals that 80.2% of farmers who used climate information adopted adaptation strategies.

1.6.2 Discussion

The household size coefficient has shown a statistically significant positive impact on the use of chemical fertiliser as a means of adapting to climate change. The finding aligns with prior studies (Ali & Erenstein, 2017; Deressa *et al.*, 2009b), which also found a direct correlation between the size of a household and the use of chemical fertiliser to adapt to climate change. Additionally, within the framework of our study, migration emerges as a viable climate risk adaptation strategy for smallholder farmers in rural Gambia. Similar to previous research on climate change in Bangladesh, where farmers who adapt sowing times or adopt stress-tolerant crop varieties experience varying impacts on production efficiency, migration offers an alternative strategy to mitigate climate risks (Zhu *et al.*, 2024). However, unlike the finding in Bangladesh, where migration opportunities can inversely correlate with other adaptation strategies and pose potential threats to food security, our study found no statistically significant correlation between household migration. This is contrary to expectation, as it was assumed that larger families, with more adults, would more likely use migration as a key adaptation method (Adamseged & Kebede, 2023a).

The relationship between farmers' accessibility to extension services and their choice of strategy for change in planting dates or crop variety was positive and significant. Thus, it implies that if farmers have understandable information and extension materials, they can be even more encouraged to adopt climate risk strategies. These findings are consistent with other studies (Adesina *et al.*, 2000; Ojo & Baiyegunhi, 2021) which demonstrates the importance of institutional support and extension services in promoting climate change adaptation. Moreover, research shows farmers benefit from being attached to an institution and having facilities for extension services (D. Maddison, 2007). Research has shown that farmers who lack experience with extension services often struggle to understand the full impacts of climate change (Bryan *et al.*, 2013b). Our findings also reinforce that farmers who have contact with extension workers experience substantial improvement in production and income (Abegunde *et al.*, 2020; Aryal *et al.*, 2021). Thus, improving access to extension services remains a critical way to support farmers in adapting to climate risks.

Furthermore, membership in social or farm groups has a significant positive influence on farmers' adoption of on-farm strategies. As highlighted by (B. T. Kassie *et al.*, 2013), farmer group gatherings offer opportunities to exchange experiences and disseminate information regarding adaptation strategies. Cognitive processes have a spill-over effect, as demonstrated by (Bandiera *et al.*, 1997), and the act of farmers joining associations results in membership. Farmers' perception of climate plays a critical role in determining their adaptation behaviour. The findings indicate that farmers' perceptions of changes in the climate significantly influence their inclination to adopt farm adaptation techniques. Our findings further indicate that farmers' perceptions of climate change significantly influence their likelihood of adopting on-farm adaptation techniques. Similar to other studies (Deressa *et al.*, 2009b) farmers who perceive climate change as a substantial risk are more likely to employ additional on-farm tactics. Therefore, a broad range of adaptation measures is essential to help farmers mitigate climate risk.

The study also found a deep connection between access to credit and the adoption of climate risk adaptation strategies, consistent with previous research (Marie *et al.*, 2020; Ojo, Adetoro, *et al.*, 2021; Ojo & Baiyegunhi, 2020b). However, while our results show that the coefficient on credit access was insignificant, potentially due to tight credit conditions among farmers, these findings align with studies that highlight similar financial constraints in rural settings (Ojo, Adetoro, *et al.*, 2021; Uddin *et al.*, 2014). Likewise, the coefficient for farmers who received climate change training was insignificant and negatively correlated with the adoption of on-farm adaptation measures, an outcome that was unexpected but aligns with other studies (Ojo, Adetoro, et al., 2021; Uddin et al., 2014).

Finally, our results highlight several constraints to adaptation, including low education (37%), lack of access to assets (35%), inadequate extension services (32%), and inadequate access to irrigation (29%) are constraints to adaptation, as confirmed by previous research (Fahad & Wang, 2018; A. A. Shah et al., 2023; R. Ullah & Shivakoti, 2014). A recent study in Bangladesh has also underscored the significant risks posed by environmental degradation driven by industrial development, which threatens rice production due to its detrimental effects on soil, water, and air quality, necessitating improved farmer awareness and targeted government interventions to mitigate these impacts (A. Rahman *et al.*, 2022). These findings emphasise the need for improved farmer awareness and targeted government intervention to mitigate these impacts.

1.7 Conclusion

The provision of climatic information plays a pivotal role in facilitating the ability of smallholder farmers in rural Gambia to effectively adjust to the consequences of climate change. This study assesses how smallholder cereal farmers in The Gambia's primary agricultural regions access and utilise climate information, their perceptions of its usefulness and reliability, and its impact on their adoption of climate risk mitigation strategies. The study's findings highlight significant implications for food security in The Gambia, where over 60% of the population relies on agriculture. Improving access to and use of climate information is crucial for enhancing agricultural productivity and resilience. Middle-aged farmers, those with higher education levels, and those who trust media sources are more likely to use climate information and adopt effective adaptation strategies. Efforts to enhance education, build trust in media, and provide targeted government support can significantly improve farmers' adaptive capacity. The study also underscores the need for targeted interventions to ensure female farmers have equal access to climate information and resources. Improving education and training for women can increase their ability to use climate information effectively, enhancing their resilience to climate risks. By adopting climate information services, farmers can make informed decisions, better manage climate risks, and improve agricultural productivity, thereby mitigating the impacts of extreme weather events, reducing crop failures, and enhancing food security. The results of this study emphasised the significance of policymakers intensifying their endeavours to ensure that climate information is provided in a timely and reliable manner while also being customised to meet the specific requirements of farmers. Integrating climate services into agricultural decision-making can lead to more sustainable practices, improved food security, and overall economic development in The Gambia. The study’s main limitation lies in its dependence on cross-sectional data, which limits the ability to establish causality between access to climate information and the adoption of adaptation strategies. Future research should consider longitudinal studies to track changes in farmers' behaviour over time and assess the long-term impact of climate information use on agricultural productivity and resilience.

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2. Essay 2: Climate Risk Perception and Adaptation Strategies of Smallholder Farmers in The Gambia[3]

Abstract

Climate risk poses significant challenges to agriculture in The Gambia, especially for smallholder farmers reliant on rain-fed farming. Adaptation efforts will be ineffective unless farmers' perspectives of climate change are understood. The objectives are to examine smallholder farmers' perceptions of climate risk, identify their adaptation strategies, and examine the factors that influence the adoption of these adaptation strategies at the farm and off-farm levels. Data were collected from 420 smallholder farmers across three regions of rural Gambia using a survey and multistage sampling technique. Binary logistic and multivariate probit models were used to analyse the determinants of farmers' decisions to adopt adaptation strategies. The empirical result of the binary logistic model indicates that land tenure, access to government support, access to markets, exposure to extreme weather events, and climate change perception influenced farmers' choice to adopt adaptation measures. The findings further indicate that female farmers are less likely to adopt adaptation measures. However, the multivariate probit model revealed that age, education, access to extension services, membership of farm groups, and perceived climate change are the main determinants of on-farm adaptation strategies. Off-farm strategies such as petty business are mainly influenced by being female, middle-aged, and having primary education. The results suggest that gender-disaggregated support and targeted policies are necessary to encourage the adoption of adaptation strategies among female farmers. It is recommended that the government enhance access to credit, provide tailored support for women farmers, and improve extension services to foster effective adaptation in rural Gambia.

Keywords: · Climate risk · Adaptation · Binary logistic · Multivariate probit · The Gambia

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2.1 Introduction

The Gambia is highly vulnerable to climate change due to its low-lying topography, with 20% of the area covered by tidally inundated swamps threatened by permanent flooding from a 1m sea level rise. Coupled with its heavy dependence on rain-fed subsistence farming, inadequate water management systems, widespread poverty, and limited adaptive capacity (Sonko *et al.*, 2020; Urquhart, 2016). According to the report of the (GCRI, 2021) Gambia ranks 41st in terms of vulnerability to climate change out of 180 countries. The country faces severe climate-related challenges such as rising temperatures, increased drought occurrence, erratic rainfall and extreme weather events, which significantly threaten agricultural productivity and rural livelihoods (Gibba *et al.*, 2020.). The country faces interseasonal droughts, water scarcity, floods, dry spells, and heat waves, which, combined with dependence on rain-fed agriculture, hinder agricultural productivity and food security (NAPA, 2007; ADB 2020; Jaiteh, 2011).

Policies that encourage climate risk adaptation frequently depend on the willing collaboration of the intended beneficiaries. The execution of the policies will fail if these beneficiaries disagree with policymakers and programme managers about the need for adaptation or the efficacy of the actions, they are being asked to take (Patt & Schröter, 2008a). Ineffective recognition of climate change impacts on agricultural systems can have a considerable influence on food production and food security, as well as obstruct poverty reduction and sustainable development efforts. A large amount of research on farm-level adaptation to climate change has been conducted across several disciplines in various countries to elucidate farmers' adaptive behaviour and its (Bryan *et al.*, 2013a; Deressa *et al.*, 2009a; Hassan *et al.*, 2008; Thomas & Benjamin, 2018). Despite substantial international research on climate change adaptation in agriculture, little work has been done in Africa (Fahad & Wang, 2018). Previous research has demonstrated that farmers always utilise a combination of approaches to adjust agriculture to climate change vulnerability (Ali & Erenstein, 2017a). At the farm level, farmers employ a variety of approaches (Abid *et al*. 2016; Deressa *et al.*, 2009b; Fahad & Wang, 2018; Hussain & Mudasser, 2007; Mendelsohn, 2006). Farmers' adaptation tactics are influenced by a variety of social, economic, and environmental factors (Bryan *et al.*, 2013b; Deressa *et al.*, 2009b). This understanding will ultimately strengthen policies' legitimacy and their ability to address the issues posed by climate change to farmers (Deressa *et al.*, 2009a). As a result, understanding how farmers perceive changes in climate-related risk, as well as what factors impact their adaptive behaviour, is important for adaptation research (Mertz *et al.*, 2011; J. A. Weber & Wong, 2010). Studies concerning climate-related risk perceptions, vulnerability, and adaptation are very limited in The Gambia, which is one of the world's most vulnerable countries. The country is ranked 28th in terms of vulnerability and 139th in terms of preparedness (Chen *et al.*, 2015).

Research question

The main research question for this essay is: How do smallholder farmers perceive climate risks, and what factors influence their decision to adopt adaptation strategies in response to climate change? Specifically;

- what are the main climate risks farmers face, and how do they perceive these risks?
- what factors influence farmers' decisions to adopt climate risk adaptation strategies in agriculture?
- what are the key determinants of farmers' adaptation strategies to climate change?

Objectives

The general objective is to examine smallholder farmers' perceptions of climate risk and analyse the factors that influence their decision to adopt adaptation strategies in response to climate change. Specifically;

- to identify the main climate risks faced by farmers and their perception of climate risks.
- to analyse the factors that influence farmers' decisions to adopt climate risk adaptation strategies.
- to examine the key determinants of farmers' adaptation strategies to climate change.

Hypothesis (Ho)

There is no significant relationship between farmers' perception of climate risk and their likelihood to adopt both on-farm and off-farm adaptation strategies.

To date, research on climate change and agriculture in The Gambia has been entirely focused on the effects of climate change on specific crops or industries. There is limited research on the impact of climate change on agriculture in the country (Belford *et al.*, 2022). Existing research on climate risk adaptation in The Gambia lacks scientific rigour and fails to provide comprehensive insights into the perception of climate risk among smallholder farmers and the factors driving their adaptation decisions (Akon-Yamga *et al.*, 2011; Amuzu *et al.*, 2018;

Belford *et al*., 2022; Gomez *et al*., 2020; Komma, 2019; Sanneh *et al*., 2014; Sillah, 2013; Sow *et al*., 2018). As a result, they are insufficient and imperfect in giving a full scientific prognosis of the country's response to climate risk. Other studies (Bojang *et al*., 2020; Cham *et al*., 2018; Yaffa *et al*., 2018) focused narrowly on specific farming sectors or farm-level adaptation, overlooking the critical role of off-farm adaptation strategies, which account for up to 50% of the income of rural households in sub-Saharan Africa (SSA) (Davis *et al*., 2017).

Most research and policies regarding climate change adaptation analyses focus on the factors, limitations, and prospects for farm households' adaptation, with a strong analytical emphasis on the adjustment of farming operations (Ali & Erenstein, 2017b; Deressa *et al*., 2009a; Di Falco *et al*., 2011; Mulwa *et al*., 2017a; Twecan *et al*., 2022). These studies scarcely consider the various livelihood possibilities undertaken by households residing in rural areas. There is strong evidence that rural households rely on a range of livelihood activities that can be categorised as farm and non-farm-level strategies (Ahmed *et al*., 2021; Andersson Djurfeldt, 2022; Kosoe & Ahmed, 2022). As a result, focusing just on farm-level adaptation only captures a portion of the comprehension narrative of climate change adaptation. Non-farm strategies are critical to rural communities’ livelihoods in The Gambia. The diversification of livelihoods is crucial for adapting to climate change (Kosoe & Ahmed, 2022). The study (Assan & Kumar, 2009) underlines the need to comprehend the full scope to which environmental variability and climate change are reshaping impoverished people's livelihood possibilities. They emphasise the importance of understanding which livelihood options and approaches result in long-term adaptation to climate change. Additionally, there is a limited understanding of gender-disaggregated factors that shape farmers’ adaptation behaviours.

To fully understand local-level susceptibility to climate change risk and adaptation measures, field-based research is becoming increasingly important (Moser & Luers, 2007). There are still gaps in our understanding of the many adaptation tactics used by rural households, as well as the elements that influence their selection of adaptation. Considering the literature deficit, this study contends that rural livelihood households should be at the forefront of research and policy agendas regarding climate change adaptation in developing countries such as The Gambia. Thus, initiatives that try to mitigate the effects of climate change on impoverished households in rural areas without taking into consideration their livelihood possibilities undervalue their capacity to respond to harsh climate patterns. Placing livelihood as the central focus of adaptation methods, on the other hand, allows for the design of appropriate policy interventions for rural households that are vulnerable based on their domestic and household circumstances.

If urban farmers' perceptions of climate change are still unclear (Olumba *et al*., 2024), rural farmers may face even more uncertainty due to potential limitations in access to information, education, and other resources needed to understand and adapt to its impact.

The research gap this study aims to address is that the current literature focuses primarily on farm-level adaptation strategies without considering the role of off-farm activities in rural farmers’ climate risk adaptation strategies. This is substantial as farmers’ perception of climate risk directly affects their ability to adapt, and comprehending these perceptions is crucial for formulating effective adaptation policies. Without a comprehensive, data-driven analysis of factors shaping these perceptions, policymakers may neglect critical obstacles that farmers have in adapting to climate change. It also seeks to fill the gap in targeted support for female farmers, whose adaptation efforts are often limited by various social and economic barriers. Furthermore, the researcher has not found any studies in The Gambia that econometrically analyse factors that determine farmers’ perception of climate-related risks. Existing studies are limited in scope, often failing to rigorously assess how farmers perceive climate risks and socioeconomic factors that influence their adaptation measures.

To achieve the objectives, this essay is structured as follows: The first section covers the introduction part of the essay. Section 2 provides a detailed background of climate risks and the agricultural context in The Gambia. Section 3 reviews theoretical and empirical literature relevant to climate risk perception and adaptation strategies. Section 4 outlines the methodology, including the data collection process and econometric models employed. Section 5 presents the key findings and discussion. Finally, Section 6 concludes with policy implications and recommendations based on the study's results.

2.2 Background

2.2.1 Global overview of climate risk

Climate risk refers to the possible effects of changes in temperature, precipitation, sea level, and other climate-related factors on human health, ecosystems, and infrastructure. Climate risk can be defined as the combination of the likelihood that a specific climate-related event will occur and the accompanying consequences if it does occur. Climate hazards are becoming increasingly relevant as the globe deals with the implications of climate change, which include more frequent and intense extreme weather events that are growing more severe. Climate change will affect countries differently at different scales, based on their particular topography, infrastructure, and degree of development, making it a global concern that will demand coordinated international action. The long-term picture for global risks, according to the Global Risks Report 2023, is characterised mostly by deteriorating environmental threats. Climate and environmental threats will be among the top 10 risks in the following decade.

Biodiversity loss and ecosystem collapse are among the top global threats that will intensify over the next decade. The destruction of natural capital as a result of species extinction or decline in both terrestrial and marine ecosystems has serious consequences for the environment, humans, and economic activity. Failure to address climate change is one of the most dangerous short-term concerns. The Intergovernmental Panel on Climate Change (IPPC, 2022) estimates that there is a 50% likelihood of surpassing the 1.5°C limit by 2030. Governments, businesses, and individuals have failed to implement and invest in effective climate change mitigation measures such as economic decarbonisation. Natural disasters and extreme weather are the second most serious threats over the next two years. Extreme weather events cause human deaths, ecosystem damage, property destruction, and financial loss on a worldwide scale. Land-based (earthquakes, volcanoes, wildfires), water-based (floods), and atmospheric (heat waves) are examples, as well as extra-terrestrial (comet attacks and geomagnetic storms). Extreme weather occurrences cause a global loss of life, ecosystem harm, property destruction, and economic loss. Terrestrial (earthquakes, volcanic wildfires), water (floods), atmospheric (heatwaves), and extra-terrestrial (comet impacts and geomagnetic storms) are examples. Failures by governments, businesses, and individuals to adapt to climate change, such as a lack of climate-resilient infrastructure, have reached all-time highs.

Large-scale environmental damage caused by human activities and/or non-coexistence with animal habitats, non-inclusion or deregulation of industrial accidents, oil spills, and radioactive pollution can result in death, economic loss, and/or ecological degradation. Natural resource crises cause severe global shortages of raw materials and natural resources as a result of human overexploitation and/or mismanagement of essential natural resources.

Extreme weather occurrences have the greatest influence on developing countries. This is because they are more vulnerable to dangers, less capable of coping, and may take longer to restore and recover. Eight of the top ten countries most affected by extreme weather occurrences in 2019 were low and middle-income countries (GCRI, 2021). Extreme weather and climate phenomena, such as droughts, heavy rain and snow, heat waves, cold waves, storms, and hurricanes, have the most severe impacts. Flooding, landslides, wildfires, and snowslides can all be exacerbated by these (SGC 2021). Temperature extremes, heavy precipitation and floods, river floods, droughts, storms (such as tropical cyclones), and compound events involving multiple types of extreme events occurring simultaneously or in close succession were all evaluated in the IPCC 2022 report (Vicente & Li, 2021).

According to the WMO (2021), over 11,000 disasters related to weather, climate, and water extremes were documented worldwide between 1970 and 2019, resulting in over 2 million fatalities and $3.64 trillion in losses. These hazards are responsible for 50% of all recorded disasters, 45% of all reported fatalities, and 74% of all reported economic losses. Over 91% of these fatalities occurred in developing nations (UN, 2022). Droughts killed the most people (650,000), followed by storms (577,232 deaths), floods (58,700 deaths), and severe temperatures (55,736 deaths). The hurricane caused the most economic devastation in the world. Floods have been related to 44% of all disasters worldwide, with tropical cyclones accounting for 17%. Between 1970 and 2019, tropical cyclones and droughts accounted for 38% and 34% of all human fatalities, respectively. Tropical cyclones cause 38% of economic losses, whereas floods of various forms cause 31%, including riverine floods (20%), general floods (8%), and flash floods (3%).

Africa was responsible for 15% of weather, climate, and water-related disasters, 35% of connected deaths, and 1% of economic losses between 1970 and 2019. Flooding (60%) was the most prevalent sort of disaster, accounting for 95% of deaths in the region. In 2019, five of the 10 most affected countries were in Africa. Asia accounts for around 31% of these disasters, with floods (47%) and storms (36%). Storms caused the most major loss of life in Asia, accounting for 72% of deaths, while floods caused the most significant economic damage, accounting for 57%. Weather, climate, and water-related disasters caused a major loss of life and economic damage in South America, accounting for 60% of all deaths and 38% of all economic losses. 90% of these disasters were caused by flooding. Between 1970 and 2019, North America, Central America, and the Caribbean region were responsible for 18% of such disasters, accounting for 4% of associated deaths and 45% of global economic losses. Storms (54%) and floods (31%), were the most common types of disasters. The majority of disasters in the southwest Pacific area were caused by storms (45%) and floods (39%). Storms killed the most people (71%), followed by floods (24%), droughts (17%), and wildfires (13%). Floods (38%) and storms (32%), while the most common weather, climate, and water-related disasters in Europe, were responsible for the greatest number of deaths (93%) over the last 50 years. 80% of the deaths were caused by significant heat waves in 2003 and 2012.

Storms and their accompanying effects, such as floods, landslides, and precipitation, were the leading source of loss and damage in 2019, according to the Global Climate Risk Index 2021. Climate-related dangers are increasing in many places around the world as the repercussions of catastrophic weather occurrences worsen. Climate change's consequences have exacerbated and escalated, with global average temperatures rising to 1.2°C over pre-industrial levels (WMO, 2021). Extreme weather events kill around 25,000 people and affect 191 million people worldwide each year, according to CRED and UNDRR (2021). As global warming continues, the effects are projected to worsen. Even if the international community maintains current emission pledges and targets, temperatures are likely to climb by more than 2°C (Friedrich-Ebert-Allee,2021). As a result, the frequency and severity of extreme weather events, as well as the spread of gradual-onset phenomena, will increase even more.

Furthermore, specific thresholds in the Earth's system may be exceeded, resulting in a cascade of hazards with potentially disastrous consequences (Lenton *et al*., 2019). Climate hazards have the potential to jeopardise sustainable development achievements such as poverty reduction, global well-being, and the sustainable use of ecosystems and marine resources. As a result, climate risks must be addressed and incorporated into future planning at all levels, from personal to national, and across all policy areas. The IPCC acknowledges that "a global temperature increase of 1.5°C will affect sustainable development, poverty, and inequality," and that this will include both residual risk and losses and damages (Roy *et al*., 2018). The residual risk is the likelihood of losses and damages persisting even after adaptation and mitigation measures have been implemented. Climate risks have the potential to imperil gains in sustainable development, such as poverty reduction, global well-being, and the sustainable use of ecosystems and marine resources. Climate risks must thus be addressed and incorporated into future planning at all levels, from personal to national, and across all policy domains.

2.2.2 Climate risk in The Gambia

According to the report of the Global Climate Risk Index (GCRI, 2021), The Gambia ranks 41st in terms of vulnerability to climate change out of 180 countries. Global climate change causes substantial challenges in The Gambia, such as the rising occurrence and severity of droughts. Hotter days and nights, as well as lengthier heatwaves, are forecast in the inland Gambia as average temperatures climb by the end of the century. As a result, droughts will escalate in frequency and severity (Gibba *et al*., 2020). Water scarcity and droughts are expected to occur every five years on average (ADB, 2020). According to The Gambia's National Adaptation Report (NAPA, 2007), the country had many droughts between 1951 and 2007. Rainwater irrigates over 99% of its arable land (Jaiteh, 2011), and rising temperatures and diminishing rainfall are projected to hinder agricultural production. Heavy rainfall, flooding, strong winds, dry spells, low temperatures, interseasonal droughts, heatwaves, and extreme rainfall are all weather-related hazards in Gambia (ADB, 2020). Due to climate change, The Gambia confronts considerable development challenges in both the near and distant future. Strong and high winds, droughts, and dust storms are examples of short-term severe climatic phenomena. Land loss, sea level rise, and coastal erosion will be important issues in the long run (Jaiteh, 2011).

According to the IPCC, (2023) climate change has a substantial influence on The Gambia, which is ranked among the top 100 countries impacted by climate change, and the population is the world's most vulnerable to the consequences of increasing sea levels and coastline erosion (Gomez *et al*., 2020). The Gambia has recently seen an increase in the frequency and severity of floods, droughts, coastline erosion, storms, severe temperatures, and unpredictable rainfall. Such weather events, particularly droughts, impede efforts toward sustainable development and poverty alleviation (Gambia LTS, 2022). Climate data analysis reveals expected temperature and precipitation patterns for The Gambia in recent years. A second national report (NDC, 2022) reveals a 0.50 °C per decade increase in temperature since the 1940s. Rainfall patterns in The Gambia have changed throughout time, according to historical climate records. Between 1951 and 2018, the country had five major droughts (Gibba *et al*., 2020). As a result, The Gambia exhibits a high sensitivity to climate change and is inadequately prepared, ranking 141st out of 192 nations in the 2018 Notre Dame Global Adaptation Index (ADB, 2020).

2.2.2.1 Temperature risks

Climate change is expected to have a wide range of effects in The Gambia. According to projections published in The Gambia Third NCoTG UNFCCC (2020), mean annual temperatures in 2050 are predicted to rise by 1.7°C to 2.1°C compared to 2000 values. Temperature rises (IPCC, 2014) demonstrate that temperatures in much of Africa have risen by more than 0.5°C during the last 50-100 years. Since the mid-1900s, there has been a high degree of assurance that the Earth's lower atmosphere has warmed globally. Throughout the twenty-first century, Africa's temperature is expected to climb faster than the global average.

West Africa is expected to warm by 3-6°C by the end of the century. In The Gambia, for example, the temperature has risen by 0.5°C every decade since 1940, and it is expected to rise from 28°C now to 31.5°C by 2100 (IPCC, 2014). The Gambia, located on the southern edge of the Sahara Desert, is a highly drought-prone country. Rainfall in The Gambia, like the rest of the Sahel, varies drastically from year to year. The Banjul Meteorological Station's records from 1951 to 1985 show significant variability in overall yearly rainfall, as well as a drop in average annual rainfall.

The average yearly temperature is currently at 28°C. However, by 2100, it is anticipated to rise by 3°C to 4.5°C, indicating a substantial warming pattern (Urquhart, 2016). During drought years, the degradation of savannah forest ecosystems, a shortage of rangeland, and a lack of water for cattle severely limit livestock and human livelihoods. Drought can have several indirect effects, including increased wildfire occurrences, changes in land use, and a reduction in biodiversity, all of which can lead to both forest growth and forest degradation (Jaiteh, 2011). During the dry season, temperatures typically vary between 18 and 30 degrees Celsius, whereas during the wet season, temperatures range between 23 and 33 degrees Celsius. However, since the 1960s, the country has seen unpredictable rainfall patterns, increased storm intensity, dry intervals between seasons, and an overall increase in average temperatures, which is frequently accompanied by cold and hot spells. Temperature measurements since the 1940s show a trend of 0.5°C per decade, increasing GoTG (2007). The average temperature was at its lowest in 1947, reaching 25.8 °C. In comparison, the highest average temperature on record was 28.2 °C in 2000 GoTG, (2012). Observing data alone is insufficient for detecting patterns, especially for the vast majority of ordinary temperature extremes. Nonetheless, between 1960 and 2003, there was an increase of 28 evenings a year with "hot" temperatures (corresponding to an additional 7.8% of nights) (Urquhart, 2016).

Collaboration between the Gambian government and the global community is critical for mitigating temperature risks and building resilience to future climate change impacts. This could involve creating drought-tolerant crops, heat-resistant infrastructure, and early warning systems for temperature extremes.

2.2.2.2 Rainfall risks

Annual precipitation decreased by around 30% between 1950 and 2000. The reduced duration of the rainy season, notably in terms of August precipitation amounts, demonstrates this decline. August precipitation was comparable to the long-term average of the prior four decades from 1968 to 1985 and from 2002. The proportion of the country receiving less than 800 mm of average summer precipitation (from July to September) grew from 36% in 1965 to 93% by the end of the century GoTG (2007).

Furthermore, between 1960 and 2006, there was a considerable fall in rainy season precipitation (from July to September) in The Gambia, with a linear trend indicating an average decrease of 8.8 mm per month for the decade. The decline in precipitation varies spatially across the country, with a greater degree of volatility in the west GoTG (2007). The observed precipitation patterns are consistent with current data from the Sahel region, which shows dramatic swings between wet and dry seasons, as well as a general drop in total precipitation. The frequency of such swings has resulted in a clear transition to this rainfall pattern, with the final 30 years of the twentieth century experiencing catastrophic droughts that alternated with torrential rains, resulting in more frequent flooding (Urquhart, 2016). Data presented in the Gambian government's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2012 suggest that most of the currently used Global Circulation Models (GCMs) predict a drop in precipitation. The estimated average annual precipitation in 2020 is expected to exceed 800 mm, however, this amount is expected to fall to fewer than 500 mm by 2100.

The decrease in projected precipitation is expected to be most pronounced during the wettest months of the year, July, August, and September. The Gambia is also projected to have greater rainfall and variability, as well as more frequent occurrences of extreme weather events such as droughts and floods. Flash floods are examples of the latter, which occur as a result of unusually strong rainfall. Poor stormwater management planning and urban infrastructure worsen this. After an unusually wet season, catastrophic seasonal flooding can occur along the Gambia River. Annual rainfall is expected to reduce by less than 1% in 2020 and by around 54% by 2100.

According to the BMRC98 model, the greatest dramatic decline in rainfall is projected in the hottest climate change scenario. The CCCM199 model, on the other hand, anticipates a 2% drop by 2100, which is commensurate with the current interannual variability in precipitation. In any event, the possibility of the opposite climatic tendency cannot be ruled out. As an example, Sylla & Wild (2012) revealed that using regional climate models (RCMS) with complex topographical features can affect the direction of precipitation change. In addition, Sanogo *et al*. (2015) discovered a positive trend in yearly total precipitation in the majority of Sahel sites.

Using percentile and threshold precipitation statistics, Gibba (2016) identified a change towards more intense precipitation in West Africa in response to growing radiative forcing. In conclusion, present information requires prudence and sensitivity analysis when using precipitation estimates in comparison to temperature change (NAPA, 2007).

Extreme rain events: The Gambia is also prone to extreme rainfall events such as torrential rains, which can create flash floods, landslides, and erosion, causing damage to housing and infrastructure as well as disrupting transport and communication networks.

Flooding: Because the Gambia is located on a low-lying floodplain, flooding during the rainy season can destroy houses, infrastructure, and crops. Floods in Gambia can be dated back to before the country's independence. Rivers and flash floods have both happened in recent years. Precipitation variability and dispersion are expected to increase, with more frequent flooding, such as flash floods, after severe rain episodes. Seasonal flooding is also possible along the Gambia River (Gibba *et al.*, 2020).. According to climate projections, there is a "high risk" of at least one river flood event occurring in the next decade (ADB, 2020). Flash floods primarily impacted the GBA, which has an inadequate drainage system, while river flooding occurred in areas of the CRR and upper reaches (URR) (Gibba *et al.*, 2020).

Inadequate drainage infrastructure and noncompliance with zoning restrictions have led to increasingly frequent and severe floods in urban areas, inflicting harm to both human life and property (Jaiteh, 2011). The occurrence and severity of heavy rainfall events are expected to increase across most of Africa and are likely to increase over continents such as North America and Europe (IPPC, 2014). The existing evidence implies that global surface and tropospheric humidity have increased during the 1970s. Simultaneously, most of Sub-Saharan Africa has seen a decline in precipitation, which has most certainly contributed to an increase in the frequency and intensity of precipitation events. This is largely visible at the local level. Precipitation in The Gambia, for example, is expected to increase by at least a factor of 20 by mid-century, increasing in intensity and frequency Second NCoTG UNFCCC, (2012).

It is critical that the Gambia's government reduces the burden of rainfall hazards and builds resilience to future climate change impacts. This could include creating flood-resistant houses and infrastructure, drought-tolerant plants, and early warning systems for extreme precipitation occurrences.

2.2.2.3 Rising sea levels and coastal erosion

Sea levels are rising as world average temperatures rise, posing a threat to low-lying coastal areas such as the Gambia River Delta, which houses the majority of the country's people and infrastructure. Due to increased CO2 emissions from both natural and manmade sources, sea level rise is anticipated to exceed 21st-century levels (IPCC, 2014). In low-emission scenarios, sea level rise is estimated to range from 0.26 to 0.55 m by 2100, whereas high-emission scenarios may result in a rise ranging from 0.52 to 0.98 m. As a result, coastal systems and low-lying regions are predicted to be more vulnerable to floods and erosion in the twenty-first century and beyond (IPPC, 2014).

(Brown *et al*., 2011) estimated that sea level rise in The Gambia could be much higher than forecast by the IPCC. According to their DIVA model, Gambia's sea level might rise by 0.35 metres by 2025, 0.72 metres by 2050, and 1.23 metres by 2100 in comparison to 1995 levels. These estimates are larger than the IPCC's estimated range of sea level rise (0.26 to 0.98 m by 2100) under low and high-emission scenarios (Church *et al*., 2013).

The average sea level of Gambia's coastal region is anticipated to rise between 26 cm and 98 cm by 2100, with the highest estimate corresponding with the RCP8.5 scenario. This suggests that sea level rise in the Gambia coastal region is projected to be within 20% of the global average (Van Vuuren *et al*., 2011). Based on a database, the Gambia's estimated sea level increase ranges from 19 cm to 43 cm by 2050 (NAPA, 2007). Approximately half of The Gambia's geographical area is less than 20 metres above sea level, with an average elevation ranging from 33 to 10 metres.

Climate change has had a significant impact on the country, and it is one of the most affected countries in Africa. Every year, flooding affects around 20% of The Gambia's land Gibba *et al*., 2020). (Brown *et al*., 2011) indicate that the sea level will rise in The Gambia, with rises of 0.13 metres in 2015, 0.35 metres in 2050, 0.72 metres in 2075, and 1.23 metres in 2100. These forecasts indicate a large rise in sea level over time, emphasising the importance of addressing the possible implications of climate change in the region. Without adaptations, a 1 m rise in sea level will flood 60% of mangrove forests, 33% of wetlands, and 20% of rice fields.

Rising sea levels will harm agricultural production, harming the poor and 33 vulnerable groups (ADB, 2020). According to the study of the first national communication report, The Gambia is witnessing increased saline water upwelling, salinisation of coastal habitats, reduced agricultural yields, and diminished coastlines (Jaiteh, 2011). Because of the country's predominantly low-lying geography, a one-meter rise in sea level may inundate more than 80% of The Gambia, including more than 60% of mangroves, 33% of swamps, and 20% of lowland rice-growing areas.

This has the potential to wreak considerable damage, flooding more than half of Banjul, as well as the cities of Janjangbureh and Kuntaur. Another source of concern is coastal erosion, which affects 80 kilometres of shoreline and threatens the tourism economy (Jaiteh, 2011). Coastal areas are especially vulnerable to the effects of climate change, which include sea level rise, land loss, changes in ocean storms and floods, and salinisation of coastal water resources. According to Elasha &Medany (2006), the number of Africans at risk of coastal flooding is expected to increase from one million in 1990 to 70 million by 2080.

About 30% of Africa's coastal infrastructure, including communities in the Gulf of Guinea, Senegal, Gambia, and Egypt, is located in the Gulf of Guinea. Furthermore, the sea level is expected to rise from 19 cm to 43 cm by 2050. Predictions for precipitation patterns are uncertain, and there is a risk of growing salinity and depletion of coastal aquifers, which might impact freshwater supplies and peri-urban agriculture. The effects of sea level rise and coastal erosion on tourism and artisanal fishing are substantial. Salinisation can also harm aquatic plants and animals, impacting human water use and potentially preventing one hectare of paddy production (Jaiteh, 2011).

As world average temperatures rise, sea levels rise, posing a threat to low-lying coastal areas such as the Gambia River Delta, which houses much of the country's people and infrastructure. Sea-level rise can cause greater flooding, saltwater intrusion into freshwater aquifers, and coastal erosion. The Gambia's coastline is prone to erosion, which could result in the loss of valuable land and infrastructure as well as an increase in the risk of flooding. Furthermore, erosion might have an impact on tourism, which is a major source of revenue for the country.

The Gambia's government must take steps to prevent the effects of coastal erosion and sea level rise, as well as to strengthen the country's resilience to future climate change effects. This includes creating adaptation methods such as embankments and other coastal protection structures, as well as encouraging coastal vegetation to prevent erosion. Furthermore, it is critical to consider sustainable development practices in coastal areas, such as avoiding structures in places prone to floods and erosion.

2.2.2.4 Windstorm risks

Many parts of the world are seeing an increase in the frequency and severity of wind and dust storms. During the cool, dry season, when dry, dusty harmattan winds cover the region for lengthy periods, atmospheric dust is a prominent factor in the Sahara and Sahel. Dust storms have been more common in The Gambia over the previous 25 years (Jaiteh, 2011). This rise can be attributed to a variety of factors, including human activities like overgrazing and deforestation, which have generated new sources of dust (Urquhart, 2016). Storms are a common occurrence in the country, particularly at the start and end of the rainy season, and they frequently cause major property damage in rural regions. The effects of severe storms are exacerbated by forest degradation and land-use changes, such as grazing (Jaiteh, 2011).

The Gambia's climate is monsoonal, with high winds (up to 50 km/h) towards the start and end of the rainy season GOTG, (2009). Over the last decade, these storms have caused significant property damage in the country's north and east, particularly in the North Bank and Upper River districts. In the chilly, dry Sahara and Sahel, atmospheric dust plays a significant role. Several times throughout the dry season, dry, dusty harmattan winds cover the region for extended periods. Dust storms have been more common in the Gambia over the last 25 years (Jaiteh, 2011). Dust storms are linked to health issues such as respiratory issues and meningitis transmission. Meningitis transmission is also linked to congested living conditions. If climate change is linked to these meningitis risk factors, the rising frequency of meningitis may be linked to climate change. Dust storms also have an impact on agriculture by eroding fertile soils, uprooting young plants, and altering fruit tree flowering cycles (Jaiteh, 2011).

The Gambia is prone to severe weather events such as strong winds and heavy rains, which can cause damage to housing and infrastructure as well as disruptions to transportation and communication networks. Storms can also severely destroy crops, resulting in food poverty and revenue loss for farmers. Strong winds can also create power outages, which can have a substantial impact on individuals and communities, particularly in locations with limited access to energy.

It is critical that the Gambia's government mitigates the consequences of storms and builds resilience to potential climate change impacts. Developing adaptation methods, such as upgrading wind-resistant buildings and infrastructure, as well as encouraging early warning systems for harsh weather, may be included. Climate risks have a significant economic, environmental, and social impact in The Gambia, and the government and the international community must work together to decrease these impacts and strengthen resilience against potential future climate change impacts.

2.2.3 Climate risk perception

How people, communities, and organisations view the threat of climate change is known as ‘climate risk perception. It involves a personal judgment about both the possible effects of climate change and the chance that these would happen. When developing adaptation measures and responses, it is imperative to consider farmers' perceptions of climate-related threats (Shah *et al.*, 2021). The risks posed by climate change to human and ecological systems include abnormal weather, rising sea levels, shortages of food and water reserves, and diminishing biodiversity. But people's judgments of such risks may differ based on their personal experience, geographic location, socioeconomic class, cultural and societal norms, along with media coverage as well as scientific fact. Take sea level rise and increased storm activity along the coast, for example. People who live near the seaside may be more concerned about these risks than people living further inland, whose biggest worries are most likely droughts and heat waves. Having experienced major weather disasters, such as hurricanes or wildfires, may make a person more likely to characterise the threats of climate change in terms of potential seriousness and importance.

Risk perception, according to IPCC (2023), is the subjectively formed judgment by people about the nature and magnitude of a risk. (Alotaibi *et al.*, 2020) found that a large proportion of farmers in the region believed climate change was caused by both human and natural processes. Also, most farmers are worried about increasing risks of pest attacks and disease outbreaks, as well as flooding, along with rising crop heat stress. Knowing how farmers view the impact of climate change on agriculture and what concerns they have is a necessary first step toward developing adaptation strategies for addressing climate change. Their experiences with climate change will alter farmers 'attitudes (Mase *et al.*, 2017; Niles & Mueller, 2016). Perception of climate risk is important because it can influence individuals and groups in their efforts to respond by mitigating or adapting to consequences. Those who do not consider climate threats to be serious or fallible may also be less willing either to cut back on greenhouse gas emissions or adapt themselves to the future effects of global warming. However, for people and society, the threats may only prompt action if they are seen as serious. Risk perception is a decision-maker’s judgment of the dangers present in any given situation. Often, they are evaluated by eliciting reactions to the idea of how “serious,” ‘‘concerned," or. For a decision maker, information about danger is risk perception. They play an important role as indicators of decision-making behaviour since it is known, from research studies (Lusk *et al*., 2014; Waterfield *et al*., 2019), that they can distort judgments, knowledge, and the ability to perform in dangerous situations. Generally speaking, risk perceptions are measured by the extent to which people feel threatened or worried about a specific event.

Climatic risk communication is important to help inspire people to act and lower their susceptibility, as well as help them adapt to changing climates. It is necessary to understand the different factors that determine what people regard as risk and to change methods of communication accordingly. For example, this could involve using a few simple words, focusing on the local impact of global warming, and highlighting gains from action. It is also not surprising that there exists a positive correlation between education and the way farmers perceive climate change, as well as how they will respond to it. Generally speaking, more highly educated people are aware of the threats involved in climate change (Asrat & Simane, 2018a). Cognitive capacities and knowledge of new technology are sure to increase with education, so that the farmers will accept these innovations. These results are in keeping with those of (Asrat *et al*., 2004; Deressa *et al*., 2009a).

2.2.4 Coping versus adaptation strategies

The idea of coping comes from the sustainable livelihood framework, developed in the 1990s to explain how people living in low-income countries deploy their assets and resources under difficult conditions to make a living amidst economic, environmental, and social obstacles. This framework points out that people's livelihoods are determined by different elements, including capital of various kinds ranging from human (competencies, expertise, and health), to social (interpersonal and networks), natural (land, water, and environmental resources), physical (equipment and infrastructure), and economic capital (money and other financial assets) (Cox *et al*., 1999). The sustainable livelihoods paradigm argues that institutions and policies influence people's access to different forms of capital, but also how they use them in ways intended to shore up their ability to cope with shocks and stresses. Coping strategies are usually short-term and focused on immediate survival in response to climate risks or stressors. Coping strategies may involve many different activities, such as diversifying sources of income, seeking help from one’s social network, or using new technologies or changing techniques of farm practices. A coping strategy tries to improve the overall quality and sustainability of intervention, but it may not necessarily reduce future vulnerability to risk. By understanding how people cope with adversity, the sustainable livelihoods framework aims to support the development of more effective and sustainable interventions that build on people's existing resources and capacities. Coping strategies are response tools that either farmers or individuals can use to deal quickly with short-term shocks and stresses. However, some coping strategies can also have a longer-term impact and may be seen as an adaptation to changing situations. For example, to ease economic and social uncertainties over the long term, individuals or farmers can diversify sources of income or invest in education and skills development.

The study (Ellis, 2000), suggests that people facing stress or crisis are likely to use five main types of coping strategies in the following order: These strategies are: (i) obtaining extra sources of income through diversification, (ii) relying upon reciprocal responsibilities or son various forms of social capital, (iii) temporal migration to reduce household size, (iv) downsizing movable assets like agricultural equipment, household belongings, and animals, and (v) selling fixed assets such as land and houses. Another study has found that permanent distress migration is often a last resort after all intervening coping strategies have proven unsuccessful (Meze-Hausken, 2000).

Adaptation refers to modifying a system to mitigate the impacts of climate change and capitalise on potential benefits. When considering rural livelihoods, what criteria should be used to measure the success of adaptation efforts? Debates in the climate change literature centre around whether risk-reducing responses are appropriate given the perspectives of other resource users both within and outside of the community, and whether they make efficient use of scarce resources (Adger *et al*., 2005). Throughout history, human societies have demonstrated their ability to adapt to changes, a crucial factor in the long-term survival of cultures. However, farmers face unique obstacles in adapting to climate change. This is because the changes are occurring amidst persistent poverty, which has not been sufficiently addressed. The complexity of the issues impedes the formulation of efficient strategies to mitigate the impacts of climate change (Schipper, 2016). Adaptation is the act of modifying oneself to suit unfamiliar circumstances, and its interpretation might differ among various academic disciplines. Within the realm of climate risk research, adaptation has been characterised in several ways. As to (Burton, 1992), the concept of adaptation should be examined within its social framework. He defines adaptation as ''*the process by which individuals and communities mitigate the negative impacts of climate on their health and overall well-being while also* *making use of the opportunities provided by their climatic environment."* Smithers & Smit (1997) shared a similar viewpoint, defining climate change adaptation as ''*any modifications made to societal behaviour or economic structures that decrease vulnerability to climate system changes.*'' Watson *et al*. (1996) emphasised the behavioural aspect of adaptation, stating that *''it can occur either spontaneously or through planned efforts*''; furthermore, adaptation can be executed in response to or in expectation of changes in circumstance. Based on the definitions discussed above, it can be concluded that adaptation involves making adjustments or modifications to natural, economic, and social systems. The purpose of these adjustments is to minimise the negative impacts of drought and increase the ability to cope by decreasing vulnerability (Islam *et al*., 2019).

Adaptation measures can be implemented at various levels, including the individual, household, community, or beyond. Adaptation actions at the household or farm level are typically self-initiated, while government agencies tend to undertake planned adaptations in anticipation of potential climate change impacts (Maddison, 2006; Smit & Pilifosova, 2001). To intentionally respond to changing conditions, planned adaptation involves policy decisions aimed at achieving desired outcomes. It is a result of a conscious effort by the government to recognise that the current or future circumstances necessitate action to achieve certain goals. This type of adaptation requires evaluating different social and economic objectives and making decisions to manage the impact of climate change (Adger & Kelly, 2003; Leal *et al*., 2014; Smit & Pilifosova, 2000; UNDP, 2012).

Kelly & Adger (2000) proposed a generational approach to adaptation, which classified adaptation strategies into two generations. The first-generation research concentrated on hazards and impacts based on vulnerability, with adaptation strategies such as irrigation, drainage systems, coastal setbacks, and settlement relocation. These strategies are implemented through economic assistance and institutional capacity building, with a focus on biophysical impacts and the identification of impacts and adaptation options using climate change scenarios, biophysical models, economic models, integrated systems models, empirical studies, and expert judgments. Second-generation adaptation studies, such as those (Adger & Kelly, 2001; Eakin, 2005; O'brien *et al*., 2004), emphasise societal vulnerability to climatic threats, with adaptation approaches that are more social than technical. Poverty reduction, the expansion of income-generating activities, the preservation of shared resources, and the enhancement of collaborative efforts are examples of these policies. The classification of a specific method as coping or adaptation may be based on the observed setting and the level of focus. Hence, it is crucial to take into account the context and scope of interest when evaluating whether a specific approach qualifies as a coping or adaptation technique. This understanding can assist policymakers and practitioners in formulating more efficient treatments that facilitate both immediate coping and enduring adjustment to evolving conditions (Vincent *et al*., 2013).

Adaptation interventions have primarily been based on globalised scenarios, neglecting the local complexities that drive systems, such as social, cultural, economic, and political realities. A study focused on climate variability in sub-Saharan Africa's rainfed farming systems suggests that the initial step to adapt to long-term climate change is to comprehend and improve existing adaptation strategies. The study predicted a future increase in climate variability (Kattumuri *et al*., 2017). In addition, it should be noted that while an adaptation measure may work well for a particular community, it could have negative impacts on others due to spatial spillover and negative externalities. For instance, if a group of farmers diverts more surface water or extracts more groundwater for their agricultural needs, it could be effective for them but may negatively impact other users downstream. Similarly, coping mechanisms may help to reduce immediate risks, but they could also lead to greater exposure to long-term risks (Osbahr *et al*., 2010).

The lack of information on how adaptation is happening, especially in developing countries and the agricultural sector, is notable, according to (Berrang-Ford *et al*., 2011). It is important to distinguish between vulnerability assessments, natural systems, and intentions to act, which are often mistakenly cited as adaptation examples but do not necessarily constitute adaptation actions (Berrang-Ford *et al*., 2011; Eriksen *et al*., 2011). According to Berman *et al*., (2012), having the ability to cope is considered a necessary condition for being able to adapt, especially in sub-Saharan Africa, as noted (Cooper & Mckenna, 2008).

2.3 Literature review

2.3.1 Theoretical

2.3.1.1 The Risk Perception Theory (RPT)

The Risk Perception Theory (RPT) underscores the link between perceived risk levels and the adoption of adaptation strategies. According to Slovic (2016), individuals are more likely to respond to risks they perceive as immediate and severe. The theory argues that people are more likely to adopt adaptation strategies when they perceive high climate change risk. Thus, households with higher risk perceptions are more likely to adopt certain adaptation strategies (Grothmann & Patt, 2005). The RPT is a broadly accepted theory that helps to explain how individuals perceive climate risk and assess the adequacy and effectiveness of climate risk adaptation strategies. The theory asserts that people's perception of risk is shaped by different factors, such as beliefs about the intensity and probability of the risks, personal experience, norms and values, which significantly influence behaviour and decision-making (E. U. Weber, 2006).

In the context of climate change, households may be more likely to take up adaptation strategies if they perceive the risk associated with climate change to be substantial and threatening. Therefore, it is very important to raise awareness and provide education about the risks posed by climate change (Patt & Schröter, 2008a). The RPT is extremely important in the area of climate change because it facilitates explaining how individuals perceive the risk associated with climate change and variability. Climate change and variability pose serious threats to human societies and the natural environment. Risks associated with climate change, such as more frequent and intense heat, droughts, floods, storms and sea level rise, are a great concern to the survival of lives. The intensity and chances of these risks may vary depending on factors such as geography, socioeconomic status, level of adaptive capacity, and personal experience (Adger *et al*., 2009). Individuals may perceive the risk as less serious or less likely if they do not understand the anticipated consequences of climate change. For instance, some people may see the risk of sea level rise as less threatening if they do not live in coastal areas or lack a clear understanding of the potential impacts it poses on infrastructure, properties, and livelihoods. Individuals who also live in regions where the impact of climate change and variability are not yet imminent may not perceive the risk associated with climate change as life-threatening (Whitmarsh *et al*., 2008). When people lack a clear understanding of the anticipated impact of climate change on their livelihood, health, and well-being, they may not perceive risk as severe. Furthermore, individuals may perceive climate change adaptation strategies as inadequate if they do not believe that the strategies will effectively mitigate the risks associated with climate change (Siegrist & Gutscher, 2006). For instance, individuals may perceive the construction of seawalls or floodgates as inadequate if they believe that these strategies will not be able to withstand the ferocity and frequency of extreme weather events that are becoming more common as a result of climate change.

The RPT underscores the subjective interpretation of risk, which is influenced by individual experiences, emotions, and cognitive biases (Slovic *et al*., 1976). However, critics contend that dependence on subjective evaluations may neglect objective and quantifiable risks. This disconnect raises essential questions on the equilibrium between personal perception and empirical evidence in policy decision-making (Douglas & Wildavsky, 1982). The theory has been critiqued for its lack of universality, particularly when applied to culturally diverse groups. The cultural theory by Douglas & Wildavsky (1982) highlights how social values influence perception of danger, with some communities focusing on technology concerns and others prioritising environmental hazards. This cultural diversity challenges the assumption that RPT frameworks can be universally applied. Although RPT explains individual differences in perceived risk, its efficacy in forecasting behaviour is still debated. For instance, while the theory might clarify that some people perceive climate change as a significant threat, it does not always explain why others, despite similar perceptions, do not take action (Dake & Wildavsky, 1990).

Empirical studies often reveal a disparity between perceived risk and actual behaviour. For example, although individuals acknowledge the health hazard of smoking, many continue to smoke, usually influenced by social pressures or addictions (Clarke & Short, 1993; Slovic *et al*., 1976). This raises questions regarding the explanatory efficacy of RPT in understanding the connection between perception and action. Cultural difference in risk perception poses additional empirical challenges. (Douglas & Wildavsky, 1982) argued that cultural values profoundly influence risk perception, resulting in variation in findings among different regions and populations (Clarke & Short, 1993).

2.3.2 Empirical

The multivariate probit model was used in both the research of Mulwa *et al*. (2017a) and Mwinkom *et al*. (2021) to analyse the interdependence of farmers' adoption of various climate change adaptation strategies. This model reduces estimation bias and offers an effective assessment of farmers' decision-making processes by successfully capturing complementarities and substitutabilities between strategies. The findings of both studies highlight that access to climate-related information significantly influences the adaptation decision. There are substantial complementarities among the key adaptation strategies that have been found, such as shifting planting time, planting drought-resistant crops, and planting early maturing crops. Additionally, household demographics, social networks, and characteristics play a crucial role in adaptation choices. To increase climate resilience, both studies recommend bolstering extension services, expanding credits, building social capital and promoting education.

The studies of (Adamseged & Kebede, 2023a; Charles *et al*., 2014a; Mnimbo *et al.*, 2016; T. Ojo & Baiyegunhi, 2018; Prakash Aryal *et al*., 2020) also employed the multivariate probit model to examine the factors that determined rural household and farmers' adoption of different climate risk adaptation strategies. These studies highlight the interdependencies, complementarities and substitutabilities among these strategies while accounting for estimation biases brought on by the correlated error terms. The results of various studies show that farmers and households use strategies like crop diversification, irrigation, soil and water conservation, changing planting and harvesting dates, mixed cropping, and the use of improved crop varieties. Wealthier households prefer farm-level strategies, while those with better access to markets choose off-farm strategies like wage employment and migration. The main determinants of adoption include education, age, credit access, household size, off-farm income, gender, extension services, and membership in a farm group. Disparities in adaptive capacity are highlighted by the fact that households headed by women and those with limited resources rely on NGO assistance.

Mpho Steve Mathithibane & Zaheenah Chummun (2021) primarily utilised multinomial logistic regression to analyse how well South African smallholder corn farmers coped with climate risk. This approach enabled the evaluation of factors affecting farmers’ readiness to manage weather risks as well as the effectiveness of various strategies. The methodology’s reliance on self-reported data and narrow geographic reach may have affected generalisability, even though it can successfully capture statistical connections and offer useful insight. The results reveal that crop insurance is the most effective strategy for minimising crop losses and enhancing preparedness.

Bagagnan *et al*., (2019) examined the impact of socioeconomic characteristics and farmers' perception on adopting climate variability adaptation strategies in the Central River of The Gambia using the binary logistic regression model. This approach provided effective insights into the adaptation behaviour by identifying key variables such as perception of drought and length of growing season, farm size, and income. Its strength lies in its ability to model binary outcomes and establish relationships between variables, though the assumption of linearity in the log-odds limits it. The findings showed that farmers' perceptions, especially drought, significantly influenced their choice of adaptation measures like chemical fertiliser.

The studies of Abid (2016), Atube *et al*. (2021), Batungwanayo *et al*. (2023), A. A. Shah *et al*. (2023), and Vo *et al*. (2021) employed a binary logistic regression model to analyse the factors that influence smallholder farmers' adaptation strategies to climate change. This model is effective in determining the connection between institutional, environmental and socioeconomic factors with the likelihood of adopting specific adaptation strategies. The findings consistently indicate that while financial constraints, lack of institutional support and inadequate knowledge impede adoption, education, farming experience, access to climate information, extension services, and farm size significantly enhance adaptation. Common adaptation strategies identified in these studies include changing crop varieties, planting shade trees, changing fertiliser type, using drought-resistant crops, and fallowing.

In Huong Phong Commune, Vietnam Hoa *et al*., (2017) used a logistic regression model to examine the variables affecting farmers' adoption of climate change adaptation strategies. In addition to accounting for the likelihood of adoption decision, this methodology successfully identified key determinants such as education, farming experience, household size, and access to extension services as main factors that determine the adoption of adaptation strategies. The study found that younger, more educated and experienced farmers with better access to resources were more likely to adopt measures such as tolerant varieties and soil conservation, while financial and informational constraints remained the primary barriers.

In addition to using the chi-square test and ANOVA to examine adaptation tactics across farming groups, Alam *et al*. (2017) employed descriptive statistics and general linear regression to analyse climate trends. To compare household perceptions of climate change and observed data, structured questionnaires were used to collect survey data. The methodology combines both qualitative and quantitative insights to classify farming groups for tailored analysis and apply robust tests to ensure reliability. The findings indicated that farmers perceive rising temperatures, decreasing rainfall and unpredictable climate patterns, which align with scientific evidence. Adaptation strategies varied, with larger farms relying on agricultural adjustments while small farmers tended toward off-farming strategies like migration. Fahad & Wang, (2018) investigated farmers' perception of risk, vulnerability and climate change adaptation strategies in rural Pakistan using a structured survey and descriptive statistical analysis. These techniques captured socio-economic factors and farming characteristics, providing practical insights into adaptation strategies and challenges. Key findings revealed that drought, floods, and temperature variation pose significant risks, with adaptation measures like shifting crop types and storing water being mainly used.

Patt & Schröter, (2008) investigated how Mozambican farmers and policymakers perceived climate risk using workshops, questionnaires and household surveys. Disparities in perception, biases in decision-making, and the impact of behavioural factors on climate adaptation strategies were all well documented by these techniques. Time-consuming data collection and difficulty changing entrenched beliefs are drawbacks. The finding revealed that farmers prioritise current drought issues over flood risks, largely underestimating flood probability compared to policymakers, whose focus on climate-related risks is influenced by action bias.

2.3.3 Conceptual framework

The conceptual framework (Figure 16) serves as a valuable instrument for comprehending the factors that shape individuals' perceptions of climate risk and how these factors can influence their perceptions and reactions to climate risk. It illustrates the determinants of climate risk perception, categorised as internal and external elements. Internal drivers refer to the factors originating from within an individual or society, which have the potential to shape their perception and response towards climate change concerns. External drivers of climate risk perception are factors originating from sources external to an individual or community, which have the potential to shape individuals' and communities' perceptions and responses to climate risk.

Identifying climate risk adaptation strategies used by farmers is critical to understanding the implementation of practical farm-level coping strategies (S. Asfaw *et al*., 2019; Thinda *et al*., 2020). Several studies have shown that household characteristics significantly influence the adoption of adaptive strategies (Ali & Erenstein, 2017a; Denkyirah et al., 2016; Ehiakpor *et al*., 2016; Mulwa *et al*., 2017a). Research by Kargbo *et al*. (2023), Mavhura *et al*. (2021), and Sanogo *et al*. (2015) highlights how socio-demographic variables influence farmers' perceptions. Education plays a key role in shaping farmers' perceptions of climate risk and their willingness to adopt adaptation strategies. Studies by Ogundari & Abdulai (2014), T. O. Ojo *et al*. (2021), T. O. Ojo & Baiyegunhi (2020a), and Roco *et al*. (2015) show that better education creates awareness of potential benefits and a willingness to adapt to new climate risk management strategies. This could mean that as household heads become more educated, they are also more likely to be aware of climate change. Farmers' ability to receive and process information, as well as their propensity to act, improves with increased education and training (Asrat & Simane, 2018b; Gaurav & Chaudhary, 2020), ultimately leading to increased cognitive performance.

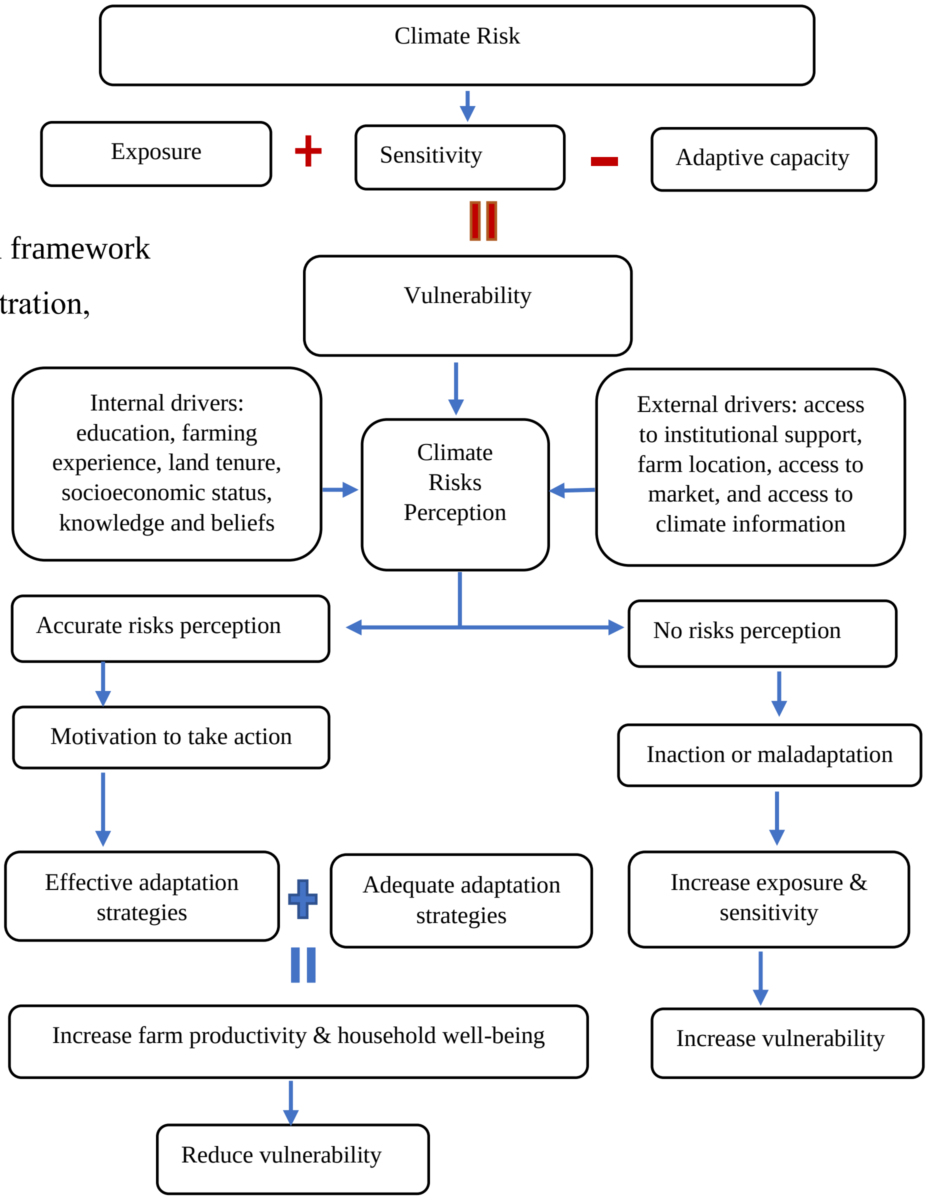


Figure 16: Conceptual framework

Source: Author’s illustration, 2024

Proximity to markets is an important factor in adapting to climate risks, and markets probably serve as an opportunity to exchange information with other farmers. Studies have shown that market access plays a significant role in managing drought risk (Maddison, 2006; Nyangena, 2008; Sam *et al.*, 2020). Long distances from markets, however, reduced the likelihood of technology adoption in agriculture (T. O. Ojo & Baiyegunhi, 2021).

Access to information and credit enhanced awareness among farmers (Chilot Yirga Tizale & Mekki Hassan, 2007; T. O. Ojo *et al.*, 2021; T. O. Ojo & Baiyegunhi, 2020b; Thinda *et al.*, 2020). Access to support services and credits gives farmers the information they need to make decisions and take adaptation measures. For example, funds enable farmers to purchase new crop varieties, irrigation techniques, and other essential inputs. The availability of credit lines increased farmers' financial resources and their ability to cover the operating costs associated with multiple adaptation options.

2.4 Method of data analysis

This essay used binary logistic models to assess farmers' decisions to adopt an adaptation strategy and multivariate probit (MVP) to evaluate the determinants of farm and off-farm adaptation strategies adopted at the farm level. The MVP model was used to examine the factors that influence farmers' decisions to implement each of the adaptation strategies to deal with extreme weather occurrences in their agricultural production.

2.5 Empirical model

The farmers' prior exposure to climate change may also influence their decision to adopt climate risk adaptation strategies (Velandia *et al.*, 2009). Farmers commonly employ multiple adaptation strategies simultaneously. The primary flaw of the multinomial model is that the assumption of mutual exclusivity of practices is erroneous. In reality, a single farmer can utilise multiple techniques at the same time (Piya *et al.*, 2013). The univariate and multinomial logit techniques are susceptible to bias and inefficiency (Young *et al.*, 2009) in the presence of correlation due to neglect of common characteristics that may be hidden and unmeasured, and influence the various adaptation strategies. In addition, the individual discrete choice independent estimation of the model disregards the connections between the adoption of distinct adaptation strategies. Univariate techniques overlook possible correlations between unobserved disruptions in adaptation measures by ignoring shared components. This leads to statistical bias and inefficiency in the estimation (Belderbos *et al.*, 2004; Lin *et al.*, 2005). The use of logistic regression methods has been prompted by behaviour to investigate determinants that influence the choice of an adaptive strategy. Prior studies (Abid aus Pakistan, 2016; Alemayehu & Bewket, 2017; Bryan *et al.*, 2013b; de-Graft Acquah & Onumah, 2011; Fadina & Barjolle, 2018; Fosu-Mensah *et al.*, 2012; Khan *et al.*, 2020; Myeni *et al.*, 2019; Wang *et al.*, 2018; Wetende *et al.*, 2018) employed a binary logistic approach to examine the factors that influence farmers' adoption of adaptation strategies. This model has various advantages, such as the ability to evaluate the choices made by farmers and predict the relevant probability. Certain adaptation measures may be perceived as complementary by farmers, while others may be viewed as competing. The explanatory variable's influence on the initial distinct adaptation measures is difficult to discern in multinomial repetitions of a multivariate decision system. It is computationally difficult to use the multinomial probit to analyse three or more possibilities (Gillespie *et al*., 2004).

This study employed binary logistic and multivariate probit (MVP) models to analyse the determinants of farmers' decisions to adopt a climate risk adaptation strategy and factors that influence the adoption of on-farm and off-farm adaptation strategies. The multivariate probit model can reduce these associations (Gebregziabher *et al*., 2016; Hassan *et al*., 2008; Huguenin-Elie *et al*., 2009). The data collected indicates that farmers in the study area have a wide range of adaptation techniques to climate risk. The MVP was developed using the specifications of (Lin *et al*., 2005), with six dummy dependent variables that represent the adaptation strategies (on-farm and off-farm) employed in the research area to mitigate the impacts of climate change. The MVP model was also chosen due to its ability to permit the simultaneous analysis of the impact of several regressors on each adaptation strategy (Adamseged & Kebede, 2023a; Lin *et al*., 2005; Tiwari *et al*., 2014) while allowing free correlation between the error terms.

The MVP regression, in particular, outspread error terms with a zero mean normal distribution with a variance-covariance matrix in which the variance and covariance allow for such a relationship (Below *et al*., 2012). Another merit of employing an MVP model is that it does not force each farmer to use only one adaptation method. Farmers can utilise multiple adaptations at the same time with a multivariate model. Furthermore, it is not necessary to satisfy the independence of irrelevant alternatives (IIA) criterion, which is often unachievable (Piya *et al*., 2013). Farmers may employ a variety of adaptation options. As a result, this model assists in obtaining as much insight as possible from the numerous adaptation processes in which a farmer is involved. According to (Gillespie *et al*., 2004), adoption decision modelling using the MVP framework increases estimation efficiency in the situation of simultaneous adoption, compensates for contemporaneous correlation, and decreases bias.

Farm households will adopt strategies to mitigate the impact of climate change only if they anticipate a decrease in agricultural production risk or a rise in predicted net farm profits. Adoption decisions require farmers to be aware of local over-time climate variability, like patterns of precipitation and temperature (Bryan *et al*., 2013a). The binary logit model analyses the multitude of factors influencing farmers' decisions in implementing adaptation strategies to extreme weather occurrences in agricultural productivity. The decision made by farmers in applying adaptation strategies follows a discrete choice model, where the options are limited to ''yes'' or ''no'').

Taking into account the following model:

$$Y_{ij}^{*} = \alpha + \sum \beta_k X_k + \varepsilon_{ij} \quad (12).$$

Where Y_{ij}^{*} is a latent variable corresponding to the expected benefit of adopting a particular adaptive strategy. The equation Y_{ij}^{*} is an unobserved parameter for the farmer i who is using adaptation strategies j climate change. The degree of climate risk adaptation options in the choice set is represented by the base category j. X_k represents a set of exogenous predictor variables that impact a farmer's decision to choose a specific adaptation strategy. And k in the subscript indicates the particular explanatory variables. The vector of regression coefficients is denoted by β_k and the error term is denoted by ε_{ij} which is uniformly distributed, characterised by a zero mean and a constant variance (Schmidheiny, 2013).

The model is defined by a collection of n binary predicted variables (Lin *et al*., 2005).

Because the latent variable Y_{ij}^{*} is not readily apparent, we utilise Y_{ij}, which accepts 0 or 1 as values in accordance with the following rules:

$$Y_{ij} = \begin{cases} 1 \; if \; Y_{ij}^{*} > 0 \\ 0 \; if \; Y_{ij}^{*} \leq 0 \end{cases} \quad (13).$$

Where Y_{ij} is an observed variable that indicates that farmer i will adapt to perceived climate risk using specific tactics j, $Y_{ij} = 1)$ if the expected gains exceed zero $(Y_{ij}^{*} > 0)$.

And otherwise, farmer i would not take for the adaptation strategy j if the expectation for gains is equal or less than zero ($Y_{ij}^{*} \leq 0)$.

Hence equation (2) can be interpreted in terms of the observed binary variable Y_{ij} as

$$Pr(Y_{ij} = 1 = Y_{ij} = G(X_k \beta_k) \quad (14).$$

Where, $G(.)$ represents specific binomial distribution (Fernihough, 2011). $Pr(Y_{ij} = 1)$ is the probability of selecting the adaptation alternatives j. β_k is a vector of the estimated parameter of the binary logistic model which describes the effect of the direction of the relationship between the explanatory and the binary observed variables, plus the statistical significance of increasing the independent variable using the OLS (ordinary least squares) coefficient (Peng *et al*., 2002).

Thus, Y_{ij} has a binary output $(Y_{ij} = 1)$ if the farmer i adopts the adaptation strategy j, and $Y_{ij} = 0\ otherwise)$. We attempt employing one or more explanatory factors to explain the variances X_k.

The coefficient of the multivariate probit method is insufficient to deduce the connection between the response and the independent variables. The only directly interpretable factor is the sign, as well as the importance of the regression coefficients (Funk *et al*., 2020). Positive β_k indicates that the independent variable X_k will improve the likelihood of implementing a specific adaptation method.

However, the coefficient β_k cannot show how likely farmer i is to choose a given adaptation strategy. $(Y_{ij} = 1)$ will change when we alter X_k i.e., the coefficient β_k does not convey the extent of a change in the independent variable X_k on Pr $(Y_{ij} = 1)$. For the results to be interpreted and quantified, we must compute the logistic model's marginal effects utilising the coefficients by computing the likelihood derivative with respect to the element, k of X.The marginal effect is usually computed at the sample mean data and changes depending on the values of X. They explain how changing the units of the predictor variables affects the probabilities of the response variable (Pr $(Y_{ij} = 1)$.

A marginal effect derivation (y'_{ij}) gives:

$$y'_{ij} = \Pr(Y_{ij} = 1).(1 - \Pr(Y_{ij} = 1))\beta_k \qquad (15).$$

Dummy variable marginal effects are underreported, and coefficients are interpreted as odds ratio marginal effects rather than probability (Funk *et al*., 2020).

The use of partial elasticities is another method for analysing the outcomes of logistic regression. It calculates the percentage change in the likelihood of the response variables (implementation of specific adaptation mechanisms in reaction to changes and variability in climate), consequently, an increase of 1% in explanatory variables X_k.

The logit model's partial elasticity calculated at the mean can be expressed as:

$$\eta\gamma(X_k = \beta_k X_k \Pr(Y_{ij} = 1))\beta_k \qquad (16)$$

In this analysis, a null hypothesis is created by setting regression coefficients in the logistic model equal to zero against the alternative that one of the regression coefficients (β_k) is nonzero (Peng *et al.*, 2002).

$$H_0: \beta_k = 0 \; and \; H_1: at \; least \; one \; \beta_k \neq 0$$

2.6 Dependent and independent variables

Adaptation options were divided into two types, farm and off-farm categories. Farm-level approaches are activities or changes done on a household's land or land obtained through cash or shared tenancy to enhance agricultural production and productivity (Ali & Erenstein, 2017b; Bryan *et al.*, 2013a; Demeke *et al.*, 2011; Mulwa *et al.*, 2017b; Twecan *et al.*, 2022). Farmers' actions outside of farming are referred to as off-farm strategy (Antwi-Agyei *et al.*, 2014). For this study, six adaptation techniques were chosen based on these categories: four farm-level and two off-farm strategies. The decision was made based on the survey data on the adaptation strategies farmers mostly employed. The explanatory variables were chosen based on a survey of existing literature on adoption research and climate change adaptation. Household characteristics (age, education, family size, household wealth, etc.) and institutional factors (access to markets, credits, extension services, etc.) are independent variables. Independent variables are chosen based on an assessment of relevant literature and data availability (Adego & Woldie, 2022; Ashraf & Routray, 2013; Batungwanayo *et al.*, 2023; Charles *et al.*, 2014; Elum *et al.*, 2017; Hardee & Mutunga, 2010; Schneider & Peter, 2010; Sileshi *et al.*, 2019; Thoai *et al.*, 2018).

2.7 Results and Discussions

2.7.1 Results

2.7.1.1 Descriptive statistics

Table 7 reveals that smallholder farmers in The Gambia predominantly adopt on-farm adaptation strategies, with crop rotation (49.05%), changing crop varieties (45.24%), and adjusting planting dates (38.57%) being the most common practices. The use of inorganic fertilisers also shows moderate uptake (34.52%), indicating farmers' efforts to manage climate risks through direct changes in farming techniques. In contrast, off-farm strategies like migration (3.1%) and petty business (5.71%) are rarely adopted, suggesting limited livelihood diversification and a strong dependence on agriculture. These findings highlight the need for policies that not only strengthen existing on-farm strategies but also expand access to financial support, skills training, and market opportunities to promote off-farm resilience pathways.

Table 8: Descriptive statistics of variables

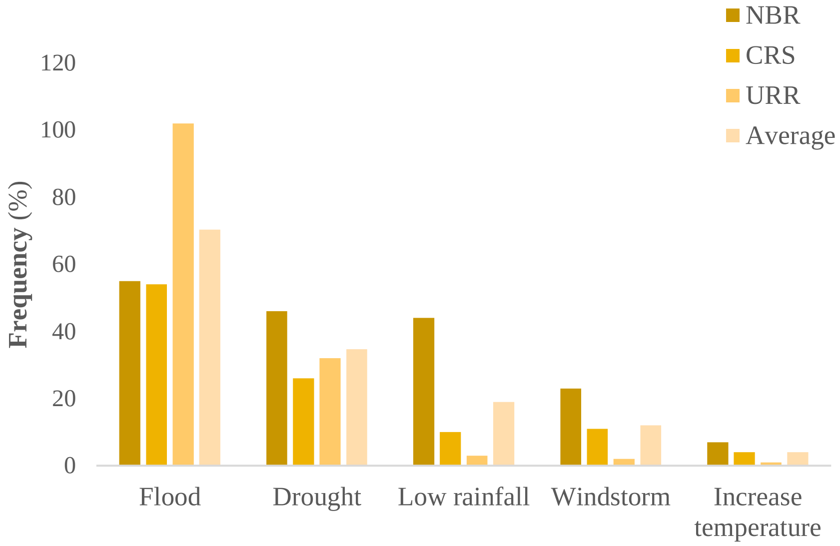
Variable	Category	Frequency	Percent (%)
Dependent variables			
Crop rotation (CR)	0	214	50.95
	1	206	49.05
Change planting date (CPD)	0	258	61.43
	1	162	38.57
Use of inorganic fertilisers (UIF)	0	275	65.48
	1	145	34.52
Change crop variety (CCV)	0	230	54.76
	1	190	45.24
Migration (Mg)	0	407	96.9
	1	13	3.1
Petty business (PB)	0	396	94.29
	1	24	5.71
Explanatory variables (see Table 1)			

NB: 1 if the farmer adopted the adaptation strategy, 0 otherwise
Source: Author's analysis based on survey data (2023)

2.7.1.2 Main climate risk faced by farmers

Figure 17 illustrates the primary climate risk experienced by farmers within the study area. Flood is the predominant climate hazard encountered by farmers in all regions, with an average of 70% of farmers reporting its occurrence.

Figure 17: Main climate risks faced by farmers

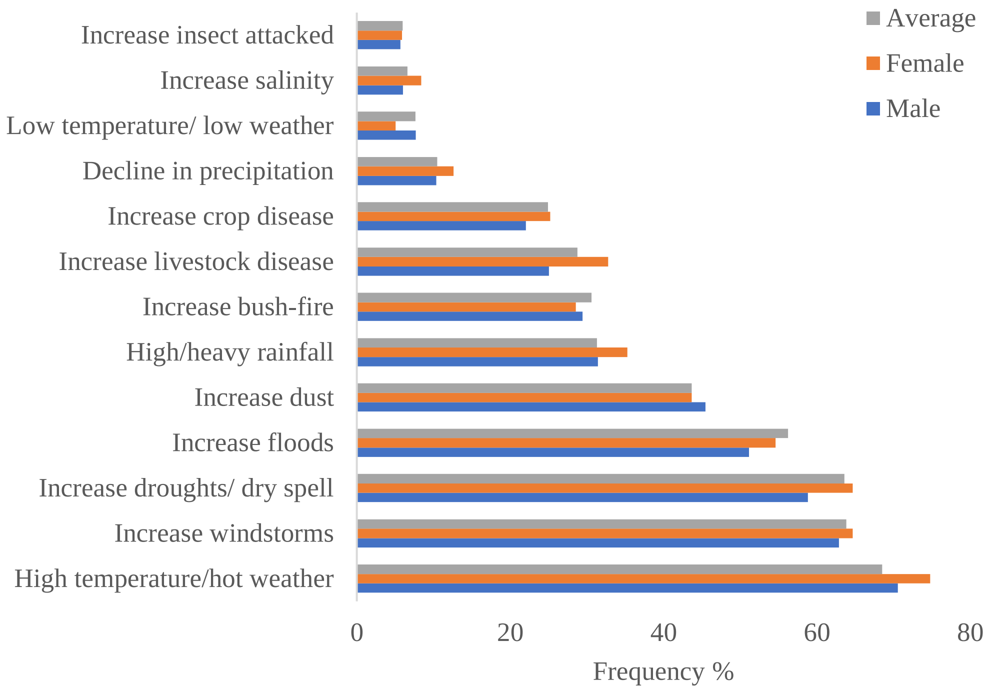


The districts of NBR and URR have the highest prevalence of farmers who reported experiencing floods, with 102 and 55 farmers, respectively. Drought ranks as the second most prevalent risk, with an average of 35% of farmers reporting its occurrence. Insufficient precipitation is the third most prevalent risk, exhibiting a notable disparity between NBR and the remaining regions. Windstorms and elevated temperatures pose the lowest frequency of dangers, with an average of 12% and 4% of farmers, respectively, reporting them.

2.7.1.3 Perception of climate risk

Figure 18 shows the perceived impacts of climate change and variability. The responses indicate that high temperature/hot weather, an increase in windstorms, an increase in droughts/dry spells, and an increase in floods are the most commonly recognised impacts. Alotaibi *et al*. (2020) found that a large proportion of farmers in the region believed climate change was caused by both human activity and natural processes. Also, most farmers are worried about increasing risks of pest attacks and disease outbreaks, as well as flooding, along with rising crop heat stress. Approximately 69% of the participants in the sample recognised high temperature as one of the most often reported climate threats in the investigated regions. Likewise, almost 64% of the entire group of participants experienced a rise in both drought and windstorms. 56% and 44% indicated a rise in occurrences of floods and dust, respectively. 31% of respondents reported a rise in cattle disease, while 25% reported an increase in crop disease.

Figure 18: Climate risk perception



Other climate risks encompass substantial precipitation (31%), reduced precipitation (11%), increased insect attack (8%), elevated salinity (7%), and cold temperatures (6%). For most climate-related issues, the percentage of female responses is slightly higher than that of male responses. This suggests that women are highly aware of the various ways in which climate change can affect communities, agriculture, and the environment. It is crucial to acknowledge farmers' perceptions of climate-related risk when formulating efficient adaptation strategies and responses. Approximately 88% of farmers have observed a discernible shift in the climate within the last 10-20 years; this is supported by the findings of Soglo & Nonvide (2019).

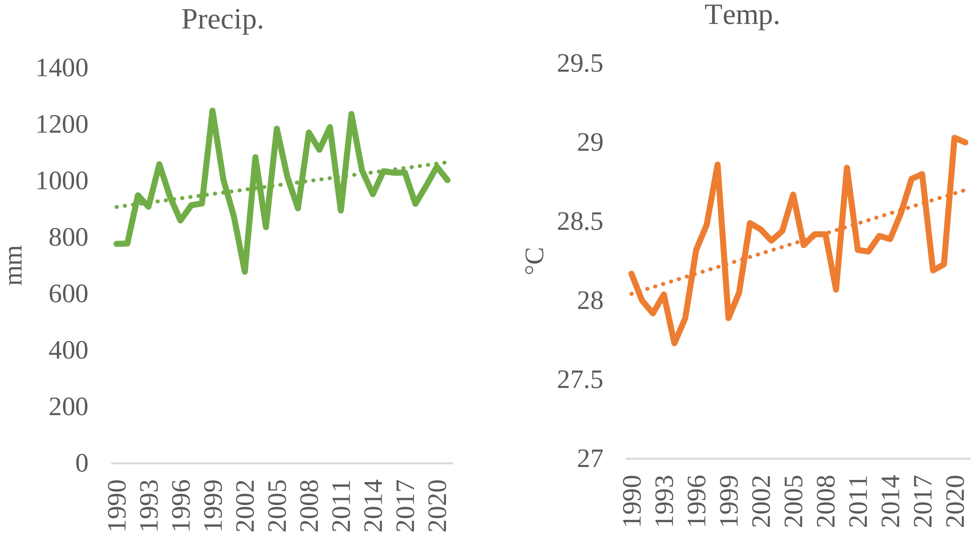
Climate risk perception among Gambian farmers shows a strong awareness of key climate-related hazards, particularly extreme heat, droughts, windstorms, and floods. These perceptions closely mirror scientific evidence, which confirms that West Africa is one of the most vulnerable regions globally. According to the IPCC (2021), global warming has intensified the frequency and severity of heatwaves, with sub-Saharan Africa experiencing disproportionate warming trends. High temperature is thus a legitimate and accurately perceived risk, particularly given its direct impacts on crop productivity, livestock health, and human well-being. Perceived risks, such as windstorms and prolonged dry spells, are also well-supported by empirical data. Shifting rainfall patterns, coupled with delayed onset and early cessation of rains, have disrupted agricultural calendars across The Gambia (Ceesay & Touray, 2022). Studies by (S. Asfaw *et al*., 2019; Mavhura *et al*., 2021) also show how changes in seasonal variability increase the exposure of smallholder farmers to climate shocks, compounding their vulnerability due to limited adaptive capacity.

Flooding also emerged as a frequently experienced climate hazard (reported by 44% of farmers), followed by drought and insufficient rainfall. These findings align with the observations of (Bueno Rubial *et al*., 2024; A. A. Shah *et al*., 2023; Soglo & Nonvide, 2019), who similarly identified floods and droughts as the top climate risks in West Africa. Farmers' perception of high temperature, windstorms, and increased droughts as key climate change impacts further affirms their awareness and lived experiences, echoing results from (Alotaibi *et al*., 2020). Similarly, dust storms and heavy rainfall are moderately perceived and are associated with increasing land degradation and erosion, which threaten agricultural sustainability (Asrat & Simane, 2018b; Tato, 2019). Bushfires, while perceived at a medium level of concern, are also recognised in the scientific literature as increasingly common, especially during prolonged dry periods. Research by (Ibol, 2022; Jones *et al*., 2022; Tiereyangn Kabo-bah *et al*., 2019) links bushfire prevalence to extreme temperature and dryness, exacerbated by deforestation and land use changes. The perception of livestock and crop diseases was rated moderately, though scientific findings strongly support this as a rising concern. Pathogen outbreaks are projected to increase due to climate-induced shifts in disease vectors and pest populations (Bett *et al*., 2017; Yadav & Upadhyay, 2023). This is especially troubling for communities whose livelihoods depend heavily on rain-fed agriculture and animal husbandry. Where the gap is most evident is in the under perception of risks such as declining precipitation, insect infestations, and salinity intrusion. These threats, although less visible, have substantial long-term impacts. Salinisation of soil and water resources, especially in coastal regions of The Gambia, is driven by sea level rise and poor irrigation practices (IPCC, 2014). Meanwhile, increased pest invasions such as fall armyworms linked to warming and erratic rainfall have significantly reduced yields of staple crops across West Africa (Gaurav & Chaudhary, 2020; T. O. Ojo & Baiyegunhi, 2021).

2.7.1.4 Mean annual precipitation and temperature

The scientific data collected also corroborated household views of climate risk perception. An increased trend in the mean annual temperature from 1901 to 2021 was discovered in the research area, as shown in Figure 19. The mean rainfall data exhibited a marginal decline throughout the same time frame, aligning with the observations made by farmers.

Figure 19: Mean annual precipitation and rainfall



a. Average annual precipitation

b. Average annual temperature

2.7.1.5 Binary logistic estimate and marginal effect on adaptation

The predicted result of the binary logit model can help illuminate what factors lead farmers to adopt climate risk strategies in agriculture. The coefficients represent the degree and direction of association between each variable with the adoption of climate risk strategies. Marginal effects showed how likely a farmer’s adaptation can change in connection to a single-unit shift in any one of the explanatory variables. The estimated coefficients of the empirical binary logit model are presented in Table 9. The value of Pseudo R^2, which is 0.501, suggests that the explanatory factors accounted for 50.1% of the probability that farmers would take climate change adaptation measures. The intensity of adaptation by farmers is driven mainly by access to information, external support, and experience with climate events. The results of the model indicate that farmers who are informed, supported, and aware of climate risk are more likely to take adaptive measures. This highlights the importance of providing targeted support, especially to women smallholder farmers. The results have shown that six major elements increase the probability of farmers adjusting their adaptation strategies in response to climate change. Among these were land tenure, average annual farming income, gov’t support, marketing information access, and witnessing unexpected events and climate change perception.

Table 9: The estimated result of the binary logit model and the marginal effects on farmers' decisions to adopt climate risk strategies in agriculture

Explanatory variables	Coefficients	Marginal effects
Gender (Base: Male)		
Female	**-1.062****	**-0.066***
Agecat (Base: Less than 35 (young farmers))		
35-55 years (Middle age)	0.088	0.005
Above 55 years (Old age farmers)	-0.584	-0.035
Education level (Base: No formal education)		
Primary	0.309	0.017
Secondary	-0.037	-0.002
Tertiary	0.000	0.000
Region (Base: NBR)		
CRS	-0.365	-0.014
URR	**-2.772*****	**-0.205*****
Household size	0.008	0.000
Farm size	**-0.164****	**-0.009****
Farming experience square	-0.005	0.000
Land tenure	**1.659*****	**0.096*****
Average annual farming income	**0.000****	**0.000*****
Access gov't support	**1.777****	**0.103*****
Off-farm income	0.115	0.007
Member of a social/farm group	0.36	0.021
Access to marketing information	**2.019*****	**0.117*****
Witness unexpected weather event	**1.289****	**0.075****
Climate change perception	**1.633****	**0.095*****
Constant	-1.493	
N	420	
Log-likelihood	-81.648	
LR chi2(18)	163.650	
Prob>chi2	0.000	
Pseudo R2	0.501	

Note: Significance levels are indicated by ***p<1%. **p<5%, *p<10%

Source: Author's analysis based on survey data (2023)

Access to marketing information was the most noteworthy and statistically significant variable affecting farmers 'probability of adopting measures to deal with global warming. The probability of adoption by farmers who had access to marketing information was 11.7 % higher than those who did not have that privilege.

The results also show that farmers with support from the government, who experienced unexpected events and a perceived change in the climate, tended to be more inclined towards an adjustment strategy for adaptation than other farmers. Adaptation probability was 10.3% higher for farmers who receive support from the government and 9.5% for farmers who believe that the climate has changed in recent years, compared to those with no such perception of change. The coefficient of gender (female) and the marginal effect are both negative. This suggests there is a negative relationship with adoption for female farmers; the probability of adoption by male farmers was 6.6% higher than females. Farm size was statistically significant but had a negative effect on the adoption of adaptation strategies. This finding contradicts the one made by Thoai *et al*. (2018).

2.7.1.6 Multivariate probit estimates of the determinant of farmers' adaptation strategies

The parameter estimate obtained from the (MVP) analysis of the factors that impact the adoption of climate risk adaptation techniques by smallholder farmers in The Gambia for both on-farm and off-farm strategies is displayed in Table 10. The positive correlation between the coefficient of petty business and gender (female) and middle-aged farmers indicates that female and middle-aged farmers are more inclined to implement off-farm adaptation techniques in comparison to male, young, and elderly farmers. The coefficient for age and primary education positively influenced the decision to adopt crop rotation as an adaptation strategy, but it did not have a meaningful effect on the other adaptation techniques. The findings of Denkyirah *et al*., (2016) contradict the current result since they found a negative correlation. Farmers in the middle-aged and older age groups exhibit a higher propensity to implement crop rotation tactics in comparison to their younger counterparts. The education coefficients exhibit variation among different degrees of schooling. Primary education appears to enhance the probability of adopting both on-farm and off-farm techniques, however, tertiary education shows negative coefficients, indicating a potential drop in the likelihood of adoption. Primary education has a statistically significant influence on the adoption of a petty business adaptation strategy when pursuing an off-farm approach.

The results of the multivariate probit model reveal significant interdependencies between farmers' adoption of on-farm and off-farm adaptation strategies, as confirmed by the likelihood ratio test of the rho parameters (Chi^2 (15) = 75.346, $p < 0.01$). This finding highlights that farmers' decisions to adopt specific adaptation measures are not made in isolation but are interconnected. For instance, middle-aged farmers and those with primary education are more likely to engage in both crop rotation and petty business, suggesting a complementary relationship between on-farm and off-farm strategies. Conversely, female farmers are more inclined towards off-farm activities such as petty business while being less likely to adopt on-farm measures, indicating a possible substitution effect. These correlations underscore the need for integrated adaptation policies that address the diverse and overlapping strategies farmers employ to cope with climate risks. The multivariate analysis confirms the alternative hypothesis that farmers who perceive climate risk are much more likely to use on-farm adaptation strategies. This affirms the essential role of perception in driving climate-resilient agricultural practice in The Gambia.

Table 10: MVP coefficient estimates for the determinants of farmers' adaptation strategies to climate change

	On-farm adaptation strategies				Off-farm adaptation strategies	
Dependent variables	CR	CPD	UIF	CCV	PB	Mg
Explanatory variables	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Female	0.143	-0.117	-0.182	-0.009	**0.424***	0.259
Middle-aged farmers	**0.320***	-0.212	0.112	0.154	**1.008****	0.252
Old aged farmer	**0.385***	0.000	0.075	0.150	0.431	0.166
Primary education	**0.413***	-0.043	0.175	**-0.624*****	**1.000*****	-5.321
Secondary education	-0.014	0.136	0.094	0.131	-0.225	-0.429
Tertiary education	**-0.122***	-0.004	**-1.099****	-0.244	-3.362	-4.309
Household size	-0.010	-0.009	**0.013****	-0.007	0.009	0.004
Average annual farming income	**0.000*****	**0.000***	**0.000****	0.000	**0.000*****	0.000
Access to credit	-0.077	-0.302	-0.086	-0.27	-0.126	-3.864
Access to extension services	**-0.318****	**0.322****	-0.215	**0.655*****	0.229	3.174
Member of a social farm group	**0.668*****	**0.389***	**0.487****	-0.169	0.700	1.414
Climate change perception	**1.791*****	**1.078*****	**0.786*****	**1.406*****	0.218	2.927
Training	-0.049	0.096	-0.054	0.184	**-1.054***	**1.294*****
Cons	**-2.377*****	**-1.430*****	**-1.792*****	**-1.588*****	**-3.897*****	-9.848

Likelihood ratio test of rho21 =rho31=rho41=rho61=rho32=rho42=rho52=rho62=rho43=rho53=rho63=rho54 = rho64 = rho65=0

Chi2(15) =75.346

Wald chi2(78) =221.75

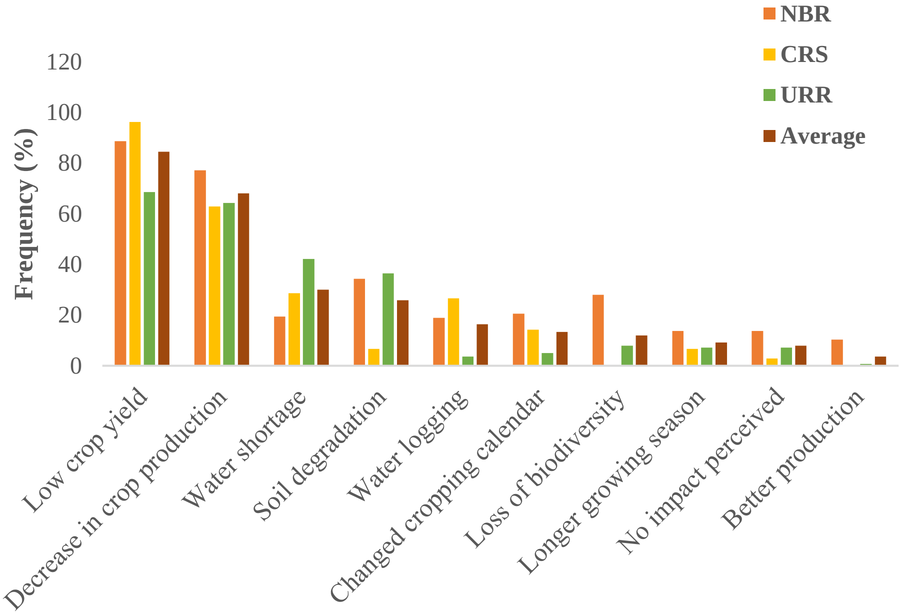
Prob>chi2 =0.000***
Log likelihood = -1073.5023
Note: Significance levels are indicated by ***p<1%, **p<5%, *p<10%

Source: Author's analysis based on survey data (2023)

2.7.1.7 Perceived impact of climate change

Figure 20 shows the perceived impact of climate risks on agricultural production. Overall, 84% of respondents reported low crop yields, and 64% reported a reduction in crop production as an adverse impact due to climate-related risks, consistent with the findings of (A. A. Shah *et al.*, 2023; Soglo & Nonvide, 2019). While 30% and 26% of respondents reported that altering the climatic conditions would increase risk to agriculture, such as water shortage and soil degradation. 16% and 12%reported water logging and change in cropping calendar conditions. The study further indicated that 8% of the farmers reported that climate risk had no impact on their farming. The concerns regarding the effect of climate change and its variability on agricultural productivity are emphasised in the studies conducted by Ali & Erenstein (2017a; Ullah *et al*., 2018).

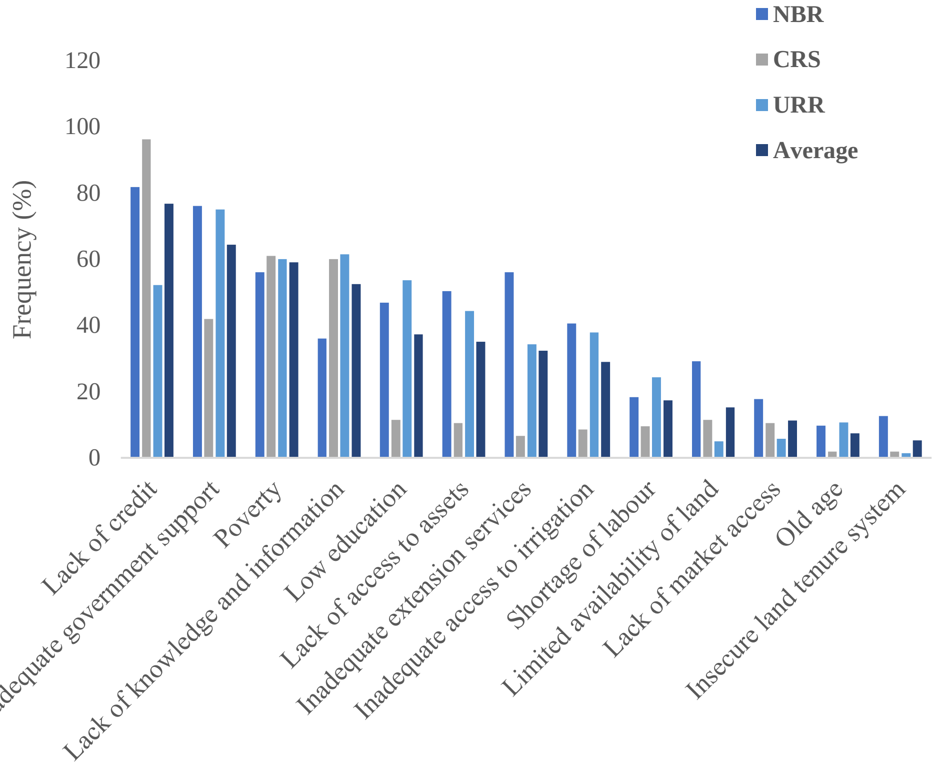
Figure 20: Perceived impact of climate risk by farmers



2.7.1.8 Adaptation constraints

The constraints of adaptation faced by farmers in adapting to the impact of climate risk are reported in Figure 21. The most significant obstacle, cited by 77%, was a lack of credit, indicating that financial constraints hinder farmers from investing in vital tools and infrastructure for climate resilience. Inadequate government support is also a major concern (64%), indicating that farmers do not receive the necessary aid or policies to support their adaptation and mitigation efforts.

Figure 21: Adaptation constraints by farmers



Additionally, 59% of the farmers are constrained by poverty to mitigate the impact of climate risk. Lack of knowledge and information was identified by 52% as a challenge in implementing adaptation and mitigation strategies. Low education is 37%, highlighting that information gaps limit their ability to implement adaptation and mitigation strategies. Other challenges include a lack of assets, inadequate extension services, and insufficient irrigation, 35%, 29%, and 32%, respectively. Barriers such as shortage of labour, limited availability of land, and lack of market access, old age, insecure land tenure system, add to these hurdles, though less frequently cited.

2.7.2 Discussions

The findings of this study demonstrate that climate risk adaptation among smallholder farmers in The Gambia is both widespread and significantly shaped by a combination of socio-economic, institutional, and perceptual factors. The descriptive analysis reveals that 87% of farmers adopted at least one adaptation strategy, with crop rotation (49%), changing planting dates (39%), and use of inorganic fertilisers (35%) being the most common. This high adoption rate is consistent with studies by Ali & Erenstein (2017) & Ullah *et al*. (2018), who found that African smallholders are increasingly resorting to low-cost adaptation practices in the face of worsening climate variability.

The binary logistic regression results reveal that key predictors of adaptation include land tenure, average annual income, access to government support, marketing information, prior experience with climate events, and climate change perception. Notably, access to marketing information was the most influential factor, increasing adaptation probability by 11.7%. This corroborates findings by (Aqib *et al.*, 2024; Asare-Nuamah & Amungwa, 2021), who emphasised the role of information flow in shaping climate responses. However, the results also highlight gender disparities in adaptation: female farmers were 6.6% less likely to adopt adaptation measures compared to males. This finding is consistent with (Adzawla *et al.*, 2019; Carr & Thompson, 2014; Mersha & Van Laerhoven, 2016), who noted that social and economic barriers often reduce women's participation in adaptive farming practices. This reinforces the call for gender-sensitive policies that bridge the gap in access to resources and decision-making autonomy.

The multivariate probit analysis provides further nuance, indicating that middle-aged farmers and those with primary education were more likely to adopt crop rotation and petty business as adaptation strategies (Ado *et al.*, 2020; K. Alam, 2015; Mwinkom *et al.*, 2021). Conversely, tertiary education showed a negative association with some practices, possibly due to higher opportunity costs or shifting livelihood preferences. Perception remains a powerful driver of adaptation. Farmers who acknowledged a changing climate were significantly more likely to adopt both on-farm and off-farm strategies, aligning with evidence from (Sertse *et al.*, 2021; Voss, 2022; ZHAI *et al.*, 2018). A perception index score of 0.66 reflects a moderate level of confidence in the effectiveness of available strategies, suggesting that while farmers are aware and responsive, there remains room to build greater trust and capacity in adaptation tools.

Nonetheless, the results also underscore critical adaptation constraints. Financial limitations (77%), lack of government support (64%), and poverty (59%) were identified as major barriers. These findings are consistent with Asfaw *et al.*, 2019), who argued that limited financial capital and institutional support often inhibit effective climate adaptation in Sub-Saharan Africa. The study affirms that adaptive behaviour among Gambian farmers is informed by experience, socio-economic conditions, institutional support, and perception of risk. However, disparities in access, particularly for women, and structural constraints such as poverty and inadequate support systems must be addressed to foster resilient agricultural systems.

2.8 Conclusion

The study has used primary farm-level data from rural Gambia to assess farmers’ perceptions of climate risk and on-farm and off-farm strategies taken to cope with the changing climate. The study indicates that most farmers had a perception of climate change (about 88%) during the past 10 -20 years. Farmers adopt different kinds of adaptation strategies to reduce the negative consequences of climate change to maintain and/or improve their livelihood. The results of the binary logit model revealed that land tenure, average annual farming income, gov’t support, marketing information access, witnessing unexpected events and climate change perception are the main factors that influence farmers to adopt a climate risk adaptation strategy. Farmers in the study area have been well aware that climate conditions are changing and that strategies should be implemented to cope with the adverse effects of these changes. Furthermore, this study pointed out that 49%, 48%, 41%, and 32% of the farmers were using change crop variety, crop rotation, change planting date, and use of inorganic fertiliser, respectively. And 6% and 3% used petty business and migration as an off-farm adaptation strategy. The Multivariate probit model was employed to determine the factors determining farmers' choice of adaptation strategies related to climate risk.

The MVP result confirms that being a female and middle-aged farmer has a significant impact on petty business as an adaptation strategy. Crop rotation as an adaptation strategy was influenced by age, primary education, membership in a social farm group, and perceptions of climate change. Access to extension services, membership in a social farm group, and perceptions of climate change positively influenced the decision to adopt changing planting dates as an adaptation strategy. The use of inorganic fertiliser was influenced by household size, average annual farming income, members of a social or farm group, and climate change perception. Change in crop variety was significantly influenced by access to extension services and climate change perception. The primary challenges faced by smallholder farmers in implementing measures to mitigate climate risk are insufficient access to credit, inadequate government support, poverty, and limited knowledge and information.

Given its major role in the agriculture sector, the government should address the credit constraint by ensuring the availability of credit opportunities, increasing support for poverty alleviation, and promoting the dissemination of climate information. Additional efforts should be made to maximise farmers' participation in the decision-making processes. Developing policies that target the enhancement of adaptation constraints for smallholder farmers poses significant potential to enhance farmer adaptability to climate risk. Directing efforts toward women's groups in smallholder rural areas can provide significant benefits in terms of enhancing the adoption of methods by smallholder farmers. Government policies should prioritise promoting research, development, and dissemination of suitable technologies to assist farmers in adapting to climate change. Improving access to climate information and extension services is critical, as it significantly enhances farmers’ ability to adopt effective adaptation strategies. Equally important is expanding government and institutional support, which plays a vital role in overcoming financial and structural barriers to climate resilience.

The findings provide an initial reference point and a more solid foundation for future research, possibly on a larger representative scale. Hence, it is imperative to broaden the study to encompass additional effects of climate change and variability on the vulnerability of farmers. One notable limitation of this study lies in its use of cross-sectional data collected during a single agricultural season, which may not adequately reflect the long-term dynamics of adaptation or seasonal fluctuations in farmers’ responses. Future research should prioritise longitudinal studies to track how adaptation strategies evolve and to assess the sustained impact of specific climate-resilient initiatives. It is equally important to evaluate the effectiveness of government interventions and programs in enhancing farmers’ adaptive capacity. Particular emphasis should be placed on understanding gender-specific vulnerabilities and the role of non-farm livelihood strategies in shaping adaptive responses. These efforts will contribute to a more comprehensive understanding of climate resilience and support the development of inclusive, evidence-informed policy frameworks for climate adaptation in The Gambia.

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3. Essay 3: Farmers’ Perceptions of the Efficacy of Current Climate Risk Adaptation and Mitigation Strategies on Agriculture in The Gambia [4]

Abstract

Agricultural systems face increasing challenges due to climate change, necessitating effective adaptation and mitigation strategies. This study investigates smallholder farmers’ perceptions of the efficacy of these strategies in The Gambia, employing a mixed-method approach that includes a perception index (PI), effectiveness score (ES), importance–performance analysis (IPA), and statistical analysis. A structured survey was conducted among 420 smallholder farmers across three agricultural regions. Farmers rated adaptation and mitigation strategies using a Likert scale, and a PI was developed to quantify their responses. The index was 0.66, indicating a moderate level of perceived effectiveness. Additionally, ES was calculated to assess the performance of various strategies, while IPA categorised strategies based on their adoption and perceived impact. Chi-square tests and factor analysis were applied to explore differences in perceptions. The findings reveal that strategies such as crop diversification, pesticide application, irrigation, and the use of inorganic fertilisers are widely adopted and perceived as effective. The IPA matrix identified key strategies needing improvement, particularly those with high importance but low performance. Barriers to adoption include limited financial resources (77%), lack of government support (64%), and insufficient knowledge (52%), with no significant gender-based differences in perceptions. Policymakers should prioritise targeted investments in adaptive technologies, financial support, and knowledge-sharing platforms to enhance the adoption and effectiveness of climate adaptation and mitigation strategies among smallholder farmers. This research provides valuable insights into the interplay between farmer perceptions, adaptation strategies, and agricultural sustainability in The Gambia.

Keywords: ·Climate risk ·Perception index · Adaptation · Mitigation ·Efficacy

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3.1 Introduction

Climate change poses a major global threat to agriculture (Lambarraa-Lehnhardt *et al*., 2024), causing disruptions in the production and food supply due to extreme weather variations. Rising temperatures, erratic rainfall, prolonged droughts, and increased frequency of extreme weather events threaten global food security, causing biodiversity loss and alteration in the ecosystem dynamics (Abbass *et al*., 2022a). Moreover, climate variations increase the risk of food and waterborne diseases, as well as the emergence of antimicrobial resistance, presenting further risks to human health. Adverse weather phenomena, including water scarcity, storms, heatwaves, floods, erratic rainfall, and pest outbreaks, are disrupting agricultural output and impacting the socioeconomic well-being of farmers (Verma *et al*., 2024). The impacts are particularly severe in sub-Saharan Africa (SSA), where agriculture is the key driver of economic development and the primary source of income for smallholder farmers.

Identifying and assessing adaptation and mitigation options are key pre-requisite steps to adaptation prioritisation and effective adaptation planning (Braimoh *et al*., 2022). Considering smallholder farmers' perception of the effectiveness of adaptation and mitigation strategies is highly pertinent for policy decisions aimed at assisting farmers in addressing the impacts of climate change (Berrang-Ford *et al*., 2019a; Singh *et al*., 2022). In developing and least-developed countries (LDCs), where interconnected climate risk may impede the attainment of the SDGs, urgent adaptation is required (Hoegh-Guldberg *et al*., 2019; Roy *et al*., 2023; Simpson *et al*., 2023). Adaptation is even more critical in highly vulnerable countries like The Gambia (Camara et al., 2023), where climate-sensitive sectors such as agriculture are vital to economic development. In a study by De Gregorio *et al*., (2022) found that while risk perception has a lesser impact, the farmers' perceived capacity to adopt mitigation measures is a strong predictor of their intentions to engage in climate change mitigation efforts.

The scarcity of evidence from The Gambia, along with the highly contextual impacts of the identified adaptation strategies, underscore the need for a thoughtful examination of barriers to implementing policies and interventions aimed at enhancing productivity and income, at the same time fostering resilience and climate risks and mitigating GHG emissions (Braimoh *et al*., 2022). The studies by Braimoh *et al*. (2022); Carr *et al*. (2022) identify significant knowledge gaps regarding the efficacy and viability of adaptation strategies in The Gambia, and the effectiveness of various adaptation and mitigation strategies in future climates remains unclear. Furthermore, the Paris Agreement mandates all parties to evaluate adaptation progress, which encompasses reviewing the efficacy of adaptation to guide climate action planning and commitments. Consequently, the assessment of adaptation and mitigation effectiveness has become imperative (Berrang-Ford *et al*., 2019b; Singh *et al*., 2022). Incorporating smallholder farmers' perspectives on the efficacy of farm-level adaptation and mitigation techniques is crucial for policy formulation aimed at assisting farmers in alleviating the effects of climate change.

As climate variability intensifies, understanding farmers’ perceptions and the effectiveness of adaptation and mitigation strategies becomes essential for developing informed, locally appropriate interventions. Despite growing awareness of climate change impacts, gaps remain in the alignment between perceived strategy effectiveness and actual performance outcomes. To address this, the study employed a mixed-method approach that combined quantitative and perception-based tools to evaluate farmers’ experiences and decision-making. A structured survey was conducted among 420 smallholder farmers across three major agricultural regions. Data collection focused on farmers’ ratings of adaptation and mitigation strategies using a Likert scale, from which a Perception Index (PI) was derived. The study further utilised an Effectiveness Score (ES) and Importance–Performance Analysis (IPA) to categorise strategies based on both adoption and perceived impact. In addition, Chi-square tests were applied to explore demographic differences. This integrated methodology offers a comprehensive assessment of how smallholder farmers perceive and engage with climate risk strategies, providing valuable insights for policy and practice.

Research question

The main research question for this essay is: How do farmers perceive the efficacy of climate risk adaptation and mitigation strategies in reducing the impact of climate risk in The Gambia?

Specifically;

- what are smallholder farmers’ perceptions of the efficacy and outcomes of current adaptation and mitigation strategies in The Gambia?
- which adaptation and mitigation strategies are most widely adopted by farmers, and how do they perceive their social, economic, and environmental impact?

Objectives

The general objective is to evaluate farmers' perceptions of the efficacy of climate risk adaptation and mitigation strategies and develop an index to quantify these perceptions. Specifically;

- to assess the perceived effectiveness of climate risk adaptation and mitigation strategies employed by smallholder farmers in The Gambia.
- to evaluate the perceived social, economic and environmental outcomes of adopted adaptation and mitigation strategies

Hypothesis (Ho)

Smallholder farmers do not have a significant perception regarding the efficacy of adaptation and mitigation strategies

Despite the growing importance of adaptation and mitigation strategies, the efficacy of climate risk adaptation has received little focus (Atteridge & Remling, 2018; Moser & Boykoff, 2013; Palutikof *et al*., 2015). The researcher has not found any study that assesses farmers' perceptions of the efficacy of current adaptation and mitigation strategies. There is limited comprehensive knowledge regarding the perception of the efficacy of climate risk adaptation and mitigation options among smallholder farmers in The Gambia. Without this understanding, it becomes difficult to design and implement appropriate adaptation strategies that align with the needs and circumstances of farmers. By examining the range of adaptation options currently utilised by farmers and their perceptions of their effectiveness, policymakers and stakeholders can identify gaps, barriers, and opportunities for improving and scaling up climate-smart practices in the agricultural sector. Addressing this problem is crucial for enhancing the adaptive capacity and resilience of farmers in The Gambia.

The research explores smallholder farmers' perceptions of the effectiveness of current climate risk adaptation and mitigation strategies in agriculture. It evaluates how these strategies impact agricultural productivity, economic outcomes, and resilience to climate change while also developing a perception index to quantify farmers' views on the effectiveness of adaptation and mitigation strategies used. The study highlights the importance of incorporating smallholder farmers' perspectives into policy decisions to enhance the adoption of sustainable agricultural practices. Engaging with farmers allows policymakers to tailor climate risk adaptation and mitigation strategies to more effectively address the specific needs of local agricultural communities.

This essay is structured as follows: The first section addresses the introduction of the essay. Section 2 presents the background and context of climate risk adaptation and mitigation in agriculture, with emphasis on the relevance of farmers' perceptions. Section 3 outlines the methodology employed, including data collection, empirical models, and analytical frameworks used. Section 4 presents the results and discussion, analysing farmers' perceptions, perceived outcomes, and barriers to adoption. Section 5 concludes the essay with key findings and policy recommendations.

3.2 Background

3.2.1 Climate risk adaptation and mitigation strategies in agricultural contexts

Many climate change adaptation strategies also contribute to mitigation, including crop diversification, soil conservation, crop rotations, and quality seeds. Planting shaded trees and halting deforestation can also trap carbon, so enhancing mitigation efforts (FAO, 2008). In their meta-analysis, Sinore & Wang, (2024) highlighted various adaptation measures, including land management practices and livelihood diversification through income-generating activities. They also outlined mitigation strategies, such as agroforestry, improved crop varieties, and soil conservation, which can help mitigate the impact of climate change. These strategies aim to strengthen resilience, reduce vulnerability, and promote sustainable agricultural practices in the face of climate change. However, limited financing, minimal stakeholder engagement, insufficient access to weather data, and weak institutional support challenge the effective implementation of these strategies. Zobeidi *et al*. (2023) explored the association between agricultural specialists' perception of climate change and their willingness to participate in mitigation efforts at both personal and professional levels. Key elements influencing mitigation and intention to engage in mitigation activities include the new ecological paradigm (NEP), risk awareness, personal efficacy, accountability, belief in climate change, and low psychological distance. Key prioritised strategies identified in SSA countries include the use of improved seeds, good agricultural practices, and conservation agriculture.

Economic assessments have shown that these practices yield high net present values (NPV) and internal rates of return (IRR) in distinct value chains (Akinyi *et al*., 2022). A study by De Gregorio *et al*. (2022) found that while risk perception has a lesser impact, the farmers' perceived capacity to adopt mitigation measures is a strong predictor of their intentions to engage in climate change mitigation efforts. Climate risk and adaptation strategies in agriculture include modifying crop production to respond to current climate impacts, such as adjusting planting dates or selecting crop varieties that effectively accommodate changing weather conditions. Mitigation strategies, on the other hand, include measures that prevent or reduce future climate change effects, such as the reduction of GHG emissions through the implementation of improved agricultural methods. Both strategies are critical for sustaining agricultural productivity and ensuring food security, particularly in climate-vulnerable regions. The study conducted by Ikehi *et al*. (2023) assesses the efficacy of climate change adaptation and mitigation strategies in the Niger Delta, with a specific emphasis on their ability to promote sustainable agricultural systems. Successful implementation of these strategies requires cooperation among farmers, government entities, and other key stakeholders.

The impact of climate change on agriculture is significant, especially considering that most countries' agriculture depends on rainfall. This has implications for crop productivity, soil processes, water availability, and pest dynamics. Pathak (2023) outlines various adaptations to mitigate climate risks in agriculture. These include developing resistant crop varieties, adopting advanced agronomic practices, and efficient use of water. Conservation agricultural techniques, such as no-till farming and alternate soaking and drying in rice cultivation, are emphasised for their capacity to decrease GHG emissions and improve soil health. Furthermore, the use of organic manure, crop residues, and balanced nutrients is recommended to enhance the process of carbon sequestration in agricultural soils. The study of Awuni *et al*. (2023) emphasises that Ghana’s agriculture sector, which relies heavily on rainfall, is highly vulnerable to climate change. Various adaptation and mitigation strategies have been adopted, including efforts to build resilience through national and community-level initiatives, improve irrigation systems, and promote sustainable farming methods. However, challenges such as insufficient financial resources and a hierarchical decision-making process continue to be obstacles to the successful execution of these strategies.

Climate change poses significant challenges to agriculture in West Africa, which creates unpredictability in crop production. Carr *et al*., (2022) outline common agricultural adaptation strategies in the region, such as adjusting planting dates, employing climate-resilient cultivars, increasing fertiliser application, diversifying crops, improving soil management, and expanding irrigation. These strategies aim to reduce the adverse effects of climate change on crop yield and boost future agricultural output. The Gambia is highly vulnerable to drought hazards due to climate change. Irregular precipitation patterns and mid-season dry spells exhibit variability and negative trends largely attributed to the effect of climate change. Insufficient hydrometeorological data poses a significant threat to the agriculture sector, which employs more than 70% of the population (Bayo & Mahmood, 2023). In their study, Braimoh *et al*. (2022) identify various adaptation and mitigation strategies for agriculture in The Gambia. These strategies include the use of climate-resilient crop varieties, crop diversification, climate information services, weather-indexed insurance, soil and water conservation, the use of manure and inorganic fertiliser, and agroforestry. In the Gambia (Amuzu *et al.*, 2018; Sanneh *et al.*, 2014) presents several climate change adaptation and mitigation strategies, such as crop diversification, drought-tolerant varieties, enhanced land management, decreased inputs derived from fossil fuels, microfinancing, bushfire control, agroforestry, education awareness, renewable energy, and reduced GHG emissions to enhance environmental sustainability.

3.2.2 Importance of farmers' perceptions of successful adaptation and mitigation

Since the 1992 Rio Conference, the world has committed to reducing GHG emissions that drive climate change and investing in efforts to minimise the impact of climate change on people’s lives and livelihoods. As a result, climate change adaptation and mitigation have become central topics in scientific research, sparking international debates and consensus (Nwobodo *et al.*, 2022). Significant attention has been directed towards global, national, and local climate change responses, leading to two main divergent reactions. The first pertains to mitigation strategies, which aim to slow the pace of climate change by reducing GHG emissions. Developed nations have led this effort, aligning with the United Nations Framework Convention on Climate Change (UNFCCC), signed in 1992, the Kyoto Protocol (1997), the EU Emissions Trading Scheme (2005), the Copenhagen Accord of 2009, the Paris Agreement (2015), and Sharm El-Sheikh Climate Change Conference, COP 27 and COP 28 in Dubai. The second approach focuses on adaptation, which includes measures that enhance the capacities of individuals, communities, and nations to manage the impact of climate change and capitalise on new opportunities (Wall & Marzall, 2006). Adaptation efforts have been emphasised in these agreements, and a further boost at COP 27 with the establishment of funding mechanisms for loss and damage, particularly for developing countries that are more vulnerable to climate change (Atwoli *et al.*, 2022).

Adaptation is gaining recognition as a crucial element of the global response to climate change, especially following the Paris Agreement, which sets a global adaptation goal and requires all parties to implement and evaluate their adaptation efforts (Berrang-Ford *et al*., 2019c; Singh *et al*., 2022). Identifying and assessing adaptation options are key pre-requisite steps to adaptation prioritisation and effective adaptation planning (Braimoh *et al*., 2022). Furthermore, the Paris Agreement mandates all parties to evaluate their adaptation progress, including assessing the effectiveness of adaptation strategies to guide climate action planning and commitments. Considering smallholder farmers' perceptions of the effectiveness of adaptation and mitigation strategies is highly pertinent for policy decisions aimed at assisting farmers in addressing the impacts of climate change (Berrang-Ford *et al*., 2019a; Singh *et al*., 2022).

3.3 Literature review

3.3.1 Theoretical review

The effectiveness of adaptation strategies depends on the perceived risk level. The risk perception theory explains how individuals perceive climate risk and assess the adequacy and effectiveness of climate risk adaptation and mitigation strategies. The theory asserts that people's perception of risk is shaped by different factors, such as beliefs about the intensity and probability of the risks, personal experience, norms, and values.

3.3.2 Empirical review

Abbass *et al*. (2022) review the impact of global climate change on various sectors, including agriculture, through a systematic literature review, and propose sustainable adaptation and mitigation strategies. The strength of the review lies in its comprehensive synthesis of diverse perspectives across sectors, enabling interdisciplinary perspectives on climate change issues. However, its reliance on secondary data may limit the inclusion of emerging research. The finding underscores the significant socio-economic and environmental consequences of climate variability, especially in agriculture and biodiversity, affecting food security, species extinction, and human health. Robust mitigation strategies such as agroforestry, policy reforms, and technological innovation are essential to bolstering resilience and ensuring sustainable development. Malhi *et al*. (2021) conducted a systematic review of the impact of climate change on agriculture, focusing on physiological, metabolic, and environmental effects,

alongside mitigation strategies for sustainable agricultural practices. The primary finding indicates that climate change negatively affects crop yields, soil fertility, pest proliferation and water availability, while mitigation strategies such as climate-smart agricultural technologies show promise in improving resilience, enhancing food security, and increasing farmers' income.
Etana *et al*. (2022) evaluate the efficacy of adaptation strategies employed by smallholder farmers in response to climate change variability in developing nations by analysing and synthesising 42 household-level studies conducted from 2000 to 2019. The approach involved a thematic analysis of both quantitative and qualitative studies, facilitating an extensive examination of various adaptation outcomes. The findings revealed that adaptation strategies, including climate-smart agriculture, modifications to farming practices, and income diversification, had a positive impact on crop yields, income, food security, and environmental conservation. However, the study identified disparities in effectiveness due to differences in adaptive capacities, resource accessibility, and institutional support.

The research by (Aldunce *et al*., 2022) evaluates the effectiveness of drought adaptation measures utilised in the Aconcagua Valley, Chile, emphasising their strengths and limitations and suggesting enhancements. The approach comprised a semi-structured interview, systematic data analysis, and a participatory evaluation procedure employing an index for the usefulness of adaptation practices (IUPA). These strategies yielded significant qualitative insights and facilitated direct interaction. The primary finding revealed strengths, including replicability, relevance, and efficacy of interventions such as small dam construction and water efficiency education. Weaknesses comprised equity, inadequate environmental protection, reduced autonomy in decision making, and poor integration with other polices.

The study of Osbahr *et al*. (2010) used a mixed method to assess effective livelihood adaptations to climate change variability in southern Africa, focusing on resilience and institutional contributions to collective action. These provided varied perspectives on adaptation at both individual and communal levels, enabling triangulation of data. the findings indicated that informal networks and social structures are vital for coping strategies, while formal institutions promote collective action, innovation and learning.

Molua (2002) examine the impacts of climate variability on security in Southern Cameroon, evaluates farm household vulnerability, and assesses the effectiveness of adaptation strategies. The research involved a cross-sectional survey of 120 households and econometric modelling to analyse adaptation methods. This approach provided statistical significance and direct insights from farmers, yielding precision and practical relevance; however, information on atmospheric and soil temperature, though necessary, is missing due to the unavailability of data. Key findings revealed that precipitation during crop growth and adaptation methods significantly increased farm income, underscoring the significance of rainfall and adaptation practices such as enhanced soil management

Dixit (2002) assessed the effectiveness of farmer-led adaptation strategies for livestock rearing in Eastern Uttar Pradesh, India, amidst the challenges posed by climate change, using a participatory approach. This approach included the climate change adaptation index (CCAI) for ranking adaptation strategies and quantification of indigenous knowledge method (QnIK) with tools such as matrix ranking and semi-structured interviews. This allowed for farmers' direct input and a comprehensive evaluation of local practices; however, potential biases arose from the limited sample size. Findings revealed that techniques such as using cattle sheds, administering vaccination, supplying fresh drinking water, and extra bathing for livestock were most efficacious in alleviating heat stress, reducing diseases, and enhancing livestock welfare.

Roy *et al*. (2023) elucidate the synergies and trade-offs among climate adaptation and mitigation, and development within coastal socio-ecological systems in Bangladesh. The study used the drivers, pressures, states, impact and responses (DPSIR) framework. This framework offered a systematic method for identifying environmental cause-and-effect relationships. The findings indicated that synergies, such as climate-smart agriculture and infrastructure and development, outweighed trade-offs like overexploitation of resources and ecosystem degradation.

The study of Ikehi *et al*., (2023) aimed to evaluate research recommended climate change adaptation and mitigation strategies in agriculture in the Niger Delta, assessing their innovativeness in fostering agricultural innovation systems (AIS). Using a mixed-method approach, the study integrated 129 previous studies, surveyed 282 agricultural extension agents and classified strategies based on their types (adaptation, mitigation, or both). Key findings revealed that while many strategies showed significant potential for innovation and enhancement, tier-wide adoption was rated low, highlighting gaps in aligning recommendations with the realities of farmers and AIS principles.

Rubio Juan & Revilla (2021) investigate the factors affecting Spaniards' support for climate change polices, specifically mitigation policy (restricting polluting car use) and adaptation policy (reducing water consumption through incentives). It applied structural equation modelling (SEM) to assess causal effects, correct for measurement errors and differentiate between direct and indirect effects. The SEM allowed a robust analysis of the correlation among attitudinal characteristics and policy support, however, limitations included reliance on a non-probability sample. Findings show that government response efficacy had the strongest influence on policy support, while personal self-efficacy and psychological distance were also significant factors, with their impacts differing according to policy type and direct personal impact.

Eleftheriou *et al*. (2023) evaluate the effectiveness of mitigation and adaptation strategies for sand and dust storms (SDS) in the Eastern Mediterranean Region, assessing their feasibility and impact at local and broader levels while accounting for socioeconomic and political obstacles, conducting a critical review. The main findings highlighted that those localised initiatives, such as farmer-managed regeneration and early warnings, were effective, but larger-scale implementation encountered barriers such as governance challenges, financial constraints, and social-political diversity.

3.4 Methodology

The methodology is built upon the approach developed by Islam *et al*. (2019) by enhancing its robustness and analytical depth. While Islam *et al*. (2019) proposed a scoring system based on frequency and Likert-weighted responses to assess the perceived effectiveness of drought adaptation strategies. The study adds value by integrating this with an Importance-Performance Analysis (IPA), Perception Index (PI), Effectiveness Score (ES), and chi-square tests. This multifaceted approach enables a richer, multidimensional analysis that captures not only farmers' perceptions and strategy performance but also allows for prioritisation of interventions through the IPA quadrants. Furthermore, the normalisation of scores and use of diagnostic tools provides a more standardised and comparative evaluation of adaptation and mitigation strategies across respondents, which was not evident in Islam *et al*. (2019) original model. This extended methodology offers more actionable insights for policy and planning by bridging perception-based data with statistical validation.

3.5 Empirical framework

This study employed a multifaceted empirical framework integrating scoring, statistical analysis, diagnostic evaluation and an indexing formula adapted from the research conducted by Islam *et al*. (2019) to assess adaptation and mitigation strategies. This formula calculates a score based on the percentage of frequency and the weight assigned to each Likert option and is used to rank the adaptation measures. The model combined the indices chi-square test and importance performance analysis (IPA).

3.5.1 Effectiveness Score (ES)

$$\mathrm{ES} = \{(\mathrm{PHI} \times 1) + (\mathrm{PI} \times 2) + (\mathrm{PNU} \times 3) + (\mathrm{PE} \times 4) + (\mathrm{PHE} \times 5)\} \tag{17}$$

Given:

PHI= Percentage of highly ineffective

PI= Percentage of ineffective

PNU= Percentage of not understanding,

PE= Percentage of effective

PHE= Percentage of highly effective

The frequency of strategies represents the percentage of farmers who identified each strategy as relevant or used in their adaptation practices. Additionally, the mean value of perceived efficacy reflects the average perceived effectiveness of each strategy on a scale of 1 to 5, with higher values indicating greater perceived effectiveness. To facilitate a relative comparison of perceived efficacy among strategies, a normalised score (NS) is derived to place the perception of each strategy on a comparable scale (ranging from 0 to 1).

$$NS = \frac{\mathrm{ES} - \mathrm{ES}_{\mathrm{min}}}{\mathrm{ES}_{max} - \mathrm{ES}_{min}} \tag{18}$$

Where ES_{min} and ES_{max} are the minimum and maximum effectiveness scores, respectively. The normalised score ranges from 0 to 1.

3.5.2 Perception Index (PI)

The PI measures the perceived effectiveness of adaptation and mitigation strategies based on frequency or relevance as reported by farmers.

$$PI_x = \sum_{i=1}^{n} \frac{F_i}{N} \qquad (19)$$

Where:

F_i is the frequency of a strategy used by farmer i

N is the total number of farmers surveyed.

The effectiveness score (ES) is modelled as a function of the independent variables:

$$ES_i = \beta_0 + \beta_1 Age_i + \beta_2 Gender_i + \beta_3 Edu_i + \beta_4 exp_i + \cdots + \epsilon_i \qquad (20)$$

Where:

β_0 =intercepts

β_x =coefficients of the explanatory variable

ϵ =error terms

3.5.3 Importance Performance Analysis (IPA)

The IPA framework, developed by (Martilla & James, 1977) and further refined by (Azzopardi & Nash, 2013) was utilised as a diagnostic tool to identify areas for improvement prioritisation. The IPA is used in analysing the attributes' importance and corresponding performance using a Likert scale (Azzopardi & Nash, 2013; Sörensson & von Friedrichs, 2013). It generates a 2-dimensional graph that measures the importance and satisfaction levels of different attributes, thereby offering insights into the existing situation and practical recommendations (Warner *et al*., 2016). Despite the significant value and application of the IPA by researchers, the original model has limitations that have prompted several researchers to use modified or extended versions of the model (Bacon, 2003). In the context of farmers' perceived effectiveness of adaptation and mitigation strategies, performance is typically assessed through direct ratings obtained from surveys. Farmers were asked to rate the effectiveness of each strategy on a 5-point Likert scale, ranging from "very ineffective" to "very effective." Similarly, the importance of these strategies is measured using the frequency of the strategies used in addressing their agricultural or climate-related challenges.

Table 10 shows the categorisation of the four quadrants. Quadrant 1 represents strategies that are highly important and are perceived as effective or highly effective by farmers. Farmers should rely on these strategies, and they consistently deliver the expected results. The management approach for this quadrant is to ‘‘keep up the good work,’’ as it reflects areas where the farmer excels in performance while addressing critical needs. These strategies should be preserved, expanded, or optimised. In this study, no adaptation strategy falls in this quadrant. Quadrant 2 represents strategies that are effective but not widely adopted by farmers due to resource constraints or specialised nature.

Table 11 Quadrant categorisation

Quadrant	Importance (Frequency)	Performance (Effectiveness)
Q1: Keep Up the Good Work	High (≥58.55)	High (<3.56, mostly scored 1-3)
Q2: Possible Overkill	High (≥58.55)	Low (≥3.56, score 4-5)
Q3: Low Priority	Low (< 58.55)	Low (<3.56, mostly score 1-2)
Q4: Concentrate Here	Low (< 58.55)	High (≥3.56, score 4-5)

Source: Author's computation (2025)

This means that the strategies are yielding positive results but are not widely adopted. The management approach for this quadrant is ‘‘possible overkill’’ suggesting that resources allocated to these strategies might be more effectively utilised in areas of greater significance to enhance overall performance.

Quadrant 3 signifies strategies that farmers do not prioritise or consider ineffective. These strategies have low adoption rates and moderately low effectiveness, often misaligning with farmers’ immediate needs or local circumstances. They are either perceived as not effective or not well understood, making them less effective in mitigating the impact of climate change. The management approach for this quadrant is ‘‘low priority.’’

Quadrant 4 includes strategies that are widely utilised and considered crucial by farmers but are not perceived as effective in mitigating the impact of climate change. Despite their low perceived effectiveness, farmers rely on these strategies in addressing climate challenges. These strategies require urgent attention for improvement to meet farmers’ needs and deliver meaningful results. Efforts should be directed towards identifying the main cause of their ineffectiveness and addressing them to enhance their performance. ‘‘concentrate here’’ is the management strategy for this quadrant.

This classification of adaptation strategies helps the prioritisation of strategies according to their perceived effectiveness, allowing for targeted initiatives to support farmers in overcoming the impact of climate risk on agricultural production.

To explore potential differences in effectiveness scores across different subgroups of the population (e.g., by age, gender, and region), statistical analyses such as the chi-square test were employed. This can highlight differences in how various demographic groups perceive adaptation measures. The comparison analyses aimed to elucidate how various demographic groups perceive adaptation measures.

3.6 Results and discussion

3.6.1 Results

3.6.1.1 Descriptive statistics

Table 12 shows the demographic characteristics of farmers in three regions: the North Bank Region (NBR=42%), the Central River Region South (CRR=25%), and the Upper River Region (URR=33%). Most of the farmers are middle-aged, with no formal education and a significant gender disparity. The average annual farming income is minimal, with most farmers earning less than GMB 30,000.00 (USD 415) annually.

Table 12: Descriptive statistics

Variable	Category	Freq.	Percent
Gender	Male	299	71
	Female	121	29
Region	NBR	175	42
	CRS	105	25
	URR	140	33
Age Category	Young farmers	80	19
	Middle-aged farmers	209	50
	Old farmers	131	31
Education	None/No formal	338	80
	Primary	35	8
	Secondary	37	9
	Tertiary	10	2
Average annual farming income	Very Low Income	255	61
	Low Income	114	27
	High Income	51	12
			100

Source: Author's analysis based on survey data (2023)

3.6.1.2 Farmers' perceptions of different adaptation and mitigation strategies

Figure 22 illustrates the frequency and perceived efficacy of adaptation and mitigation strategies implemented by farmers. Strategies like crop rotation (CR), use of inorganic fertilisers (UIF), change planting date (CPD), and change crop variety (CCV) are the most used strategies and have high perceived efficacy. UIF is widely adopted with a high perceived efficacy, supporting (Bagagnan *et al*., 2019) findings that chemical fertilisers are preferred despite their cost. Agroforestry-related strategies such as stop cutting trees (SCT), soil conservation (SC), and non-agricultural strategies like praying (Pr) and petty business have low adoption. Still, they are considered effective in mitigating the impact of climate change. External support from the government and non-governmental organisations, and migration, is perceived as effective but less commonly used by smallholder farmers. Irrigation (Ir) is perceived as effective by smallholder farmers, it has low adoption rates likely due to high initial costs, labour requirements, and maintenance expenses as outlined by Charles Boliko, (2019a).

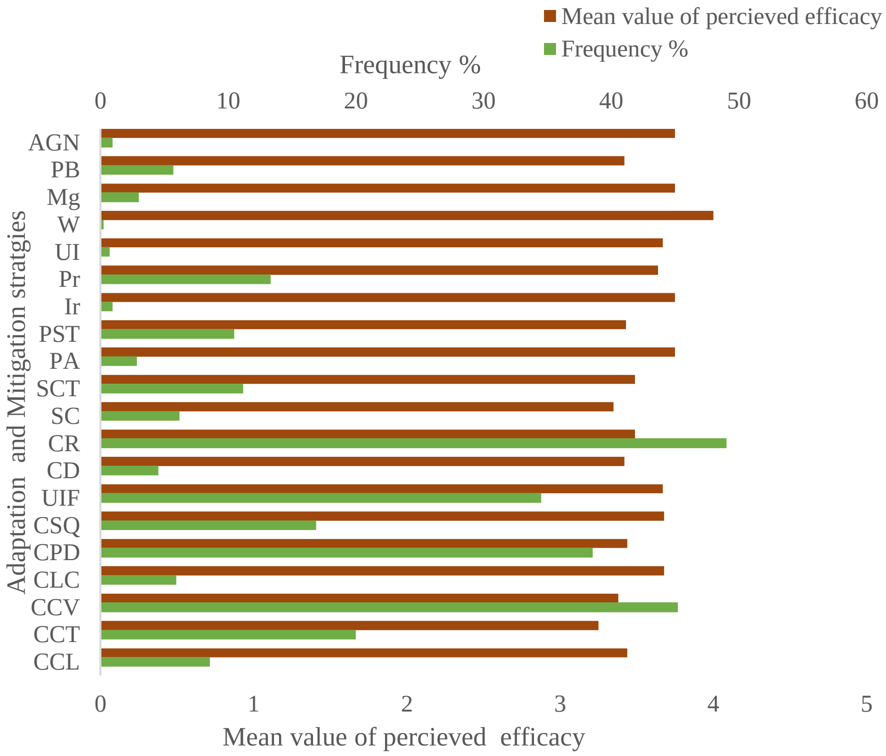

Figure 22: Frequency of adaptation and mitigation strategies and their perceived efficacy [5]

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[5] CCL=Change crop to livestock, CCT=Change crop type, CCV=Change crop variety, CLC=Change livestock to crop, CPD=Change planting date, CSQ=Change seed quality, UIF=Use of inorganic fertilisers, CD=Crop diversification, CR=Crop rotation, SC=Soil conservation, SCT=Stop cutting trees, PA=Pesticide application, PST=Planting shaded trees, Ir=Irrigation, Pr=Praying, UI=Use insurance, W=Wage, Mg=Migration, PB=Petty business, AGN= Assistant from government /NGOs

Despite their low frequency of use, their significant perceived efficacy reflects their potential impacts if barriers were mitigated. Despite the low adoption rate, insurance is highly perceived to be effective in mitigating the impact of climate change. Braimoh *et al.* (2022) mirror the lack of empirical studies in The Gambia evaluating the effectiveness of microfinance and weather-indexed insurance in bolstering household resilience.

Wage employment functions as a crucial economic diversification strategy that enhances farmers' resilience to climate variability. In periods of agricultural productivity decline due to climate-related factors such as droughts and erratic rainfall, rural households often supplement their income through off-farm employment. Empirical studies indicate that a significant proportion of farm households engage in wage or self-employment activities as part of their adaptation strategies.

Furthermore, wage labouring has been recognised as a long-standing adaptation strategy historically utilised by rural households to manage economic shocks and environmental uncertainties(Piya *et al*., 2013). Similarly, research by Below *et al*. (2012) found that 29.4% of households in the administrative wards of the Morogoro region of Tanzania employed wage labour as an adaptation mechanism. This widespread adoption underscores its importance in sustaining rural livelihoods amid climate-induced challenges.

Praying serves as a cultural and spiritual adaptation strategy among farmers, reflecting their reliance on religious practices to seek divine intervention in response to climate-related uncertainties. Empirical studies highlight the prevalence of prayer as an adaptation measure in various agricultural communities. For instance, Tessema *et al*. (2013) reported that 9.2% of respondents identified praying as an adaptation strategy. The inclination to perceive climate issues as being influenced by supernatural forces is particularly common in highly religious societies, such as Ethiopia. Similarly, Ibe *et al*. (2018) found that 77.8% of respondents in his study considered prayer as a means to mitigate the effects of climate change. Additionally, Feliciano *et al*. (2022) noted that some farmers exclusively relied on prayer without adopting any other adaptation practices. The study of Fahad & Wang, (2018) further observed that 22.8% of surveyed farmers employed prayer as a coping mechanism against climate variability.

Table 13 presents the frequency of each adaptation and mitigation strategy implemented by farmers, indicating the number of farmers adopting each measure. Additionally, it includes the effectiveness score for each strategy based on farmers' perceptions. Strategies such as Change livestock to crop (CLC), Pesticide application (PA), Use of inorganic fertilisers (UIF), Praying (Pr), Use insurance (UI), Wage (W), Migration (Mg), Irrigation (Ir), Assistant from gov't/NGOs (AGN), Stop cutting trees (SCT) and Change seed quality CSQ) are perceived as effective strategies by farmers, as evidenced by higher effectiveness scores. While some strategies are widely used and perceived as effective, there remains a significant gap in farmers' understanding of critical strategies, which could limit their ability to fully address climate change's impact.

Adaptation and mitigation strategies are essential for tackling the multifaceted challenges posed by climate change. However, the perceived effectiveness of these strategies significantly varies across farmers and scientific evaluations. Farmers often prefer strategies that deliver immediate, tangible results, such as changing livestock to crops (CLC), applying pesticides (PA), and using inorganic fertilisers (UIF), which are commonly perceived as effective based on their practicality and direct impact on productivity. Conversely, scientific evidence supports a more cohesive strategy that aligns these immediate solutions with broader, systemic intervention to enhance long-term sustainability (Gupta & Shukla, 2024; NASA Science, 2024; Puig *et al.*, 2025).

Strategies such as irrigation (Ir) and receiving support from government or non-governmental organisations (NGOs) are also perceived as effective by smallholder farmers, particularly in mitigating water scarcity and financial vulnerability. Meanwhile, mitigation strategies like stopping cutting trees (SCT) and changing seed quality (CSQ) are recognised for their capacity to mitigate environmental deterioration and improve agricultural resilience (Robinson *et al.*, 2024). Nevertheless, critical strategies such as crop diversity (CD) and soil conservation (SC) are often underappreciated by farmers due to insufficient understanding, despite their proven benefits in enhancing agroecological outcomes (NASA Science, 2024; IPCC, 2014)).

Scientific research emphasises the importance of integrating local knowledge with empirical data to assess the true efficacy of adaptation and mitigation strategies. For instance, while some strategies are not widely perceived as effective by farmers, they have proven benefits in improving soil health and reducing greenhouse gas emissions (Gupta & Shukla, 2024). The success of these interventions ultimately depends on a combination of governance, access to resources, and substantive community engagement. Thus, promoting scientifically validated, context-specific strategies is crucial for ensuring that climate responses are both effective and sustainable in the long term (Campbell & Krol, 2023; NASA Science, 2024).

Table 13: Adaptation and mitigation strategies implemented by farmers and their effectiveness

Strategies	Frequency of respondents against each Likert option					Percentage of respondents against each Likert option					Effectiveness
	1	2	3	4	5	1	2	3	4	5	
Adaptation											
Change crop to livestock (CCL)	0	0	20	16	0	0	0	56	44	0	Not understanding
Change crop type (CCT)	0	0	63	21	0	0	0	75	25	0	Not understanding
Change crop variety (CCV)	0	2	111	77	0	0	1	58	41	0	Not understanding
Change livestock to crop (CLC)	0	0	8	17	0	0	0	32	68	0	Effective
Change planting date (CPD)	0	0	91	71	0	0	0	56	44	0	Not understanding
Pesticide application (PA)	0	0	3	9	0	0	0	25	75	0	Effective
Use of inorganic fertilisers (UIF)	0	0	48	97	0	0	0	33	67	0	Effective
Praying (Pr)	0	0	20	36	0	0	0	33	67	0	Effective
Use insurance (UI)	0	0	1	2	0	0	0	33	67	0	Effective
Wage (W)	0	0	0	1	0	0	0	0	100	0	Effective
Migration (Mg)	0	0	3	10	0	0	0	23	77	0	Effective
Petty business (PB)	0	0	14	10	0	0	0	58	42	0	Not understanding
Irrigation (Ir)	0	0	1	3	0	0	0	36	64	0	Effective
Assistant from gov't/NGOs (AGN)	0	0	1	3	0	0	0	25	75	0	Effective
Mitigation											
Crop diversification (CD)	0	0	11	8	0	0	0	58	42	0	Not understanding
Crop rotation (CR)	0	1	103	102	0	0	0	51	49	0	Not understanding
Soil conservation (SC)	0	0	17	9	0	0	0	65	35	0	Not understanding
Planting shaded trees (PST)	0	1	23	20	0	0	2	52	45	0	Not understanding
Stop cutting trees (SCT)	2	0	18	27	0	4	0	38	57	0	Effective
Change seed quality CSQ)	0	0	23	48	0	0	0	32	68	0	Effective

Note: 1 = Totally Ineffective, 2 = Ineffective, 3 = Not Understandable, 4 = Effective, 5 = Highly Effective

Pearson Chi2 (57): 111.44, p = 0.000

Likelihood Ratio Chi2 (57): 98.99, p = 0.000

Source: Author's analysis based on survey data (2023)

The result of the chi-square test showed a statistically significant ($p < 0.05$) association between the adaptation strategies and the effectiveness score. Both the Pearson and likelihood-ratio chi-square tests had a *p*-value of 0.000, indicating that different strategies lead to varying levels of perceived efficacy.

3.6.1.3 Analysis of the Perception Index

Table 14 presents the perception index of various strategies implemented by smallholder farmers. It highlights the percentage of strategies, mean perceived efficacy, and normalised score. The perception index was developed to assess farmers’ perceptions of the efficacy of adaptation and mitigation strategies in The Gambia.

Table 14: Perception index

Strategies	Frequency of Strategies %	Mean value of perceived efficacy	Normalised Score
CCL	9	3.77	0.44
CCT	20	3.75	0.25
CCV	45	3.38	0.79
CLC	6	3.68	0.68
CPD	39	3.44	0.43
CSQ	17	3.68	0.68
UIF	35	3.67	0.67
CD	5	3.62	0.42
CR	49	3.49	0.75
SC	6	3.75	0.45
SCT	11	3.49	0.83
PA	3	3.75	0.75
PST	10	3.43	0.72
Ir	1	3.75	0.75
Pr	13	3.64	0.64
UI	1	3.67	0.67
W	0	4	0,77
PB	6	3.42	0.42
AGN	1	3.75	0.75

Source: Author's analysis based on survey data (2023)

The index was calculated by assigning numerical values based on the Likert scale responses provided by farmers for each adaptation strategy. The mean scores for each adaptation strategy were then normalised to a scale of 0 to 1 to ensure consistency and comparability across different strategies.

The perception index for each adaptation strategy was computed by averaging the normalised scores across all farmers. Change crop variety and crop rotation are the most adopted strategies employed by smallholder farmers, with a robust normalised score of 0.79 and 0.75, respectively, underscoring their importance in agricultural resilience. Despite their low adoption rates, changes in seed quality, crop diversification, stop cutting trees, pesticide application, planting shaded trees, irrigation, praying, the use of insurance, and using wages valued highly by smallholder farmers indicate the need for more awareness and promotion of these strategies. The overall perception index of farmers in the study was determined to be 0.66, indicating a moderate level of perceived effectiveness of climate risk adaptation and mitigation strategies among farmers in The Gambia. This index serves as a quantitative measure of farmers' perceptions, offering valuable insights into the efficacy of different adaptation measures and highlighting areas where awareness and understanding may need improvement. The perceived efficacy of various strategies is evaluated by farmers using the perception index. Each strategy is accompanied by three metrics: frequency of strategies (%), mean value of perceived efficacy, and a normalised score.

Highly perceived efficacy strategies

The SCT has a high normalised score of 0.83 with a mean perceived efficacy score of 3.49, indicating it is considered one of the most effective strategies. The CR and PA both show strong perceived efficacy with normalised scores of 0.75, suggesting that they are valued by farmers. Wage also has a high perceived efficacy score of 4 and a normalised score of 0.77, despite being used by a small number of respondents.

Moderate to low-perceived efficacy strategies

The CCT had a frequency of 20% but a low normalised score of 0.25, indicating that while it is relatively known or used, its perceived efficacy is comparatively weak. The CCL, CD, and PB have moderate mean efficacy scores of around 3.4 and normalised scores of around 0.4, reflecting a moderate but less significant perceived impact.

The result revealed a Perception Index of 0.66, indicating a moderate level of perceived efficacy. Given that this value is considerably higher than the neutral benchmark (0.50), the alternative hypothesis is supported. This suggests that farmers in The Gambia do not view the strategies as ineffective or neutral but rather as moderately effective in addressing climate-related challenges. These findings reinforce earlier studies (IPCC, 2014b; Taylor *et al*., 2014) that highlight the value of integrating farmer perspectives into climate response frameworks. Although the perception is not uniformly "high," it demonstrates a positive engagement with adaptation and mitigation strategies, particularly those that offer observable short-term benefits. However, for strategies with long-term benefits, like soil conservation and tree planting, perception remains low, underscoring the need for enhanced awareness and capacity-building interventions.

3.6.1.4 Relationship between effectiveness score and region and gender

Table 15 shows the results of the chi-square test comparing the effectiveness scores across different regions, which are statistically significant at 1%, indicating that the effectiveness score varies across regions. This implies that different regions have different patterns of effectiveness, providing strong evidence against the null hypothesis of independence.

Table 15: [6]Chi-square test on regions and gender

Region and Gender	Score 1	Score 2	Score 3	Score 4	Total
NBR	1	0	325	283	609
CRS	1	0	189	100	290
URR	3	2	62	206	273
Pearson Chi2 (6): 117.28, p = 0.000					
Likelihood Ratio Chi2 (6): 121.45, p = 0.000					
Male	3	1	393	433	830
Female	2	1	183	156	342
Pearson Chi2 (3): 4.64, p = 0.200					
Likelihood Ratio Chi2 (3): 4.60, p = 0.204					
Total	5	2	576	589	1,172

Source: Author's analysis based on survey data (2023)

It also shows that the relationship between gender and perceived effectiveness is not statistically significant. This means there is no difference between the perceived effectiveness of adaptation strategies among men and women. Gender does not influence the perceived effectiveness of various adaptation strategies used by farmers.

3.6.1.5 IPA analysis of adaptation and mitigation strategies

Figure 23 illustrates the IPA matrix that categorises adaptation and mitigation strategies based on their importance (frequency) and performance (perceived effectiveness). The IPA reflects the importance of adaptation and mitigation strategies farmers employ and their performance. The mean of performance and importance divides the matrix into four quadrants, each showing actionable insights into priority areas. The categorisation of the adaptation strategies is based

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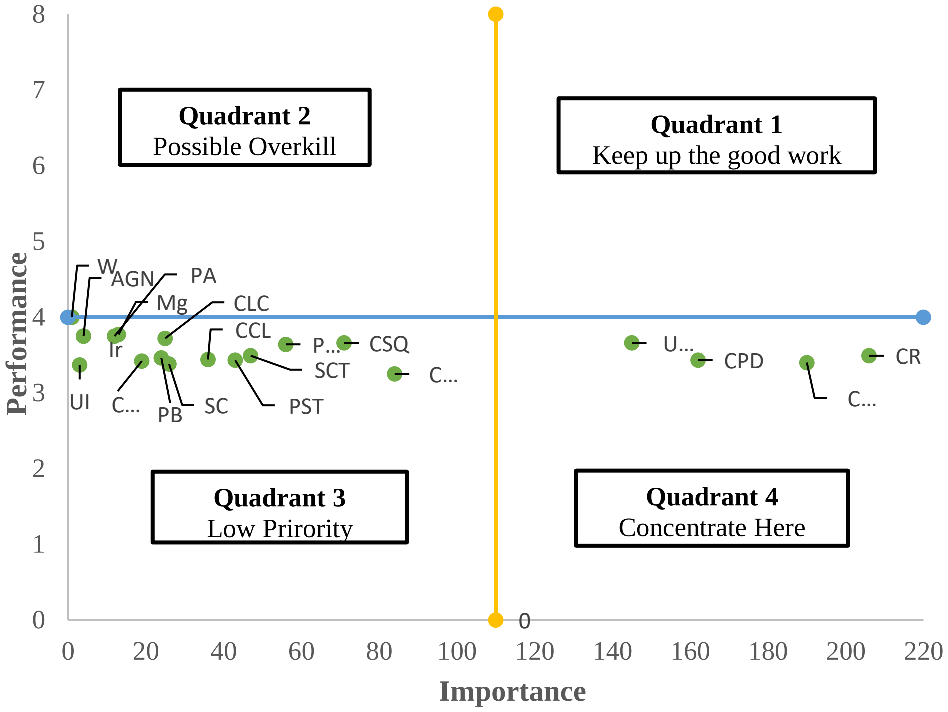
[6] 1=Totally ineffective, 2= Ineffective 3= not understanding, 5=highly effective

on their importance (frequency) and performance (perceived effectiveness) (Deng *et al*., 2017; Esmailpour *et al*., 2020; Phadermrod *et al*., 2019a). IPA is extensively used in various sectors where customer satisfaction is crucial for business success (Hosseini & Ziaei Bideh, 2014; Phadermrod *et al*., 2019b; Shieh & Wu, 2009; Taplin, 2012; Wong *et al*., 2011). Consumer satisfaction is determined by consumer perceptions, which encompass the quality of the organisation's product or service and customer expectations. (Kanyangale & Lee, 2023) examine farmers' and non-farmers' adaptation and management perspectives regarding Invasive Alien Plant Species (IAPS), highlighting their understanding, importance, and effectiveness in IASP management. More recently**,** Rohit *et al*. (2024) employed the IPA to assess farmers' satisfaction, facilitating the ongoing adoption of Agromet Advisory Services.

Figure 23:
IPA Matrix

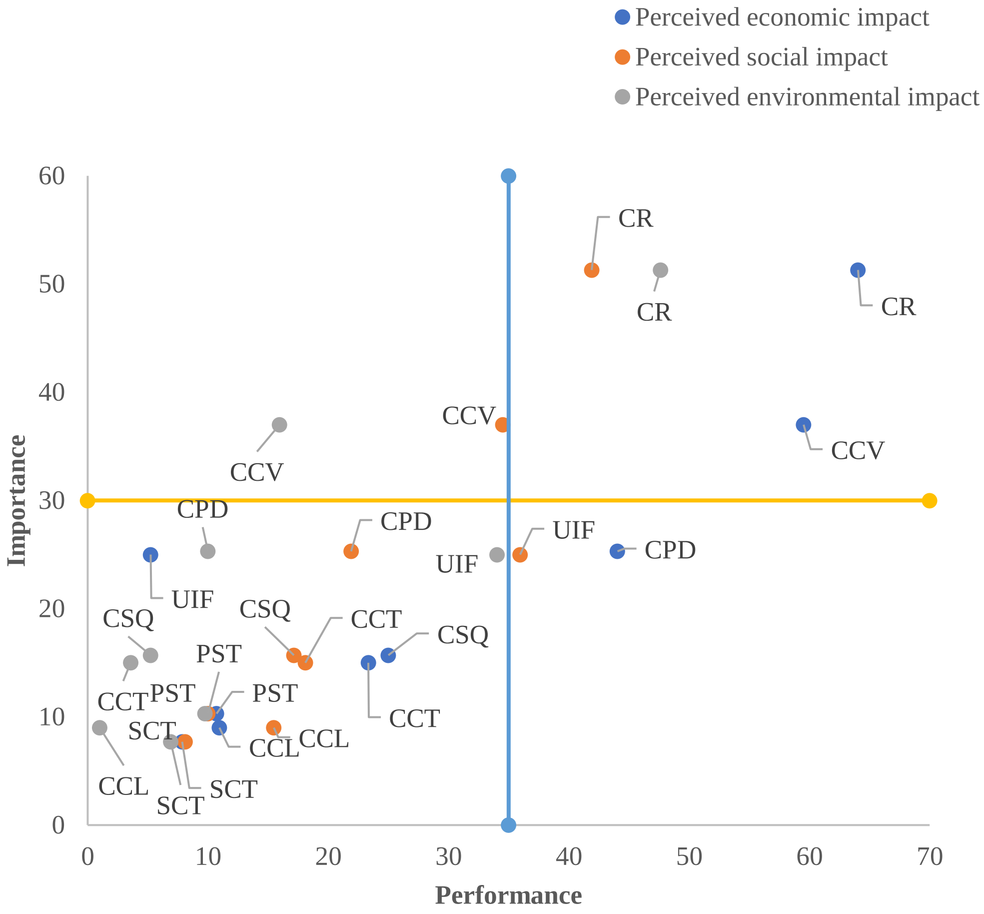


The positioning of all strategies in quadrants 3 and 4 raises substantial concerns about the agricultural strategies for climate adaptation. Quadrant 3, characterised by strategies perceived as ineffective, suggests a discount between what is available and what farmers truly need, indicating obstacles in effectively implementing these strategies. In quadrant 4, farmers relying on these strategies signify a paradox in which farmers persist in using strategies that fail to produce intended outcomes. This situation calls for immediate adjustment of current measures to address farmers' challenges. It requires understanding the causes of the ineffectiveness of the current adaptation strategies, highlighting critical needs for innovation and research to develop new, more effective alternatives. Involving farmers in the development and evaluation of these strategies will guarantee that solutions are practical and pertinent to their experience.

3.6.1.6 IPA analysis of perceived outcomes of adaptation and mitigation strategies

In Figure 24, the perceived economic impact of various adaptation strategies in the IPA matrix offers valuable insights into how stakeholders can assess the performance of each adaptation strategy in relation to its importance.

Figure 24: IPA matrix of economic, social and environmental impact



In quadrant 1, CR and CCV are rated highly in both importance and performance, meaning farmers recognise their economic value and believe it will increase crop yield and income. These strategies should be maintained and further promoted. In quadrant 3, CCT, CSQ, CCL, PST, SCT, and UIF fall in this quadrant. These strategies are neither performed nor perceived as economically important. In quadrant 4, CPD is found to be highly important but not performing well. This means that it has the potential to increase the crop yield and income of the farmers.

In quadrant 1, CR is perceived to be socially relevant by farmers, which means that they contribute to reducing poverty, improving nutrition, and increasing food security. In quadrant 2, the CCV strategy is effective but not widely adopted by farmers. This means that despite their potential of reducing poverty, improving nutrition, and increasing food security, they are not well utilised by farmers. In quadrant 3, CPD, CCT, CSQ, CCL, PST, and SCT fall in this quadrant.

These strategies are neither performed nor perceived as socially important, they provide limited social benefits in reducing poverty, improving nutrition, and increasing food security. In quadrant 4, UIF is found to be highly important but not performing well. This means that it has the potential to reduce poverty, improve nutrition, and increase food security if implemented well.

In quadrant 1, CR is perceived to be environmentally relevant by farmers, thereby regulating soil moisture and temperature, enhancing soil fertility, and reducing soil contamination. In quadrant 2, the CCV strategy is effective but not widely adopted by farmers. This means that despite their potential to regulate soil moisture and temperature, enhance soil fertility, and reduce soil contamination, they are not well utilised by farmers. In quadrant 3, CPD, CSQ, PST, CCT, CCL, and SCT fall in this quadrant. These strategies are neither performing nor perceived as socially important, they provide limited environmental benefits in regulating soil moisture and temperature, enhancing soil fertility, and reducing soil contamination. Farmers do not see these strategies as delivering significant environmental benefits.

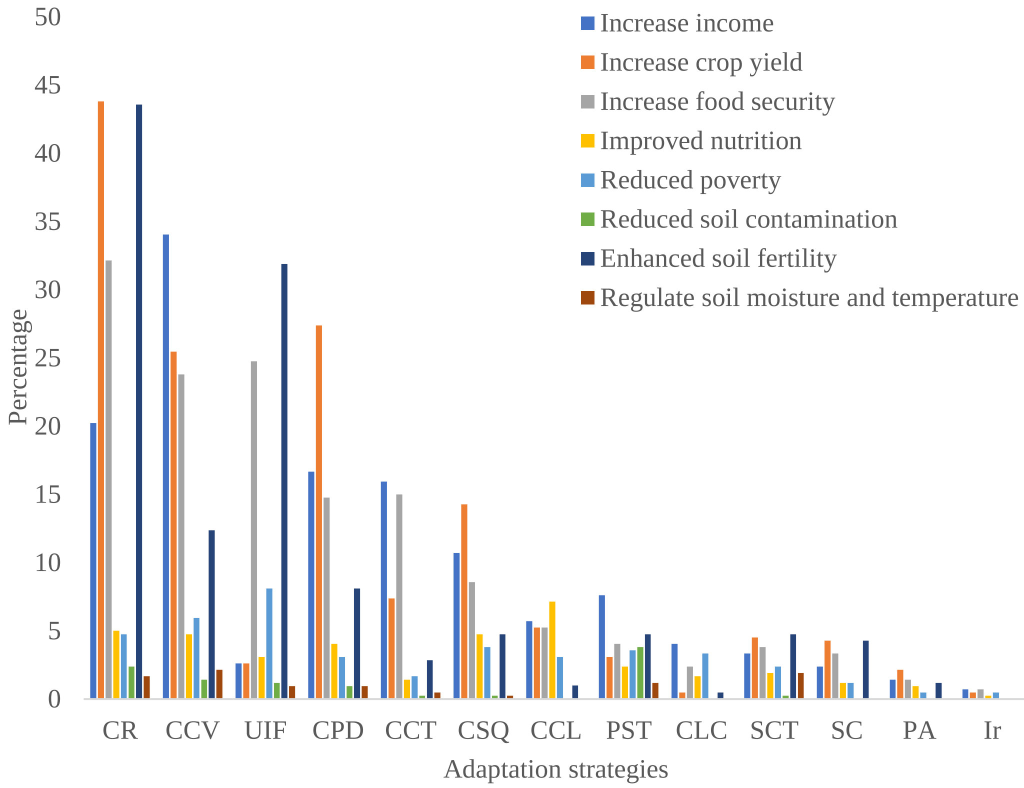
3.6.1.7 Perceived economic, social, and environmental impact of strategies

Figure 25 shows the perceived impact of adaptation and mitigation strategies. The perceived economic impact of adaptation and mitigation strategies was measured across two key outcomes: increased crop yield and increased income (Etana *et al.*, 2022).

Farmers view CCV to have a positive impact, as 34% anticipate a rise in income and 25% predict a boost in crop yield. CCT as an adaptation strategy is believed to increase farmers' income by 16%, while 7% expect a higher crop yield. CR enhances income by 20% and boosts crop yield by 44%. The implementation of CPD is expected to increase income by 17% and increase yield by 27%. The CSQ is believed to increase income and yield by 11% and 14%, respectively.

The economic benefit of CLC production seems very minimal, as just 4% of farmers expect increased income. These adaptation strategies aim to mitigate the negative effects of climate change, particularly the declining crop yields documented in previous studies, such as those by Jalloh *et al*. (2013) and Roudier *et al*. (2011). CR demonstrates the most significant positive impact on crop yield, contributing nearly 50%, which is consistent with prior research indicating yield reductions in cereal crops in Africa due to climate change.

Figure 25: Perceived impact of adaptation and mitigation strategies



Changing crop variety also significantly enhances both yield and income, suggesting that crop diversification is an effective adaptation strategy to mitigate the adverse effects of rising temperatures and increased evapotranspiration demands in West Africa. Conversely, strategies such as pesticide application and the use of inorganic fertilisers exhibit minimal effects on yield and income, indicating that these measures alone may not adequately address climate-related losses. Overall, adaptation strategies like crop rotation, changing crop variety, and adjusting planting dates show the highest potential for mitigating the negative impacts of climate change on crop yield and income. This supports the notion that, while some studies have reported yield reductions of up to 17% due to climate change (Knox *et al*., 2012), implementing strategic agricultural interventions can help offset these losses, thereby stabilising agricultural productivity and enhancing farmer income. The perception of farmers can influence the adoption of these measures to mitigate the impact of climate on agricultural production, emphasising the importance of taking economic concerns into account in adaptation planning.

The perceived social impact of adaptation and mitigation strategies is measured across three key outcomes: reducing poverty, improving nutrition, and increasing food security. The perceived social impact of adaptation strategies varies among different strategies. Implementing crop rotation (CR) is perceived to be the most effective strategy for enhancing food security, with about 32% of respondents acknowledging its significance, although its effect on reducing poverty and improving nutrition is relatively modest. The use of inorganic fertilisers (UIF) has the potential to increase food security by 25%, but has minimal effects on poverty reduction. Strategies like change crop variety (CCV) and change seed quality (CSQ) show balanced effectiveness across all three outcomes, confirming the results (Arouna *et al*., 2017; Diagne *et al*., 2013; Dibba *et al*., 2012). Additionally, change planting date (CPD) is perceived to increase food security by 15%. Other strategies, such as pesticide application (PA), irrigation (Ir), and soil conversion (SC), show minimal perceived benefits across the three dimensions, signifying their lesser role in enhancing livelihoods. Agroforestry strategies like stop cutting trees (SCT) and planting shaded trees (PST) aim to enhance nutrition and food security, with similar findings reported by Braimoh *et al*. (2022). Additional strategies, such as change livestock to crop (CLC) and soil conservation (SC), are perceived to have little social impact by farmers. These perceptions can influence the adoption and implementation of strategies in agricultural practices, emphasising the importance of considering social factors in adaptation planning. Anderson (2011) reported that on-farm crop diversification improved food security and facilitated effective adaptation to climate change. Van Der Geest & Warner (2015) also found that households that planted drought-resistant crop varieties were better able to mitigate loss and damage during the 2011 drought in The Gambia. Agroforestry strategies in West Africa made a significant impact on adaptation, mitigation, and improved food security (Bayala *et al*., 2014; Mbow *et al*., 2014; Partey *et al*., 2018).

The perceived environmental impact of adaptation and mitigation strategies is measured across three dimensions: regulating soil moisture and temperature, enhancing soil fertility, and reducing soil contamination. Crop rotation (CR) and the use of inorganic fertilisers (UIF) are perceived as the most effective strategies for enhancing soil fertility. Smallholder farmers perceived that crop variety (CCV) can positively impact the environment. Specifically, 12% of farmers believe that this strategy can enhance soil fertility. Change in crop type (CCT) is perceived to have minimal environmental impact, with no significant perceived benefits in terms of reducing soil contamination, improving nutrition, or enhancing the environment. Other strategies are also perceived to have minimal environmental impacts.

Overall, farmers perceive that certain adaptation strategies, particularly changing crop variety and converting livestock to crop production, have positive environmental impacts by enhancing soil fertility, regulating soil moisture, and improving overall environmental conditions. These perceptions can influence the adoption and implementation of these strategies in agricultural practices, emphasising the importance of considering environmental factors in adaptation planning. No studies were found that assess the impact of conservative agriculture (CA) on the pillars of climate-smart agriculture (CSA) in the Gambia (Braimoh *et al*., 2022). However, in West Africa, evidence shows that CA supports the productivity and adaptability of CSA by improving soil structure, water retention, and organic matter, replenishing soil fertility, and mitigating soil erosion (Bayala *et al*., 2014; Partey *et al*., 2018). Additionally, a CA-based system greatly improves soil health, leading to higher farm productivity and income (Araya *et al*., 2022; Bayala *et al*., 2014). It has the potential to reduce GHG emissions associated with ploughing (Charles Boliko, 2019b; Partey *et al*., 2018).

3.6.2 Discussions

The findings of this study reveal critical insights into the perception and effectiveness of climate adaptation and mitigation strategies employed by smallholder farmers in The Gambia. These results align with prior research, reinforcing both the challenges and opportunities that lie in adopting effective agricultural practices to mitigate climate risks. A notable aspect of this study is the moderate level of perceived efficacy of the strategies, as reflected in the perception index of 0.66. This suggests that while smallholder farmers acknowledge the importance of certain adaptation and mitigation strategies, their understanding and usage of these strategies remain limited. These findings are consistent with the work of Braimoh *et al*., (2022), who reported significant knowledge gaps regarding the efficacy of climate adaptation strategies in The Gambia, noting that the effective implementation of such strategies remains hindered by a lack of awareness and accessibility.

For strategy improvement, emphasis should be placed on promoting strategies with high perceived efficacy, such as SCT, CR, and W, to strengthen adaptation measures. Strategies like CCT may require additional support to improve their perceived effectiveness and adoption.

Highly perceived efficacy strategies with a low frequency of adoption (e.g., W) suggest an opportunity for increased awareness and training. Strategies with lower normalised scores but relatively high frequencies (e.g., CCT) may require further refinement or additional resources to enhance their perceived effectiveness. highly rated strategies like CR and SCT could improve overall resilience and adaptation outcomes.

The frequent use of strategies such as crop rotation, use of inorganic fertilisers, and changing planting dates, which were highly rated for their perceived efficacy, mirrors findings from (Bagagnan *et al*., 2019), who highlighted the preference for inorganic fertilisers among farmers despite their costs. These strategies are recognised for their ability to boost agricultural productivity, especially in areas like West Africa, where erratic rainfall and changing climatic conditions have necessitated adaptive responses. However, this preference for inorganic inputs may need to be balanced with more sustainable practices, as pointed out by (Awuni *et al*., 2023) who emphasise the need for long-term solutions that promote environmental health.

Low adoption rates of agroforestry-related strategies, such as stop cutting trees and soil conservation, despite their perceived effectiveness, highlight a critical barrier to scaling sustainable agricultural practices. This is in line with findings by (Partey *et al*., 2018), who observed similar challenges in West Africa, where agroforestry practices, though beneficial, are not widely adopted due to financial and labour constraints. The low uptake of such strategies in The Gambia indicates the need for stronger policy frameworks and support systems to encourage the adoption of agroforestry and other environmentally sustainable practices.

The economic impact of adaptation strategies is also noteworthy. Strategies like crop rotation and changing crop varieties are perceived as having the most significant positive effect on income and crop yields. This finding corresponds with the studies by Knox *et al*., (2012; Roudier *et al*., (2011), who demonstrated the effectiveness of crop rotation and varietal changes in improving yields under climate stress. Conversely, strategies like pesticide application and inorganic fertilisers showed minimal effects on income, suggesting that while these methods may temporarily mitigate losses, they are not sustainable solutions for enhancing long-term productivity.

Moreover, the social impact analysis of these strategies suggests that while agricultural interventions can improve food security, their impact on other socio-economic factors like poverty alleviation requires a more comprehensive approach that includes access to markets, financial support and education (Arouna *et al*., 2017). The environmental benefits of adaptation strategies also show a discrepancy between perception and adoption. Strategies like crop rotation and the use of inorganic fertilisers are perceived as effective for enhancing soil fertility (Bayala *et al*., 2014), there is still a need for increased awareness and education about the long-term environmental advantages of certain adaptation strategies, a gap that (Sanneh *et al*., 2014) also identified in The Gambia.

Research in Ghana (Partey *et al*., 2018) and Nigeria (Bamidele *et al*., 2025) indicates that smallholder farmers in both locations face similar challenges in implementing climate adaptation and mitigation strategies. In Ghana, farmers struggle with access to climate information and financial assistance, hindering their ability to adopt sustainable agricultural practices. Similarly, in Nigeria, the adoption rates of agroforestry and soil conservation practices are low due to economic constraints and little government intervention. Comparing the context of The Gambia to these countries underscores the importance of targeted intervention, policy support and education programs to enhance farmers' adaptive capacities.

This study highlights the urgent need for more targeted interventions and support, such as increased governmental support, financial aid, and enhanced knowledge-sharing platforms, to enhance the understanding, adoption, and effectiveness of climate risk adaptation and mitigation strategies in The Gambia. It shows the importance of integrating farmers' perceptions into the development of climate adaptation and mitigation policies for their efficacy and sustainability. While farmers are aware of the strategies available to them, there is still considerable room for improving their knowledge and capacity to implement these strategies effectively. Addressing these gaps will be crucial in ensuring that Gambian agriculture can adapt to the increasing pressures of climate change.

3.7 Conclusion

This study highlights the important role of integrating farmers' perceptions into the design and implementation of climate change adaptation and mitigation strategies to better meet the needs of local agricultural communities. Smallholder farmers are not just recipients of climate interventions but active agents whose experiences and judgments shape the success of those interventions. By grounding policy and programmatic responses in the realities of local farming communities, adaptation and mitigation efforts can become more relevant, effective, and sustainable.

The findings reveal a moderate level of perceived efficacy of these strategies, with practices such as crop rotation, the use of inorganic fertilisers, and changing planting dates seen as the most effective. These practices are associated with tangible improvements in yields, income, and food security. Conversely, low perceived efficacy of agroforestry-related practices and other environmentally sustainable strategies highlights critical knowledge gaps and the need for improved awareness and technical support. The perceived efficacy of the economic, social, and environmental impacts of these strategies reveals that crop rotation and changing crop varieties have the greatest potential to improve yields and income, enhance food security, and promote soil fertility.

Importantly, while short-term solutions like pesticide application and inorganic fertilisers may be widely accepted, their long-term sustainability remains questionable. This calls for a balanced approach—one that combines immediate coping mechanisms with long-term resilience-building measures. Enhanced access to education, extension services, infrastructure, and financial resources, alongside stronger institutional support, can help overcome barriers to adoption and ensure that farmers are equipped to make informed decisions.

The study offers practical insights for policymakers and development practitioners, stressing the importance of participatory adaptation and mitigation planning that reflects farmers' voices. Integrating these insights into climate policy can accelerate the shift toward more sustainable agricultural systems in The Gambia. To improve the adoption and long-term viability of adaptation and mitigation strategies, it is recommended that policymakers invest in targeted training programs, broaden access to rural credits, and promote agroecological practices through farmers' field schools and participatory extension services. Investment should aim to bridge knowledge gaps and empower farmers, especially women and youth, to implement strategies that are locally pertinent and environmentally sustainable.

Future research should delve deeper into the economic trade-offs and synergies between different adaptation and mitigation strategies. A better understanding of these dynamics will support more coherent, cost-effective, and inclusive climate action in the agricultural sector.

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4 General conclusion

4.1 Practical Implications

The findings highlight the critical role of enhancing access to climate information on early warning, which empowers farmers to make informed and data-driven decisions, mitigate climate risks and sustain agricultural productivity. This research provides practical insights for developing climate adaptation strategies tailored for smallholder farmers in The Gambia. Integrating climate information services into agricultural practices enables farmers to manage risks, boost productivity, and mitigate the negative impacts of extreme weather events, thus improving food security and reducing crop failures. These findings are crucial for policymakers and practitioners at the national and local levels to design evidence-based interventions.

The study offers empirical evidence to guide the development of adaptation solutions at both farm and off-farm levels that align with farmers' needs and perceptions of climate change. The results underscore the imperative for targeted policy and program initiatives to enhance the adoption of climate risk adaptation strategies, particularly among smallholder farmers in The Gambia. The research emphasises the necessity of addressing gender-specific obstacles encountered by women farmers and improving access to climate-related information, external support, and prior experience with climate disasters. Policymakers can leverage these findings to address barriers such as credit constraints and poverty, ensuring the dissemination of customised climate information to better support farmers in adapting to climate risk.

The findings also provide valuable insights for policymakers and stakeholders in formulating climate adaptation and mitigation strategies that target the specific requirements of local agricultural communities. The study indicates the importance of integrating farmers' perceptions into the development of climate adaptation and mitigation policies to their efficacy and sustainability. By establishing interventions to tackle the distinct challenges posed by climate change on agricultural productivity, policymakers can develop targeted initiatives that support farmers in alleviating the adverse effects of climate risks. The results provide a framework for creating impactful, community-oriented solutions that promote resilience in agricultural systems.

Based on these results, the study confirms the first hypothesis that farmers with greater access to climate information services are more likely to adopt effective adaptation strategies. The second alternative hypothesis is also confirmed, showing who perceive climate risk are much more likely to use on-farm adaptation strategies. Finally, the third hypothesis is also confirmed, showing that farmers in The Gambia do not perceive the strategies as ineffective but rather as moderately effective in addressing climate-related challenges.

4.2 Policy recommendations

The following recommendations, rooted in the empirical findings of this study, aim to address the key challenges faced by smallholder farmers in The Gambia. They focus on enhancing adaptive capacity, improving access to climate services, building resilience to climate risks, improving agricultural productivity, and promoting sustainable practices to ensure long-term food security in the context of climate change.

1. Leverage popular tools such as radios and mobile phones by partnering with community radio stations to disseminate timely and accurate climate information using formats like talk shows, drama, and jingles to improve understanding.
2. Explore affordable internet-based platforms for those with access, by developing low-data mobile applications where extension workers and farmers can share real-time weather updates.
3. Provide climate information in local dialects and simplify technical language to improve accessibility for farmers with low literacy levels. Translates forecast and advisories services into local languages and broadcasts them via community radio, village meetings, and mobile audio messages.
4. Implement gender-sensitive policies to reduce disparities by improving women's access to education, training, and resources, such as climate information services, while addressing barriers and promoting equal opportunities for female farmers to actively participate in climate adaptation efforts. Develop community-based training programs targeting women farmers, establish women-only farmer groups to ensure safe and inclusive spaces and address socio-cultural barriers through awareness campaigns and involving community leaders.
5. Enhance access to tailored credit schemes by partnering with microfinance institutions to offer low-interest loans, particularly for women and rural smallholder farmers, and coordinate with agricultural agencies to deliver inputs such as subsidised fertilisers, improved seeds, and irrigation systems directly to farmers.

6. Train extension workers to promote the adoption of climate-resilient practices, including crop rotation, adjusted planting dates, and improved crop varieties, alongside agroforestry measures such as planting shade trees and halting deforestation to enhance environmental sustainability.
7. Facilitate the registration and training of farmer groups with support from the local agricultural department to enhance the exchange of ideas and collaborative adoption of strategies.
8. Support off-farm income-generating activities like petty businesses through vocational training, such as food processing, soap-making, to reduce reliance on rainfed agriculture.
9. Recruit and train more extension agents, prioritising local hires who understand the cultural context and equip them with mobile tools to deliver timely climate information, technical support, and guidance for adopting climate-resilient practices and adaptation strategies.
10. Promote highly effective strategies like crop rotation and improved crop varieties through awareness campaigns to enhance yields and incomes, and address barriers to adopting underutilised practices such as irrigation through subsidies and collaborate with local insurance providers to pilot affordable weather-indexed insurance schemes.

4.3 Limitations and future work to study

The study acknowledges that the identified factors influencing adaptation decisions are not exhaustive, and future research is needed to encompass additional effects of climate change on farmers' vulnerability. Additionally, the study does not comprehensively analyse the cost-benefits of various adaptation strategies; future work should focus on assessing the economic trade-offs associated with adaptation strategies and the possible interactions between different adaptation strategies. Furthermore, exploring the underlying causes of the ineffectiveness of existing adaptation and mitigation measures and developing more effective alternatives is essential. Research should also investigate the role of digital tools such as mobile-based weather services in enhancing the adoption of climate adaptation measures. Finally, analysing the influence of current government policies on the adoption of climate change adaptation strategies and identifying areas for policy improvement will contribute to more effective interventions.

APPENDIX

Appendix 1: Glossary

Climate change: Climate change refers to statistically significant changes, or variability in average climate conditions that persist over long periods, usually decades.

Climate forecast: A climate forecast refers to the prediction of future climate conditions, often made over a longer time horizon than a typical weather period forecast.

Weather forecast: A weather forecast refers to the prediction of future atmospheric conditions, usually for a specific location and over a relatively short time frame, such as hours or days.

Agrometeorological warnings: Agrometeorological warnings are an early warning information that provides farmers, agricultural extension workers, and other stakeholders in agriculture with information on upcoming weather conditions that may have an impact on crop production, animal husbandry, and other aspects of agricultural livelihoods.

Risk: A risk is a potential adverse effect on life, livelihood, health and wellness. It affects economic, social and cultural assets, ecosystems, species, infrastructure and services.

Risk management: Risk management is an action plan, strategy or policy for reducing the likelihood and/or magnitude of potential negative impacts based on measured or perceived risks

Adaptation: Adaptation refers to modifying a system to mitigate the impacts of climate change and capitalise on potential benefits.

Mitigation: Mitigation is a measure that prevents or reduces future climate change effects, such as the reduction of GHG emissions

Appendix 2: Questionnaire

University Cheikh Anta Diop, WASCAL GRP-CCE, BP 5683, Dakar-Senegal.
Enumerators: Start with greetings in the local language. Please read out aloud the following to each respondent.
I am a PhD student. As part of my degree, I am carrying out research on Climate risk and climate services perception, and the efficacy of adaptation and mitigation strategies in agriculture through the lens of a globally changing climate: A case study of The Gambia. The goal is to identify access to climate services, the perception of farmers on climate risk, and their adaptation strategies amid climate change. Taking part in this study is voluntary. I kindly request your participation in the research by answering several questions. Your responses are solely for this research and your privacy is assured.
Are you willing to be a participant in our study?
Thank you. We can now proceed.

Variable name	Description/ measurement
Enumerator name	Full name of enumerator
Enumerator Code	Code of enumerator
Date of interview	The date of the interview
Household ID	Household ID of the household interviewed
Household characteristics	
Gender	Dummy: 1 if male, 0 otherwise
Region	Categorical: 5=NBR 7=CRS 8=URR
District	Categorical: 50=Lower Niumi 51=Upper Niumi 53=Lower Baddibu 56=Sabach Sanjar 70=Niamina Dankunku 71=Niamina West 72=Niamina East 73=Lower Fuladu West 81=Basse 82=Tumana 84=Wuli West 86=Sandu

Village	Categorical: 5114=Jufureh 5138=Kerr Sait Cham 5137=Chamen Sosseh 5113=Kerr Cherno Baba 5134=Nyofelleh 5009=Kerr Pateh 5014=Mbahen 5024=Njoufain 5003=Medina Daru 5015=Bakindick Wollof 5621=Mbayen 5624=Sabach Sukoto 5609=Bassik 5625=Ndowen 5610=Kerr Bamba Lowe 5313=Amdalai/Pallen 5301=Kerewan 5303=Gunjur 5307=Njawara 5302=Saaba 7001= Dankunku 7002= Babou Jobe 7003= Wellingara Yorroba (Kerr Laye) 7005= Barrow Kunda 7006= Sinchu Njugary (Madina Njugary) 7104= Sambang Mandinka Kunda 7112= Wellingara Momodou Jallow 7111= Jamara Nema 7105= Pinai Mandinka 7113= Kumbaney Buniadu 7206=Kerewan Demba 7207=Batty Njoll 7211= Macca Mbayen 7225= Missira 7220=Jockul 7304= Brikamanding 7327= Nema 7318= Wellingara Kejaw 7313= Sankuleh Kunda 7306= Kerewan Samba Sire Fula) 8109= Wellingara Samba Tacko(Samba Tacko) 8104= Sabi 8115= Sare Pirasu 8107= Bassending 8103=Mansajang Kunda 8216= Kulkuleh =8224 Kolli Kunda 8222= Dandu 8212= Bisandugu 8226= Sare Gela 8408= Jar Kunda 8412= Bajonkot /Perri Mamadi 8403= Barrow Kunda 8421= Sare Ngaba 8416=Limbanbulu Bambo 8613= Changally Lang Kaddy 8617= Jakaba 8622= Sare Yerrori 8611= Sare Fodikay 8616= Jagajary
GPS coordinates	Geopoint
Age	Continuous: In years
Age squared	Continuous: In years
Education	Categorical: 0=None, 1=Basis, 2=Secondary, 3=Tertiary
Household size	Continuous: In numbers
Farming experience	Continuous: In years
Farming experience square	Continuous: In years
Farm size	Continuous: Number of hectares
Main farming occupation	Categorical: 1-Crop farming 2-Livestock rearing 3-Horticulture 4-Others-specify
On-Farm income	Continuous: Amount in '000 GMD
Log (Annual income)	Continuous: Amount in '000 GMD
Off-farm income	Dummy: 1 if the farmer has off-farm income, 0 otherwise
Distance to the main market	Continuous: In km
Technology Adoption	Categorical: 1-Irrigation systems 2-Tractor 3-Trucks 4-Ploughs 5-Disk harrows 6-Cultivators 7-Spraying machine 8-Water pump 9-Mechanical harvesters 10-Others-specify
Number of family labour	Continuous: Number of people who work on the farm

Number of people hired	Continuous: Number of hired labourers who work on the farm
Cost of hired labour	Continuous: Amount in '000 GMD
Average wage per day	Continuous: Amount in '000 GMD
Hours worked per day	Continuous: In hours
Land tenure	Dummy: 1 if plot owned, 0 otherwise
Institutional characteristics	
Access to irrigation	Dummy: 1 if farmers have access to irrigation, 0 otherwise
Access to fertilizer	Dummy: 1 if farmers have access to fertilizer, 0 otherwise
Access to improved seeds	Dummy: 1 if farmers have access to improved seeds, 0 otherwise
Access to climate information	Dummy: 1 if the farmer has access to climate information, 0 otherwise
Use of climate information	Dummy: 1 if the farmer uses climate information, 0 otherwise
Access to credit	Dummy: 1 if the farmer has access to credit, 0 otherwise
Access gov't support	Dummy: 1 if the farmer has access to gov't support, 0 otherwise
Access to marketing information	Dummy: 1 if the farmer has access to marketing information, 0 otherwise
Access to extension services	Dummy: 1 if the farmer has access to extension services, 0 otherwise
Training on climate risk adaptation strategies	Dummy: 1 if the farmer has received training, 0 otherwise
Social/farm group	Dummy: 1 if the farmer is a member of a group, 0 otherwise
Expenditure on Inputs	Dummy: 1 if the farmer purchased any input in the past season, 0 otherwise
Fertilizer	Continuous: Amount in '000 GMD
Improved seeds	Continuous: Amount in '000 GMD
Pesticide	Continuous: Amount in '000 GMD
Others	Continuous: Amount in '000 GMD
Perception and knowledge of climate change	
Climate change is important	Dummy: 1 if the farmer thinks climate change phenomena is an important issue to be concerned about, 0 otherwise
Climate change awareness	Dummy: 1 if the farmer is aware of a change in climate, 0 otherwise
Climate change perception over the past 10 -20 years	Dummy: 1 if the farmer perceived change in climate, 0 otherwise
Witness unexpected weather events	Dummy: 1 if the farmer had witnessed unexpected weather events, 0 otherwise
Trust in the media	Dummy: 1 if the farmer has trust in the media, 0 otherwise
Type of Climate information	

Climate information on early warning	Dummy: 1 if the farmer has received information on climate information on early warning, 0 otherwise
Forecast of an extreme event	Dummy: 1 if the farmer has received information on a forecast of an extreme event, 0 otherwise
Unseasonal rainfall	Dummy: 1 if the farmer has received information on unseasonal rainfall, 0 otherwise
Forecast of the start of the rain	Dummy: 1 if the farmer has received information on a forecast of the start of the rain, 0 otherwise
Forecast of the end of the rain	Dummy: 1 if the farmer has received information on a forecast of the end of the rain, 0 otherwise
Forecast for plant or animal diseases	Dummy: 1 if the farmer has received information on a forecast for plant or animal diseases, 0 otherwise
Early warning for an outbreak of pests	Dummy: 1 if the farmer has received information on a forecast of an extreme event, 0 otherwise
Forecast of rainfall volume	Dummy: 1 if the farmer has received information on early warning for an outbreak of pests, 0 otherwise
Forecast of daily weather	Dummy: 1 if the farmer has received information on a forecast of daily weather, 0 otherwise
Early warning for a flood	Dummy: 1 if the farmer has received information on early warning for a flood, 0 otherwise
Early warning for a drought	Dummy: 1 if the farmer has received information on early warning for a drought, 0 otherwise
Early warning for a severe storm	Dummy: 1 if the farmer has received information on early warning for a severe storm, 0 otherwise
Sources of information	
Radio	Dummy: 1 if the farmer had access to radio, 0 otherwise
Television (TV)	Dummy: 1 if the farmer had access to TV 0 otherwise
Extension workers	Dummy: 1 if the farmer had received info from extension worker, 0 otherwise
Farmer groups	Dummy: 1 if the farmer belongs to farm group 0, otherwise
Mobile phone	Dummy: 1 if the farmer had access to mobile 0, otherwise
Newspaper	Dummy: 1 if the farmer had access to Newspaper 0, otherwise
Weather stations	Dummy: 1 if the farmer had access to weather station 0, otherwise
Village meetings	Dummy: 1 if the farmer had received info from village meeting 0, otherwise
Internet	Dummy: 1 if the farmer had access to the internet 0, otherwise
NGOs	Dummy: 1 if the farmer had received info from NGOs 0, otherwise
MECCNAR	Dummy: 1 if the farmer had received info from MECCNAR, 0, otherwise

Community leaders	Dummy: 1 if the farmer had received info from community leaders 0, otherwise
Market actors	Dummy: 1 if the farmer had received info from market actors 0, otherwise
Friends	Dummy: 1 if the farmer had received info from friends 0, otherwise
Relatives	Dummy: 1 if the farmer had received info from relatives 0, otherwise
Neighbours	Dummy: 1 if the farmer had received info from neighbours 0, otherwise
Teacher	Dummy: 1 if the farmer had received info from teacher 0, otherwise
Meteorological Officer	Dummy: 1 if the farmer had received info from meteorological officer 0, otherwise
Climate information usefulness and relevancy	
The usefulness of climate information	Categorical: 0=not useful 1=useful 2=very useful
Reliability of climate information	Categorical: 0=not reliable 1=reliable 2=very reliable
Extent of using climate information	Categorical: 0-Not at all 2-Small extent 3-Large extent
Use climate information to inform farming decision-making	
Use climate services to inform your farming decision-making	Dummy: 1 if the farmer had used climate information to inform your farming decision-making, 0 otherwise
Land preparation	Dummy: 1 if the farmer had used information for land preparation, 0 otherwise
Types of crops to grow	Dummy: 1 if the farmer had used information for types of crops to grow, 0 otherwise
Land allocation	Dummy: 1 if the farmer had used information for land allocation, 0 otherwise
Ploughing time	Dummy: 1 if the farmer had used information for ploughing time, 0 otherwise
Planting/sowing time	Dummy: 1 if the farmer had used information for planting/sowing time, 0 otherwise
Weeding time	Dummy: 1 if the farmer had used information for weeding time, 0 otherwise
Fertilizer application	Dummy: 1 if the farmer had used information for fertilizer application, 0 otherwise
Harvest time	Dummy: 1 if the farmer had used information for harvest time, 0 otherwise

Time mainly receives climate information	Categorical: 1-Before growing seasons 2-During growing season 3-Before and during 4-All time
Main Livelihood Activity and Assets	
Main livelihood activity in 2022	Categorical: 1-Crop production & sales 2-Livestock production & sales 3-Milk production and sales 4-labour in urban areas 5-Agricultural labouring 6-Employment in the village surroundings 7-Small business 8-Petty trade 9-Employment in tourism 10-Housework 11-Rent out the property 12-Other, please specify
Electricity/Generator/solar panel	Dummy: 1 if the farmer has access to a source of power, 0 otherwise
Radio	Dummy: 1 if the farmer has a radio, 0 otherwise
Cell phone	Dummy: 1 if the farmer has a cell phone, 0 otherwise
Televisions	Dummy: 1 if the farmer has television, 0 otherwise
Car	Dummy: 1 if the farmer has a car, 0 otherwise
Motorbike	Dummy: 1 if the farmer has a motorbike, 0 otherwise
Bicycle	Dummy: 1 if the farmer has a bicycle, 0 otherwise
Horse/donkey cart	Dummy: 1 if the farmer has a horse/donkey cart, 0 otherwise
Number of animals owned by the household	
Cow	Continuous: In numbers
Donkey	Continuous: In numbers
Horse	Continuous: In numbers
Goat	Continuous: In numbers
Sheep	Continuous: In numbers
Poultry	Continuous: In numbers
Perceptions of climate-related risk	
Observed changes in the environment in the last 10-20 years	Dummy: 1 if the farmer observed change in the environment, 0 otherwise
Droughts/ dry spell	Dummy: 1 if the farmer perceived an increase in droughts, 0 otherwise
Floods	Dummy: 1 if the farmer perceived an increase in floods, 0 otherwise
Windstorms	Dummy: 1 if the farmer perceived an increase in windstorms, 0 otherwise
Dust	Dummy: 1 if the farmer perceived an increase in dust, 0 otherwise
Bush-fire	Dummy: 1 if the farmer perceived an increase in bush-fire, 0 otherwise

High temperature/hot weather	Dummy: 1 if the farmer perceived an increase in temperature, 0 otherwise
Low temperature/ low weather	Dummy: 1 if the farmer perceived a decrease in temperature, 0 otherwise
High/heavy rainfall	Dummy: 1 if the farmer perceived an increase in rainfall, 0 otherwise
Decline in precipitation	Dummy: 1 if the farmer perceived a decrease in rainfall, 0 otherwise
Salinity	Dummy: 1 if the farmer perceived an increase in salinity, 0 otherwise
Crop disease	Dummy: 1 if the farmer perceived an increase in crop disease, 0 otherwise
Livestock disease	Dummy: 1 if the farmer perceived an increase in livestock disease, 0 otherwise
Insect attacked	Dummy: 1 if the farmer experienced insect attack over the last, 0 otherwise
The main climate risk faced	Categorical: 1-Drought 2-Flood 3-Windstorms 4-Increase temperature 5-Low rainfall 6-Other-specify
Impact of climate-related events	
Farmers perception of the impact of climate change	Categorical: 0-No climate change impact, 1-Decrease in crop production, 2-Low crop yield, 3-Water logging, 4-Better production, 5-Changed cropping calendar, 6-Longer growing season, 7-Soil degradation, 8-Water shortage, 9-Loss of biodiversity
Adaptation strategies	
Adopted adaptation strategy	Dummy: 1 if the farmer adopted an adaptation strategy, 0 otherwise
Farm adaptation strategies	
Change crop to livestock (CCL)	Dummy: 1 if the farmer adapted change crop to livestock as an adaptation strategy, 0 otherwise
Change crop type (CCT)	Dummy: 1 if the farmer adapted change crop type as an adaptation strategy, 0 otherwise
Change crop variety (CCV)	Dummy: 1 if the farmer adapted change crop varieties as an adaptation strategy, 0 otherwise
Change livestock to crop (CLC)	Dummy: 1 if the farmer adapted change livestock to crop as an adaptation strategy, 0 otherwise
Change planting date (CPD)	Dummy: 1 if the farmer adapted change planting date as an adaptation strategy, 0 otherwise
Change seed quality CSQ)	Dummy: 1 if the farmer adapted change seed quality as an adaptation strategy, 0 otherwise
Use of inorganic fertilizers (UIF)	Dummy: 1 if the farmer adapted changing fertilizer as an adaptation strategy, 0 otherwise

Crop diversification (CD)	Dummy: 1 if the farmer adapted crop diversification as an adaptation strategy, 0 otherwise
Crop rotation (CR)	Dummy: 1 if the farmer adapted crop rotation an adaptation strategy, 0 otherwise
Soil conservation (SC)	Dummy: 1 if the farmer adapted soil conservation as an adaptation strategy, 0 otherwise
Stop cutting trees (SCT)	Dummy: 1 if the farmer adapted stop cutting trees as an adaptation strategy, 0 otherwise
Pesticide application (PA)	Dummy: 1 if the farmer adapted pesticide application as an adaptation strategy, 0 otherwise
Planting shaded trees (PST)	Dummy: 1 if the farmer adapted planting shaded trees as an adaptation strategy, 0 otherwise
Irrigation (Ir)	Dummy: 1 if the farmer adapted irrigation as an adaptation strategy, 0 otherwise
Non-farm adaptation strategies	
Praying (Pr)	Dummy: 1 if the farmer adapted praying to God/Allah as an adaptation strategy, 0 otherwise
Use insurance (UI)	Dummy: 1 if the farmer adapted insurance as an adaptation strategy, 0 otherwise
Wage (W)	Dummy: 1 if a farmer received a wage, 0 otherwise
Migration (Mg)	Dummy: 1 if a family member adapted migration as an adaptation strategy, 0 otherwise
Petty business (PB)	Dummy: 1 if the farmer adapted petty trading business as an adaptation strategy, 0 otherwise
Assistant from gov’t/NGOs (AGN)	Dummy: 1 if the farmer can rely on government/NGO support in times of need, 0 otherwise
Perception of the efficacy adaptation strategies	
Farm adaptation strategies	
Change crop to livestock (CCL)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Change crop type (CCT)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Change crop variety (CCV)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Change livestock to crop (CLC)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Change planting date (CPD)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Change seed quality CSQ)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Use of inorganic fertilizers (UIF)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective

Crop diversification (CD)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Crop rotation (CR)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Soil conservation (SC)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Stop cutting trees (SCT)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Pesticide application (PA)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Planting shaded trees (PST)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Irrigation (Ir)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Non-farm adaptation strategies	
Praying (Pr)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Use insurance (UI)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Wage (W)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Migration (Mg)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Petty business (PB)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Assistant from gov’t/NGOs (AGN)	Categorical: 1= Totally ineffective, 2= Ineffective, 3= Not understanding, 4= Effective, 5= Highly effective
Economic impact of farm-level adaptation strategies	
Change crop to livestock (CCL)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Change crop type (CCT)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Change crop variety (CCV)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Change livestock to crop (CLC)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Change planting date (CPD)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others

Change seed quality CSQ)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Use of inorganic fertilizers (UIF)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Crop diversification (CD)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Crop rotation (CR)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Soil conservation (SC)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Stop cutting trees (SCT)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Pesticide application (PA)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Planting shaded trees (PST)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Irrigation (Ir)	Categorical: 0=no economic impact 1=increase income 2=increase crop yield 3=increase employment opportunity 4=others
Social impact of farm level adaptation strategies	
Change crop to livestock (CCL)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Change crop type (CCT)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Change crop variety (CCV)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Change livestock to crop (CLC)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Change planting date (CPD)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities

Change seed quality CSQ)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Use of inorganic fertilizers (UIF)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Crop diversification (CD)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Crop rotation (CR)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Soil conservation (SC)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Stop cutting trees (SCT)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Pesticide application (PA)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Planting shaded trees (PST)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Irrigation (Ir)	Categorical: 0=no social impact 1=increase food security 2=improved nutrition 3=reduced poverty 4=increase time for off-farm activities
Environmental impact of farm-level adaptation strategies	
Change crop to livestock (CCL)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Change crop type (CCT)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Change crop variety (CCV)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others

Change livestock to crop (CLC)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Change planting date (CPD)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Change seed quality CSQ)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Use of inorganic fertilizers (UIF)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Crop diversification (CD)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Crop rotation (CR)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Soil conservation (SC)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Stop cutting trees (SCT)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Pesticide application (PA)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Planting shaded trees (PST)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Irrigation (Ir)	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others

Constraints to climate risk adaptation	Categorical:0= no environmental impact 1= reduced soil contamination 2=reduced water contamination 3=improved the environment 4=enhanced soil fertility 5=regulate soil moisture and temperature 6=others
Lack of knowledge and information	Dummy: 1 if farmer have knowledge and information, 0 otherwise
Lack of credit	Dummy: 1 if farmer have access to credit, 0 otherwise
Lack of access to assets	Dummy: 1 if farmer have access to assets, 0 otherwise
Inadequate government support	Dummy: 1 if farmer have access to government support, 0 otherwise
Poverty	Dummy: 1 if farmer is not face with poverty, 0 otherwise
Lack of market access	Dummy: 1 if farmer have access to market, 0 otherwise
Insecure land tenure system	Dummy: 1 if insecure land tenure system is constraint, 0 otherwise
Shortage of labor	Dummy: 1 if farmer had faced shortage of labor is constraint, 0 otherwise
Old age	Dummy: 1 if old age is constraint, 0 otherwise
Limited availability of land	Dummy: 1 if limited availability of land is constraint, 0 otherwise
Inadequate extension services	Dummy: 1 if inadequate extension services is constraint, 0 otherwise
Low education	Dummy: 1 if low education is constraint, 0 otherwise
Inadequate access to irrigation	Dummy: 1 if inadequate irrigation is constraint, 0 otherwise
Climate variables	
Temperature	Continuous: Annual average over the period 1990-2021
Precipitation	Continuous: Annual average over the period 1990-2021

Appendix 2 Regression analysis

Testing the assumption of logistic regression: No multicollinearity and VIF for multicollinearity (MNL), linear relationship between any continuous independent variable

```
. corr Gender Agecat Farmingexp Memberofasocialfarmgroup Trustinthemedia  Accesstomarketinginformation
>  Accesstoextensionservices Witnessunexpectedweatherevent
(obs=420)

             |   Gender   Agecat Farmin~p Member~p Trusti~a A~mark~n Acces~es Witnes~t
-------------+------------------------------------------------------------------------
      Gender |   1.0000
      Agecat |  -0.1859   1.0000
  Farmingexp |  -0.2170   0.7213   1.0000
Memberofas~p |   0.1789  -0.1008  -0.0238   1.0000
Trustinthe~a |  -0.0082  -0.1350  -0.1162   0.0622   1.0000
Accesstoma~n |  -0.0631   0.0719   0.0996   0.1878   0.0847   1.0000
Accesstoex~s |  -0.0324   0.0195  -0.0168  -0.0308   0.1913   0.0002   1.0000
Witnessune~t |  -0.0289  -0.0321  -0.0245   0.0604   0.4573   0.1989   0.1255   1.0000
```

```
. estat vif

    Variable |       VIF       1/VIF  
-------------+----------------------
      Gender |
          2  |      1.28    0.784041
      Agecat |
          2  |      2.04    0.489914
          3  |      2.15    0.465684
Educationl~l |      6.13    0.163021
      Gender#|
Educationl~l |
        1 1  |      1.71    0.584603
        1 2  |      3.65    0.273950
        1 3  |      3.41    0.293429
        2 1  |      1.21    0.824801
Accessgovt~t |      1.09    0.920502
Accesstoma~n |      1.14    0.876670
Accesstoex~s |      1.17    0.856072
Trainingon~t |      1.18    0.846655
Memberofas~p |      1.12    0.896271
Trustinthe~a |      1.39    0.717722
Witnessune~t |      1.33    0.754545
-------------+----------------------
    Mean VIF |      2.00
```

```
. leastlikely

Outcome: 0 (No)

     +-----------+
     |      Prob |
     |-----------|
 41. |  .1401021 |
 43. |  .1131954 |
 53. |  .0682305 |
 71. |  .0155556 |
402. |  .0915924 |
     +-----------+

Outcome: 1 (Yes)

     +-----------+
     |      Prob |
     |-----------|
 96. |  .6512348 |
100. |  .7056043 |
207. |  .7027372 |
245. |  .3984792 |
355. |  .6539295 |
     +-----------+
```

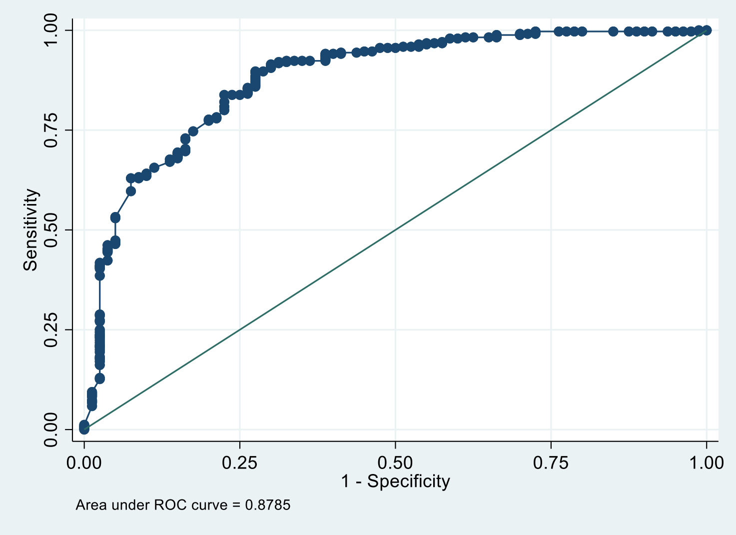
```
. logistic Accesstoclimateinformation i.Gender i.Educationlevel  i.Gender#i.Educationlevel i.Agecat Ac
> cessgovtsupport Accesstomarketinginformation Accesstoextensionservices Trainingonclimateriskadaptat
> Memberofasocialfarmgroup Trustinthemedia Witnessunexpectedweatherevent, coef
note: 2.Gender#3.Educationlevel identifies no observations in the sample

Logistic regression                             Number of obs     =        420
                                                LR chi2(15)       =     144.31
                                                Prob > chi2       =     0.0000
Log likelihood = -132.34991                     Pseudo R2         =     0.3528

------------------------------------------------------------------------------------------------
   Accesstoclimateinformation |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+-----------------------------------------------------------------
                       Gender |
                      Female  |  -.7829713   .3826467    -2.05   0.041    -1.532945   -.0329975
                              |
               Educationlevel |
                     Primary  |   .0869512   .6947704     0.13   0.900    -1.274774    1.448676
                   Secondary  |  -.2514323   .7185297    -0.35   0.726    -1.659725     1.15686
                    Tertiary  |  -.4301522   1.042102    -0.41   0.680    -2.472634     1.61233
                              |
        Gender#Educationlevel |
              Female#Primary  |   1.343895   1.183531     1.14   0.256    -.9757834    3.663574
            Female#Secondary  |   3.240645   1.578099     2.05   0.040     .1476278    6.333662
             Female#Tertiary  |          0  (empty)
                              |
                       Agecat |
           Middle age farmers |   .9960392   .4334611     2.30   0.022      .146471    1.845607
              Old age farmers |   .2581757   .4578575     0.56   0.573    -.6392086     1.15556
                              |
             Accessgovtsupport|  -.2615273   .3997307    -0.65   0.513    -1.044985    .5219304
 Accesstomarketinginformation |   1.802618   .4254306     4.24   0.000     .9687894    2.636447
    Accesstoextensionservices |   .7111153   .3329279     2.14   0.033     .0585886    1.363642
 Trainingonclimateriskadaptat |   1.711819   .7756051     2.21   0.027      .191661    3.231977
     Memberofasocialfarmgroup |  -.8899272   .5726158    -1.55   0.120    -2.012234    .2323791
              Trustinthemedia |    2.34264   .4010495     5.84   0.000     1.556598    3.128683
Witnessunexpectedweatherevent |   1.133235   .3968164     2.86   0.004     .3554893    1.910981
                        _cons |  -2.796147   .7704717    -3.63   0.000    -4.306243    -1.28605
------------------------------------------------------------------------------------------------
```

Post estimation test

*Hosmer-Lemeshow goodness of fit test

```
. estat gof, group(10)

Logistic model for Accesstoclimateinformation, goodness-of-fit test

  (Table collapsed on quantiles of estimated probabilities)

       number of observations =       420
             number of groups =        10
      Hosmer-Lemeshow chi2(8) =         9.23
                  Prob > chi2 =         0.3229
```

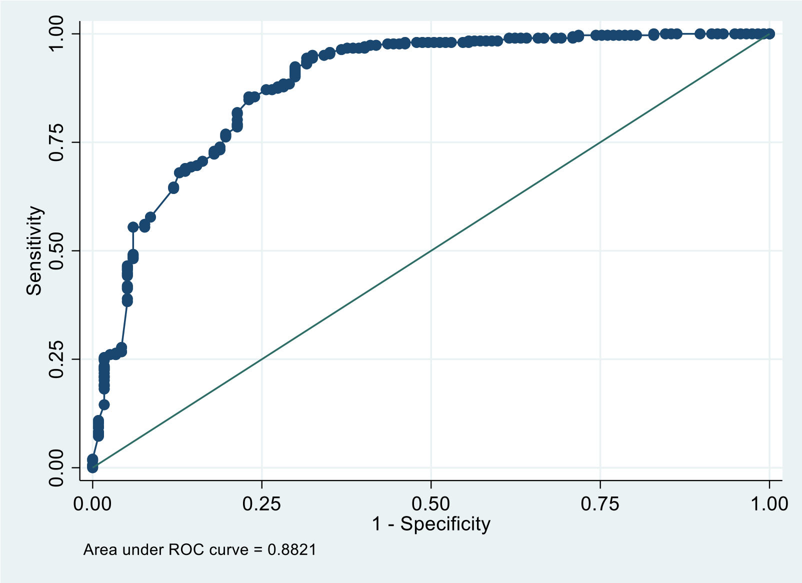
ROC curve



Sensitivity and Specificity of the model

```
. estat classification, all

Logistic model for Accesstoclimateinformation

              ──────── True ────────
Classified │         D            ~D  │      Total
───────────┼──────────────────────────┼───────────
     +     │       325            38  │        363
     -     │        15            42  │         57
───────────┼──────────────────────────┼───────────
   Total   │       340            80  │        420

Classified + if predicted Pr(D) >= .5
True D defined as Accesstoclimateinformation != 0
──────────────────────────────────────────────────
Sensitivity                     Pr( +| D)   95.59%
Specificity                     Pr( -|~D)   52.50%
Positive predictive value       Pr( D| +)   89.53%
Negative predictive value       Pr(~D| -)   73.68%
──────────────────────────────────────────────────
False + rate for true ~D        Pr( +|~D)   47.50%
False - rate for true D         Pr( -| D)    4.41%
False + rate for classified +   Pr(~D| +)   10.47%
False - rate for classified -   Pr( D| -)   26.32%
──────────────────────────────────────────────────
Correctly classified                        87.38%
──────────────────────────────────────────────────
```

```
. logistic Useofclimateinformation i.Gender i.Educationlevel i.Gender#i.Educationlevel i.Agecat  Acces
> sgovtsupport Accesstomarketinginformation Accesstoextensionservices Trainingonclimateriskadaptat Mem
> berofasocialfarmgroup Trustinthemedia Witnessunexpectedweatherevent, coef
note: 2.Gender#3.Educationlevel identifies no observations in the sample

Logistic regression                             Number of obs     =        420
                                                LR chi2(15)       =     202.88
                                                Prob > chi2       =     0.0000
Log likelihood = -147.02927                     Pseudo R2         =     0.4083

-----------------------------------------------------------------------------------------------
      Useofclimateinformation |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+----------------------------------------------------------------
                       Gender |
                      Female  |  -.6722577   .3615764    -1.86   0.063    -1.380934     .036419
                              |
               Educationlevel |
                     Primary  |  -.8942138   .5759465    -1.55   0.121    -2.023048    .2346206
                   Secondary  |   .2330903   .6987285     0.33   0.739    -1.136392    1.602573
                    Tertiary  |   .1995528   1.106446     0.18   0.857    -1.969041    2.368146
                              |
        Gender#Educationlevel |
              Female#Primary  |   3.160593   1.222591     2.59   0.010     .7643579    5.556828
            Female#Secondary  |   2.339879   1.596608     1.47   0.143    -.7894147    5.469172
             Female#Tertiary  |          0  (empty)
                              |
                       Agecat |
           Middle age farmers |   .9187665    .396897     2.31   0.021     .1408627     1.69667
              Old age farmers |    .306445   .4221547     0.73   0.468    -.520963     1.133853
                              |
            Accessgovtsupport |  -.1449876   .3977635    -0.36   0.715    -.9245898    .6346146
 Accesstomarketinginformation |   1.550053   .4372847     3.54   0.000     .6929902    2.407115
    Accesstoextensionservices |    .437676   .3172657     1.38   0.168    -.1841534    1.059505
 Trainingonclimateriskadaptat |   1.277533   .5450948     2.34   0.019     .2091668    2.345899
     Memberofasocialfarmgroup |  -.5457658   .5258496    -1.04   0.299    -1.576412    .4848805
              Trustinthemedia |   3.259825   .4896626     6.66   0.000     2.300104    4.219546
Witnessunexpectedweatherevent |   2.077417   .4595378     4.52   0.000      1.17674    2.978095
                        _cons |  -5.127091   .8517962    -6.02   0.000    -6.796581   -3.457601
-----------------------------------------------------------------------------------------------

. estat gof, group(10)

Logistic model for Useofclimateinformation, goodness-of-fit test

  (Table collapsed on quantiles of estimated probabilities)

       number of observations =       420
             number of groups =        10
      Hosmer-Lemeshow chi2(8) =         5.54
                  Prob > chi2 =         0.6988
```



```
. estat classification, all

Logistic model for Useofclimateinformation

              ──────── True ────────
Classified │         D            ~D  │      Total
───────────┼──────────────────────────┼───────────
     +     │       290            41  │        331
     -     │        13            76  │         89
───────────┼──────────────────────────┼───────────
   Total   │       303           117  │        420

Classified + if predicted Pr(D) >= .5
True D defined as Useofclimateinformation != 0
──────────────────────────────────────────────────
Sensitivity                     Pr( +| D)   95.71%
Specificity                     Pr( -|~D)   64.96%
Positive predictive value       Pr( D| +)   87.61%
Negative predictive value       Pr(~D| -)   85.39%
──────────────────────────────────────────────────
False + rate for true ~D        Pr( +|~D)   35.04%
False - rate for true D         Pr( -| D)    4.29%
False + rate for classified +   Pr(~D| +)   12.39%
False - rate for classified -   Pr( D| -)   14.61%
──────────────────────────────────────────────────
Correctly classified                        87.14%
──────────────────────────────────────────────────
```

```
. ivregress 2sls UsefulnessofClimateinformatio Gender Householdsize Educationlevel Age Averageannualfa
> rmingincome Accessgovtsupport Memberofasocialfarmgroup (Accesstoextensionservices = Distancetothemai
> nmarket)

Instrumental variables (2SLS) regression          Number of obs   =        420
                                                  Wald chi2(8)    =       7.29
                                                  Prob > chi2     =     0.5053
                                                  R-squared       =          .
                                                  Root MSE        =     1.2118

--------------------------------------------------------------------------------------------
UsefulnessofClimateinfor~o |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------------------+----------------------------------------------------------------
 Accesstoextensionservices |  -1.685049   1.612536    -1.04   0.296    -4.845562    1.475463
                    Gender |  -.2585934   .1581804    -1.63   0.102    -.5686213    .0514345
             Householdsize |  -.0079943   .0055788    -1.43   0.152    -.0189285      .00294
            Educationlevel |  -.0716082   .1095809    -0.65   0.513    -.2863827    .1431664
                       Age |  -.0043209   .0052179    -0.83   0.408    -.0145478     .005906
Averageannualfarmingincome |   1.29e-06   1.41e-06     0.91   0.361    -1.48e-06    4.05e-06
         Accessgovtsupport |  -.3245359   .1615419    -2.01   0.045    -.6411522   -.0079196
  Memberofasocialfarmgroup |   .0656934   .2074365     0.32   0.751    -.3408748    .4722615
                     _cons |   2.880874   1.423177     2.02   0.043     .0914993    5.670249
--------------------------------------------------------------------------------------------
Instrumented:  Accesstoextensionservices
Instruments:   Gender Householdsize Educationlevel Age Averageannualfarmingincome
               Accessgovtsupport Memberofasocialfarmgroup Distancetothemainmarket

. ivregress 2sls Adaptationstrategy Gender Educationlevel Age Agesqu logAverageannual Memberofasocialf
> armgroup Trustinthemedia (Useofclimateinformation = Accessgovtsupport)

Instrumental variables (2SLS) regression          Number of obs   =        420
                                                  Wald chi2(8)    =       1.10
                                                  Prob > chi2     =     0.9976
                                                  R-squared       =          .
                                                  Root MSE        =     2.7525

------------------------------------------------------------------------------------------
      Adaptationstrategy |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------------------+----------------------------------------------------------------
 Useofclimateinformation |  -7.240358   27.47056    -0.26   0.792    -61.08166    46.60095
                  Gender |  -.4257124   1.579203    -0.27   0.787    -3.520894    2.669469
          Educationlevel |   .1921974   .6426222     0.30   0.765    -1.067319    1.451714
                     Age |   .0994116   .3284501     0.30   0.762    -.5443388     .743162
                  Agesqu |  -.0009838   .0032298    -0.30   0.761    -.0073141    .0053465
        logAverageannual |   .0342404   .1679019     0.20   0.838    -.2948414    .3633221
Memberofasocialfarmgroup |   .0189027   .4462854     0.04   0.966    -.8558006     .893606
         Trustinthemedia |   5.497591   19.68231     0.28   0.780    -33.07902     44.0742
                   _cons |  -.7720222   2.839111    -0.27   0.786    -6.336578    4.792533
------------------------------------------------------------------------------------------
Instrumented:  Useofclimateinformation
Instruments:   Gender Educationlevel Age Agesqu logAverageannual
               Memberofasocialfarmgroup Trustinthemedia Accessgovtsupport
```

```
. rbiprobit Adaptationstrategy i.Gender i.Educationlevel Householdsize Age Agesq logAverageannual Memb
> erofasocialfarmgroup Accesstoextensionservices  Trustinthemedia Accessgovtsupport, endog(Useofclimat
> eservicestoinfor i.Gender i.Educationlevel Householdsize Age Agesq logAverageannual Memberofasocialf
> armgroup Accesstoextensionservices  Trustinthemedia Accessgovtsupport) vce(robust)

Univariate Probits for starting values

Fitting comparison outcome equation:

Iteration 0:   log pseudolikelihood = -164.92328
Iteration 1:   log pseudolikelihood = -110.15941
Iteration 2:   log pseudolikelihood = -106.43434
Iteration 3:   log pseudolikelihood = -106.20456
Iteration 4:   log pseudolikelihood = -106.17105
Iteration 5:   log pseudolikelihood = -106.16585
Iteration 6:   log pseudolikelihood = -106.16493
Iteration 7:   log pseudolikelihood = -106.16476
Iteration 8:   log pseudolikelihood = -106.16473
Iteration 9:   log pseudolikelihood = -106.16472

Fitting comparison treatment equation:

Iteration 0:   log pseudolikelihood = -239.41981
Iteration 1:   log pseudolikelihood = -153.61615
Iteration 2:   log pseudolikelihood = -153.11763
Iteration 3:   log pseudolikelihood = -153.11736
Iteration 4:   log pseudolikelihood = -153.11736

Comparison:    log pseudolikelihood = -259.28208

Fitting full model:

Iteration 0:   log pseudolikelihood = -259.28208
Iteration 1:   log pseudolikelihood = -259.14795
Iteration 2:   log pseudolikelihood = -259.09154
Iteration 3:   log pseudolikelihood = -259.09112
Iteration 4:   log pseudolikelihood = -259.09111

Recursive Bivariate Probit Regression          Number of obs     =        420
                                               Wald chi2(25)     =     705.00
Log pseudolikelihood = -259.09111              Prob > chi2       =     0.0000

---------------------------------------------------------------------------------------------
                            |               Robust
                            |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
----------------------------+----------------------------------------------------------------
Adaptationstrategy          |
Useofclimateservicestoinfor |
                        Use |   1.008895   .5136337     1.96   0.050     .0021915    2.015599
                            |
                     Gender |
                     Female |  -.1333362   .2423826    -0.55   0.582    -.6083973    .3417248
                            |
             Educationlevel |
                    Primary |    .236919   .3465207     0.68   0.494    -.4422492    .9160871
                  Secondary |   .0649007    .370023     0.18   0.861     -.660331    .7901324
                   Tertiary |   6.082706   .3238762    18.78   0.000      5.44792    6.717492
                            |
              Householdsize |  -.0159589   .0074687    -2.14   0.033    -.0305974   -.0013205
                        Age |   .0511148   .0382582     1.34   0.182      -.02387    .1260996
                     Agesqu |  -.0005301   .0003712    -1.43   0.153    -.0012576    .0001975
           logAverageannual |   .3800668   .1208201     3.15   0.002     .1432637    .6168699
   Memberofasocialfarmgroup |   .0860411    .287776     0.30   0.765    -.4779894    .6500716
  Accesstoextensionservices |   .1174499   .1985189     0.59   0.554      -.27164    .5065399
            Trustinthemedia |   .6272311   .4139884     1.52   0.130    -.1841713    1.438634
          Accessgovtsupport |   .6707068   .2857908     2.35   0.019     .1105671    1.230847
                      _cons |  -4.712544   1.727016    -2.73   0.006    -8.097433   -1.327655
----------------------------+----------------------------------------------------------------
Useofclimateservicestoinfor |
                     Gender |
                     Female |  -.5134865   .1917717    -2.68   0.007    -.8893522   -.1376209
                            |
             Educationlevel |
                    Primary |  -.2016274   .2780681    -0.73   0.468    -.7466308    .3433759
                  Secondary |   .4754602   .3310294     1.44   0.151    -.1733455    1.124266
                   Tertiary |  -.0610248   .5056704    -0.12   0.904    -1.052121     .930071
                            |
              Householdsize |  -.0051951   .0058419    -0.89   0.374     -.016645    .0062548
                        Age |   .0405082   .0342798     1.18   0.237    -.0266791    .1076954
                     Agesqu |  -.0003422   .0003422    -1.00   0.317    -.0010129    .0003285
           logAverageannual |  -.0330119   .0948427    -0.35   0.728    -.2189001    .1528763
   Memberofasocialfarmgroup |  -.0441008   .2765528    -0.16   0.873    -.5861344    .4979328
  Accesstoextensionservices |   .1818642   .1639316     1.11   0.267    -.1394358    .5031642
            Trustinthemedia |   2.501207   .2517457     9.94   0.000     2.007795    2.994619
          Accessgovtsupport |  -.1368906   .1910289    -0.72   0.474    -.5113003    .2375191
                      _cons |  -1.967375   1.263331    -1.56   0.119    -4.443459    .5087085
----------------------------+----------------------------------------------------------------
                    /atanrho |   .3137526   .2304056     1.36   0.173    -.1378341    .7653394
----------------------------+----------------------------------------------------------------
                        rho |   .3038472   .2091339                      -.1369678    .6442112
---------------------------------------------------------------------------------------------
Wald test of rho=0: chi2(1) = 1.85434                    Prob > chi2 = 0.1733
```

```
. rbiprobit tmeffects, tmeffect(ate)

Treatment effect                                Number of obs     =        420
Model VCE    : Robust

Expression   : Pr(Adaptationstrategy=1), predict(pmarg1)
Effect       : Average treatment effect
dydx w.r.t.  : 1.Useofclimateservicestoinfor

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         ate |    .1876177   .1110244     1.69   0.091     -.029986    .4052215
------------------------------------------------------------------------------


. rbiprobit tmeffects, tmeffect(atet)

Treatment effect                                Number of obs     =        312
Model VCE    : Robust

Expression   : normal(Adaptationstrategy=1|Useofclimateservicestoinfor=1) -
               normal(Adaptationstrategy=1|Useofclimateservicestoinfor=0)
Effect       : Average treatment effect on the treated
dydx w.r.t.  : 1.Useofclimateservicestoinfor

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        atet |    .2376638   .1030645     2.31   0.021     .0356611    .4396665
------------------------------------------------------------------------------

. rbiprobit tmeffects, tmeffect(atec)

Treatment effect                                Number of obs     =        420
Model VCE    : Robust

Expression
                  : Pr(Adaptationstrategy=1|Useofclimateservicestoinfor=1)-Pr(Adaptationstrategy=1|U
               > seofclimateservicestoinfor=0), predict(pcond1)-predict(pcond10)
Effect       : Average treatment effect on conditional probability
dydx w.r.t.  : 1.Useofclimateservicestoinfor

------------------------------------------------------------------------------
             |            Delta-method
             |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        atec |    .3371545   .0613117     5.50   0.000     .2169857    .4573233
------------------------------------------------------------------------------
```

Pearson chi square test for the relation between Useofclimateinformation and adaptation

```
. tabulate Useofclimateinformation Adaptationstrategy, chi2 column row V rowsort

+-------------------+
| Key               |
|-------------------|
|     frequency     |
|  row percentage   |
| column percentage |
+-------------------+

    Use of |
   climate |
informatio |   Adaptation strategy
         n | Non-Adapt      Adapt |     Total
-----------+----------------------+----------
       Yes |        11        292 |       303
           |      3.63      96.37 |    100.00
           |     19.64      80.22 |     72.14
-----------+----------------------+----------
        No |        45         72 |       117
           |     38.46      61.54 |    100.00
           |     80.36      19.78 |     27.86
-----------+----------------------+----------
     Total |        56        364 |       420
           |     13.33      86.67 |    100.00
           |    100.00     100.00 |    100.00

          Pearson chi2(1) =  88.6185   Pr = 0.000
               Cramér's V =  -0.4593
```

Testing the significant difference for those who use climate information and those that do not with adaptation

```
. prtesti 292 .8022 72 .1978

Two-sample test of proportions                     x: Number of obs =      292
                                                   y: Number of obs =       72
------------------------------------------------------------------------------
             |       Mean   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           x |      .8022   .0233111                      .7565111    .8478889
           y |      .1978   .0469449                      .1057897    .2898103
-------------+----------------------------------------------------------------
        diff |      .6044    .052414                      .5016704    .7071296
             |  under Ho:   .0612438     9.87   0.000
------------------------------------------------------------------------------
        diff = prop(x) - prop(y)                                  z =   9.8688
    Ho: diff = 0

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(Z < z) = 1.0000         Pr(|Z| > |z|) = 0.0000          Pr(Z > z) = 0.0000
```

Testing the significance difference for those who use climate information and those who do not with non-adapt

```
. prtesti 11 .1964 45 .8036

Two-sample test of proportions                     x: Number of obs =       11
                                                   y: Number of obs =       45
------------------------------------------------------------------------------
             |       Mean   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           x |      .1964   .1197828                     -.0383699    .4311699
           y |      .8036   .0592222                      .6875266    .9196734
-------------+----------------------------------------------------------------
        diff |     -.6072   .1336233                     -.8690968   -.3453032
             |  under Ho:   .1563297    -3.88   0.000
------------------------------------------------------------------------------
        diff = prop(x) - prop(y)                                  z =  -3.8841
    Ho: diff = 0

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(Z < z) = 0.0001         Pr(|Z| > |z|) = 0.0001          Pr(Z > z) = 0.9999
```

```
. mlogit UsefulnessofClimateinformatio i.Gender i.Agecat i.Educationlevel Accessgovtsupport Accesstoma
> rketinginformatio Accesstoextensionservices Trainingonclimateriskadaptat Memberofasocialfarmgroup Tr
> ustinthemedia Witnessunexpectedweatherevent Climatechangeperception, baseoutcome(0)

Iteration 0:   log likelihood = -446.96535
Iteration 1:   log likelihood = -342.81754
Iteration 2:   log likelihood = -335.02549
Iteration 3:   log likelihood = -334.38203
Iteration 4:   log likelihood = -334.37965
Iteration 5:   log likelihood = -334.37965

Multinomial logistic regression                 Number of obs     =        420
                                                LR chi2(28)       =     225.17
                                                Prob > chi2       =     0.0000
Log likelihood = -334.37965                     Pseudo R2         =     0.2519

-----------------------------------------------------------------------------------------------
UsefulnessofClimateinformatio |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+----------------------------------------------------------------
Not_useful                    |  (base outcome)
------------------------------+----------------------------------------------------------------
Useful                        |
                       Gender |
                      Female  |  -.8718255    .366104    -2.38   0.017    -1.589376   -.1542749
                              |
                       Agecat |
          Middle age farmers  |   .4404558   .4383702     1.00   0.315    -.4187341    1.299646
             Old age farmers  |   .4173655    .487536     0.86   0.392    -.5381875    1.372918
                              |
               Educationlevel |
                     Primary  |   .3881646   .5951002     0.65   0.514    -.7782103     1.55454
                   Secondary  |   .0721144   .6503445     0.11   0.912    -1.202537    1.346766
                    Tertiary  |  -.1334073    1.08008    -0.12   0.902    -2.250326    1.983511
                              |
            Accessgovtsupport |  -.0088818   .4159565    -0.02   0.983    -.8241415    .8063779
 Accesstomarketinginformation |   1.488853   .4386403     3.39   0.001     .6291342    2.348572
    Accesstoextensionservices |   .2767357   .3389092     0.82   0.414    -.3875141    .9409855
 Trainingonclimateriskadaptat |   1.072023   .7186812     1.49   0.136    -.3365667    2.480612
     Memberofasocialfarmgroup |  -.3052202   .5625979    -0.54   0.587    -1.407892    .7974514
              Trustinthemedia |   2.678878   .4470707     5.99   0.000     1.802635     3.55512
Witnessunexpectedweatherevent |   .2949254   .6070043     0.49   0.627    -.8947811    1.484632
      Climatechangeperception |   1.299367    .646537     2.01   0.044     .0321779    2.566556
                        _cons |  -3.968816   .8429274    -4.71   0.000    -5.620923   -2.316708
------------------------------+----------------------------------------------------------------
Very_useful                   |
                       Gender |
                      Female  |   -.787132   .4048388    -1.94   0.052    -1.580602    .0063375
                              |
                       Agecat |
          Middle age farmers  |   .5171829    .481857     1.07   0.283    -.4272394    1.461605
             Old age farmers  |   .0687221   .5433909     0.13   0.899    -.9963046    1.133749
                              |
               Educationlevel |
                     Primary  |   .4122279   .6690021     0.62   0.538    -.8989921    1.723448
                   Secondary  |   .2731004   .6951315     0.39   0.694    -1.089332    1.635533
                    Tertiary  |  -1.174067   1.296988    -0.91   0.365    -3.716117    1.367983
                              |
            Accessgovtsupport |  -.6839532   .4879161    -1.40   0.161    -1.640251    .2723447
 Accesstomarketinginformation |   2.151795   .6069932     3.55   0.000     .9621107     3.34148
    Accesstoextensionservices |    .856222   .3892444     2.20   0.028     .0933169    1.619127
 Trainingonclimateriskadaptat |    2.11828   .7212879     2.94   0.003     .7045812    3.531978
     Memberofasocialfarmgroup |  -.4789678   .6245847    -0.77   0.443    -1.703131    .7451958
              Trustinthemedia |   2.951994   .6888341     4.29   0.000     1.601904    4.302084
Witnessunexpectedweatherevent |   1.872296   .9487341     1.97   0.048     .0128116    3.731781
      Climatechangeperception |   1.290399    .956042     1.35   0.177    -.5834089    3.164207
                        _cons |  -7.015749   1.289585    -5.44   0.000    -9.543289   -4.488208
-----------------------------------------------------------------------------------------------
```

Post-estimation test: Akaike's information criterion and Bayesian information criterion

```
. estat ic

Akaike's information criterion and Bayesian information criterion

-----------------------------------------------------------------------------
       Model |          N   ll(null)  ll(model)      df         AIC        BIC
-------------+---------------------------------------------------------------
           . |        420  -446.9654  -334.3796      30    728.7593   849.9669
-----------------------------------------------------------------------------
Note: BIC uses N = number of observations. See [R] BIC note.
```

```
. mlogit Reliabilityofclimateinformati i.Gender i.Agecat i.Educationlevel Accessgovtsupport Accesstoma
> rketinginformatio Accesstoextensionservices Trainingonclimateriskadaptat Memberofasocialfarmgroup Tr
> ustinthemedia Witnessunexpectedweatherevent Climatechangeperception, baseoutcome(0)

Iteration 0:   log likelihood = -448.96484
Iteration 1:   log likelihood = -332.02228
Iteration 2:   log likelihood =  -325.1295
Iteration 3:   log likelihood = -324.40138
Iteration 4:   log likelihood = -324.39875
Iteration 5:   log likelihood = -324.39875

Multinomial logistic regression                 Number of obs     =        420
                                                LR chi2(28)       =     249.13
                                                Prob > chi2       =     0.0000
Log likelihood = -324.39875                     Pseudo R2         =     0.2775

-----------------------------------------------------------------------------------------------
Reliabilityofclimateinformati |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+----------------------------------------------------------------
Not_reliable                  |  (base outcome)
------------------------------+----------------------------------------------------------------
Reliable                      |
                       Gender |
                      Female  |  -.9690498   .3809359    -2.54   0.011     -1.71567   -.2224292
                              |
                       Agecat |
           Middle age farmers |   .2938232   .4576473     0.64   0.521    -.6031491    1.190795
              Old age farmers |   .4870113   .5072245     0.96   0.337    -.5071304    1.481153
                              |
               Educationlevel |
                     Primary  |  -.1819475   .5962208    -0.31   0.760    -1.350519    .9866237
                   Secondary  |   -.095632   .6802978    -0.14   0.888    -1.428991    1.237727
                    Tertiary  |  -.3587332   1.134636    -0.32   0.752    -2.582579    1.865113
                              |
            Accessgovtsupport |  -.0588754   .4302052    -0.14   0.891    -.9020621    .7843113
 Accesstomarketinginformation |   1.838561   .4784352     3.84   0.000     .9008456    2.776277
    Accesstoextensionservices |    .253799   .3516627     0.72   0.470    -.4354472    .9430452
 Trainingonclimateriskadaptat |   1.009284   .7545608     1.34   0.181    -.4696282    2.488196
     Memberofasocialfarmgroup |   .0262813    .579524     0.05   0.964    -1.109565    1.162128
             Trustinthemedia |   3.141014   .4901493     6.41   0.000     2.180339    4.101689
Witnessunexpectedweatherevent |  -.0609639   .6486047    -0.09   0.925    -1.332206    1.210278
      Climatechangeperception |   1.618034   .7046863     2.30   0.022     .2368743    2.999194
                        _cons |  -4.849805   .9154695    -5.30   0.000    -6.644092   -3.055518
------------------------------+----------------------------------------------------------------
Very_reliable                 |
                       Gender |
                      Female  |  -.7198288   .4085719    -1.76   0.078    -1.520615    .0809575
                              |
                       Agecat |
           Middle age farmers |   .4938723   .4845813     1.02   0.308    -.4558895    1.443634
              Old age farmers |  -.0144528   .5501933    -0.03   0.979    -1.092812    1.063906
                              |
               Educationlevel |
                     Primary  |  -.0679722   .6467878    -0.11   0.916    -1.335653    1.199709
                   Secondary  |   .4624586   .7063292     0.65   0.513    -.9219212    1.846838
                    Tertiary  |  -.7912843    1.22829    -0.64   0.519    -3.198688    1.616119
                              |
            Accessgovtsupport |  -.9193832   .4960884    -1.85   0.064    -1.891699    .0529321
 Accesstomarketinginformation |   1.367265   .5158751     2.65   0.008     .3561687    2.378362
    Accesstoextensionservices |   .3989909    .384978     1.04   0.300    -.3555522    1.153534
 Trainingonclimateriskadaptat |   2.359292   .7548012     3.13   0.002     .8799093    3.838676
     Memberofasocialfarmgroup |  -.4113566   .6110172    -0.67   0.501    -1.608928    .7862151
              Trustinthemedia |   2.923736   .6773189     4.32   0.000     1.596216    4.251257
Witnessunexpectedweatherevent |   2.743042   1.199721     2.29   0.022     .3916315    5.094452
      Climatechangeperception |   1.111066   .9683593     1.15   0.251    -.7868834    3.009015
                        _cons |  -6.633229   1.414758    -4.69   0.000    -9.406103   -3.860355
-----------------------------------------------------------------------------------------------
```

```
. estat ic

Akaike's information criterion and Bayesian information criterion

-----------------------------------------------------------------------------
       Model |          N   ll(null)  ll(model)      df        AIC        BIC
-------------+---------------------------------------------------------------
           . |        420  -448.9648  -324.3988      30   708.7975   830.0051
-----------------------------------------------------------------------------
Note: BIC uses N = number of observations. See [R] BIC note.
```

```
. logistic Adaptationstrategy i.Gender i.Agecat i.Educationlevel i.Region Householdsize Farmsize Farmi
> ngexp Landtenure Averageannualfarmingincome Accessgovtsupport Offfarmincome Memberofasocialfarmgroup
>  Accesstomarketinginformation Witnessunexpectedweatherevent Climatechangeperception, coef
note: 3.Educationlevel != 0 predicts success perfectly
      3.Educationlevel dropped and 10 obs not used


Logistic regression                             Number of obs     =        410
                                                LR chi2(18)       =     163.65
                                                Prob > chi2       =     0.0000
Log likelihood =  -81.64825                     Pseudo R2         =     0.5005

-----------------------------------------------------------------------------------------------
           Adaptationstrategy |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+----------------------------------------------------------------
                       Gender |
                      Female  |  -1.061843     .537989    -1.97   0.048    -2.116282   -.0074042
                              |
                       Agecat |
          Middle age farmers  |   .0879159    .6744223     0.13   0.896    -1.233928    1.409759
             Old age farmers  |  -.5844422    .9432444    -0.62   0.536    -2.433167    1.264283
                              |
               Educationlevel |
                     Primary  |   .3088829    .7931066     0.39   0.697    -1.245577    1.863343
                   Secondary  |  -.0368681    .8513873    -0.04   0.965    -1.705557     1.63182
                    Tertiary  |          0  (empty)
                              |
                       Region |
                         CRS  |  -.3647057    .8084349    -0.45   0.652    -1.949209    1.219798
                         URR  |  -2.771855     .694993    -3.99   0.000    -4.134016   -1.409693
                              |
                Householdsize |   .0075898    .0171423     0.44   0.658    -.0260085    .0411881
                     Farmsize |  -.1636906    .0774454    -2.11   0.035    -.3154808   -.0119004
                   Farmingexp |  -.0050667    .0256957    -0.20   0.844    -.0554294    .0452961
                   Landtenure |   1.659312    .5710968     2.91   0.004     .5399832    2.778642
   Averageannualfarmingincome |   .0000147    5.84e-06     2.51   0.012     3.23e-06    .0000261
            Accessgovtsupport |   1.777367    .6987088     2.54   0.011     .4079233    3.146811
                Offfarmincome |   .1147956    .4986827     0.23   0.818    -.8626045    1.092196
     Memberofasocialfarmgroup |   .3596115    .6839848     0.53   0.599    -.9809741    1.700197
 Accesstomarketinginformation |   2.019454    .5617189     3.60   0.000     .9185049    3.120402
Witnessunexpectedweatherevent |   1.288682    .6278411     2.05   0.040     .0581359    2.519228
      Climatechangeperception |   1.633018    .6613376     2.47   0.014       .33682    2.929216
                        _cons |  -1.493181    1.255965    -1.19   0.234    -3.954828    .9684651
-----------------------------------------------------------------------------------------------
```

```
. margins, dydx (i.Gender i.Agecat i.Educationlevel i.Region Householdsize Farmsize Farmingexp Landten
> ure Averageannualfarmingincome Accessgovtsupport Offfarmincome Memberofasocialfarmgroup Accesstomark
> etinginformation Witnessunexpectedweatherevent Climatechangeperception)

Average marginal effects                        Number of obs     =        410
Model VCE    : OIM

Expression   : Pr(Adaptationstrategy), predict()
dy/dx w.r.t. : 2.Gender 2.Agecat 3.Agecat 1.Educationlevel 2.Educationlevel 3.Educationlevel
               7.Region 8.Region Householdsize Farmsize Farmingexp Landtenure
               Averageannualfarmingincome Accessgovtsupport Offfarmincome Memberofasocialfarmgroup
               Accesstomarketinginformation Witnessunexpectedweatherevent Climatechangeperception

-----------------------------------------------------------------------------------------------
                              |            Delta-method
                              |      dy/dx   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------------------------+----------------------------------------------------------------
                       Gender |
                      Female  |  -.0657671   .0343748    -1.91   0.056    -.1331404    .0016062
                              |
                       Agecat |
          Middle age farmers  |   .0047576   .0367544     0.13   0.897    -.0672797    .0767949
             Old age farmers  |  -.0350984   .0560894    -0.63   0.531    -.1450316    .0748347
                              |
               Educationlevel |
                     Primary  |   .0172246   .0426174     0.40   0.686    -.0663038    .1007531
                   Secondary  |   -.002162   .0501437    -0.04   0.966    -.1004418    .0961178
                    Tertiary  |          .  (not estimable)
                              |
                       Region |
                         CRS  |  -.0144175   .0327092    -0.44   0.659    -.0785264    .0496914
                         URR  |  -.2051455   .0480325    -4.27   0.000    -.2992875   -.1110035
                              |
                Householdsize |   .0004399   .0009945     0.44   0.658    -.0015092    .0023891
                     Farmsize |  -.0094881   .0044391    -2.14   0.033    -.0181885   -.0007877
                   Farmingexp |  -.0002937    .001489    -0.20   0.844    -.0032121    .0026247
                   Landtenure |   .0961797   .0321405     2.99   0.003     .0331855    .1591739
   Averageannualfarmingincome |   8.51e-07   3.31e-07     2.57   0.010     2.02e-07    1.50e-06
            Accessgovtsupport |   .1030226   .0395676     2.60   0.009     .0254716    .1805736
                Offfarmincome |    .006654    .028927     0.23   0.818    -.0500419    .0633499
     Memberofasocialfarmgroup |   .0208444   .0396462     0.53   0.599    -.0568607    .0985494
 Accesstomarketinginformation |   .1170548   .0316932     3.69   0.000     .0549373    .1791723
Witnessunexpectedweatherevent |   .0746966   .0351124     2.13   0.033     .0058777    .1435156
      Climatechangeperception |   .0946556    .036937     2.56   0.010     .0222604    .1670507
------------------------------+----------------------------------------------------------------
Note: dy/dx for factor levels is the discrete change from the base level.
```

```
Multivariate probit (SML, # draws = 5)            Number of obs   =        420
                                                  Wald chi2(78)   =     221.75
Log likelihood = -1073.5023                       Prob > chi2     =     0.0000

----------------------------------------------------------------------------------------------
                             |       Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-----------------------------+----------------------------------------------------------------
CR                           |
                  _IGender_2 |    .1427428   .1560257     0.91   0.360    -.1630619    .4485476
                  _IAgecat_2 |    .3200976   .1823324     1.76   0.079    -.0372673    .6774625
                  _IAgecat_3 |    .3851337   .2045465     1.88   0.060    -.0157701    .7860375
               _IEducation_1 |    .4125226   .2492427     1.66   0.098    -.0759841    .9010292
               _IEducation_2 |   -.0138403   .2330193    -0.06   0.953    -.4705498    .4428691
               _IEducation_3 |   -.1219766   .4361196    -0.28   0.780    -.9767553    .7328022
               Householdsize |   -.0096635   .0061584    -1.57   0.117    -.0217337    .0024067
  Averageannualfarmingincome |    4.25e-06   1.49e-06     2.85   0.004     1.33e-06    7.17e-06
              Accesstocredit |   -.0771945   .2326049    -0.33   0.740    -.5330917    .3787026
   Accesstoextensionservices |    -.317523   .1473789    -2.15   0.031    -.6063804   -.0286656
    Memberofasocialfarmgroup |    .6675359   .2328382     2.87   0.004     .2111814     1.12389
     Climatechangeperception |    1.791214   .3022072     5.93   0.000     1.198898    2.383529
Trainingonclimateriskadaptat |   -.0494692   .1692577    -0.29   0.770    -.3812081    .2822698
                       _cons |   -2.376582   .4358082    -5.45   0.000     -3.23075   -1.522413

-----------------------------+----------------------------------------------------------------
CPD                          |
                  _IGender_2 |   -.1165175   .1542509    -0.76   0.450    -.4188436    .1858087
                  _IAgecat_2 |   -.2119689   .1779673    -1.19   0.234    -.5607784    .1368406
                  _IAgecat_3 |   -.0000363   .2001698    -0.00   1.000    -.3923619    .3922893
               _IEducation_1 |    -.043105   .2389356    -0.18   0.857    -.5114102    .4252001
               _IEducation_2 |    .1358426   .2281223     0.60   0.552    -.3112689     .582954
               _IEducation_3 |   -.0040539    .403477    -0.01   0.992    -.7948542    .7867465
               Householdsize |   -.0089809   .0061874    -1.45   0.147     -.021108    .0031462
  Averageannualfarmingincome |   -2.86e-06   1.53e-06    -1.87   0.061    -5.85e-06    1.33e-07
              Accesstocredit |   -.3020379   .2365521    -1.28   0.202    -.7656716    .1615957
   Accesstoextensionservices |    .3221653   .1472603     2.19   0.029     .0335403    .6107903
    Memberofasocialfarmgroup |    .3885235   .2274063     1.71   0.088    -.0571847    .8342316
     Climatechangeperception |    1.078368   .2814846     3.83   0.000     .5266688    1.630068
Trainingonclimateriskadaptat |    .0955945   .1686832     0.57   0.571    -.2350184    .4262074
                       _cons |   -1.429934   .4031391    -3.55   0.000    -2.220072   -.6397955
-----------------------------+----------------------------------------------------------------
UIF                          |
                  _IGender_2 |   -.1819587   .1565299    -1.16   0.245    -.4887518    .1248343
                  _IAgecat_2 |    .1120479   .1824444     0.61   0.539    -.2455365    .4696323
                  _IAgecat_3 |    .0749929   .2051572     0.37   0.715    -.3271079    .4770936
               _IEducation_1 |    .1750693   .2425351     0.72   0.470    -.3002907    .6504294
               _IEducation_2 |    .0938359   .2319014     0.40   0.686    -.3606824    .5483543
               _IEducation_3 |   -1.099409   .5530168    -1.99   0.047    -2.183302   -.0155156
               Householdsize |    .0130143    .005483     2.37   0.018     .0022678    .0237608
  Averageannualfarmingincome |    2.74e-06   1.29e-06     2.13   0.034     2.13e-07    5.26e-06
              Accesstocredit |   -.0858435   .2393195    -0.36   0.720     -.554901     .383214
   Accesstoextensionservices |    -.215215   .1446501    -1.49   0.137    -.4987239    .0682939
    Memberofasocialfarmgroup |    .4871733   .2274737     2.14   0.032     .0413331    .9330136
     Climatechangeperception |    .7856242   .2375992     3.31   0.001     .3199382     1.25131
Trainingonclimateriskadaptat |   -.0536355   .1724452    -0.31   0.756    -.3916217    .2843508
                       _cons |   -1.791538   .3817152    -4.69   0.000    -2.539686    -1.04339
```

```
------------------------------+----------------------------------------------------------------
CCV                           |
                    _IGender_2 |  -.0085885   .1566252    -0.05   0.956    -.3155683    .2983913
                    _IAgecat_2 |   .1538643   .1817699     0.85   0.397    -.2023982    .5101267
                    _IAgecat_3 |   .1501764   .2054248     0.73   0.465    -.2524489    .5528016
                 _IEducation_1 |  -.6238648   .2530902    -2.46   0.014    -1.119912   -.1278171
                 _IEducation_2 |   .1314562   .2313997     0.57   0.570    -.3220789    .5849913
                 _IEducation_3 |  -.2437871   .4297098    -0.57   0.570    -1.086003    .5984286
                 Householdsize |  -.0070072   .0059614    -1.18   0.240    -.0186914    .0046769
  Averageannualfarmingincome |  -1.46e-06   1.28e-06    -1.15   0.251    -3.96e-06    1.04e-06
              Accesstocredit |  -.2703314   .2300414    -1.18   0.240    -.7212043    .1805415
   Accesstoextensionservices |    .655108   .1473817     4.44   0.000     .3662452    .9439708
    Memberofasocialfarmgroup |  -.1689761   .2148415    -0.79   0.432    -.5900577    .2521054
     Climatechangeperception |    1.40553   .3041568     4.62   0.000     .8093933    2.001666
Trainingonclimateriskadaptat |   .1844229   .1723694     1.07   0.285    -.1534149    .5222607
                       _cons |  -1.588394   .4179096    -3.80   0.000    -2.407482   -.7693065
-----------------------------+----------------------------------------------------------------
PB                           |
                  _IGender_2 |   .4242638   .2690086     1.58   0.115    -.1029835    .9515111
                  _IAgecat_2 |   1.008344   .4712479     2.14   0.032     .0847155    1.931973
                  _IAgecat_3 |   .4308509   .5438705     0.79   0.428    -.6351157    1.496818
               _IEducation_1 |    1.00034    .339099     2.95   0.003     .3357185    1.664962
               _IEducation_2 |  -.2249633    .568729    -0.40   0.692    -1.339652     .889725
               _IEducation_3 |  -3.362052    513.444    -0.01   0.995    -1009.694     1002.97
               Householdsize |   .0085384   .0089773     0.95   0.342    -.0090567    .0261335
  Averageannualfarmingincome |   4.30e-06   1.55e-06     2.78   0.005     1.27e-06    7.33e-06
              Accesstocredit |  -.1263601   .4832425    -0.26   0.794    -1.073498    .8207777
   Accesstoextensionservices |   .2293549   .2467322     0.93   0.353    -.2542313    .7129411
    Memberofasocialfarmgroup |   .6998109   .5655537     1.24   0.216    -.4086539    1.808276
     Climatechangeperception |   .2180193   .3625557     0.60   0.548    -.4925769    .9286154
Trainingonclimateriskadaptat |  -1.054293   .5872702    -1.80   0.073    -2.205321    .0967358
                       _cons |  -3.896754   .9001213    -4.33   0.000    -5.660959   -2.132549

-----------------------------+----------------------------------------------------------------
Mg                           |
                  _IGender_2 |   .2592866   .3871979     0.67   0.503    -.4996074    1.018181
                  _IAgecat_2 |   .2519476   .4426533     0.57   0.569    -.6156369    1.119532
                  _IAgecat_3 |   .1664916   .5406458     0.31   0.758    -.8931548    1.226138
               _IEducation_1 |  -5.320855   3263.677    -0.00   0.999     -6402.01    6391.368
               _IEducation_2 |  -.4287329    .570028    -0.75   0.452    -1.545967    .6885015
               _IEducation_3 |    -4.3094   385.1107    -0.01   0.991    -759.1125    750.4937
               Householdsize |   .0041578   .0196057     0.21   0.832    -.0342686    .0425842
  Averageannualfarmingincome |  -4.03e-06   4.04e-06    -1.00   0.319    -.0000119    3.89e-06
              Accesstocredit |  -3.863502   183.7491    -0.02   0.983    -364.0052    356.2782
   Accesstoextensionservices |   3.173607   135.1328     0.02   0.981    -261.6818     268.029
    Memberofasocialfarmgroup |   1.414234   1.342344     1.05   0.292    -1.216712    4.045179
     Climatechangeperception |   2.926617   239.5025     0.01   0.990    -466.4896    472.3428
Trainingonclimateriskadaptat |   1.293521   .3390846     3.81   0.000     .6289278    1.958115
                       _cons |  -9.847986   274.9981    -0.04   0.971    -548.8344    529.1384
```

/atrho21	.0898295	.0810444	1.11	0.268	-.0690147	.2486736
/atrho31	.405772	.0911377	4.45	0.000	.2271453	.5843987
/atrho41	-.0435948	.0808066	-0.54	0.590	-.2019729	.1147833
/atrho51	.3536675	.1562847	2.26	0.024	.0473551	.6599798
/atrho61	-.1810306	.1866641	-0.97	0.332	-.5468856	.1848243
/atrho32	-.0158652	.0803072	-0.20	0.843	-.1732645	.141534
/atrho42	.3120842	.0820246	3.80	0.000	.151319	.4728494
/atrho52	-.3993782	.1617589	-2.47	0.014	-.7164198	-.0823366
/atrho62	-.06871	.2050301	-0.34	0.738	-.4705616	.3331417
/atrho43	-.1622363	.0804858	-2.02	0.044	-.3199855	-.0044871
/atrho53	.3184332	.1474219	2.16	0.031	.0294915	.6073748
/atrho63	-.0445493	.1799505	-0.25	0.804	-.3972457	.3081471
/atrho54	-.5280385	.1617396	-3.26	0.001	-.8450423	-.2110348
/atrho64	-.1353952	.2021896	-0.67	0.503	-.5316795	.2608891
/atrho65	-.6082798	.2647155	-2.30	0.022	-1.127113	-.0894468
rho21	.0895886	.0803939	1.11	0.265	-.0689053	.2436714
rho31	.3848769	.0776375	4.96	0.000	.2233178	.5258551
rho41	-.0435672	.0806532	-0.54	0.589	-.1992706	.1142818
rho51	.339624	.1382581	2.46	0.014	.0473197	.57835
rho61	-.1790786	.180678	-0.99	0.322	-.4981824	.1827481
rho32	-.0158639	.080287	-0.20	0.843	-.1715512	.1405964
rho42	.302332	.0745271	4.06	0.000	.1501746	.4404987
rho52	-.3794168	.1384726	-2.74	0.006	-.6146868	-.0821511
rho62	-.068602	.2040652	-0.34	0.737	-.4386529	.3213409
rho43	-.1608278	.078404	-2.05	0.040	-.3094938	-.0044871
rho53	.3080895	.1334287	2.31	0.021	.029483	.5422765
rho63	-.0445198	.1795938	-0.25	0.804	-.3775898	.2987506
rho54	-.4838803	.1238699	-3.91	0.000	-.6884706	-.2079567
rho64	-.1345739	.1985279	-0.68	0.498	-.4866639	.2551269
rho65	-.542915	.1866889	-2.91	0.004	-.8100288	-.089209

```
Likelihood ratio test of  rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho4
> 3 = rho53 = rho63 = rho54 = rho64 = rho65 = 0:
             chi2(15) =  75.3463   Prob > chi2 = 0.0000
```

```
Multivariate probit (SML, # draws = 5)            Number of obs    =       420
                                                  Wald chi2(78)    =    331.62
Log likelihood = -1339.3515                       Prob > chi2      =    0.0000

-----------------------------------------------------------------------------------------------------
                             |      Coef.   Std. Err.        z    P>|z|     [95% Conf. Interval]
-----------------------------+-----------------------------------------------------------------------
Hightemperaturehotweather    |
                  _IGender_2 |    .289745   .1753483     1.65   0.098    -.0539314    .6334213
                         Age |  -.0075605   .0093472    -0.81   0.419    -.0258807    .0107597
               _IEducation_1 |   .3164837   .2768103     1.14   0.253    -.2260544    .8590219
               _IEducation_2 |   .4452112   .2809941     1.58   0.113    -.1055271    .9959495
               _IEducation_3 |  -.1429685   .4207928    -0.34   0.734    -.9677073    .6817702
               Householdsize |   .0116154   .0060519     1.92   0.055     -.000246    .0234769
                  Farmingexp |   .0208398   .0095768     2.18   0.030     .0020696    .0396101
  Averageannualfarmingincome |  -2.39e-07   1.32e-06    -0.18   0.857    -2.83e-06    2.35e-06
              Accesstocredit |   .1393882   .2533417     0.55   0.582    -.3571525    .6359289
   Accesstoextensionservices |  -.6671557   .1758933    -3.79   0.000      -1.0119   -.3224112
    Memberofasocialfarmgroup |   .2703338   .2329737     1.16   0.246    -.1862863    .7269538
     Climatechangeperception |   1.913704   .2383703     8.03   0.000     1.446507    2.380901
Trainingonclimateriskadaptat |  -.0190388   .1877159    -0.10   0.919    -.3869553    .3488776
                       _cons |  -1.446161    .482302    -3.00   0.003    -2.391456   -.5008665
-----------------------------+-----------------------------------------------------------------------
Increasedroughtsdryspell     |
                  _IGender_2 |   .1067289    .159272     0.67   0.503    -.2054385    .4188963
                         Age |   .0107308   .0090511     1.19   0.236    -.0070091    .0284706
               _IEducation_1 |   .1143919   .2455115     0.47   0.641    -.3668018    .5955856
               _IEducation_2 |   .1180836   .2408569     0.49   0.624    -.3539872    .5901544
               _IEducation_3 |   .1335025   .4348669     0.31   0.759     -.718821     .985826
               Householdsize |   .0066136   .0054992     1.20   0.229    -.0041647    .0173919
                  Farmingexp |  -.0135992   .0091844    -1.48   0.139    -.0316004    .0044019
  Averageannualfarmingincome |  -1.98e-06   1.27e-06    -1.56   0.118    -4.46e-06    5.00e-07
              Accesstocredit |  -.7894941   .2330007    -3.39   0.001    -1.246167    -.332821
   Accesstoextensionservices |   .5556788   .1433165     3.88   0.000     .2747836    .8365741
    Memberofasocialfarmgroup |   .4096835   .2131101     1.92   0.055    -.0080047    .8273717
     Climatechangeperception |   .6955125   .2069099     3.36   0.001     .2899765    1.101048
Trainingonclimateriskadaptat |   .2318421   .1845818     1.26   0.209    -.1299317    .5936158
                       _cons |  -1.279082   .4383781    -2.92   0.004    -2.138287   -.4198767
```

```
-----------------------------+----------------------------------------------------------------
Increasewindstorms           |
                   _IGender_2 |   .0414503   .1591891     0.26   0.795    -.2705546    .3534551
                          Age |   .0124528   .0091413     1.36   0.173    -.0054638    .0303694
               _IEducation_1 |  -.1329558   .2510947    -0.53   0.596    -.6250924    .3591807
               _IEducation_2 |  -.3427708   .2398681    -1.43   0.153    -.8129035     .127362
               _IEducation_3 |   -.556049   .4414462    -1.26   0.208    -1.421268    .3091696
               Householdsize |   .0120905   .0060202     2.01   0.045     .0002912    .0238898
                  Farmingexp |  -.0255384    .009503    -2.69   0.007     -.044164   -.0069128
 Averageannualfarmingincome |   1.47e-06   1.37e-06     1.07   0.284    -1.22e-06    4.16e-06
              Accesstocredit |  -.0473745   .2300492    -0.21   0.837    -.4982627    .4035137
  Accesstoextensionservices |   .4409175   .1475965     2.99   0.003     .1516337    .7302014
   Memberofasocialfarmgroup |    .256047   .2163744     1.18   0.237    -.1680391    .6801331
    Climatechangeperception |   1.554521   .2423884     6.41   0.000     1.079448    2.029593
Trainingonclimateriskadaptat |   -.115012   .1806029    -0.64   0.524    -.4689872    .2389631
                       _cons |  -1.639055   .4646894    -3.53   0.000    -2.549829   -.7282802
-----------------------------+----------------------------------------------------------------
Increasefloods               |
                  _IGender_2 |  -.0754345   .1576793    -0.48   0.632    -.3844802    .2336113
                         Age |  -.0092025   .0090917    -1.01   0.311    -.0270219     .008617
               _IEducation_1 |  -.6406736   .2516813    -2.55   0.011     -1.13396   -.1473874
               _IEducation_2 |  -.3820586   .2345477    -1.63   0.103    -.8417636    .0776464
               _IEducation_3 |   -.686443   .4870951    -1.41   0.159    -1.641132    .2682459
               Householdsize |  -.0120523   .0062119    -1.94   0.052    -.0242275    .0001228
                  Farmingexp |   .0065322   .0092841     0.70   0.482    -.0116642    .0247286
 Averageannualfarmingincome |  -6.99e-08   1.35e-06    -0.05   0.959    -2.72e-06    2.58e-06
              Accesstocredit |  -.5700237   .2459907    -2.32   0.020    -1.052157   -.0878908
  Accesstoextensionservices |   .8715668    .148375     5.87   0.000     .5807572    1.162376
   Memberofasocialfarmgroup |   .3176252   .2231825     1.42   0.155    -.1198044    .7550549
    Climatechangeperception |   1.102117   .2522615     4.37   0.000     .6076941    1.596541
Trainingonclimateriskadaptat |   .1100856   .1807182     0.61   0.542    -.2441156    .4642868
                       _cons |  -1.149322   .4700967    -2.44   0.014    -2.070695   -.2279495

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Increaselivestockdisease     |
                  _IGender_2 |   .0415272   .1598822     0.26   0.795    -.2718361    .3548905
                         Age |  -.0410461   .0096759    -4.24   0.000    -.0600106   -.0220816
               _IEducation_1 |  -.3170215   .2555959    -1.24   0.215    -.8179804    .1839373
               _IEducation_2 |  -.2875324   .2556128    -1.12   0.261    -.7885243    .2134596
               _IEducation_3 |   .9050156   .4484176     2.02   0.044     .0261332    1.783898
               Householdsize |   .0119004   .0058847     2.02   0.043     .0003666    .0234342
                  Farmingexp |   .0503189   .0096463     5.22   0.000     .0314126    .0692252
 Averageannualfarmingincome |  -3.55e-06   1.54e-06    -2.31   0.021    -6.56e-06   -5.40e-07
              Accesstocredit |  -.5612966   .2609165    -2.15   0.031    -1.072684   -.0499096
  Accesstoextensionservices |   .0140699   .1514488     0.09   0.926    -.2827643     .310904
   Memberofasocialfarmgroup |   .5205505   .2612962     1.99   0.046     .0084193    1.032682
    Climatechangeperception |   1.535469   .3428707     4.48   0.000     .8634547    2.207483
Trainingonclimateriskadaptat |   .2228146   .1742807     1.28   0.201    -.1187693    .5643986
                       _cons |  -1.956572   .5656614    -3.46   0.001    -3.065248   -.8478957
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Increasebushfire             |
                  _IGender_2 |   .1114061   .1559531     0.71   0.475    -.1942564    .4170686
                         Age |  -.0223326   .0092382    -2.42   0.016    -.0404392   -.0042261
               _IEducation_1 |   .3716594   .2459874     1.51   0.131    -.1104671    .8537858
               _IEducation_2 |  -.1848209   .2506825    -0.74   0.461    -.6761495    .3065077
               _IEducation_3 |   .3350765   .4386752     0.76   0.445     -.524711    1.194864
               Householdsize |   .0116283   .0055835     2.08   0.037     .0006849    .0225717
                  Farmingexp |   .0212577   .0092388     2.30   0.021       .00315    .0393654
 Averageannualfarmingincome |   9.29e-08   1.29e-06     0.07   0.943    -2.44e-06    2.62e-06
              Accesstocredit |  -.0252628   .2307769    -0.11   0.913    -.4775771    .4270516
  Accesstoextensionservices |   .3312414   .1510771     2.19   0.028     .0351358     .627347
   Memberofasocialfarmgroup |   .9575553   .2952421     3.24   0.001     .3788913    1.536219
    Climatechangeperception |   .7477829   .2520479     2.97   0.003      .253778    1.241788
Trainingonclimateriskadaptat |   .0071834   .1747183     0.04   0.967    -.3352582    .3496251
                       _cons |  -2.178431   .5025206    -4.34   0.000    -3.163353   -1.193508
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    /atrho21 |   .0025513   .0873237     0.03   0.977    -.1686001    .1737026
    /atrho31 |   .2018455   .0883816     2.28   0.022     .0286207    .3750702
    /atrho41 |  -.1846741   .0903478    -2.04   0.041    -.3617526   -.0075957
    /atrho51 |   .3316784   .0967505     3.43   0.001     .1420509     .521306
    /atrho61 |   .3694309   .0941168     3.93   0.000     .1849653    .5538964
    /atrho32 |   .1758294   .0812003     2.17   0.030     .0166798     .334979
    /atrho42 |   .0659094   .0800597     0.82   0.410    -.0910048    .2228236
    /atrho52 |   -.156331   .0864535    -1.81   0.071    -.3257766    .0131147
    /atrho62 |    .359934   .0870746     4.13   0.000     .1892709    .5305971
    /atrho43 |   .1478285    .080409     1.84   0.066    -.0097701    .3054272
    /atrho53 |   .1966436   .0845325     2.33   0.020     .0309628    .3623243
    /atrho63 |   .4378763   .0929198     4.71   0.000      .255757    .6199957
    /atrho54 |   .3891255   .0855652     4.55   0.000     .2214208    .5568302
    /atrho64 |   .1220178    .083629     1.46   0.145    -.0418921    .2859276
    /atrho65 |   .1633433   .0824185     1.98   0.047      .001806    .3248807
       rho21 |   .0025513   .0873232     0.03   0.977    -.1670205    .1719764
       rho31 |   .1991482   .0848764     2.35   0.019     .0286129    .3584186
       rho41 |   -.182603   .0873353    -2.09   0.037    -.3467568   -.0075955
       rho51 |   .3200281   .0868415     3.69   0.000     .1411031    .4787074
       rho61 |   .3534938   .0823562     4.29   0.000     .1828845    .5034348
       rho32 |   .1740396   .0787407     2.21   0.027     .0166783    .3229875
       rho42 |   .0658141    .079713     0.83   0.409    -.0907544    .2192077
       rho52 |  -.1550698   .0843745    -1.84   0.066    -.3147208    .0131139
       rho62 |   .3451559   .0767012     4.50   0.000     .1870428    .4858374
       rho43 |    .146761   .0786771     1.87   0.062    -.0097698    .2962714
       rho53 |   .1941475   .0813462     2.39   0.017     .0309529    .3472597
       rho63 |   .4118826   .0771562     5.34   0.000     .2503226    .5511251
       rho54 |   .3706061   .0738129     5.02   0.000     .2178719    .5056218
       rho64 |   .1214158   .0823962     1.47   0.141    -.0418676    .2783823
       rho65 |    .161906    .080258     2.02   0.044      .001806    .3139134

Likelihood ratio test of  rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho4
> 3 = rho53 = rho63 = rho54 = rho64 = rho65 = 0:
             chi2(15) =  113.759   Prob > chi2 = 0.0000
```