UNIVERSITY of RWANDA

College of Science and Technology
School of Architecture and Built Environment

MSc in Geo-Information Science for Environment and Sustainable Development

CLIMATE CHANGE IMPACTS ON FARMING ACTIVITIES AND COPING STRATEGIES OF LOCAL FARMERS IN RWIMIYAGA AND KARANGAZI SECTORS IN NYAGATARE DISTRICT

Thesis submitted to the University of Rwanda: College of Science and Technology in partial fulfillment of the requirements for the award of the Degree of Master of Science in Geo-Information for Environment and Sustainable Development.

Presented by: TURATSINZE EDOUARD

Reg N°: 221027700

Supervisors: (1) Assoc. Prof. MUHIRE Innocent
(2) Dr. MUYOMBANO Emmanuel

Kigali, August 2024

Declaration

I declare that the thesis entitled "Climate change impacts on farming activities and coping strategies of local farmers in Rwimiyaga and Karangazi sectors in Nyagatare District" is entirely my own work. It has not been previously submitted to any other university or institution of higher learning. Any external works I referenced are duly acknowledged through citations and references within this study.

Signed:

………………………………. Date: ……/……/……

APPROVAL

It is hereby confirmed that this thesis entitled **“**Climate change impacts on farming and coping strategies of local farmers in Rwimiyaga and Karangazi sectors, Nyagatare District**”** submitted by Mr. **Edouard TURATSINZE** has been assessed and accepted by the post-graduate coordination team in the school of Architecture and Built Environment

- **Supervisors**

Ass. Prof. MUHIRE Innocent

Signature: ………………………...   Date: …. /… … …/ 2024

Dr. MUYOMBANO Emmanuel

Signature: ………………………...   Date: …. /… … …/ 2024

- **Post-graduate coordinator**

Dr. UWAYEZU Ernest

Signature: ………………………...   Date: …. /… … …/ 2024

- **Dean of School of Architecture and Built Environment**

Dr. Josephine MALONZA

Signature: ………………………...   Date: …. /… … …/ 2024

Acknowledgement

First and foremost, the accomplishment of this work was made possible with the invaluable support of numerous individuals, to whom I owe deep gratitude. First and foremost, I am thankful to God for enabling me to complete this journey, from my earliest days to the culmination of my thesis.

I am also grateful to the Government of Rwanda for granting me a scholarship to pursue my studies at the University of Rwanda, where I gained invaluable knowledge and skills.

Special thanks go to my supervisor, Associate Professor MUHIRE Innocent, and Co-Supervisor Dr. MUYOMBANO Emmanuel whose guidance and encouragement were instrumental in conducting my study in a rational and practical manner. His responsiveness, availability, and flexibility greatly facilitated my work.

I extend my appreciation to all lecturers in the Department of SABE for imparting profound knowledge and skills. Additionally, I acknowledge the classmates who collaborated with me on various group assignments and shared their life experiences.

I am deeply indebted to my wife UWASE Emima and my child MUGISHA Elodia for their unwavering love and moral support throughout my studies. Their continuous care and encouragement, including their assistance in proofreading this thesis, were invaluable. Without their exceptional support, my academic journey would not have been as successful.

Lastly, I extend my heartfelt thanks to everyone else who supported me in any way, whether through moral encouragement or material assistance. Your contributions are deeply appreciated.

Abstract

This study examines the impacts of climate change on agriculture in Karangazi and Rwimiyaga Sectors in Nyagatare District, with a focus on farmers' perceptions and coping strategies. Data were collected from 94 farmers across 15 cooperatives via questionnaires, supplemented by focus group discussions with local farmers, cooperatives and key informant interviews. The findings reveal that climate change significantly affects crop yields and livestock production, with farmers citing irregular rainfall and prolonged droughts as the main key challenges. From 2000 to 2021, Nyagatare District experienced significant temperature fluctuations, peaking in 2004, 2007, 2014, and 2017, with an average around 27°C. Precipitation trends were initially stable but declined around 2008, hit a low in 2015, peaked in 2020, and then declined again, leading to droughts, flooding, and soil erosion. Droughts and heavy winds significantly affected crops and livestock. Over 50% of respondents reported decreased yields, especially in maize, beans, and bananas. Heavy winds damaged infrastructure and caused water scarcity, with 86% noting damage to maize drying shelters. Invasive pests like the fall armyworm were reported by 80% of respondents, with 93% linking them to hunger. The study highlights the need for effective water management, sustainable land practices, and pest control strategies. Coping strategies such as afforestation, crop diversification, irrigation, and traditional knowledge practices were identified as common adaptations. Investing in climate-resilient crops, improving irrigation, promoting sustainable practices, and enhancing capacity building will increase skills to the farmer's and support sustainable farming activities in the region. Addressing gender disparities and increasing youth engagement through agriculture best practice methods are also crucial for building resilience in Nyagatare's farming communities.

Keywords: Climate change, farming, coping strategies

Table of contents

LIST OF TABLES

LIST OF FIGURES:

CHAPTER 1: GENERAL INTRODUCTION

1.1. **Study Background**

As per the Intergovernmental Panel on Climate Change (IPCC) (2014), climate change is an intricate and pressing global phenomenon that affects various sectors of human life. It is defined as long-term alterations in temperature, precipitation, winds, seasonal variations, and humidity, primarily attributed to human activities such as the burning of fossil fuels and deforestation. Climate change exposes the planet to clear and extraordinary risks, including intensifying heatwaves, heavy precipitation, droughts, fires, and tropical cyclones, which are expected to impact all regions' economies and societies (Masson-Delmotte et al., 2021).

Food availability is particularly vulnerable due to climate change, negatively affecting crop yields, fish productivity, and livestock productivity. This issue is especially critical in Sub-Saharan Africa (SSA) and South Asia, where many people are food insecure. Without appropriate interventions, the ongoing effects of climate change and variability—characterized by fluctuations and droughts—will significantly compromise agricultural yields, food security, biodiversity, and water availability, exacerbating poverty in regions where agriculture is predominantly rain-fed (El Bilali et al., 2020).

The economic and social impacts of climate change, creating a cycle of poverty and hunger. Factors such as rising food prices, loss of arable land, and intensified competition for resources contribute to this crisis. The Food and Agriculture Organization (FAO) reported that climate-related issues resulting in a rise in undernourishment, with around 282 million people in Africa facing hunger in 2021. There is an urgent need for action to enhance resilience and promote sustainable practices to combat this growing food crisis (FAO, 2022).

Rwanda's climate is tropical and influenced by its hilly terrain, divided into four main regions. The eastern plains receive 700 to 1,100 mm of annual rainfall and have average temperatures of 20°C to 22°C. specifically in Nyagatare district (Matimba, Rwimiyaga and Karangazi sector) has monthly average temperature of above 20°C while annual mean precipitation turns between 740 mm and around 1000 mm which differ from central plateau sees 1,100 to 1,300 mm of rainfall with temperatures ranging between 18°C and 20°C. The highlands, of the Congo-Nile Ridge and Birunga volcanic chains, receive 1,300 to 1,600 mm of rain and have temperatures from 10°C to 18°C. Areas near Kivu Lake and the plains Bugarama receive 1,200 to 1,500 mm of rainfall, with temperatures ranging from 18°C to 22°C (REMA, 2021; MoE, 2020).

Rwanda faced significant challenges related to droughts, particularly in the eastern and southeastern regions. The most recent occurred during the 2020-2022 period, when prolonged drought conditions exacerbated food insecurity, leading to heightened vulnerability among communities in affected areas like Bugesera and Nyagatare (World Food Programme 2020; Rwanda Meteorological Agency 2021).

Rwanda's farming activities are primarily rain-fed, which increases its vulnerability to extreme weather conditions such as severe and frequent droughts and pest and disease outbreaks. Existing issues such as soil erosion, poor soil fertility practices, and severely degraded land compound these vulnerabilities. According to the National Institute of Statistics of Rwanda (NISR), the agriculture sector, which employs over 70% of the population, is particularly at risk. Climate change impacts are expected to be multifaceted, with some estimates suggesting costs could rise to an additional 1% of GDP per year by 2030 (NISR, 2022). Furthermore, Rwanda loses and wastes 40% of its total food production annually, representing 21% of its total land use, 16% of its greenhouse gas emissions, and a 12% loss to its annual GDP (Sethi et al., 2020).

Climate change factors such as altered rainfall patterns, rising atmospheric CO2 concentrations, pollution levels, and climatic variability directly impact agricultural productivity in Rwanda. The country is increasingly experiencing the adverse effects of extreme weather events like droughts, floods, and severe storms. These events are becoming more frequent and intense, contributing to a range of environmental issues. For instance, heavy rains, coupled with the ongoing loss of ecosystem services and deforestation, exacerbate soil erosion, rock falls, landslides, and floods—factors that severely damage crops and undermine agricultural output. The increasing unpredictability of rainfall and the intensification of extreme weather conditions pose significant challenges to Rwanda's predominantly rain-fed agriculture, further stressing an already vulnerable sector.

Nyagatare District in Eastern Province exhibits specific climate trends. Since the 1980s, average temperatures have increased by about 0.35°C per decade, exceeding the global average. The district's temperature has risen by 1°C to 2°C according to the Third National Communication. Monthly average temperatures range from 20°C to 22°C, with annual rainfall ranging from 700 mm and 1,150 mm. Rain primarily fall during two wet seasons: the long rainy season from March to May and the short rainy season from September to December. This is followed by a long dry season from late May to early September and a short dry season from mid-December to February (REMA,2021).

1.2. Problem statement

Globally, Agriculture is particularly vulnerable to the impacts of climate change, more so than other natural resources like water and forests (Nsabiyeze et al. 2024). Understanding this vulnerability is crucial for devising effective strategies to mitigate the adverse effects (Ojumu, et al., 2020). Climate change leads to long-term shifts, such as rising temperatures and increased frequency of extreme weather events, which in turn result in reduced crop yields and other severe consequences. These impacts are especially pronounced in regions like Africa, where the warming rate is approximately 1.5 times faster than the global average, leading to more frequent and intense weather events (FAO, 2022).

The agricultural sector, particularly in developing regions, faces significant challenges due to climate change. In Rwanda, where agriculture employs about 70% of the population and contributes around 27% to the national GDP, the sector is vital to the economy (Rwanda Development Board, 2023; FAO Rwanda 2024).

However, erratic rainfall patterns, soil degradation, and frequent natural disasters, such as droughts and floods, threaten crop yields and exacerbate food insecurity. Despite modernization efforts, most farmers in Rwanda engage in subsistence farming, leading to low yields and increasing food insecurity (World Bank, 2023). Geographically, the sector is also vulnerable to environmental risks. The south-eastern lowlands are prone to drought, while the western and north-western highlands face threats from flooding, fluvial erosion, and landslides. These natural events not only endanger lives but also cause significant damage to homes, crops, and infrastructure, thereby impacting the economy and contributing to shortages of essential resources such as food and water (Muhire, et al. 2015).

Rwanda is making strategic efforts to enhance environmental protection and sustainability through initiatives like the Green Growth and Climate Resilience Strategy and the Updated Nationally Determined Contribution (MoE, 2019). These initiatives demonstrate a strong commitment to mitigating the adverse effects of climate change. However, in regions like Nyagatare District, particularly in the Karangazi and Rwimiyaga sectors, these challenges are compounded by a lack of research, inadequate agricultural technology, deteriorating irrigation infrastructure, and insufficient dissemination of professional farming techniques (Nyagatare District Administrative Report, 2022).

Farmers in these regions are expected to adopt new agricultural practices and technologies to cope with the changing climate. This includes improving irrigation systems, using climate-resilient crops, and implementing sustainable farming techniques. However, the ability of farmers to adapt effectively is often constrained by a lack of resources, knowledge, and access to modern technologies (Annappa et al., 2023). Despite the importance of these coping strategies, there is a significant gap in knowledge about the actual practices farmers are using to manage the impacts of climate change. Limited research exists to evaluate the effectiveness of these strategies or to understand the challenges faced by farmers in implementing them. This gap in knowledge impedes the development of targeted interventions that could better support farmers in adapting to climate change (FAO, 2022).

Given the critical role of agriculture in Rwanda's economy and the severe impacts of climate change on this sector, comprehensive research is urgently needed. Such a study would aim to understand the current coping strategies employed by farmers, identify the challenges they face, and develop recommendations for more effective adaptation measures. Addressing this knowledge gap could significantly enhance the resilience of the agricultural sector in the Karangazi and Rwimiyaga sectors, ultimately improving food security and livelihoods in the region (MoE, 2020). Records indicate that higher maximum seasonal and annual temperatures are in the Bugarama valley and Kagitumba in Nyagatare district between 30 and 32^{o}C, Amayaga areas and Bugesera district between 28 and 30^{o}C (METEO Rwanda and REMA 2022). Furthermore, increased frequency of extreme flood events, increased duration and frequency of droughts and increased average temperatures are expected to become more severe over the coming decades, with intense adverse effects on agriculture including threats to crop yields and livestock, forestry and water supplies. A rise in temperature is predicted across Rwanda in the coming years up to 2050 with a projection of seasonal increase of between 0.1 °C and 0.3 °C on top of the annual mean temperature throughout the country, except for the northern region where a decrease of 0.06°C is expected (MoE, 2020).

1.3. Research objectives

This study generally investigates climate change impacts on farming and coping strategies of local farmers in Rwimiyaga and Karangazi sectors, Nyagatare District (2003-2024) and specifically:

i. Assess the climate change impacts on agriculture at karangazi and Rwimiyaga Sectors in Nyagatare District.
ii. Evaluate the farmers' perceptions on the impacts of climate change on farming at Karangazi and Rwimiyaga Sectors in Nyagatare District.
iii. Suggest coping strategies used by local farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors in Nyagatare District.

1.4. Research questions

1. What are the climate change impacts on agriculture?
2. What are the farmers' perceptions on the impacts of climate change on farming at Karangazi and Rwimiyaga Sectors in Nyagatare District?
2. What are coping strategies used by local farmers to deal with climate change impacts on farming?

1.5. Significance of the Study

This study provides valuable insights into several key aspects of climate change impacts on agriculture in the Rwimiyaga and Karangazi sectors. It offers a detailed analysis of temperature and precipitation trends over the past two decades, highlighting significant fluctuations that have led to increased instances of drought, flooding, and soil erosion. These environmental changes have had a profound effect on local farming, with over 50% of respondents reporting decreased yields, particularly in staple crops like maize, beans, and bananas. The study also identifies the widespread damage caused by windstorm, including infrastructure damage and water scarcity, which severely impacts agricultural productivity. Furthermore, the study sheds light on the prevalence of invasive pests, such as the fall armyworm, which 80% of respondents linked to increased hunger. In response to these challenges, the research highlights the coping strategies adopted by local farmers, including afforestation, agroforestry, and irrigation, which were supported by most respondents. It also underscores the effectiveness of capacity building and extension services, although it notes the inadequacy of early warning systems, as reported by 88% of participants.

These insights highlight the need for policymakers to invest in climate-resilient crops, improved irrigation, and sustainable land management in Nyagatare. The study also emphasizes addressing gender disparities, boosting youth engagement through technology, and enhancing capacity-building to strengthen farming community resilience.

By providing these specific and actionable insights, the study equips policymakers with the necessary information to develop effective strategies that mitigate the adverse effects of climate change on agriculture, ensuring food security and promoting sustainable development in Rwanda.

In summary, this research is vital for ensuring food security, supporting economic stability, protecting biodiversity, guiding policy, and fostering innovation. It provides the foundation for a resilient agricultural sector capable of adapting to the challenges posed by a changing climate.

1.6. Structure of the Thesis

Chapter 1 provides an overview encompassing the background of the study, problem statement, research objectives, research questions, and thesis structure.

Chapter 2 extensively reviews literature, focusing on theoretical, empirical, and conceptual frameworks relevant to the study.

Chapter 3 details the study's methodology, including research design, study population, sampling methods and size, data collection techniques, data analysis, validity and reliability tests, coding, editing, tabulation, and ethical considerations.

Chapter 4 presents the research findings as will be detailed in the four chapter.

Chapter 5 analyzes the findings, draws conclusions, and offers recommendations based on the study's outcomes.

CHAPTER 2: LITERATURE REVIEW

Introduction

Climate change presents significant challenges to global agriculture, impacting crop yields, water resources, and farmers' livelihoods. Key factors such as altered precipitation patterns, more frequent extreme weather events, and rising temperatures are reshaping agricultural environments (Smith, 2023). Adaptive measures like advanced irrigation techniques, resilient crop varieties, afforestation, and early warning systems have been suggested to mitigate these impacts (Brown & Johnson, 2022; Quandt et al., 2023; Rosa, 2022). However, socio-economic studies reveal varying levels of vulnerability and adaptive capacity among farming communities (Jones et al., 2021).

Additionally, extreme weather events like landslides and storms further threaten farming activities and infrastructure, displacing communities and posing long-term sustainability challenges. To address these risks, there is a critical need for enhanced agricultural practices and increased investment in climate-smart technologies, as emphasized by the World Bank (2023), which advocates for comprehensive strategies to build resilience against climate-induced challenges in Rwanda.

2.1. Definition of the key concepts

2.1.1. Climate change

Climate change refers to long-term alterations in temperature, precipitation, wind patterns, and other elements of Earth's climate system. These alterations are predominantly caused by human activities such as burning fossil fuels, deforestation, and industrial processes, which release greenhouse gases into the atmosphere. These greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap heat in the atmosphere, leading to a warming effect known as the greenhouse effect. Other elements of climate change include rising sea levels, ocean acidification, and increased frequency and intensity of extreme weather events such as hurricanes, droughts, and heatwaves. The Intergovernmental Panel on Climate Change (IPCC) systematically assesses and reports on climate change, drawing upon global scientific research and evidence to inform its findings (IPCC, 2021; IPCC, 2023).

2.1.2. Climate change impacts

"Climate change impacts refer to the various effects that alterations in climate patterns have on natural and human systems. These effects may encompass alterations in temperature and precipitation patterns, sea level rise, and the frequency and intensity of extreme weather events such as long droughts, floods and storms (Intergovernmental Panel on Climate Change (IPCC, 2021).

In Rwanda, agriculture faces increasing vulnerability to climate change impacts. Heightened rainfall during the long rainy season leads to soil erosion and crop damage, particularly affecting staple crops like maize and beans. The Rwanda Meteorology Agency reports a significant rise in intense rainfall events exceeding 100 mm in a day, disrupting planting schedules and reducing yields. Conversely, recurrent droughts exacerbate food insecurity, affecting 1.3 million people during the 2020-2021 dry season and causing a 20% decline in crop yields in affected regions, pushing farmers into poverty and reliance on food aid. Rising temperatures, with a 1.5°C increase over the past 50 years, threaten to halve coffee yields by 2050, necessitating urgent climate-resilient agricultural strategies promoted by the Rwanda Agricultural Board (RAB, 2022).

2.1.3. Coping strategies

In agriculture, coping strategies refer to the specific techniques or behaviors that farmers use to manage stress, adversity, or other challenging situations such as droughts, pest infestations, market fluctuations, or financial difficulties. These strategies can vary widely and may include both adaptive and maladaptive methods. Adaptive coping strategies typically involve constructive approaches such as implementing improved farming practices, diversifying crops, seeking community support, utilizing weather forecasting information, or adopting stress-tolerant crop varieties. Maladaptive coping strategies, on the other hand, might include neglecting farm maintenance, over-reliance on a single crop, excessive use of chemical inputs, or resorting to short-term, unsustainable practices, which can be less effective or even harmful in the long term (Lazarus & Folkman, 1984).

2.1.4. Farming

Farming involves cultivating soil, growing crops, and raising animals to produce essential goods like food, fiber, and medicinal plants, crucial for sustaining human life (Smith, 2023). This encompasses activities such as tilling, planting, watering, pest management, harvesting, and livestock care. Farming operates at various scales: small-scale farming focuses on limited acreage and traditional methods for subsistence or local markets; medium-scale farming employs advanced machinery to supply local and regional markets; and large-scale farming utilizes industrialized techniques to maximize efficiency for national and international markets (Smith, 2023).

Martinez et al. (2010) also categorize farming by scale. Small-scale farms operate on modest landholdings with intensive manual labor, primarily for family consumption. Medium-scale farms expand beyond subsistence, using mechanization and hired labor to increase productivity and sustainability. Large-scale farming encompasses extensive operations with significant mechanization and specialized systems, catering broadly to national and international markets. Understanding these scales is vital for assessing agricultural impacts on economies, societies, and environments across different farm sizes.

2.2. Droughts as an impact of climate change on farming

Rwanda is experiencing significant impacts from climate change, characterized by increased weather variability and extreme weather events. Average temperatures have risen by approximately 1.5°C since the 1960s, and the frequency of heavy rainfall events has increased, leading to more frequent and severe flooding (Nkurunziza et al., 2022). The agricultural sector, which is vital to Rwanda's economy, faces threats from changing precipitation patterns and increased pest and disease pressures. For example, erratic rainfall has disrupted planting and harvest seasons, affecting crop yields, particularly for staple crops like maize and beans (Munyabugingo et al., 2023). Additionally, heavy winds and storms have caused significant damage to crops and infrastructure, compounding the challenges faced by farmers (Gakwaya et al., 2021).

Droughts, worsened by climate change, pose a significant threat to agricultural productivity in Rwanda. Erratic rainfall patterns, prolonged dry spells, and intense storms increasingly affect the region, as highlighted by the Rwanda Meteorology

Agency (2023). These conditions contribute to soil erosion, crop damage, and heightened vulnerability among farmers. Over the past decade alone, Rwanda has seen a 15% increase in extreme rainfall events, exacerbating these challenges (Smith, 2023).

Globally, droughts have had catastrophic consequences, leading to food insecurity, economic instability, and hindering poverty reduction efforts (Sibongiseni and Chari, 2020). These impacts extend beyond Rwanda, affecting economies such as South Africa, where droughts have devastated agricultural production and raised concerns about food security (Sibongiseni and Chari, 2020). Effective adaptation strategies and resilient farming practices are crucial to mitigate these effects and safeguard livelihoods.

Over the past 30 years, Rwanda has experienced significant climate change, marked by a noticeable shift in rainfall seasons across different regions. Data from Meteo-Rwanda and the Ministry of Environment (MoE) 2022 indicate an increase in rainfall intensity, with predicted variability rising by 5% to 10%. This intensification heightens the risk of erosion, particularly in Northern and Western provinces. Conversely, Eastern Rwanda faces reduced agricultural productivity due to more frequent below-normal rainfall. Additionally, floods and droughts have become more frequent, leading to degraded water quality from increased erosion and siltation of dams, as well as drier wetlands. These changes have reduced river base flows, affecting downstream irrigation projects. Furthermore, tree cover has declined notably in Eastern and Southeastern regions.

According to Muneza (2022), droughts have rendered parts of Rwanda vulnerable, with decreased annual rainfall and prolonged, cyclical droughts leading to food insecurity. Regions like Bugesera, which historically received 700-800 mm/year before the 1990s, now receive only around 300 mm/year, resulting in over 70% water deficit. Consequently, staple crops such as maize and beans have been severely affected.

2.3. Windstorm as an impact of climate change on farming

Heavy winds have increasingly impacted farming in Rwanda, particularly in Nyagatare District and the Eastern Province. Reports from the Rwanda Environment Management Authority (REMA) indicate that windstorms have risen in frequency and intensity since 2003. For example, a severe windstorm in 2008 destroyed over 300 hectares of crops, causing RWF 150 million in losses (REMA, 2019). From 2010 to 2020, such events led to approximately a 2% annual decrease in agricultural yield, with a significant windstorm in 2016 causing RWF 200 million in damage to 500 hectares of maize and beans (MINAGRI, 2021). The Rwanda Meteorological Agency (RMA) and the University of Rwanda found that windstorm have exacerbated soil erosion and land degradation. Between 2003 and 2020, soil erosion increased by 15% in windstorm-prone areas, reducing soil fertility and crop yields by up to 10% (RMA & University of Rwanda, 2021)**.**

2.4. Variability in Precipitation as an impacts of climate change on farming

The frequency of extreme weather events, including droughts and floods, has also increased. REMA reported that the 2006 drought led to significant crop losses and food insecurity, while excessive rainfall has caused flooding, erosion, and infrastructure damage (REMA, 2009; REMA, 2011). From 2003 to 2013, Rwanda experienced a 30% increase in droughts, notably affecting maize and bean yields with reductions of 24% and 30%, respectively, during the 2010-2011 season (MINAGRI, 2014; NISR, 2012). Additionally, research by Muneza (2022) notes that erosion affects about 50% of farmers, leading to a 30% decline in farm productivity, which jeopardizes food security for over 90% of Rwanda's population dependent on agriculture. The study also highlights that while precipitation is abundant, high winds and soil erosion pose significant risks to agriculture.

In response, the Rwandan government has been implementing initiatives such as the Crop Intensification Program (CIP) and the Land Husbandry, Water Harvesting, and Hillside Irrigation (LWH) project to improve water management and soil conservation (MINAGRI, 2018). Efforts are also being made to adopt climate-resilient crops and diversify agricultural practices. Despite these measures, the unpredictable nature of precipitation and extreme weather events continues to challenge sustainable agriculture, highlighting the need for ongoing adaptation and resilience strategies (World Bank, 2020).

2.5. Pests and diseases (invasive pests) affect farming

Since crop domestication 10,000 years ago, farmers have contended with a diverse array of pests, resulting in significant pre- and postharvest losses globally. Approximately 10% to 16% of the world's crop production annually falls victim to pests, enough to feed about 8.5% of the global population. The spectrum of crop pests, encompassing fungi, bacteria, viruses, and insects, continues to expand due to evolutionary shifts and the emergence of new pathotypes (Bebber Dp and Gurr, 2013).

In Rwanda, escalating temperatures contribute to heightened pressures from pests and diseases, resulting in diminished crop yields and livestock productivity. Parasites like caterpillars and predators pose significant threats to staple crops such as sweet potatoes and beans, further constraining production (Muneza 2022).

The invasion of pests like the Fall Armyworm and diseases such as Cassava Brown Streak Disease has emerged as critical challenges to Rwandan agriculture, leading to substantial crop losses and escalating financial burdens on farmers due to high costs associated with pest management (FAO, 2019; Songa et al., 2020).

The socioeconomic ramifications are profound, with reduced agricultural output exacerbating food shortages, escalating prices, and increasing poverty levels among rural communities. Mitigating these impacts involves initiatives such as training farmers in sustainable practices, bolstering pest surveillance, and promoting resilient crop varieties (Rwiza et al., 2021; Kamanzi and Mugisha, 2022).

2.6. Afforestation and agroforestry adoption as strategy to deal with climate change impacts on farming.

Rwanda has observed a 1.4°C rise in average temperature since 1970, with projections indicating a potential increase of up to 2.5°C by mid-century (RFA 2017). These temperature shifts, alongside erratic rainfall patterns and increased variability in rainfall volumes, threaten Rwanda's agrarian economy and rural livelihoods, compounded by the country's dependence on agriculture and hydropower (RFA 2017).

To address these challenges, the Rwandan government has implemented a forest investment program, recognizing forests' role in enhancing rainfall and regulating atmospheric water vapor flows (RFA 2017). Agroforestry, integrating trees or shrubs with crops and livestock, emerges as a crucial climate change adaptation strategy. It mitigates climate change through carbon sequestration, enhances food security, boosts income opportunities, and provides ecosystem services while conserving biodiversity (Quandt et al., 2023). Agroforestry practices improve soil health by increasing nitrogen and carbon levels, promoting spatial heterogeneity in soil microbial communities, and enhancing soil structure. Shade trees in these systems regulate microclimates, reduce crop transpiration, improve water retention, and protect against soil erosion during heavy rainfall and floods (Isaac, 2024).

Smallholder farmers globally have reported that agroforestry supports soil and water conservation, increases drought resilience, and mitigates flood impacts (Quandt et al., 2023). Forests are vital in preventing soil degradation and boosting agricultural productivity through agroforestry and sustainable forest management (Karamage et al., 2016). They serve as natural buffers against flooding, landslides, and water pollution, filtering rainwater and reducing sedimentation in water bodies (Karamage et al., 2016). Additionally, forests mitigate climate change by absorbing greenhouse gases and providing essential ecosystem services such as food, medicine, and biodiversity conservation (Ramni, 2015). They protect watersheds, maintain soil fertility, and support local economies through timber, fuelwood, and non-timber forest products (RFA 2017).

2.7. Irrigation mechanism as coping strategy by farmers to the climate change impacts

Globally, irrigation is a critical strategy for adapting agriculture to climate change, addressing the increasing food demands without further degrading natural ecosystems. It mitigates heat and water stress on crops and reduces climate variability impacts. Despite its environmental and hydro-climatic effects, irrigation significantly enhances agricultural productivity, making it indispensable for global food security. Over the past six decades, the area of irrigated land has more than doubled, now comprising 22% of global croplands, with productivity at least double that of non-irrigated agriculture (Rosa, 2022).

Rwanda has significantly expanded its irrigation infrastructure to counteract the adverse effects of climate change, particularly droughts. The Rwanda Agricultural Board (RAB) reports a substantial increase in irrigated land from 13,000 hectares in 2017 to about

24,000 hectares in 2022. This expansion caters to various scales of irrigation needs through diverse methods, including dams, rivers, lakes, marshlands, groundwater, and runoff. Rwanda's irrigation potential stands at 501,509 hectares, highlighting its commitment to enhancing agricultural productivity and resilience (RAB, 2020).

In Nyagatare District, irrigation has proven to be a vital adaptation strategy for farmers facing unpredictable rainfall patterns and droughts. A study by Kamanzi et al. (2024) reveals that small-scale irrigation schemes have increased crop productivity by up to 30% compared to non-irrigated fields, underscoring irrigation's role in food security. The National Institute of Statistics of Rwanda (NISR) also notes that households engaged in irrigated farming from 2020 to 2023 experienced a 20% increase in income, attributed to more reliable yields and the ability to grow multiple crops per year.

Furthermore, irrigation has bolstered the economic resilience of farmers in Nyagatare District. The Rwanda Water Resources Board (RWB) found that farmers using irrigation systems suffered fewer financial losses due to drought-induced crop failures. This stability emphasizes irrigation's role in economic improvement and climate change adaptation, making it essential for sustainable agricultural development in Rwanda.

2.8. Capacity Building and Extension Services as a coping strategy to the climate change impacts on farming

Climate change that lead to unpredictable weather patterns, prolonged droughts, and severe flooding capacity building and extension services are essential. Capacity building enhances farmers' knowledge, skills, and competencies, enabling them to adopt more resilient agricultural practices. Extension services disseminate up-to-date agricultural information and technologies. Together, these strategies empower farmers to adapt to changing climates and sustain their livelihoods. Smith (2023) highlights that these efforts are crucial for transitioning to climate-smart agriculture and ensuring food security in the face of climate change.

The government of Rwanda collaborates with international organizations to promote capacity building and extension services as part of its climate adaptation strategy. Programs like the Rwanda Climate Resilient Agriculture program train farmers in sustainable practices such as using drought-resistant crop varieties, efficient water management, and integrated pest management. These initiatives provide farmers with the necessary tools and knowledge to cope with adverse effects. A report by the International Fund for Agricultural Development (IFAD) (2023) notes that these efforts have significantly increased agricultural productivity and resilience among smallholder farmers in Rwanda.

Extensive training and support have led to notable improvements in crop yields and reductions in crop losses due to extreme weather events in Nyagatare District. This success is attributed to a comprehensive approach that combines capacity building with continuous extension services. The World Bank (2023) emphasizes the importance of such integrated approaches in building resilient agricultural systems. Wright Morton et al. (2016) stress the need for training farmers to adapt to increased weather variability and understand the causes of climate change. By using adaptive management tools and practices based on science and experience, farmers can manage weather variability, reduce soil erosion, and enhance productivity.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter focuses on the research methodologies employed in this study. It explains the research design, study area, population, sample size, data collection techniques and tools, validity and reliability, data processing, data analysis methods, limitations, and ethical considerations. These procedures were instrumental in addressing the research questions, objectives, and hypotheses within the study.

3.2. Research Design

A research design is a structured plan that guides data collection, analysis, and interpretation, ensuring the reliability of the research hypothesis. It provides a clear framework detailing participant involvement, research procedures, objectives, and actions. This strategic blueprint addresses research questions through organized data handling. Methodologies and methods in a research design are influenced by the researcher's philosophical stance and disciplinary background. This study employed a mixed-method approach, integrating both qualitative and quantitative methods (Sarah Wright et al., 2016, pp. 97-98; Harish K., T., 2016; Creswell & Creswell, 2017).

Secondary data sources in this study included reports from agencies such as the Rwanda Meteorology Agency and the World Bank, documenting weather patterns, extreme events, and their effects on agricultural productivity. Additional sources like academic papers and reports from the FAO and IFAD provided context on how pests, droughts, and other factors impact farming. The review synthesized this data to highlight trends, impacts, and adaptation strategies for enhancing agricultural resilience in Rwanda.

The study used a convergent parallel design, collecting both quantitative and qualitative data simultaneously. Quantitative methods involved gathering individual views and analyzing numerical data to produce statistical reports on the effects of droughts, floods, winds, erosion, invasive pests, and diseases on farming in the Karangazi and Rwimiyaga Sectors. Qualitative approaches involved key informant interviews (KII), focus group discussions (FGD), and direct observations to explore farmers' perceptions and adaptive responses to climate change. Data were collected from various stakeholders, including farming cooperative leaders, local farmers, local leaders, and

NGOs, and integrated to provide a comprehensive understanding of the research problem and formulate recommendations beneficial to other farmers.

In addition, Land Use Land Cover (LULC) classification in Rwimiyaga and Karangazi sectors of Nyagatare District, Eastern Province was used and involved a systematic approach to analyze spatial and temporal changes in land cover. These two sectors, part of the Eastern Province of Rwanda, are mapped using the WGS84 UTM Zone 36S coordinate system, which is suitable for regions in the Southern Hemisphere.

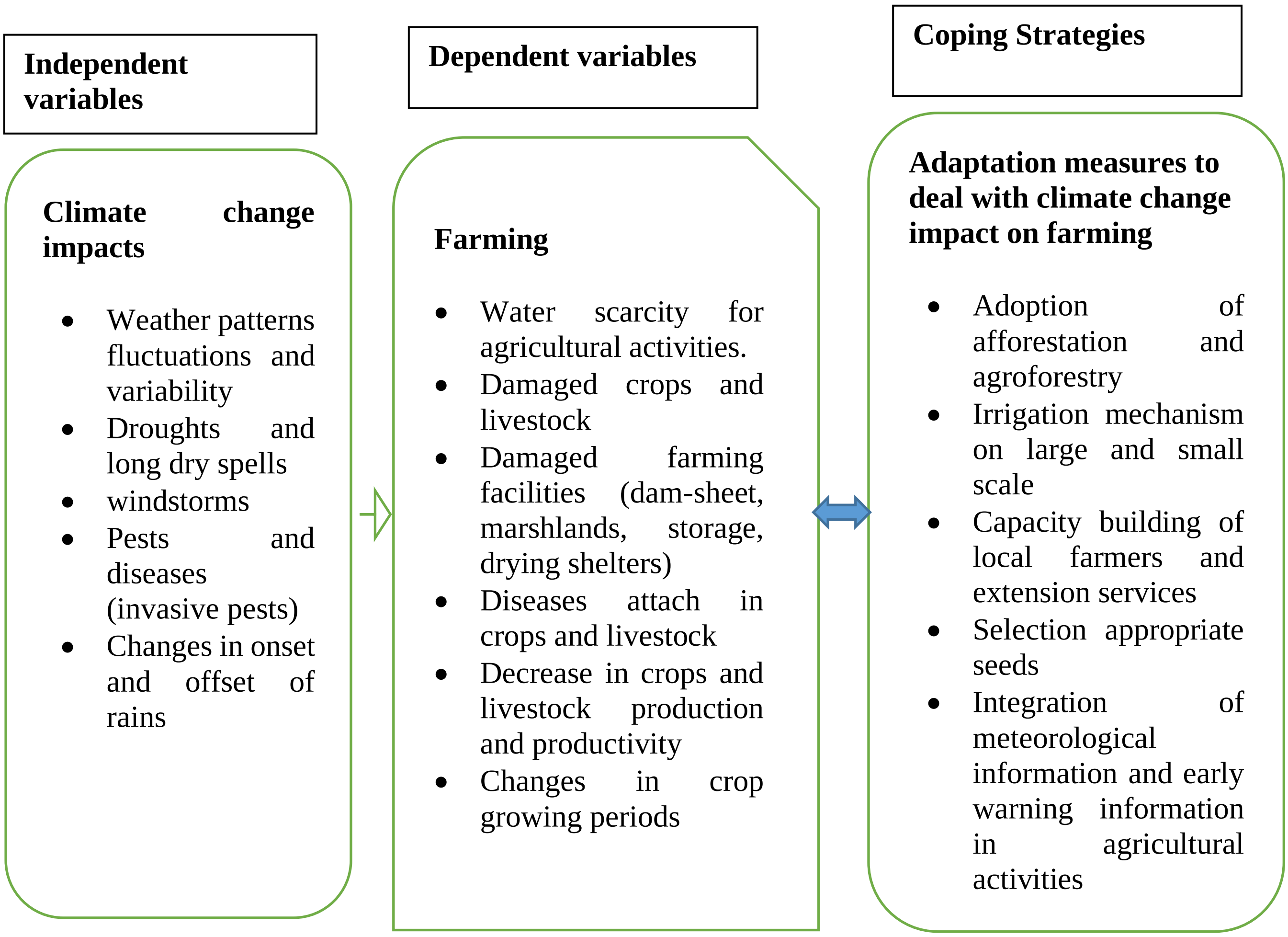
The analysis was conducted for four specific years: 2003, 2010, 2017, and 2024. These years were selected to capture significant changes over time, providing valuable insights into the evolution of land use and cover in the study area over two decades.

Landsat imagery, sourced from Landsat 7 and Landsat 8 satellites, served as the primary data for this study. The images were carefully selected and downloaded from the USGS Earth Explorer platform, with a focus on acquiring scenes with minimal cloud cover, particularly in the month of July, to ensure clear and accurate observations. The spatial resolution of 30 meters provided by these images allowed for the detailed detection of land cover features across the sectors.

A supervised classification method was employed, specifically using the Maximum Likelihood algorithm. This method involved training the classifier with known land cover types, which were then used to categorize the entire image. The Maximum Likelihood algorithm, a widely recognized parametric rule in remote sensing, was chosen for its accuracy and reliability in classification tasks.

The processing and analysis of the imagery were carried out using ERDAS software, which was utilized for advanced image processing and visualization, enabling the precise interpretation of the Landsat data. ArcGIS Pro was employed for spatial analysis, facilitating the integration and examination of geospatial data across the two sectors. Finally, Excel was used for further data analysis, including the calculation of area statistics, generation of charts, and trend analysis to understand the changes in land cover over the years studied.

Figure 1: Research Framework



3.3. Study area presentation

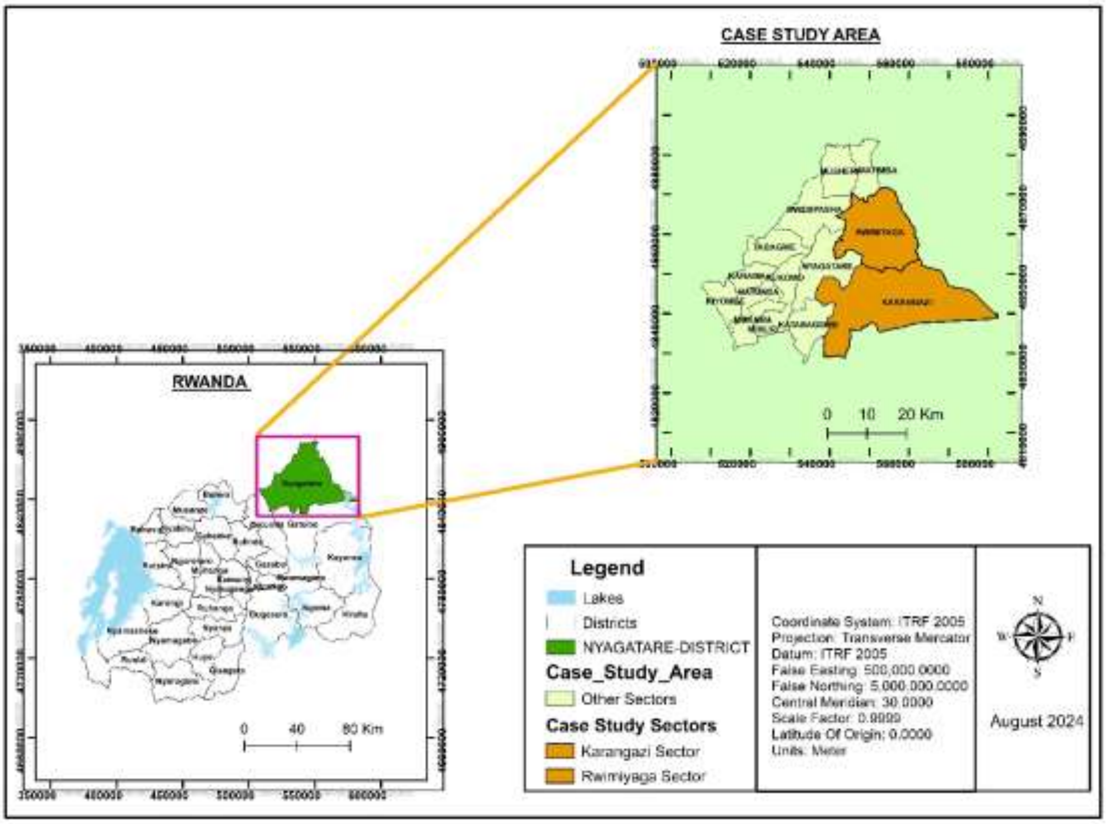
3.3.1 Study population

This study focuses on the Karangazi and Rwimiyaga Sectors within the Nyagatare District, which comprises 14 sectors and spans 1,919 km². The district has a population of 653,861, distributed across 160,435 households, 66.3% of which engage in farming (NISR 2022). Karangazi and Rwimiyaga were selected due to their substantial populations—96,915 and 82,620, respectively—and their extensive arable land, making them particularly susceptible to the impacts of climate change. Among the population of the two sectors 720 are specifically involved in 15 farming cooperatives from which this study draws a sample size.

3.3.2 Study Area

The map below indicates Nyagatare District in northeastern Rwanda, and shows its borders with Gatsibo to the south, Gicumbi to the west, and international borders with Uganda and Tanzania to the north and east. Rwimiyaga and Karangazi Sectors located in Nyagatare District were specifically taken as a case in this study. The geographical scope of the research, also highlight key boundaries and features including scale, coordinates, and legend to help in understanding distance and location of the study area.

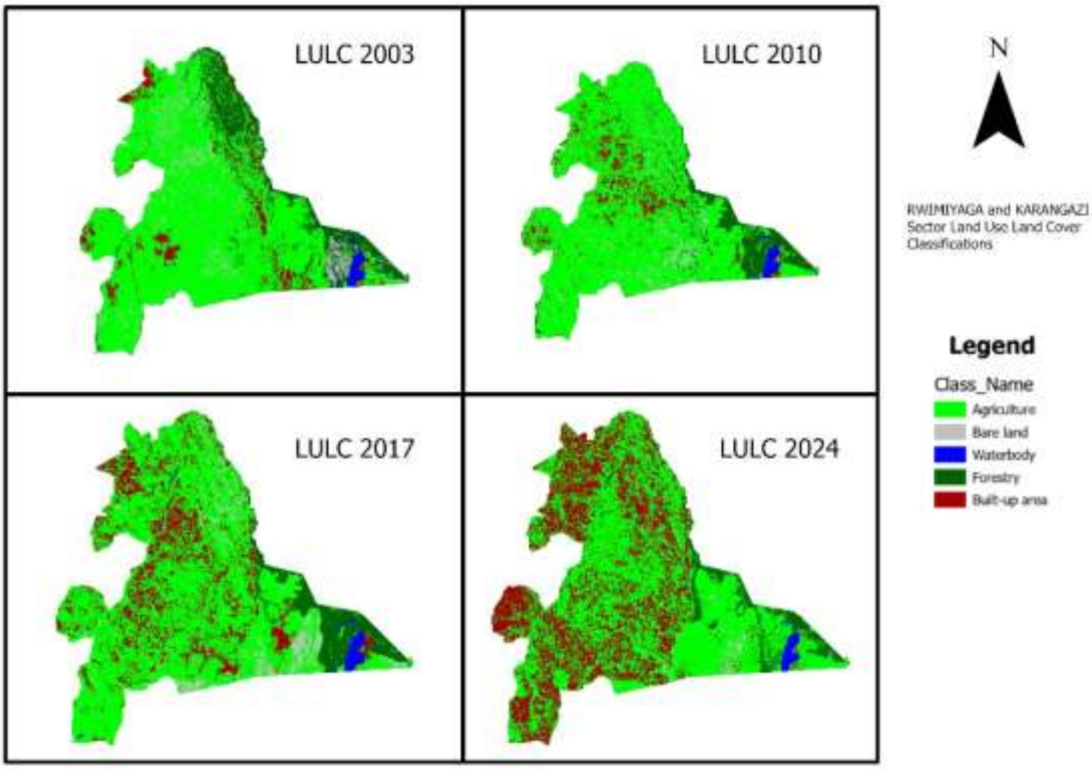
Figure 2: Study area of Rwimiyaga and Karangazi Sector



Source: National Institute of Statistics Rwanda, 2005

This section examines the land use and land cover changes in the study area from 2003 to 2024.

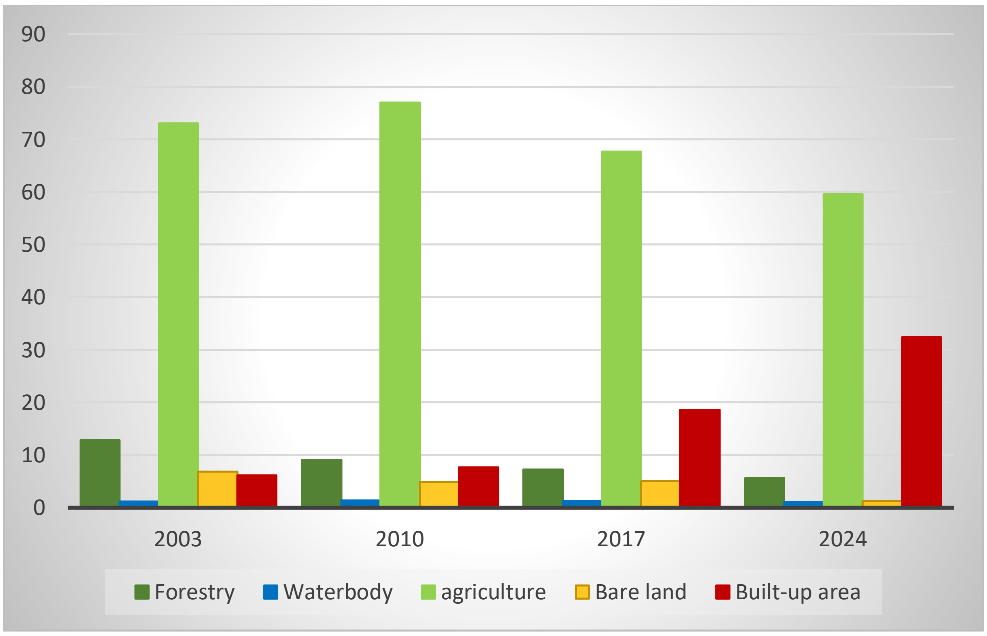
Figure 3: Land Use and Land Cover Change Analysis



As reflected in the figure above from 2003 to 2024, land use changes in the study area reveal significant shifts. Forestry land declined from 12.88% in 2003 to 5.67% in 2024, indicating deforestation or conversion to other uses. Water bodies showed slight fluctuations, peaking at 1.34% in 2010 before declining to 1.04% in 2024, suggesting minimal but notable changes. Agricultural land increased from 73.03% in 2003 to 77.00% in 2010, then decreased sharply to 59.57% by 2024, indicating urbanization, policy changes, or economic shifts affecting farming. Bare land decreased from 6.83% in 2003 to 1.31% in 2024, with a minor increase in 2017, suggesting development or conversion to other uses. Built-up areas increased dramatically from 6.12% in 2003 to 32.41% in 2024, reflecting significant urban expansion due to population growth, industrialization, and infrastructure development.

The figure 3 above illustrate agricultural expansion and intensity (light green), Urbanization (dark red) reduces arable land, prompting farmers to intensify production or diversify crops to meet market demands. Changes in natural areas, such as forestry (dark green) and water bodies (blue), affect environmental resilience and farming conditions by influencing microclimates and irrigation availability.

Figure 4: Land use land cover change over time in Rwimiyaga and Karangazi Sectors



The figure4 above shows how climate change has altered land use in Rwimiyaga and Karangazi over the years. Forestry and water bodies have decreased, affecting agricultural resilience. Agricultural changes suggest crop diversification and climate-resilient techniques. The rise in built-up areas indicates urban expansion, reducing farmland and impacting local food security. These trends call for sustainable land management and policies to help farmers manage climate risks and ensure food security.

3.4. Sampling and sample size

Sample size determination is the act of choosing the number of observations or replicates to include in a statistical sample. In other words, sample size is the mathematical estimation of the number of subjects or units to be included in a study (Simarjeet, 2017).

Data collection was done among 94 respondents selected through purposive sampling among 720 as total population of the study embodied in 15 farming cooperatives located at both Karangazi and Rwimiyaga Sectors as indicated in the table 1 below.

Table 1: Population of the study embodied in 15 farming cooperatives located at both Karangazi and Rwimiyaga Sectors

No	Name of cooperatives	Sector	Function	Members	Respondents
1	DUKORANE INGUFU MUSENYI	Karangazi	Ubuhinzi (Ibigori)	24	3
2	TWUZUZANYE MUSENYI	Karangazi	Ubuhinzi (Ibigori)	24	3
3	KATRECO	Karangazi	Ubuhinzi (Ibigori, Ibishyimbo, Soya)	16	3
4	IKNC	Karangazi	Ubuhinzi (Ibigori)	32	4
5	URUMURI MUSENYI	Karangazi	Ubuhinzi (Imboga(amashu), Imboga(poivron))	24	3
6	TECON	Karangazi	Ubuhinzi (Ibigori)	39	5
7	RWISIRABO BARAKA 2013	Karangazi	Ubuhinzi (Ibigori, Ibishyimbo)	20	3
8	UBUDEHE Karangazi	Karangazi	Ubuhinzi (ibigori)	19	2
9	NFC	Karangazi	Ubuhinzi (ibigori)	23	3
10	KLFFCO	Karangazi	Ubuhinzi(Ibigori n'ibishyimbo)	30	4
11	AFCO	Karangazi	Ubuhinzi bw'ibigori n'ibishyimbo	122	16
12	ABIBUMBYE RWIMIYAGA	RWIMIYAGA	UBUHINZI BW'IBIGORI	28	4
13	COTABU	RWIMIYAGA	UBUHINZI BW'IBIGORI	172	22
14	BANDEBEREHO	RWIMIYAGA	UBUHINZI BW'IBIGORI	51	6
15	ICYERECYEZO	RWIMIYAGA	UBUHINZI BW'IBIGORI	96	13
Total				**720**	**94**

Source: field survey, 2024

The sample size was determined using appropriate statistical methods to ensure it adequately reflects the population's characteristics. The sample size (n) is calculated according to Cochran, W. G. (1977) formula whereby this study deals with finite populations where it also possible to count the population size of the study equal to 720 in both Karangazi and Rwimiyaga Sector.

$$no = \frac{Z2. p. (1 - p)}{E2}$$

no *is the initial sample size estimate*

Z *is the* ***Z****-score corresponding to the desired confidence level,*

p *is the estimated population proportion*

E is the margin of error.

$$n = \frac{no}{1 + \frac{no - 1}{N}}$$

Where:

n *is the adjusted sample size*

N is the population size

Given Values:

Confidence level = 96% *→ Z ≈ 2.05 (using z tables o normal distribution calculators)*

Margin error = 5% → E =0.05

Population proportion = 93% → p =0.93

Step 1: $no = \frac{(2.05)2.093.(1-0.93)}{(0.05)2}$=

$$no = \frac{4.2025.0.93. 0.07}{0.0025}$$

$no = \frac{0.27258375}{0.0025} = n = 109.03$

Step 2: Adjust for finite population size

$$n = \frac{109.03}{\frac{1 + 109.03 - 1}{720}}$$

$$n = \frac{109.03}{1+108.03/720}$$

$$n = \frac{109.03}{1 + 0.1500}$$

$$n = \frac{109.03}{1.1500}$$

n= 94

3. 5. Data collection and data analysis

This study investigated the impacts of climate change on farming and coping strategies used by local farmers. The research employs both qualitative and quantitative data collection methods. Secondary data is gathered from existing literature, including books, internet sources, annual reports, and statistics. Primary data collection involves semi-structured and informal interviews to uncover underlying motives and desires, as well as distributing questionnaires to gather information on facts, perceptions, opinions, attitudes, and behaviors.

The study used purposive sampling to select knowledgeable and interested individuals to respond to questions about how climate change affects farming and the coping strategies employed. Questionnaires, focus group discussion and key informant interviews were used to understand the extent to which the citizens perceive climate change impacts farming.

Interview guidelines were developed for individual interviews with representatives of farming cooperatives in Rwimiyaga and Karangazi Sectors, key informants from relevant government and agricultural organizations, local leaders, and civil society representatives. Focus group discussions (FGDs) among local farmers supplement the questionnaire data.

Data analysis employs descriptive and inferential statistics to derive necessary dataset values. Key findings from questionnaires are presented in tables and graphics, while FGDs and key informant interviews (KIIs) are analyzed thematically to complement quantitative data. Triangulation of quantitative and qualitative results is used to enhance the findings. Additionally, content analysis of climate change impacts on farming over the past two decades (2003-2024) is conducted. The final results are compiled into a thesis for submission to the University of Rwanda.

3.6. Validity and Reliability

Validity and reliability are crucial aspects of research. Validity, as defined by Altheide and Johnson (1994), concerns the truthfulness and appropriateness of findings, supported by empirical evidence and theoretical rationale. Reliability focuses on the consistency of results across repeated measurements. Mohajan (2017) underscores that ensuring both validity and reliability is essential for producing accurate and replicable data. In this study, the researcher balanced primary data from informants with existing empirical information to assess the effect of climate change on farming in the Karangazi and Rwimiyaga sectors. The reliability of the data was supported by consistent responses from participants, as shown in the tables.

3.7. Data Processing and analysis

The data processing involved linking, analyzing, categorizing, and transforming data to enhance understanding. Both qualitative and quantitative data were utilized, with software tools namely SPSS (Statistical Package for the Social Sciences) and Microsoft Excel employed for processing and analysis. SPSS allowed for advanced statistical analysis, including descriptive statistics, cross-tabulation, and inferential statistics to uncover relationships and patterns. Microsoft Excel facilitated data organization, visualization, and preliminary analysis through charts and tables, making it easier to interpret trends and correlations.

The analysis techniques included both descriptive and statistics. Descriptive statistics summarized demographic information of respondents, such as gender distribution, age, marital status, and education levels, using frequencies and percentages. Statistics to determine the significance levels of relationships between variables, such as the impact of drought on crop yield and livestock productivity. Additionally, thematic analysis of qualitative data from interviews identified common themes and coping strategies reported by local farmers. Furthermore, Geographic Information Systems (GIS) was also used to enable detailed analysis and visualization of land use and land cover (LULC) changes in Nyagatare District from 2003 to 2024, illustrating the spatial distribution and temporal evolution of various land cover classes. This mixed-methods approach ensured a comprehensive understanding of the data, enabling the identification of key factors affecting farming and the strategies employed by farmers to mitigate the impacts of climate change.

3.7.1. Coding

Coding involves classifying answers into meaningful categories to reveal essential patterns, as defined by Kumar (2005). In this study, it helped to summarize data and determine the frequency of responses in each category.

3.7.2. Data processing

Data processing for this study involved collecting quantitative data through questionnaires from 94 farmers across 15 cooperatives and gathering qualitative insights from focus group discussions and key informant interviews. The analysis focused on significant temperature fluctuations and precipitation trends in Nyagatare District from 2000 to 2021, correlating these changes with their impacts on farming activities, such as crop yield and livestock health. Quantitative responses were statistically analyzed to assess the prevalence of issues like droughts, heavy winds, and pest invasions, while qualitative data provided contextual understanding of local farmers' coping strategies. Additionally, the study evaluated farmers' views on mitigation measures like afforestation, agroforestry, and irrigation, using this comprehensive dataset to formulate recommendations for enhancing agricultural resilience in the region.

3.7.3. Editing

Editing is the process of identifying and eliminating errors from the data collection phase, ensuring the study's accuracy, completeness, and comprehensibility. According to Daniel and Gates (1991), editing enhances the quality of the research by revising and standardizing the information from 94 respondents involved in this study.

3.7.4. Tabulation

Tabulation involves presenting numeric data systematically in rows and columns, facilitating comparison and statistical analysis (Lindgren, 1975). The researcher used tables to compare the frequency of responses across different variables, explaining each table to aid in understanding the gathered data.

3.8. Ethical Considerations

Ethical considerations in research encompass a set of principles that guide the design and execution of research projects. These principles are crucial in the planning stages and ensure that scientists and researchers adhere to a code of conduct, particularly when collecting data from participants. This includes ensuring that the information provided by respondents is kept confidential and anonymous. Additionally, researchers must ensure that participation is voluntary, with no respondent being coerced into providing information (Cacciattolo, 2015).

3.9. Limitation of the study

This study is primary limited to a small sample size of 94 respondents, despite calculations with Cochran's formula to ensure statistical accuracy. This sample, drawn from specific cooperatives in Karangazi and Rwimiyaga Sectors than extending to a wide number of respondents including farmers. It may have limitation to the diverse experiences of the entire farmer's population in Nyagatare District. This may hinder a generalization across the broader farming community, potentially skewing results due to the concentrated nature of the sample. Another limitation stems from the use of purposive sampling, which targets individuals with specific knowledge or characteristics relevant to the study.

CHAPTER 4: DATA PRESENTATION, INTERPRETATION AND ANALYSIS

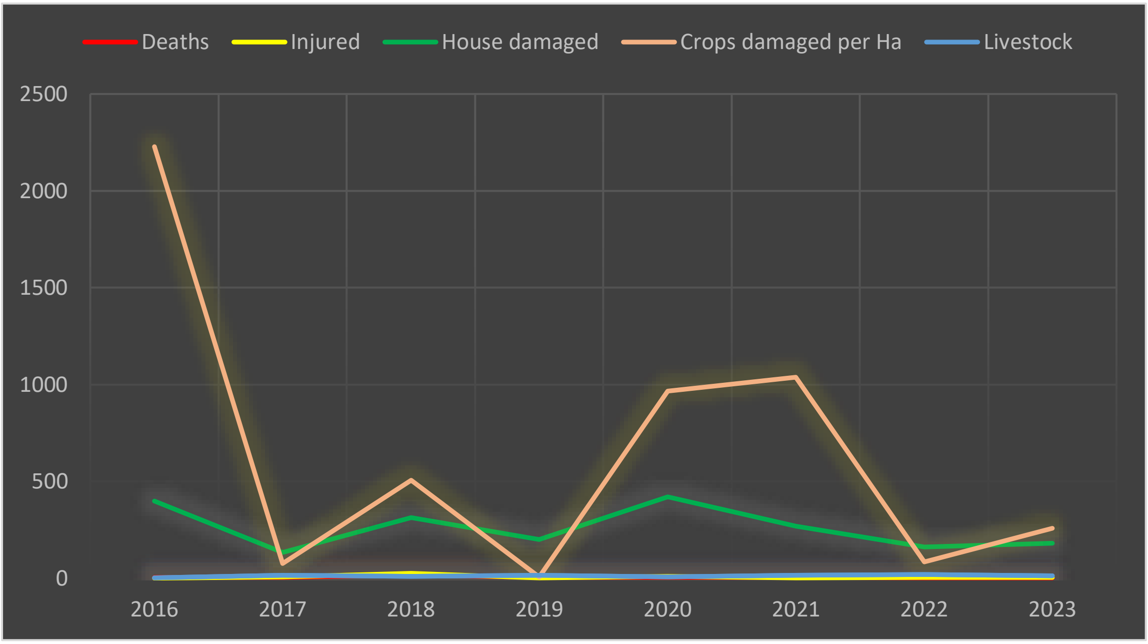
4.0. Introduction

Chapter four of this study analyzes trends in maximum temperature, minimum temperature, and precipitation in Nyagatare District since 2000. It presents and interprets data on the impacts of climate change on farming and the coping strategies of local farmers in the Karangazi and Rwimiyaga Sectors. The region's semi-arid climate, with significant rainfall and temperature variations, severely affects agricultural productivity. In addition, the chapter demonstrates and assesses climate change impacts caused by disasters as revealed by data from MINEMA and Meteo data in different period with comparison of Nyagatare district as case study and other districts.

Data collection involved questionnaires and interviews to understand farmers' perceptions of climate change impacts and their coping strategies. Both qualitative and quantitative data were used to describe and quantify community trends and strategy effectiveness. The analysis is also based on a purposive sample of 94 respondents from a population of 720 farmers in 15 cooperatives in Karangazi and Rwimiyaga Sectors. The sample includes local farmers, leaders, civil society organizations, and MINAGRI staff specializing in irrigation and mechanization.

4.1 Disaster Damages, caused by floods, landslides and heavy rains to livelihood

Figure 5: Disaster Damages, caused by floods, landslides and heavy rains to livelihood (Nyagatare District 2016-2023)



Source: Ministry in Charge of Emergency Management (MINEMA). (n.d.). *Contingency plan for floods and landslide reports*.

The chart above illustrates the significant impacts caused by disasters or damaging events from 2016 to 2023, detailing the number of deaths, injuries, damaged houses, crops affected in hectares, and livestock impacted.

In terms of **deaths**, the year 2018 stands out as particularly tragic, with 16 fatalities—substantially higher than the other years. Most of the different years saw a relatively low death toll, ranging from 1 to 4 deaths. This sharp increase in 2018 suggests that a major event or disaster had far more severe consequences than usual. By 2023, the death toll had dropped to just 1.

The number of **injuries** follows a similar trend, with 2018 and 2020 seeing significantly higher numbers of injuries, 25 and 10 respectively. These spikes indicate that while fatalities in most years were relatively low, certain events caused substantial harm to many individuals. Other years show fewer injuries, with only 1-7 individuals affected, pointing to less severe or more localized incidents.

House damage fluctuates widely over the years. In 2020, 420 houses were damaged, making it the year with the most destruction to homes. The number of houses affected was also high in 2016 (397) and 2018 (312). However, in years like 2017 and 2022, few homes were impacted, with 133 and 160 houses damaged, respectively. This variation might indicate different scales of events or differing geographical distributions of the disasters.

The data on **crop damage** per hectare also highlights significant variability. The most severe agricultural impact occurred in 2016 when a staggering 2228 hectares of crops were damaged. After a significant drop in 2017, crop damage surged again in 2021, with 1036.75 hectares affected, indicating another large-scale disruption to farming activities. In the other years, crop damage was relatively lower, although still concerning, particularly in 2018 and 2023 when hundreds of hectares of crops were lost.

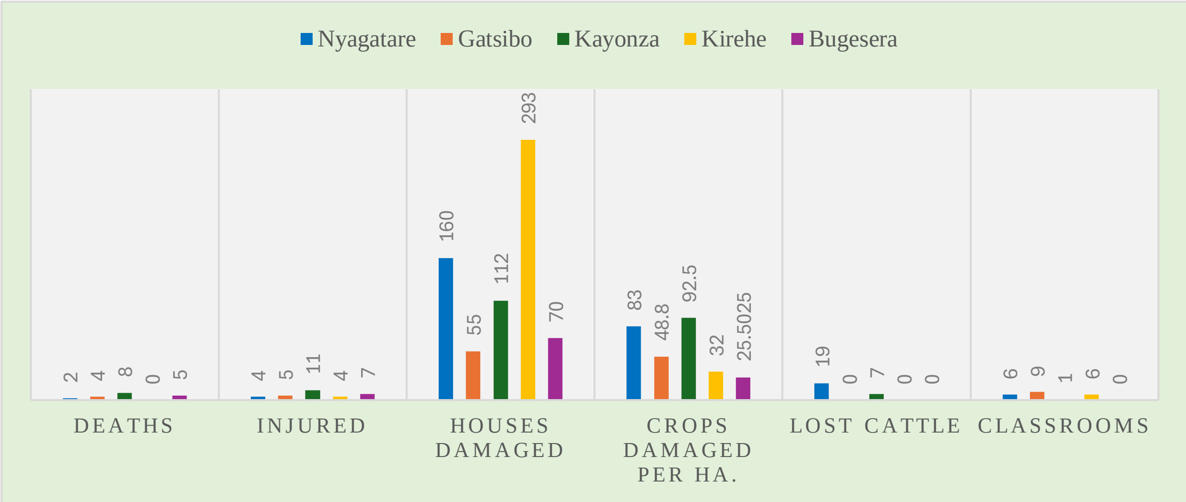
Finally, the impact on **livestock** shows moderate fluctuations. In 2016, only 2 livestock were affected, but by 2017, this number had jumped to 14. The trend remains somewhat erratic, with the highest number recorded in 2022 (19 livestock affected). This suggests that, while less visible compared to house or crop damage, the loss of livestock also varied depending on the nature and location of the events.

Overall, the chart reveals that certain years, particularly 2016, 2018, and 2021, were marked by severe impacts across multiple categories, suggesting major disasters that affected both human lives and livelihoods in those years.

4.2. Disaster effects situation in Eastern Region (January - December 2022)

The chart below also presents the effects of disasters on livelihoods in Rwanda's Eastern Region throughout 2022, with a focus on Nyagatare District. Nyagatare experienced notable impacts, including damage to 160 houses, loss of 19 cattle, and significant crop damage affecting 83 hectares. These figures highlight the ongoing vulnerability of Nyagatare to extreme weather events and other disasters, reinforcing the importance of developing effective coping strategies and resilience measures. This study seeks to further explore the specific impacts within Nyagatare, understanding the challenges faced by local farmers, and evaluating the strategies they employ to mitigate these impacts.

Figure 6: Disaster effects situation in Eastern Region (January - December 2022)

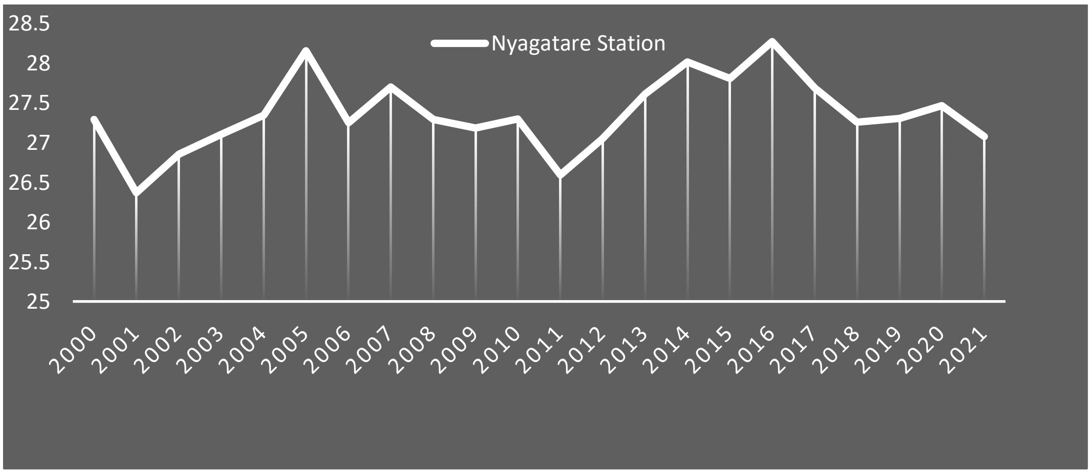


Source: Ministry in Charge of Emergency Management (MINEMA). (2022). *Annual disaster report 2022*.

4.3. Maximum temperature trends in Nyagatare District from 2000 to 2021

The line graph shows the maximum temperature trends in Nyagatare District from 2000 to 2021, highlighting key observations and potential impacts on agricultural activities.

Figure 7: Maximum temperature trends in Nyagatare District from 2000 to 2021



Source: Rwanda Meteorology Agency. (2024). *Meteorological data from Nyagatare Station*.

Significant temperature fluctuations are observed, with peaks around 2004, 2007, 2014, and 2017, and dips around 2001, 2009, and 2021. Despite these fluctuations, the overall temperature trend hovers around 27°C, with some years exceeding 28°C and others dipping below 26°C.

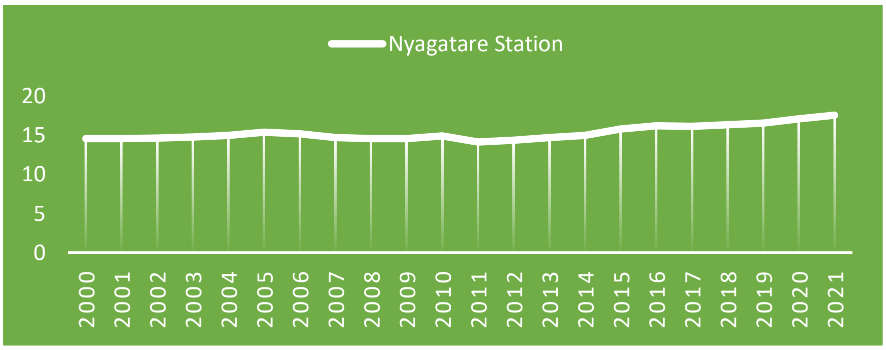
Temperature changes have several potential impacts on agriculture. Crops have specific temperature ranges for optimal growth, and fluctuations above 28°C could stress certain crops, reducing yields. Higher temperatures can also increase the prevalence of pests and diseases, as many pests thrive in warmer conditions. Additionally, temperature changes affect evaporation rates and soil moisture levels, leading to increased water loss and necessitating more efficient irrigation practices.

To address these challenges, Nyagatare District should invest in research and development of climate-resilient crop varieties and promote efficient irrigation systems. Enhancing pest and disease management, strengthening agricultural extension services, and encouraging crop and livestock diversification are also crucial. By implementing these measures, the district can better manage the impacts of temperature fluctuations on agriculture, ensuring sustainable productivity and food security.

4.4. Minimum temperature trends in Nyagatare District

The line graph depicts data from Nyagatare Station, illustrating a general trend from 2000 to 2021. The y-axis displays measured minimum temperature ranging from 0 to 20, while the x-axis represents the years.

Figure 8: Minimum temperature trends in Nyagatare District



Source: Rwanda Meteorology Agency. (2024). *Meteorological data from Nyagatare Station*.

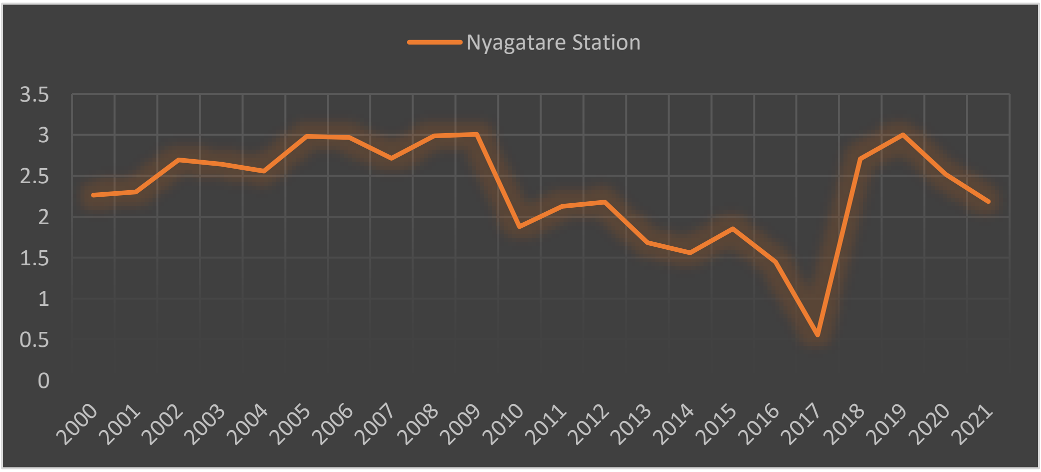
Between 2000 and 2008, temperatures consistently ranged from 14 to 15 degrees Celsius, creating stable conditions that supported agricultural productivity. However, a slight dip in temperatures during 2009 and 2010 pointed to a temporary climatic event that likely disrupted crop yields and heightened susceptibility to pests and diseases. Fortunately, the subsequent stabilization observed from 2011 to 2014 demonstrated the resilience of farming practices, enabling recovery from these earlier challenges.

From 2015 to 2021, a marked increase in minimum temperatures was recorded, reaching its peak in 2021. This upward trend indicates improved environmental conditions and may reflect the adoption of more effective farming practices that enhance crop yields and prolong growing seasons. Overall, the data illustrates the adaptability of Nyagatare's agricultural systems to changing climate conditions, highlighting the necessity of implementing resilience strategies to address climate change's impacts and ensure long-term food security in the region.

4.5. Precipitation trends in Nyagatare District from 2000 to 2021.

The graph below illustrates the precipitation trends in Nyagatare District from 2000 to the present.

Figure 9: The precipitation trends in Nyagatare District from 2000 to 2021.



Source: Rwanda Meteorology Agency. (2024). *Meteorological data from Nyagatare Station*.

Over this period, precipitation levels have fluctuated significantly. Initially, from 2000 to 2008, the district experienced relatively stable and moderate precipitation levels, mostly ranging between 2 and 3 units. This period appears to have been fairly consistent, providing relatively predictable rainfall patterns that could have been beneficial for agricultural activities.

However, starting around 2008, there is a noticeable decline in precipitation levels, reaching a particularly low point around 2015. This drop suggests a period of reduced rainfall, which could have posed challenges for farming, potentially leading to drought conditions and affecting crop yields. The sharp decline indicates a significant shift in climate patterns, exacerbating the vulnerability of local agriculture to weather-related stresses.

Post-2015, the graph shows a dramatic increase in precipitation levels, peaking around 2020, before another decline. This volatility highlights the increasing unpredictability of weather patterns in the region. Such fluctuations were challenging for farmers, who struggled to adapt to these rapid changes. The peak in 2020 suggests a period of heavy rainfall, which, while beneficial in replenishing water resources, but also lead to issues such as flooding or soil erosion in some parts of Nyagatare especially at Kagituma scheme and Muvumba marshland despite the involvement of local official to manage such temporal flooding. The recent downward trend indicates a return to lower precipitation levels, suggesting continued climate variability. This ongoing unpredictability underscores the importance of developing resilient agricultural practices and infrastructure to mitigate the impacts of such erratic weather patterns

4.6. Demographic characteristics of respondents

The interpretation and analysis of this study involve some identification of the respondents remarkably: the respondents according to gender distribution, respondents according to age distribution, marital status, respondents according to the distribution of education, and the identification according to the daily profession of the respondents. These identifications are intended to attain rational information from the particularities and similarities of identification of every respondent.

4.6.1. Respondents' Gender Distribution

This part describes, interprets and analyses the information of respondents based on their gender distribution whereby the sampled respondents who involved in providing primary information of this research were both male and females as indicated in the table below and its description.

Table 2: Respondents' Gender Distribution

Gender category	Frequency	Percentage
Male	44	47%
Female	50	53%
Total	94	100%

Source: Field survey, 2024

As presented in the table above, the gender distribution in the research sample of 94 respondents, who are farmers embodied in farming cooperatives from both Karangazi and Rwimiyaga Sectors, included 50 females (53%) and 44 males (47%). This balanced representation is important for diverse perspectives in analysis and decision-making. The slight female majority suggests a trend towards more female involvement in farming and conservation, indicating their significant role and addressing gender disparities in these activities. The male representation (47%) also highlights men's involvement and concern with the impacts of climate change on farming. Overall, the balanced gender representation benefits farming, promoting joint efforts to address climate change and enhance productivity in Karangazi and Rwimiyaga Sectors.

4.6.2. Respondents' Age Distribution

In this study, people respondents were classified basing on their age group. The table below clarifies their levels of age.

Table 3: Respondents' Age distribution

Respondents' Age distribution		
Age group	**Frequency**	**Percentage**
18-30	22	23%
31-43	43	46%
44-55	16	17%
Above 55	13	14%
Total	**94**	**100%**

Source: Field survey, 2024

The study indicates that the majority of respondents were aged 31-43, comprising 46% (43 individuals) of the sample. This group's dominance is attributed to their extensive farming experience and skills, ability to invest in farming, and physical capability to manage demanding tasks, thereby contributing significantly to their families' incomes.

The second-largest group was aged 18-30, making up 23% (22 respondents). This group, considered youth by Rwandan policy, is physically strong and vital for agricultural productivity, especially in areas with limited job opportunities. Their involvement in farming is encouraged by government policies, which offer subsidies, grants, and training, facilitating technological integration and climate change awareness in agriculture.

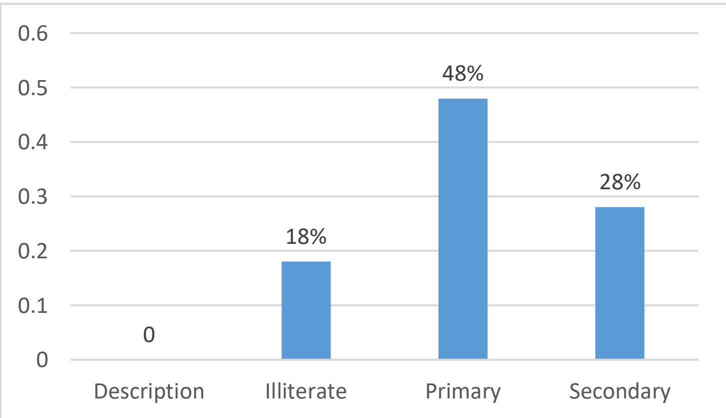
Respondents aged 44-55 accounted for 17% (16 individuals). This group participates in farming due to land ownership, farming experience, and the need to support their families through farming as a primary livelihood.

The smallest group, those above 55, represented 14% (13 respondents). Their participation in farming is driven by historical engagement in agriculture, land inheritance, and the necessity of farming for subsistence and supplementary income, especially given limited pension and social security systems.

4.6.3. Marital status of respondents

The figure below indicates the marital status according to respondents involved in the study.

Figure 10: Marital status of the respondents



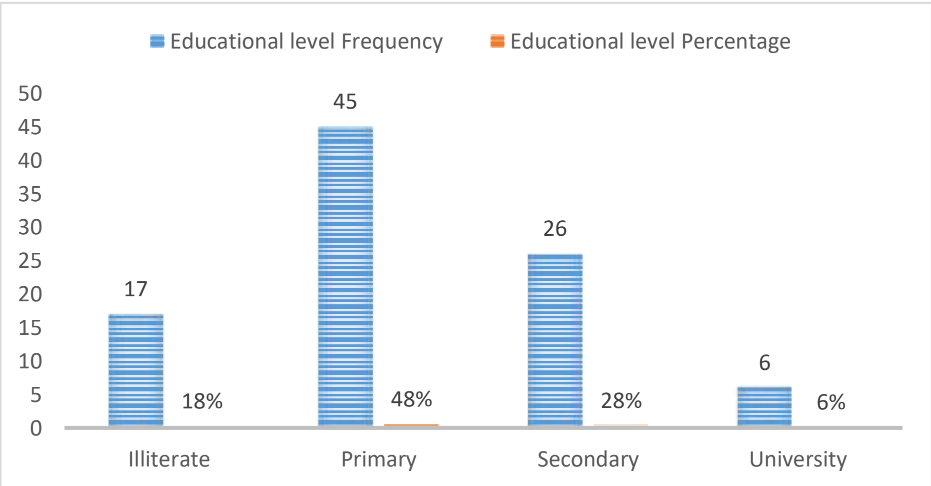
Source: Field survey, 2024

The information about climate change impacts on farming and coping strategies at Karangazi and Rwimiyaga Sectors was collected from informants of different marital status. As the figure above indicates, more than half (54%) of the respondents in the dataset are married. Married people in this study makes sense since parents are them who are responsible to provide food for their families. Single people are occupying 33% of the informants who contributed in providing information of this study. This helped the researcher to gain and understand the perspectives of single people regarding climate change's impacts on farming. About one-third (33%) of the respondents were single including those who have never been married, as well as those who are not currently married. Even if single people do not have responsibility to provide for families, they also need get involved in farming activities to raise their incomes but also supporting in coping up with strategies climate change impact on farming at Karangazi and Rwimiyaga Sectors. Widows were also involved in providing information of this study with representation of 11% among the total 94 sampled respondents. A very small percentage (2%) of individuals are divorced. This indicates that divorce is relatively uncommon among the sample.

4.6.4. Respondents According to the level of Education

The figure below presents data on the educational levels of individuals, represented by both frequency and percentage.

Figure 11: Respondents According to the level of Education



Source: Field survey, 2024

The largest group consists of individuals with primary education, comprising nearly half (48%) of the sampled respondents. This suggests that primary education is the most common educational level attained and their main work is to practice farming as most of these respondents belong to farming cooperatives.

The second largest group is those with secondary education, accounting for 28% of the population. This indicates a significant portion of the population progresses beyond primary education but does not necessarily advance to higher education. This also indicates that faming activities and agriculture sector has different potentialities that people of different levels of education explore including those who studied secondary school level. In addition, involvement of educated people in farming denotes also increase in understanding the risks caused by climate change on farming and also identifying strategies to address climate change impacts on farming.

A notable 18% of the respondents is illiterate, highlighting a substantial segment that lacks basic reading and writing skills. This might point to socio-economic factors or insufficient access to education but were still involved since they practice farming and may face quite similar climate change impacts like other farmers. Only 6% of the respondents has attained a university degree. This low percentage suggests factors that prevented other respondents to study up to higher education, which could include financial constraints, limited availability of higher education institutions, or other socio-economic factors.

4.7. Analysis of farmers' perceptions on climate change impacts on farming

4.7.1. Droughts damaged crops at Karangazi and Rwimigayaga sectors

The following data in the table 5 presents the responses to a statement regarding the extent to which crops such as maize, beans, cassava, and animal fodder are damaged by droughts.

Table 4: Crops Damaged by droughts (maize, beans, cassava, folders of animals) at Karangazi and Rwimigayaga sectors

Description	**Frequency**	**Percentage**
Strongly agree	34	36%
Agree	50	53%
Neutral	6	6%
Disagree	2	2%
Strongly disagree	2	2%
Total	94	100%

Source: Field survey, 2024

The biggest respondents equal to 50 representing 53% among the total number of respondents equal to 94 agreed that droughts damaged crops including maize, beans, soybeans, rice, cassava, banana plantation folders of animals at both Karangazi and Rwimiyaga Sectors. This indicates a strong consensus on the negative impact of droughts on agriculture.

Respondents mentioned that crops which rely on regular rainfall suffered since rain did not fall regularly instead long sunshine occurred and resulted in droughts which impacted crop varieties. Farming in both sectors depend on rain fed rather than irrigation. During the period of droughts, insufficiency of facilities and tools used in irrigation including moto pumps, field located far from river water etc. Farming practices at both Karangazi and Rwimiyaga sectors were damaged by the droughts.

The second majority of respondents strongly agreed droughts damaged crops including maize, beans, soybeans, rice, cassava, banana plantation folders of animals at both Karangazi and Rwimiyaga Sectors.

This category constitutes of 34 representing 36% among total number of respondents equal to 94. Karangazi and Rwimiyaga are sectors in Nyagatare District which are significantly affected by droughts which have profound impacts on its agriculture and water resources particularly key crops such as maize, beans, banana are vulnerable. Farmers explained that prolonged dry periods lead to reduced yield and crop failures, threatening food security for local communities.

Respondents also mentioned that droughts pose a risk to their livestock due to the reduction of water and dried pasture which also lead to the decrease of milk production.

The scarcity of water also hampers irrigation efforts. A small portion, 6%, are neutral on the issue. These respondents neither agree nor disagree, possibly indicating either a lack of strong opinion or insufficient information to make a judgment. Only 4% (2% disagreed and 2% strongly disagreed) of respondents do not believe that droughts have caused damage to crops. This indicates that there is very little opposition to the idea that droughts have been harmful to crop yields.

4.7.2. Droughts decreased crops and livestock production and productivity at Karangazi and Rwimiyaga Sectors

The following data in the table 6 presents the responses to a statement regarding the extent to which droughts decreased crops and livestock production and productivity at Karangazi and Rwimiyaga Sectors.

Table 5: Decrease of crops and livestock production and productivity due to droughts at Karangazi and Rwimiyaga Sectors

Description	**Frequency**	**Percentage**
Strongly agree	40	43%
Agree	47	50%
Neutral	4	4%
Disagree	2	2%
Strongly disagree	1	1%
Total	94	100%

Source: Field survey, 2024

The data in the table above shows the results of a survey on the impact of droughts on crops and livestock production and productivity. Specifically, the survey asked respondents whether they believed that droughts had decreased the production and productivity of maize, beans, cassava, banana, and milk. Half of the respondents (50%) agreed that droughts had a negative effect on the productivity and production of the specified yields and livestock. They mentioned maize, beans, cassava, banana, peanuts at Karangazi and Rwimiyaga Sectors faced water stress and such crops production and such water stress often happen in the second season between March to June especially for the year 2022 and 2024.

43% of the respondents strongly believe that droughts have significantly decreased the production and productivity of crops and livestock. They mentioned that when sunset and last long during the germination or flowering stages, planted crops face severe risks and that often results in very low production of maize, beans, peanuts at both Karangazi and Rwimiyaga Sectors. Farmer respondents mentioned that prolonged drought depletes soil moisture, making it difficult for crops to access necessary water. In addition, droughts lead to nutrient deficiencies, affected the quality of the production, including its size, flavor, and nutritional value.

A small portion (4%) of respondents neither agree nor disagree, indicating neutrality or uncertainty regarding the impact of droughts. On the other side, 2% of the respondents disagreed with the statement, suggesting that they do not believe droughts have decreased production and productivity. Just 1% of the respondents strongly disagreed with the statement, indicating a very small minority who believe that droughts have not had a negative impact.

4.7.3. Droughts induced diseases to the crops and livestock at Karangazi and Rwimiyaga Sectors

The following data in the table 7 presents the responses to a statement regarding the extent to which droughts decreased caused diseases to the crops and livestock at Karangazi and Rwimiyaga Sectors.

Table 6: Droughts caused diseases to the crops and livestock

Description	**Frequency**	**Percentage**
Strongly agree	37	39%
Agree	48	51%
Neutral	0	0%
Disagree	9	9%
Strongly disagree	0	0%
Total	94	100%

Source: Field survey, 2024

Droughts is among climate change impacts affecting farming through different mechanisms as evidenced by respondents in this study. Among 94 sampled

respondents, 48 respondents representing 51% agreed that droughts caused diseases to the crops and livestock at Karangazi and Rwimiyaga Sectors. Droughts stress weakened plants' natural defenses and made crops to be susceptible to diseases. Respondents mentioned that main crops at Karangazi and Rwimiyaga Sectors such as maize, beans and peanuts became water stressed and lost the ability to produce to growth. Some mentioned maize, beans, banana, cassava to have been attached by fungi, bacteria, and viruses while the pesticides to fight against such diseases are expensive and sometimes not available at the market. Similarly, respondents declared drought to have weakened the immune systems of animals due to nutritional shortages, dehydration, and heat stress. This increased susceptibility to infections and diseases among livestock not only at Rwimiyaga and Karangazi sector but also in other sectors of Nyagatare District.
Respondents equal to 37 representing 39% among the total respondents strongly agreed that droughts caused diseases attach in crops and livestock. Similarly, to the first category of respondents, droughts create a challenging environment for both crops and livestock, leading to increased vulnerability to diseases. For crops, the stress from lack of water and nutrient deficiencies made them more susceptible to pathogens at both Karangazi and Rwimiyaga sectors. The combination of dehydration, poor nutrition, and stress weakens the immune systems of for livestock making them more prone to diseases. Additionally, the changes in the environment caused by drought cause the proliferation of pests and pathogens.

Unlike the respondents who agreed droughts to have caused diseases attach in crops and livestock, 9 respondents representing 9% among the total sampled 94 respondents disagreed with the statement that droughts caused diseases attach in crops and livestock. Even if it is rare, certain conditions can prevent disease outbreaks even during drought periods. Such scenarios include planting drought-resistant or drought-tolerant crop varieties can reduce the impact of drought on plant health and susceptibility to diseases. Good soil health practices, such as maintaining organic matter, using cover crops or cultivating in greenhouse can help retain moisture and reduce plant stress, thereby lowering the risk of disease. Efficient irrigation techniques, like drip irrigation or the use of moisture sensors, can ensure that crops receive adequate water even during drought, preventing stress that makes them susceptible to diseases.

For livestock, ensuring livestock have access to clean and sufficient water even during drought conditions can prevent dehydration and related health issues that can predispose animals to diseases.

4.7.4. Windstorm damaged crops and livestock in Karangazi and Rwimiyaga Sectors.

The following data in the table 8 presents the responses to a statement regarding the extent to which windstorm damaged crops and livestock at Karangazi and Rwimiyaga Sectors

Table 7: Windstorm damaged crops and livestock in Karangazi and Rwimiyaga Sectors

Description	Frequency	Percentage
Strongly agree	29	30.8%
Agree	37	39.3%
Neutral	0	0%
Disagree	28	29.78%
Strongly disagree	0	0%
Total	94	100%

Source: Field survey, 2024

Karangazi and Rwimiyaga Sectors are predominantly agrarian economy, frequently faces challenges from natural disasters such heavy winds. This event has impacts on rural areas, damaging crops and livestock, which are vital to the livelihoods of many farmers from both sectors. The majority of respondents equal to 37 representing 39.3% agreed on the statement that winds damaged crops and livestock in Karangazi and Rwimiyaga Sectors. Maize and bean, rice, fields were among the most affected with inundation and with many farms experiencing complete crop loss. Sweet potato and cassava fields also suffered from root rot due to excessive moisture.

In addition, 29 respondents representing 30.8% strongly agreed to that winds destroyed crops and livestock of the community at Karangazi and Rwimiyaga Sectors.

Farmers respondents reported a number of cattle were to have died due to the windstorm and floods. Other small-scale livestock farmers reported losing goats and sheep, poultry farms affected and chickens suffered from disease due to wet. Farmers also struggled with diseases like foot rot in cattle, animals suffered from diseases spread and a decline in milk production. The rains led to outbreaks of diseases like pneumonia and mastitis among cattle due to the humid conditions (Interview with a farmer at Karangazi Sector, May 2024).

Unlike the majority, 28 respondents, representing 29.7%, disagreed with the statement that erosion damaged crops and livestock in Karangazi and Rwimiyaga Sectors. This could be attributed to the fact that some farms are located on flat areas and are situated far from rivers, where the risk of windstorm is minimal.

4.7.5. Damages to arable land and farming facilities at Karangazi and Rwimiyaga Sectors

The following data in the table 8 presents the responses to a statement regarding the extent to which windstorm damaged arable land and farming facilities at Karangazi and Rwimiyaga Sectors

Table 8: Windstorm damaged arable land and farming facilities

Description	**Frequency**	**Percentage**
Strongly agree	55	58.51%
Agree	39	41.48%
Neutral	0	0%
Disagree	0	0%
Strongly disagree	0	0%
Total	94	100%

Source: Field survey, 2024

According information collected from the respondents, 44 informants representing 58.51% strongly agreed with the statement that heavy winds damaged arable land and farming facilities at Karangazi and Rwimiyaga Sectors. Likewise, 29 respondents representing 41.48% agreed to the same statement. These indicate that heavy winds contribute to wash away the topsoil which is rich in nutrients and organic matter that are essential for growth of main crops such as maize, beans, cassava. Some of the interviewed respondents mentioned that windstorm contributed to the reduction of soil fertility and makes the land less productive. “winds carry large amounts of sediment, excessive sediment damaged vegetation and disrupted plant growth including maize, beans, and soybeans and lead to yield losses. windstorm damaged arable land, flora and fauna by stocking siltation in the water channels of marshlands and valley dams" (Interview with farmers at Karangazi and Rwimiyaga Sectors, May 2024).

On the other side, some farmer respondents declared that windstorm damaged their shelters including drying shelters. "The winds blew drying shelters of maize and that become a challenge for farmers who use the drying shelters as a temporal stock to keep the maize yield before bringing them to the market". (Interview with farmers at Karangazi and Rwimiyaga Sectors, May 2024).

4.7.6. Windstorm decreased crops production and productivity at Karangazi and Rwimiyaga Sectors

The following data in the table 11 presents the responses to a statement regarding the extent to which windstorm decreased crops production and productivity at Karangazi and Rwimiyaga Sectors

Table 9: Windstorm decreased crops production and productivity

Description	**Frequency**	**Percentage**
Strongly agree	21	22%
Agree	60	64%
Neutral	5	5%
Disagree	0	0%
Strongly disagree	8	9%
Total	94	100%

Source: Field survey, 2024

The majority of respondents agree (64%) or strongly agree (22%) that windstorm have decreased crop production and productivity. This sums to 86% of respondents expressing a positive agreement with the statement that windstorm decreased crops production and productivity at Karangazi and Rwimiyaga Sectors.

windstorm have significantly impacted crop production and productivity in karangazi and Rwimiyaga sectors. Dependence on agriculture for livelihoods in at Karangazi and Rwimiyaga Sectors makes communities particularly vulnerable to such disruptions. Windstorm causing physical damage to crops and leading to reduced yields or total crop loss. Windstorm washed away the nutrient-rich topsoil, which is essential for healthy crop growth. This depletion of fertile soil reduces the agricultural productivity of the land.

A small percentage of respondents (5%) are neutral, indicating neither agreement nor disagreement with the statement while a minority (9%) strongly disagree with the statement, suggesting that they believe winds do not have a significant impact on crop production and productivity, or they may have other reasons for this viewpoint.

Generally, the data indicates a strong perception among the respondents that windstorm negatively affect crop production and productivity, with 86% in agreement and only 9% in strong disagreement.

4.7.7. Invasive pest and diseases affected crop production at Karangazi and Rwimiyaga Sectors

The following data in the table 12 presents the responses to a statement regarding the extent to which Invasive pest and diseases affected crop production at Karangazi and Rwimiyaga Sectors

Table 10: Invasive pest and diseases affected crop production

Description	**Frequency**	**Percentage**
Strongly agree	30	32%
Agree	45	48%
Neutral	5	5%
Disagree	6	6%
Strongly disagree	8	9%
Total	94	100%

Source: Field survey, 2024

A significant portion of the respondents (32%) strongly believe that invasive pests and diseases have a major impact on crop production. Nearly half (48%) of the respondents agreed that invasive pests and diseases affect crop production. Combined with those who strongly agree, this indicates that 80% of the respondents see a negative impact.

Respondents mentioned that banana were affected by disease and resulted in wilting and yellowing of leaves, premature ripening of fruits, and eventual plant death. Diseases attached maize and lead to severe yield losses due to plant death and poor grain growth. They also mentioned the Invasive pest and diseases affect leaves, stems, and cobs, fruits, tubers of crops and lead to significant harvest reductions. The reduction in staple crop harvests due to the pests and diseases has threatened food security, particularly affecting smallholder farmers who rely heavily on these crops (Interview with farmers at Karangazi and Rwimiyaga Sectors, May 2024).

A small portion (9%) of respondents strongly disagreed, indicating a strong belief that invasive pests and diseases do not affect crop production. Minority of the respondents (6%) disagree with the statement, suggesting they do not believe invasive pests and diseases significantly affect crop production. In addition, another small percentage (5%) of respondents were neutral, neither agreeing nor disagreeing with the statement about the impact of invasive pests and diseases.

Overall, the majority of respondents perceive invasive pests and diseases as having a negative impact on crop production, while a smaller fraction either do not perceive it as a problem or are neutral on the issue. This suggests a strong consensus among the majority about the detrimental effects of invasive pests and diseases on crop production.

4.7.8. Invasive pests increased diseases to the crops and livestock at Karangazi and Rwimiyaga Sectors.

The following data in the table 13 presents the responses to a statement regarding the extent to which invasive pests increased diseases attach in crops and livestock at Karangazi and Rwimiyaga Sectors

Table 11: Invasive pests increased diseases attach in crops and livestock

Description	Frequency	Percentage
Strongly agree	30	31.9%
Agree	50	53%
Neutral	0	0%
Disagree	8	8.5%
Strongly disagree	6	6%
Total	94	100%

Source: Field survey, 2024

More than half (53%) of the respondents agree with the statement. Nearly one-third (31.9%) of the respondents strongly believe that invasive pests have increased the incidence of diseases in crops and livestock. Combining those who agreed and those who strongly agree, this makes up 84.9% of the total respondents, showing a strong consensus that invasive pests are indeed increasing disease problems in crops and livestock.

Invasive pests can introduce new diseases to crops and livestock. These pests often carry pathogens that local species have not encountered before, making them more susceptible to infections. Intensive farming practices at both Karangazi and Rwimiyaga Sectors can exacerbate the spread of invasive pests. Mono-cropping and the use of certain agricultural inputs can also create environments where pests can flourish, increasing the risk of disease outbreaks.

Invasive pests such as the fall armyworm (Spodoptera frugiperda) have significantly impacted maize and other cereal crops at Karangazi and Rwimyaga Sectors. Changes in climate has ever become a factor to the introduction of invasive pests mentioned by respondents at Karangazi and Rwimiyaga Sector. Warmer temperatures and altered precipitation patterns helped these pests establish themselves in the areas leading to increased interactions with crops and livestock.

On the other side, a small percentage of respondents disagree with the statement. This indicates that there are a few individuals who do not perceive invasive pests as a significant factor in increasing diseases in crops and livestock. Another smaller group (8.5%) strongly disagreed with the statement. This further supports the notion that the majority believe invasive pests are an issue, with only 14.5% (disagreed and strongly disagreed combined) thinking differently.

4.7.9 Invasive pest and diseases causes hunger among local farmers at Karangazi and Rwimiyaga Sectors

The following data in the table 14 presents the responses to a statement regarding the extent to which invasive pests and diseases causes hunger among local farmers at Karangazi and Rwimiyaga Sectors

Table 12: Invasive pest and diseases causes hunger among local farmers

Description	Frequency	Percentage
Strongly agree	40	43%
Agree	47	50%
Neutral	0	0%
Disagree	7	7%
Strongly disagree	0	0%
Total	94	100%

Source: Field survey, 2024

The data presented above illustrates the opinions of local farmers on the statement "Invasive pests and diseases cause hunger among local farmers." A significant majority of respondents (93%) either "strongly agreed" (43%) or "agreed" (50%) that invasive pests and diseases cause hunger among local farmers. This indicates a strong consensus among the farmers that these factors have a substantial negative impact on their food security and livelihoods. However, on the other side, a small portion of respondents (7%) disagreed. This emphasizes that the majority view is that invasive pests and diseases are indeed a critical problem leading to hunger among farmers.

Informants declared that invasive pests and disease such as armyworms, maize lethal necrosis affected agricultural productivity, leading to hunger among local farmers at both Karangazi and Rwimiyaga Sectors. When crops are destroyed or severely damaged, farmers harvested less than expected, lose their primary source of income and food, leaving them with insufficient food to feed their families and inadequate surplus for sale. In addition, controlling invasive pests and diseases often requires expensive pesticides, fungicides, or other management practices (Interview with farmers at Karangazi and Rwimiyaga Sectors, May 2024).

The data strongly suggests that invasive pests and diseases are recognized by local farmers as a significant cause of hunger. This majority agreement highlights the urgent need for measures to address these agricultural challenges to improve food security and the livelihoods of farmers. Policymakers, agricultural support organizations, and researchers should take note of these findings and consider prioritizing interventions that mitigate the impact of invasive pests and diseases.

4.7.10 Adoption of afforestation and agroforestry reduced the windstorm pressure on crops and livestock at Karangazi and Rwimiyaga Sectors

The following data in the table 15 presents the responses to a statement regarding the extent to which adoption of afforestation and agroforestry reduced the windstorm pressure on crops and livestock at Karangazi and Rwimiyaga Sectors.

Table 13: Adoption of afforestation and agroforestry reduced windstorm pressure on crops and livestock

Description	**Frequency**	**Percentage**
Strongly agree	43	46%
Agree	51	54%
Neutral	0	0%
Disagree	0	0%
Strongly disagree	0	0%
Total	94	100%

Source: Field survey, 2024

Every respondent either "Strongly agreed" or "agreed" that afforestation and agroforestry reduce windstorm pressure on crops and livestock. A slight majority of respondents "agree" with (54%) rather than "strongly agree," with (46%) indicating that while most people see the benefits, they may perceive them to varying extents. This common agreement suggests a very strong positive perception of the benefits of these practices.

Respondents in the survey mentioned that trees and shrubs planted in afforestation and agroforestry systems helped to fix soil particles together with their roots, reducing erosion during strong rainfall. This stabilization of soil prevented soil from being washed away. Trees and vegetation act as natural sponges, absorbing water from rainfall. The roots of trees and shrubs in agroforestry systems also helped improve soil structure by enhancing soil aggregation. Afforestation and agroforestry also promoted biodiversity by providing habitat for different plant and animal species (Interview with farmers at Karangazi and Rwimiyaga Sectors, May 2024).

Given the common agreement, it can be concluded that adoption of afforestation and agroforestry are well-regarded and likely supported by the Nyagatare district or stakeholders. This support can be essential for policymaking, scaling up, funding, and implementation of such environmental practices at Karangazi, Rwimigaga sectors and other sectors in Nyagatare District.

4.7.11 Adoption of afforestation and agroforestry reduced the droughts pressure on crops and livestock at Karangazi and Rwimiyaga Sectors

The following data in the table 16 presents the responses to a statement regarding the extent to which Adoption of afforestation and agroforestry reduced the droughts pressure on crops and livestock at Karangazi and Rwimiyaga Sectors

Table 14: Adoption of afforestation and agroforestry reduced the droughts pressure on crops and livestock

Description	**Frequency**	**Percentage**
Strongly agree	38	40%
Agree	47	50%
Neutral	0	0%
Disagree	6	6%
Strongly disagree	3	3%
Total	94	100%

Source: Field survey, 2024

A significant majority of respondents (90%) summing up both those who agreed (50%) and those who strongly agreed (40%) that afforestation and agroforestry have reduced drought pressure on crops and livestock. This indicates a strong positive perception of these practices of afforestation and agroforestry to reduce pressure of droughts on crops and livestock at both Karangazi and Rwimiyaga Sectors. Nevertheless, a small minority of respondents (9%) either disagree (6%) or strongly disagree (3%) with the statement. This indicates that very few people feel that afforestation and agroforestry have not helped reduce drought pressure.

Trees and shrubs planted through afforestation and agroforestry helped retain soil moisture by reducing evaporation and improving water infiltration. This means that during dry periods, the soil retains more moisture, which can be crucial for sustaining crops and providing water for livestock. Trees planted as part of afforestation and agroforestry act as natural windbreaks, reducing the drying effect of winds on crops and soil and that retain humidity and create more favorable microclimates for agriculture. In addition, agroforestry leaves get decomposed and becomes compost for crop but also some agroforestry species are fodders for livestock. Overall, the survey results indicate that the majority of respondents recognize the benefits of afforestation and agroforestry in reducing drought pressure on crops and livestock.

4.7.12 Irrigation mechanism on large and small scale increased farmers' crops production and productivity at Karangazi and Rwimiyaga Sectors

The following data in the table 17 presents the responses to a statement regarding the extent to which irrigation mechanism on large and small scale increased farmers' crops production and productivity at Karangazi and Rwimiyaga Sectors

Table 15: Irrigation mechanism on large and small scale increased farmers' crops production and productivity

Description	**Frequency**	**Percentage**
Strongly agree	40	43%
Agree	42	45%
Neutral	2	2%
Disagree	6	6%
Strongly disagree	4	4%
Total	94	100%

Source: Field survey, 2024

The data presented in the table above shows the results of a survey about the impact of adopting and enforcing irrigation systems on crop production and productivity for farmers. Respondents equal to **(**88%) combining (45%) who agreed and (43%) who "strongly agreed" believe that the adoption and enforcement of irrigation systems have positively impacted crop production and productivity. This majority suggests strong support for the benefits of irrigation systems among the surveyed farmers at both

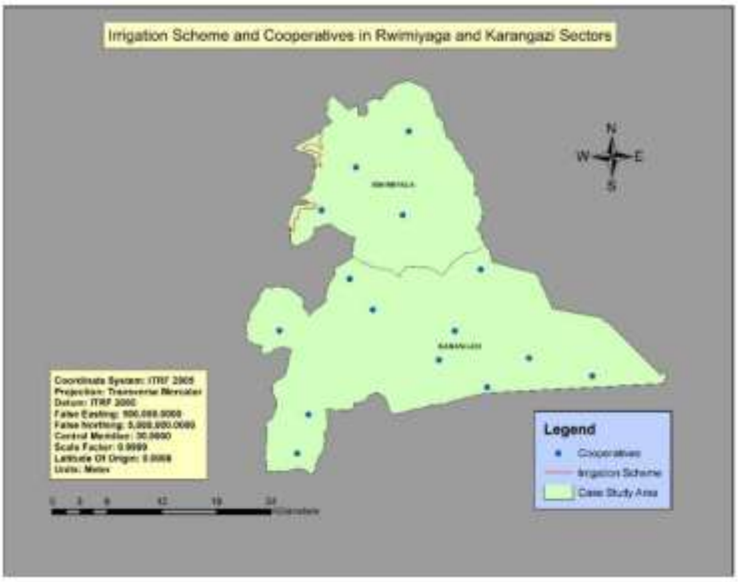
Karangazi and Rwimiyaga Sectors but also the data shows a positive perception of irrigation systems among farmers, suggesting that these systems are likely effective in enhancing crop production and productivity.

Conversely, (10%) of respondents (combining "Disagree" and "Strongly disagree") do not believe that irrigation systems have had a positive impact. This small percentage indicates that a very few farmers are skeptical about the benefits or may have not used irrigation system or probably experienced loss in their farming. In addition, a very small proportion (2%) of respondents were neutral, indicating that almost all respondents have a positive opinion on the matter. While the disagreement responses were low, understanding the concerns of the 10% who disagreed can be beneficial but also addressing their issues may help in achieving satisfaction and further improving the adoption rate of irrigation system among farmers at Karangazi and Rwimyaga Sectors.

Farmers at Karangazi and Rwimiyaga sectors mentioned they were supported with moto pumps, dam sheets, sprinkler heads, pipes, and pumps, Sprinklers, solar panels to facilitate practicing small scale irrigation but also trainings on how to use subsidies, and extension services at irrigated farmland in order to increase production and productivity as well as protecting environment (Interview with farmers at Karangazi sector, May 2024).

The government on its journey of increasing crop production to fight against hunger and famine has started establishing project of irrigation within two sectors of Nyagatare district which are Rwimiyaga and Karangazi with main objectives of soil conservation, flood and soil erosion control, irrigation and water supply to the livestock areas. One of those project called Muvumba multipurpose Dam project which will construct a dam of 30.5m high and will impound 35 million cubic meter of water in Karama, Gatunda and Rukomo sectors and will supply water for domestic use to Karangazi, Rwempasha and Nyagatare sectors. The dam will impound water to be used for domestic water supply, water for irrigation of 7380 ha (net command area) and water for 16 reservoirs for livestock watering production.

Figure 12: Irrigation scheme and cooperatives in Rwimiyaga and Karangazi Sectors



Source: Nyagatare district, 2024.

The map above mentions the part of irrigation scheme which is under-implementation and also covers small areas of Rwimiyaga sector, this will help farmers and cooperatives in the project location to increase yields and improving their livelihood due to irrigation to their farming and livestock. This is very important project in the area and government should keep investing on it so that all remaining part of two sectors should be covered with irrigation scheme on large scale to boost agriculture productivity.

4.7.13 Capacity building and extension services facilitated local farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors

The following data in the table 18 presents the responses to a statement regarding the extent to which Capacity building of local farmers and extension services facilitated farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors

Table 16: Capacity building of local farmers and extension services facilitated farmers to deal with climate change impacts on farming

Description	Frequency	Percentage
Strongly agree	40	43%
Agree	45	48%
Neutral	0	0%
Disagree	4	4%
Strongly disagree	5	5%
Total	94	100%

Source: Field survey, 2024

The data in the table above represents the responses of individuals regarding the effectiveness of capacity building of local farmers and extension services in helping farmers deal with climate change impacts on farming. A significant majority, 85 out of 94 respondents, which is 91% (48% who agreed and 43% who strongly agreed), believe that capacity building and extension services are effective in helping farmers deal with the impacts of climate change on farming. This indicates a high level of satisfaction and perceived effectiveness among the majority of respondents in a way that capacity-building initiatives and extension services are successful in equipping farmers to handle climate change related challenges.

On the other side, a small minority, 9 respondents (5% who strongly disagreed and 5% who disagreed), do not believe that these measures are effective. Although a minority, this 9% represents a group that might be experiencing barriers or challenges not addressed by the current capacity building and extension services. This informs the need to investigate specific reasons why some farmers feel unsupported but can also help in enhancing the programs to ensure capacity building is scaled up to all farmers at both Karangazi and Rwimiyaga Sectors.

In Nyagatare District, extensive training and support have led to notable improvements in crop yields and reductions in crop losses due to extreme weather events. This success is attributed to a comprehensive approach that combines capacity building with continuous extension services. The World Bank (2023) emphasizes the importance of such integrated approaches in building resilient agricultural systems. Wright Morton et al. (2016) stress the need for training farmers to adapt to increased weather variability and understand the causes of climate change. By using adaptive management tools and practices based on science and experience, farmers can manage weather variability, reduce soil erosion, and enhance productivity.

4.7.14 Early Warning Systems facilitated farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors

The table 17 below summarizes farmers' responses to the effectiveness of Early Warning Systems (EWS) in helping them deal with the impacts of climate change on farming.

Table 17: Early Warning Systems facilitated farmers to deal with climate change impacts on farming

Description	Frequency	Percentage
Strongly agree	0	0%
Agree	11	11.7%
Neutral	0	0%
Disagree	57	60.63%
Strongly disagree	26	27.65%
Total	94	100%

The data indicated in the table above shows responses to a statement about early warning systems (EWS) and their effectiveness in helping farmers deal with climate change impacts on farming. The majority of farmers (88.28) summing up both (60.63% who disagreed and 27.65% who strongly disagreed) that early warning systems on the statement that early warning system effectively facilitated them in dealing with climate change impacts on farming. This indicates a significant ineffectiveness of the early warning systems among the surveyed farmers. However, a few respondents equal to (11.7%) agreed that early warning systems have been effective. This is a clear contrast to the majority who expressed disagreement. The existing early warning systems may not be well implemented or sufficiently effective in providing actionable information at both Karangazi and Rwimiyaga Sectors or else farmers may not have seen tangible benefits or responses to the warnings provided by these systems. Hence, there is a need for improvements in communication, accessibility, or relevance of the information provided by early warning systems to better meet farmers' needs to ensure farmers copy up with climate change by preparing seasons earlier to ensure the rainfall comes after arable land are prepared, securing on time agricultural extension services, radio broadcasts, or community meetings, offering guidance on agronomic practices, pest and disease management.

CHAPTER 5: SUMMARIES, CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

This chapter summarizes the research findings, draws conclusions, and provides recommendations based on these findings in relation to the initial research questions and objectives. The study focused on the impacts of climate change on farming and the coping strategies of local farmers in the Rwimiyaga and Karangazi sectors of Nyagatare district, Rwanda. The research involved 94 informants from a population of 720 farmers embodied in 15 farming cooperatives, local leaders, practitioners, and representatives of civil society organizations in the agricultural sector. The study employed a mixed-method approach, combining quantitative and qualitative techniques, and utilized a descriptive research design. Data was primarily collected through distributed questionnaires, interviews, and documentary analysis.

5.2. Summary of the findings

From 2000 to 2021, Nyagatare District experienced significant temperature fluctuations, with peaks around 2004, 2007, 2014, and 2017, and dips around 2001, 2009, and 2021, while the overall trend hovered around 27°C. Some years exceeded 28°C, and others dipped below 26°C, stressing crops and increasing pests and diseases. Rising minimum temperatures disrupted crop growth cycles and promoted pests. Precipitation trends initially stable, declined significantly around 2008, reached a low in 2015, peaked dramatically around 2020, and then declined again, causing droughts, flooding, and soil erosion. Nyagatare District should invest in climate-resilient crops, efficient irrigation, pest management, agricultural extension services, and diversify crops and livestock.

The survey findings revealed a strong consensus among respondents regarding the severe impact of droughts, windstorm, erosion, invasive pests, and diseases on agriculture in Karangazi and Rwimiyaga sectors. Specifically, a majority (53%) agreed that droughts significantly damaged crops such as maize, beans, soybeans, rice, cassava, and bananas, with 36% strongly agreeing. Additionally, 50% of respondents noted the negative impact of droughts on crop productivity during the second season in 2022 and 2024, with 43% strongly agreeing.

Droughts also weaken crops and livestock, making them more susceptible to diseases. While some respondents noted that good agricultural practices and efficient irrigation can mitigate these effects, windstorm have damaged irrigation infrastructure, leading to water scarcity. 58.51% of respondents strongly agreed, and 41.48% agreed that windstorm washed away nutrient-rich topsoil, reducing soil fertility and overall productivity. Windstorm also damage drying shelters for storing maize. These natural phenomena strip away fertile topsoil and deposit sediments that hinder agricultural practices. A majority (86%) strongly believe that windstorm have significantly decreased crop production and productivity.

Moreover, 80% of respondents believe that invasive pests and diseases significantly negatively impact crop production, particularly affecting bananas and maize. A significant majority (84.9%) agreed that invasive pests have increased disease incidence in crops and livestock, with intensive farming, climate change, and specific pests like the fall armyworm exacerbating the problem. 93% of local farmers believe invasive pests and diseases cause hunger by severely damaging crops.

Additionally, every respondent agreed that afforestation and agroforestry reduce winds pressure on crops and livestock, with 54% agreeing and 46% strongly agreeing. 90% of respondents believe these practices reduce drought pressure on crops and livestock. 88% of farmers believe irrigation systems positively impact crop production, and 91% believe capacity building and extension services effectively help manage climate change impacts. However, 88.28% found early warning systems ineffective in dealing with climate change impacts, indicating a need for better implementation and more actionable information.

5.3. Conclusions of the study

The study on the impacts of climate change on farming in Karangazi and Rwimiyaga Sectors reveals a comprehensive overview of the community's demographics, education levels, and perceptions of various environmental challenges. The balanced gender distribution and the significant involvement of younger farmer’s highlight evolving dynamics in agricultural participation. The age diversity among respondents underscores the different roles and contributions across generations, with younger individuals embracing technological advancements and older farmers relying on traditional practices and land ownership.

Educational attainment among respondents varies, with a large proportion having primary education, suggesting the need for more advanced educational opportunities to enhance farming practices. The pervasive impact of droughts on crops and livestock, as reported by a majority of respondents, underscores the critical challenge of water scarcity and the urgent need for effective water management strategies. Furthermore, the consensus on the detrimental effects of windstorm on soil fertility and crop productivity indicates significant vulnerabilities that must be addressed through sustainable land management practices.

Invasive pests and diseases are another major concern, with a strong consensus on their negative impact on crop yields and food security, highlighting the need for robust pest management strategies. The positive perception of afforestation and agroforestry practices demonstrates community support for these interventions as effective measures against environmental degradation and climate pressures. The favorable view of irrigation systems and capacity-building initiatives reflects the community's recognition of these tools' benefits in enhancing agricultural productivity and resilience.

However, the dissatisfaction with early warning systems suggests a gap in the effectiveness and communication of climate-related information, calling for improvements in these systems to better support farmers in mitigating climate change impacts. Overall, the findings emphasize the necessity of integrated and community-supported approaches to address the multifaceted challenges posed by climate change, ensuring sustainable agricultural practices and improved livelihoods for the farmers in Karangazi and Rwimiyaga Sectors.

5.4. Recommendations

To mitigate the negative impacts of drought on agriculture, it is essential to develop and implement comprehensive drought management strategies focused on water conservation, efficient irrigation, and the use of drought-resistant crop varieties. Investing in infrastructure such as advanced irrigation systems and practices like afforestation and agroforestry can help prevent windstorm. Additionally, integrated pest management programs and disease control measures should be targeted at specific invasive pests and diseases affecting local crops and livestock. Supporting afforestation and agroforestry initiatives not only reduces windstorm and drought pressures but also enhances soil stability and biodiversity.

To further enhance agricultural productivity and resilience, continued support for the development of irrigation systems and farmer training is crucial. Addressing the barriers faced by farmers who feel unsupported in capacity building and extension services can improve the effectiveness of these programs in managing climate change impacts. Upgrading early warning systems to provide timely and relevant information will aid farmers in coping with climate challenges. Promoting female participation in farming and conservation efforts and strengthening policies to encourage youth involvement in agriculture, particularly with technological integration and climate change awareness, are key. Additionally, providing tailored support for older farmers, addressing their specific needs related to land ownership, subsistence farming, and limited pension and social security, is necessary to ensure their continued contribution to the agricultural sector.

REFERENCES

1. Altheide, D. L., & Johnson, J. M. (1994). Criteria for assessing interpretive validity in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 485-499).
2. Annappa, N. N., et al. (2023). *Climate change's threat to agriculture: Impacts, challenges, and strategies for a sustainable future* (pp. 113-136). New Delhi: AkiNik Publications.
3. Gakwaya, A., et al. (2021). "Impact of Extreme Weather Events on Agriculture in Rwanda." Journal of Climate and Agricultural Research, 18(4), 215-230.
4. Munyabugingo, E., et al. (2023). "Climate Variability and Its Impact on Crop Production in Rwanda." African Journal of Agricultural Research, 14(6), 290-304.
5. Nkurunziza, J., et al. (2022). "Climate Change Impacts and Adaptation Strategies in Rwanda." East African Journal of Sciences, 16(1), 12-25"
6. Bebber, D. P., & Gurr, S. J., et al. (2013). Crop pests and pathogens move poleward in a warming world. *Nature Climate Change, 3*(11).
7. Brown, A., & Johnson, L. (2022). Adapting Agriculture to Climate Change: Strategies and Challenges. *Environmental Research Reviews, 19*(1), 78-95.
8. Cacciattolo, M. (2015). Ethical considerations in research. In *The praxis of English language teaching and learning (PELT)* (pp. 61-79).
9. Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications.
10. Daniel, W. W. (1999). *Biostatistics: A foundation for analysis in the health sciences* (7th ed.). New York: John Wiley & Sons.
11. El Bilali, H., Bassole, I. H. N., Dambo, L., & Berjan, S. (2020). Climate change and food security. *Agriculture and Forestry, 66*(3), 197-210.
12. FAO. (2022). *State of Food Security and Nutrition in Rwanda*
13. Food and Agriculture Organization (FAO) et al. (2021). *The state of food security and nutrition in the world: Transforming food systems for food security, improved nutrition and affordable healthy diets for all*. Rome.
14. Food and Agriculture Organization (FAO). (2022). *Food and Agriculture Organization strategy on climate change 2022–2031*. Rome.
15. Food and Agriculture Organization (FAO). (2022). *The state of food security and nutrition in the world 2022: Repurposing food and agricultural policies to*

make healthy diets more affordable. Retrieved from https://www.fao.org/publications/sofi/2022/en/

16. Food and Agriculture Organization (FAO)**.** (2023). *Rwanda Country Profile*. Retrieved from FAO website.
17. Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59-82.
18. Harish, K. T. (2016). *Research methodology in social sciences: A short manual*. New Delhi: Corvette.
19. Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.
20. Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate change 2022: Impacts, adaptation, and vulnerability.* Retrieved from https://www.ipcc.ch/report/ar6/wg2/
21. Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2023: Synthesis Report. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/
22. Interview with farmers at Karangazi and Rwimiyaga sectors, May 2024.
23. Isaac, M. E. (2024). Shade tree trait diversity and functions in agroforestry systems: A review of which traits matter. *Journal of Applied Ecology*, *00*, 1–11.
24. Jones, R., et al. (2021). Socio-Economic Vulnerability to Climate Change in Agricultural Communities: A Global Perspective. *Global Environmental Change*, *55*, 102367.
25. Karamage, F., et al. (2016). Modeling rainfall-runoff response to land use and land cover change in Rwanda (1990–2016).
26. Keerthana, M., & Shashank, D. U. (2023). Emerging insect pest threats. In R. M. Waykule, P. K. Nagarjuna Reddy, & S. A. Mujee (Eds.), *Entomological mosaic: Varied visions on insect science* (Vol. 1, pp. 382-404). Stella International TM Publication.
27. Kumar, R. (2005). *Research methodology: A step-by-step guide for beginners* (2nd ed.). Singapore: Pearson Education.

28. REMA.(2021). B*aseline study for the project "Building the capacity of Rwanda's government to advance the national adaptation planning process."* Final report submitted to Rwanda Environment Management Authority. Social Economic Studies, Surveys, Monitoring and Evaluation Consult Limited.
29. Lazarus, R. S., & Folkman, S. (1984). Stress, Appraisal, and Coping. New York: Springer Publishing Company.
30. Lindgren, B. W. (1975). *Basic ideas of statistics*. New York: Macmillan Publishing Co. Inc.
31. Lobell, D. B., et al. (2013). The critical role of extreme heat for maize production in the United States. *Nature Climate Change, 3*(5), 497-501.
32. Marsh, D., & Stoker, G. (1997). *Theory and method in political science*. Washington: St. Martin's Press, Inc.
33. Martinez, J., Garcia, R., Lopez, M., & Sanchez, P. (2010). Scale categorization in farming: Small, medium, and large scale. *Journal of Agricultural Economics*, *42*(3), 215-230.
34. Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., & Zhou, B. (2021). Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the Intergovernmental Panel on Climate Change, *2*(1), 2391.
35. METEO and REMA. (2022). *Downscaled climate projections for national adaptation plan in Rwanda: Summary of technical report*. Kigali.
36. Ministry of Environment (MoE). (2019). *National environment and climate change policy*. Government of Rwanda.
37. Ministry of Environment (MoE). (2020). *Rwanda's nationally determined contribution*. Government of Rwanda.
38. Mohajan, H. K. (2017). Two criteria for good measurements in research: Validity and reliability. *Annals of Spiru Haret University Economic Series*, 17(4), 59-91.
39. Mohajan, H., K. (2017). Two Criteria for Good Measurements in Research: Validity and Reliability, *Annals of Spiru Haret University Economic Series, pp 59-91*
40. Muhire, I. (2015). Climate change and variability and their impacts on the yields of major food crops in Rwanda.

41. Muneza, L. (2022). Droughts and floodings implications in agriculture sector in Rwanda: Consequences of global warming. IntechOpen. https://doi.org/10.5772/intechopen.98922
42. Mupenzi, J. P., et al. (2012). Radical terraces in Rwanda. *East African Journal of Science and Technology, 1*(1), 53-58.
43. National Institute of Statistics of Rwanda (NISR). (2018). *Rwanda fourth population and housing census 2012 – Thematic report on climate change and agriculture*.
44. National Institute of Statistics of Rwanda (NISR). (2022). *5th Rwanda population and housing census (PHC)*. Government of Rwanda.
45. National Institute of Statistics of Rwanda (NISR). (2022). *Agriculture sector overview*. National Institute of Statistics of Rwanda.
46. National Institute of Statistics of Rwanda (NISR). (2023). *Gross domestic product – 2023 Q1*.
47. National Strategy for Transformation (NST1)**.** (2023). *Government of Rwanda*. Available on the Ministry of Finance and Economic Planning website.
48. Ojumu, O., et al. (2020). A theoretical framework for assessing the impact of climate change on crop yields. *AIMS International Journal of Management, 14*(2), 65-87.
49. Onah, M. (2011). Out-of-pocket payments, health care access and utilisation in south-eastern Nigeria: A gender perspective (Master's dissertation, University of Cape Town, South Africa).
50. Pretty, J. N., Smith, D., Goulding, K. W. T., Groves, S. J., Henderson, I. C., Hine, R. E., van der Bijl, G., Bonn, A., Jones, P., Morris, C., Penning de Vries, F. W. T., & Sutherland, W. J. (2010). The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability, 8*(4), 219-236.
51. Quandt, A., et al. (2023). Climate change adaptation through agroforestry: Opportunities and gaps. *Environmental Sustainability*.
52. Ramni, J. (2015). Forests, trees, and landscapes for food security and nutrition: A global assessment report. In B. Vira, C. Wildburger, & S. Mansourian (Eds.).
53. Republic of Rwanda, (2018). Third National Communication, Kigali, Rwanda.

54. Rosa, L. (2022). Adapting agriculture to climate change via sustainable irrigation: Biophysical potentials and feedbacks. *Environmental Research Letters, 17*(6), 14.
55. Rwanda Agriculture Board (RAB). (2020). *Improving and updating Rwanda irrigation master plan*.
56. Rwanda Forestry Authority (RFA). (2017). *Forest investment program for Rwanda*. Kigali: World Bank.
57. Rwanda Meteorological Agency. (2021). *Climate Monitoring Report*. Kigali: Rwanda Meteorological Agency.
58. Rwanda Ministry of Agriculture and Animal Resources (MINAGRI)**.** (2023). *Annual Agriculture Sector Report*. Available on the official website.
59. Rwanda National Institute of Statistics**.** (2023). *Economic and Social Indicators*. Available on their official website
60. Sethi, P., Gautam, S., & Sharma, M. (2020). *Food loss and waste in Rwanda: Challenges and solutions*. Journal of Agriculture and Food Research, 12(3), 123-135.
61. Simarjeet, K. (2017). Sample size determination. *International Journal of Current Research, 9*(3), 48365-48367.
62. Smith, J. (2023). Modern agricultural practices and sustainability. *Journal of Agricultural Sciences*, *12*(3), 145-162.
63. Smith, J. (2023). Modern Agricultural Practices and Sustainability. *Journal of Agricultural Sciences*, *12*(3), 145-162.
64. World Bank. (2023). *Rwanda Agriculture Sector Review*.
65. World Bank**.** (2023). *Rwanda Economic Update: Agriculture and Economic Growth*. Retrieved from World Bank website.
66. World Food Programme. (2020). *Rwanda: Drought Impacts on Food Security*. Retrieved from [WFP website].
67. Wright, S., O'Brien, B. C., Nimmon, L., Law, M., & Mylopoulos, M. (2016). Research design considerations. *Journal of Graduate Medical Education, 8*(1).
68. Rwanda Meteorological Agency. (2023). *Climate Change Impacts in Rwanda: Annual Report*.
69. WFP. (2021). *Drought Impact Assessment in Rwanda*.
70. RAB (Rwanda Agriculture Board). (2022). *Climate Change and Coffee Yields in Rwanda*.

71. World Bank. (2023). *Building Resilience in Rwandan Agriculture: Strategies for Climate Change*
72. FAO. (2019). Fall Armyworm: Impact and Implications for Africa. Food and Agriculture Organization of the United Nations.
73. Songa, J., et al. (2020). Climate Change and the Spread of Invasive Pests in East Africa. *Journal of Climate Research, 22*(3), 123-135.
74. Rwiza, E., et al. (2021). Farmer Knowledge and Practices in Pest Management in Rwanda. *Agricultural Systems, 182*, 102760.
75. Kamanzi, F., & Mugisha, J. (2022). Socio-economic Impacts of Pest and Disease Outbreaks in Rwanda's Agriculture. *African Journal of Agricultural Research, 17*(4), 245-256.Rwanda Environment Management Authority (REMA). (2019). *State of the environment report 2019*. Kigali, Rwanda: Author.
76. Ministry of Agriculture and Animal Resources (MINAGRI). (2021). *Annual agricultural report 2020*. Kigali, Rwanda: Author.
77. Rwanda Meteorological Agency (RMA) & University of Rwanda. (2021). *Impact of climate change on agriculture in Rwanda: A focus on heavy winds*. Kigali, Rwanda: Author.
78. Rwanda Environment Management Authority (REMA). (2009). *Rwanda state of environment and outlook report*. Kigali, Rwanda: Author.
79. Rwanda Environment Management Authority (REMA). (2011). *Rwanda state of environment and outlook report*. Kigali, Rwanda: Author.
80. Ministry of Agriculture and Animal Resources (MINAGRI). (2014). *Strategic plan for the transformation of agriculture in Rwanda Phase III*. Kigali, Rwanda: Author.
81. National Institute of Statistics of Rwanda (NISR). (2012). *Seasonal agricultural survey*. Kigali, Rwanda: Author.
82. Ministry of Agriculture and Animal Resources (MINAGRI). (2018). *Crop intensification program*. Kigali, Rwanda: Author.
83. World Bank. (2020). *Building resilient agriculture systems in Rwanda*. Washington, DC: Author.
84. Rwanda Agricultural Board (RAB). (2023). *Annual Report on Irrigation Expansion in Rwanda*. Kigali: RAB.

85. Kamanzi, M., Nsabimana, B., & Uwizeye, B. (2024). "Impact of Small-Scale Irrigation Schemes on Crop Productivity in Nyagatare District." *Journal of Agricultural Research and Development,* 15(2), 123-134.
86. National Institute of Statistics of Rwanda (NISR). (2024). *Economic Impact of Irrigation on Household Income*. Kigali: NISR.
87. Rwanda Water Resources Board (RWRB). (2024). *Survey Report on Farmers' Perceptions of Irrigation Systems*. Kigali: RWRB.
88. Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). Wiley.

Annexes

QUESTIONNAIRES AND INTERVIEW GUIDES

Introduction

I; TURATSINZE Edouard; am regular student from University of Rwanda, school of architecture and built Environment (UR) college of Science and Technology (CST) do research under Nyagatare District, Approval letter **No 3346/07/05/02/HR/NY/08**. I am conducting a research on project entitled "**Climate Change Impacts on Farming activities and Coping Strategies of Local Farmers in Rwimiyaga and Karangazi Sectors, Nyagatare District (2003-2024).)".** My research shall gather information from different categories of including representative of farming cooperatives, local farmers, key informant from MINAGRI and its affiliated agencies, MoE, METEO Rwanda, local leaders as well as representatives of civil society organisation involved in agricultural sector in Nyagatare District especially in Karangazi and Rwimiyaga Sectors. The data collection from different respondents mentioned will help the research to:

iv. Assess the climate change impacts on agriculture at Karangazi and Rwimiyaga Sectors in Nyagatare District.

v. Evaluate the farmers' perceptions on the impacts of climate change on farming at Karangazi and Rwimiyaga Sectors in Nyagatare District.

vi. Suggest coping strategies used by local farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors in Nyagatare District.

The information provided by respondents will be used only for the purpose of this research and will be kept confidentially. Information will be collected by distributing questionnaires to be filled, conducting semi-structured and informal interviews and through focus groups discussions. The researcher will not impose any of the respondents to answer to his questions instead the respondents shall willingly accept to be interviewed or fill the questionnaire. If the informant gets any questions to be clarified, he/she will be given clarification.

SECTION ONE: PERSONAL DETAILS

Questions

1. **Respondents' Gender Distribution**

Male ☐

Female ☐

2. **Respondents' Age Distribution**

Between 18 and 30 ☐

Between 31 and 43 ☐

Between 44 and 55 Yes

Above 55 ☐

3. Marital status of respondents

Single ☐

Divorced ☐

Married ☐

Widow ☐

4. Respondents According to the level of Education

Illiterate ☐

Primary level ☐

Secondary ☐

Bachelor's Degree ☐

Master's Degree ☐

PhD ☐

SECTION TWO:

a. Droughts affected farming at Karangazi and Rwimiyaga Sectors in the following manner:

Indicate how agreeable you are with the statement by placing a tick (V) against correct option of your choice in the table below:

1. Very high, 2. High, 3. Low, 4. Neutral, 5. Not at all

No	**Alternative choices**	**1**	**2**	**3**	**4**	**5**
1	Droughts damaged crops (maize, beans, cassava, folders of animals)					
2	Droughts decreased crops and livestock production and productivity (maize, beans, cassava, banana, milk production)					
3	Droughts caused diseases attach in crops and livestock					

b. Windstorm and erosion affected farming at Karangazi and Rwimiyaga Sectors in the following manner:

Indicate how agreeable you are with the statement by placing a tick (V) against correct option of your choice in the table below:

1. Strongly disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Strongly agree

No	**Alternative choices**	**1**	**2**	**3**	**4**	**5**
1	Windstorm and erosion damaged crops and livestock in Karangazi and Rwimiyaga Sectors.					
2	Windstorm and erosion damaged arable land and farming facilities (marshlands, drying shelters,					

	storages, valley dams, shelters) in Karangazi and Rwimiyaga Sectors					
3	Windstorm and erosion decreased crops production and productivity (maize, beans, cassava, banana)					

C. Invasive pests and diseases affected farming at Karangazi and Rwimiyaga Sectors since 2003?

Indicate how agreeable you are with the statement by placing a tick (V) against correct option in the table below:

1. Strongly disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Strongly agree

No	**Alternative choices**	**1**	**2**	**3**	**4**	**5**
1	Invasive pest and diseases affected crop production					
2	Invasive pests increased diseases attach in crops and livestock (Cyumya, etc)					
3	Invasive pest and diseases causes hunger among local farmers					

D. Coping strategies which facilitated farmers to deal with climate change impacts on farming at Karangazi and Rwimiyaga Sectors since 2003.

Indicate how agreeable you are with the statement by placing a tick (V) against correct option in the table below:

1. Strongly disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Strongly agree

No	**Alternative choices**	**1**	**2**	**3**	**4**	**5**
1	Adoption of afforestation and agroforestry reduced the windstorm (erosion) pressure on crops and livestock					
2	Adoption of afforestation and agroforestry reduced the droughts pressure on crops and livestock					

3	Adoption and enforcement of irrigation system on large and small scale increased farmers' crops production and productivity					
4	Adoption and enforcement of irrigation system on large and small scale reduced droughts effects on farming					
4	Capacity building of local farmers and extension services facilitated farmers to deal with climate change impacts on farming					
5	Early Warning Systems facilitated farmers to deal with climate change impacts on farming					

Interview guide used

a. Can you tell me a bit about what you do as farming cooperative?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………

b. What do you understand by climate change?

…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………

c. Have you notice any kind of climate change in this area (Karangazi and Rwimiyaga Sector) since 2003?

Yes

No

d. If yes, what are the climate change impacts manifestation have you noticed specifically at Karangazi and Rwimiyaga Sectors?

…………………………………………………………………………………
…………………………………………………………………………………

……………………………………………………………………………………
……………………………………

e. How and to what extend did windstorm affect farming at Karangazi and Rwimiyaga Sectors ?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………

f. What are farming facilities damaged by droughts at Karangazi and Rwimiyaga Sectors since 2003?

g. ……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………

h. How did invasive pests and diseases affect farming at Karangazi and Rwimiyaga Sectors since 2003?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
………………………

i. How did adoption of afforestation and agroforestry reduce the floods (erosion) pressure on crops and livestock?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
………………………

j. How did adoption of afforestation and agroforestry reduce the droughts pressure on crops and livestock?

……………………………………………………………………………………
……………………………………………………………………………………

………………………………………………………………………………
……………………………………

k. How did adoption and enforcement of irrigation system on large and small scale reduce droughts effects on farming?

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
………………………

l. How did capacity building of local farmers and extension services facilitate farmers to deal with climate change impacts on farming?

…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
………………………

m. How did Early Warning Systems facilitate farmers to deal with climate change impacts on farming?

n. ………………………………………………………………………………
………………………………………………………………………………
………………………………………………………………………………
……………………………………

DATA COLLECTION AUTHOLIZATION LETTER

REPUBLIC OF RWANDA

Nyagatare, On 15th /04/2024

No..................07/05/02/HR/NY/08

3346

RWIMIYAGA SECTOR DATE 29 /04 /2024 RECEPTION

RECEPTION 29 APR 2024 KARANGAZI SECTOR Signature:

EASTERN PROVINCE
NYAGATARE DISTRICT
B.P 20 NYAGATARE
info@Nyagatare.gov.rw

TO: Dr. Josephine MALONZA

Dean, School of Architecture and Built Environment (SABE)

College of Science and Technology- UR

Ref: Research Approval Letter

I **HATEGEKIMANA Fred,** District Executive Secretary of Nyagatare, I accept **TURATSINZE Edouard** a Student from University of Rwanda, School of Architecture and Built Environment to do research in Nyagatare District upon the research on project entitled "**Climate Change Impacts on Farming Activities and Coping Strategies of Local Farmers in Rwimiyaga and Karangazi Sectors, Nyagatare District (2003-2024)".** The research will start on 22nd April to 31th May 2024, you will work with under supervision of Director of Agricultural and Natural Resources Unit.

Best Regards.

HATEGEKIMANA Fred

District Executive Secretary of Nyagatare

CC:

Mayor of Nyagatare District

Vice Mayors (Both)

Corporates Service Division Manager

REPUBLIC OF RWANDA

MINISITERI Y'UBUHINZI N'UBWOROZI

MINISTRY OF AGRICULTURE AND ANIMAL RESOURCES

OFFICE OF THE PERMANENT SECRETARY

Kigali, 30 APR 2024
Nº 0909/11:30/PS

Mr. Edouard TURATSINZE
University of Rwanda
Tel: 0788915032

Dear Mr. Edouard,

Subject: Authorization to collect data

Reference is made to your letter addressed to the Ministry of Agriculture and Animal Resources (MINAGRI) requesting for authorization to conduct data collection as part of academic requirements;

In this regard, we formally authorize you to conduct data collection activities within the Ministry of Agriculture and Animal Resources (MINAGRI). This authorization is granted under the understanding that you will adhere to the guidelines and protocols set forth regarding data collection procedures with professionalism and respect towards MINAGRI staff and facilities during the data collection process.

The authorization is valid from April 30th to May 2nd, 2024 and Mr. Emmanuel TWAGIRAYEZU; Irrigation and Mechanization Specialist; telephone: 0788640537 will facilitate you.

Sincerely,

Dr. Olivier KAMANA
Permanent Secretary

Cc
- Honourable Minister of Agriculture
- Honourable Minister of State in the Ministry of Agriculture and Animal Resources
- Mr. Emmanuel TWAGIRAYEZU Irrigation and Mechanization Specialist

P.O Box 621, Kigali e-mail: info@minagri.gov.rw Website: www.minagri.gov.rw