Sarnoh, Yusuff Mohammed (2024) *Assessment of climate risks in Central and Northern Liberia.* PhD thesis.

Assessment of Climate Risks in Central and Northern Liberia

Yusuff Mohammed Sarnoh

Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

School of Geographical and Earth Sciences
College of Science and Engineering

February 2024

Abstract

Climate change and variability is adversely affecting smallholder farming households in Africa and particular in Liberia because their activity depends on climate-regulated water resources such as rainfall. However, the responses of affected districts have elicited relatively limited attention from policy makers and academic researchers, and in particular, little is understood about the complex factors that shape how farming households have sought to tackle the impact of climate change and variability. This thesis addresses this gap by analyzing the ways in which rural farmers in six districts in central and northern counties of Liberia have sought to adapt to climate variability. The study combined insights from a risk analysis framework with sustainable livelihoods approaches and the concept of adaptation strategies to advance the understanding of climate risk. This research deploys a mixed method, multi-scale approach in central and northern Liberia where rural farmers continue to be affected by climate variability. Questionnaires, semi-structured interviews, key informants' interviews, policy discussion with experts and desk review of national policy documents are used to elicit the extent of crop production (mainly rice and cassava) and livelihood risk as a result of climate change and variability across multiple scales: mapping exposure, vulnerability and risk at the district levels. The study results show that Liberia has been impacted by climate variability, as evidenced in the average temperature and rainfall variability. Results demonstrate that risk of crop production to climate variability (especially dry spells or delayed rainfall) has obvious geographical and socioeconomic patterns, with the central and northern counties being exposed and vulnerable. The results of the risk assessment are used to guide local level research and demonstrate the need for county-specific policies to reduce climate risk and enhance delayed rainfall or dry spells preparedness within dryland farming districts. Within the same agroecological environment, different districts experience different risks attributed to differences in socioeconomic characteristics. The results of the study also indicate that climate risk of farming households can be linked to access to livelihood capital assets and that exposed, and susceptible districts tend to have farmers that are considered by low levels of natural, financial, physical and social capitals. Although farmers use a variety of coping and adaptive strategies such as crop diversification, planting of drought resistant plants, changing the time of planting and early maturing varieties of crops, livelihood diversification, crop rotation/shifting cultivation, temporary migration, relying on help from family and friends and reducing food consumption to manage climate variability, these are insufficient to prevent them from being affected by food insecurity. Results further indicate a variety of challenges such as poor access to information on climate adaptation, limited access to markets, lack of financial resources, complex land tenure systems, social cultural barriers, limited access to improved varieties of crops, as well as a lack of institutional support pose serious barriers to adaptation.

The implication of this study is that policy makers need to play a significant role in formulating appropriate and targeted climate adaptation policies that promote the development and planting of improved varieties of crops; enable farmers to engage in different livelihood diversification strategies; and allow for the provision of institutional support such as access to information on climate adaptation and adequate all-year-round extension services. Such policies should be linked to programmes that promote asset building as well as enhance institutional capacity and social capital in the study counties and Liberia in general.

Table of Contents

List of Tables

List of Figures

Acknowledgements

Firstly, I am pleased to express my thanks to the Almighty God for giving me the opportunity, courage, and strength to attend this great University (University of Glasgow), to pursue a PhD in Geographical and Earth Science (with emphasis in Environment and Climate Change). Secondly, I want to acknowledge the United States Department of Education for giving me the opportunity to benefit from the student loan which allow me to pursue this programme. Without their financial support, this PhD would not have been possible.

The completion of this PhD would not have been possible without the input and support from several people to whom I am extremely indebted and grateful. Special thank-you and appreciations are to my supervisors Professor Jaime Toney, Dr. Brian Barrett and Professor Fabrice Renaud. Jaime, thanks for all your help and guidance throughout this research. In particular, the weekly Lab Meetings during the COVID -19 periods and after, and all the time and efforts you put into edits and going over (and over) my works were fantastic. Fieldwork to Liberia was an absolute highlight of my PhD study, thanks for the guidance throughout the data collection and analysis. Everything you have done has helped me progress throughout my PhD and I appreciate it. Brian, I must extend many thanks for being on hand in meetings and making sure I stay on track for completing my PhD. Your advice has been invaluable to me most especially during the learning of my data analysis tools such as R software package and ArGIS Pro. The technical advice giving me during the analysis and presentation of my tables and figures and also reading through my chapters over and over were very incredible. Fabrice, even though you were not involved as a primary supervisor, I would like to say a massive thank-you for giving me such a wonderful opportunity and also for continuing to be involved with this study. This study would not have been possible without all your hard work reading through my chapters as well. I appreciate your support so much.

My thanks and appreciations go to my both parents who could not live to witness me complete this programme, but I am always inspired by their love for educational development and contribution to the community. I wish you both were alive to see your son coming with a PhD from one of the best Universities in the World. May your souls continue to Rest in Perfect Peace! My gratitude also goes to my dearest wife Sara V. S Sarnoh and my children for giving me the required support through my study. I love you all so much for your care and contributions during my studies.

My thanks goes to my weekly BECS members, that have listened, questioned, and assisted me during countless talks about my research. In particular, I would like to thank Charlotte

Slaymark, Dr. Bianca Cavazzin, and Mr Mohammad Salik. Thank you all for your help supplying me with good papers to read, and R codes for my analysis. Having you part of the group has been inspirational and I can’t thank you enough. I will always remember you for the wonderful advice during my studies.

I am also grateful to the IT unit of the University of Glasgow, for their support throughout the period of my study.

To my fellow postgraduate research students, we have had a lot of highs and lows in that office, and I couldn’t imagine spending the past three years with anyone else: Fakhri Bintang, Kang Xie, Cameron Floyd, Seyi Adewale Adebange, Neve Norris, Faisal Khudhur, Md Janhangir Alam Ruben and the rest of the PGR students. I’m not sure I could have done this without you. Thanks for being the friendly face in the office when I started. You were my first friend in Glasgow, and you will always be my friends after Glasgow.

Many thanks to my best friend and apartment mate, Kwetishe Joro Danjuma. Danjuma and I started our research together in the same month at the University of Glasgow. We collaborated throughout during the COVID- 19 period, given one another advice and supports. Thanks for all the support, encouragement, and friendship over the years. Thanks for the nights in, nights out. Above all, thanks for our daily and weekly phone calls and discussion, and for all the good times in between.

Many thanks are due to the World Bank Climate Change Portal, Climate Research Unit (CRU), University of East Anglia for giving easy access to download all the necessary climate data for this study. Many thanks also go to the Liberian people, most especially the six districts of Bong and Lofa Counties, LISGIS, MOA and the EPA for giving me the time to answer to my questionnaires.

Finally, my love and gratitude are expressed to my family and friends, especially, my big Brothers Salieho M. Sarnoh and Family, Sekou N Sarnoh and family, Mohammed M. Daramay and family, Talata M. Sheriff and family, my friend Amara Keita, and my nephew Abrahim Bility and family, my friend, and brother Alhaji Mohammed M. Kiawhen and family, Hassan Kromah and family, and T. Calvin Kollie and family for your help and concern. Without your advice and encouragement, this study would not have been successful. With all my heart, I thank you all for your wonderful support.

Yusuff Mohammed Sarnoh

February 2024

Author’s Declaration

I declare that this research, except where acknowledged to others, represents my own work carried out in the School of Geographical and Earth Sciences, University of Glasgow, Central and Northern Liberia, the Liberia Institute of Statistics and Geo-Information Services (LISGIS), the Ministry of Agriculture (MOA), Liberia and the Environmental Agency of Liberia (EPA).

The research presented here has not been submitted for any other degree at the University of Glasgow, nor at any other institution. Any published or unpublished work by other authors has been given full acknowledgment in the text.

Yusuff Mohammed Sarnoh

February 2024

Abbreviations

AfT	Agenda for Transformation
APFS	Agricultural Policy and Food Security in Liberia
CBL	Central Bank of Liberia
EPA	Environmental Protection Agency of Liberia
FAPS	Food and Agricultural Policy and Strategy
FDA	Forestry development authority
GCF	Green climate fund
GDP	Gross domestic product
GEF	Global environment facility
GHG	Greenhouse gas
GoL	Government of Liberia
HIES	Household Income and Expenditure Survey
INC	Initial national communication
IPCC	Intergovernmental Parnel on Climate Change
KII	Key informant interview
LASIP	Liberia agriculture sector investment plan
LC	Land commission
LISGIS	Liberia Institution of Statistics and Geo-Information Services
LNDP	Liberia national drought plan
M&E	Monitoring and Evaluation
MFDP	Ministry of Finance and Development Planning
MOA	Ministry of Agriculture, Liberia
MOFA	Ministry of Foreign Affairs
MOGSP	Ministry of Gender and Social Protection
MOLME	Ministry of Lands Mines and Energy
MOT	Ministry of Transport
MPEA	Ministry of Planning and Economic Affairs
MRV	Measurement, Reporting, and Verification
NAP	National adaptation plan
NAPA	Liberia National Adaptation Programme of Action
NCCSC	National climate change steering committee

NDA	National designated authority
NDC	Liberia’s nationally determined contribution
NDMA	National disaster management agency
NEP	National Environmental Policy of Liberia
NGOs	Non-governmental Organization
NPRSCC	National Policy and Response Strategy on Climate Change
PAPD	Pro-Poor Agenda for Prosperity and Development
RAs	Research assistant
SDGs	Sustainable development goals
SNC	Second national communication
SSA	South Sahara Africa
UN	United nations
UNCCD	United Nations Convention to Combat Drought
UNECA	United Nations Economic Commission for Africa
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1 Assessment of Climate Risks in Central and Northern Liberia

1.1 Introduction

The Earth's climate system has gradually changed since the last glacial period with more climatic risks intensifying in the 21st century (Intergovernmental Panel on Climate Change (Osei-Amponsah et al., 2023). According to the IPCC (2014) synthesis report, climate change poses both risks and disasters, and generates opportunities for adaptation learnings of social systems. Climate risk encapsulates the magnitude of a climatic event, its likelihood, and associated consequences of that event (Challinor et al., 2018). It manifests in diverse ways across different spatial and temporal scales (Dickinson et al., 2017). Climate sensitive sectors such as agriculture and forestry will be disproportionately affected by changing rainfall patterns and increasing temperature (Loucks, 2021; Dube et al. 2016). Africa is particularly at risk and vulnerable to the threats posed by climate change due to socio-economic and political problems, low adaptive capacity and multiple stressors across different scales and sectors (Busby et al. 2020). Climate-crop modelling studies suggest that agriculture will be disproportionately affected compared with other sectors (Farooq et al. 2022; Campbell et al. 2016; Thornton et al. 2019; Owusu-Sekyere, 2024). There is an urgent need for interdisciplinary study that combines insights into crop food production with socioeconomic evaluations of farming communities in order to better understand how climate change and variability may affect crop food production systems and rural livelihoods (Gomez-Zavaglia et al. 2020). This approach is important because it allows different dimensions of climate change and variability to be explored. By bringing together different disciplines such as agricultural science, ecology and environmental sustainability, a more comprehensive explanation of climate change and its impacts on people can be achieved (Osinski, 2021; Silva et al. 2022). This is particularly important in Africa, especially sub-Saharan Africa which is projected to be severely affected by climate change and variability (Haile et al. 2018; Pironon et al. 2019; Ezekannagha, 2020), where substantial proportion of the farmers heavily depend on rain-fed agriculture for their livelihood (Wudil et al. 2022; Ayanlade et al., 2022).

Africa faces multiple development challenges, including food insecurity, resource degradation, poverty, gender inequality, and social exclusion, aggravated by yield stagnation and climate change. Smallholder production is estimated to account for 50-70% of global food production (Giller et al. 2021) and increasing food demand for the growing population was mostly coming from land expansion, with a 34% crop land increase in Africa between 2003 and 2019 (Potapov et al. 2022). Climate models suggest that SSA will experience a temperature rise of 2-4 °C by 2100, which represents an increase of about 1.5 times higher than the projected mean global temperature increase (Egbebiyi et al. 2020; Christensen et al. 2022). Furthermore, increases in agricultural productivity have been slowest in SSA compared with the rest of the world (Adamou et al. 2021; Giller et al. 2021). In an assessment of risk to climate related mortality, 33 out of the 59 countries found to be highly or moderately-highly vulnerable were situated in SSA (Quinn et al. 2020).

Liberia is an appropriate place to investigate these issues because agriculture is the backbone of its economy, contributing more than 30% of the country's Gross Domestic Product (GDP) and sustains the livelihoods for ~60% of the population (MOA, 2010; HIES, 2016). Agriculture is the main source of income for many low-income Liberians' families, employing about 47% of the population (CBL, Annual Report, 2016, HIES, 2014), while the agricultural sector contributes significantly to the foreign exchange earnings of the country. It is also important to note that the agricultural sector contributes to development through its provision of raw materials such as rubber, cocoa and coffee to local industries (MOA, 2012). Despite the socioeconomic importance of the agricultural sector, Liberia's agricultural sector is arguably one of the most climate sensitive sectors because of its dependence on rain-fed cultivation. The amount and pattern of rainfall plays a key role in determining agricultural productivity (Haile et al. 2020). Crops yields in Liberia are projected to decrease by more 10% by 2026 due to projected decreases in rainfall and increases in temperature linked to climate change and variability (EPA, 2021). This has the potential to severely affect food security because maize is grown and consumed in almost every part of the country.

Liberia has experienced considerable variations in temperature and rainfall patterns since the 1980s (EPA, 2019; 2021). Whilst uncertainties remain on future estimates of rainfall and temperature change, the general sense is that temperature will increase whilst rainfall decreases in all agro-ecological zones in Liberia (EPA, 2019). The ensemble of 21 climate models used by the Intergovernmental Panel on Climate Change (IPCC) suggests that there will be increased total precipitation in the south of the country whilst the northern parts of Liberia will become drier (Christensen et al., 2007). For instance, the IPCC model ensemble has projected that a reduction of 80 mm in monthly rainfall is possible in the north, particularly during the March - May farming season (EPA, 2019, 2021). This will be exacerbated by high interannual rainfall variability, characterized by a reduction in the number of rainy days (Giller et al. 2021). Sixty years climate projection by the Liberia Environmental Protection Agency (EPA) revealed a rise of about 0.8 °C in temperature and a variability in rainfall (EPA, 2019). Whilst the country's temperature has been predicted to increase, based on future climate change scenarios using General Circulation Models, by 0.8 °C by the years 2100, rainfall, on the other hand, has been predicted to increase with severe variability. Increased temperature coupled with variability in rainfall will affect water resources. Reduction in water flow will result in enhanced soil moisture deficits and increased evapotranspiration, shortening the length of the growing season. This could have serious implications for agricultural productivity in several communities across the country. Coupled with extreme events such as delayed rainfall or dry spells and floods, it could result in crop failure and food insecurity across many parts of the country.

Food security and rural livelihoods in Liberia and SSA more widely will therefore be placed under considerable stress due to climate change and variability (Chirwa and Adeyemi, 2020; Momolu, 2023). Cereals including maize, millet and sorghum, which serve as important staple food crops are extremely vulnerable (particularly to drought) (Muiruri et al. 2021), as these crops require an appreciable quantity of rainfall for their growth. Similarly, yields of other crops such as potatoes beans are expected to reduce by 12.8%, 25% in 2025, 2027 respectively. In addition, the livelihoods of poor smallholder farmers are disrupted by delayed rainfall or dry spells and floods due to climate variability, thereby increasing their vulnerability to food insecurity (HIES 2016, MOA, 2012).

The intra-annual rainfall variability and increased temperature are also situated in a myriad of other political, economic, social and environmental challenges (EPA, 2019). This has adverse consequences for Liberia's development because the economy is dependent on rain-fed agriculture. This shows that the agricultural sector in Liberia is extremely sensitive to the adverse impacts of climate variability (EPA, 2019), hence the need to explore the extent of climate risk and provide appropriate policy interventions. Despite the projected increase in temperature and variability in rainfall, data on the nature and extent of climate risk of Liberia's crop food systems and rural livelihoods to climate change and variability are lacking and this hampers the development of effective policy to reduce the adverse impacts of climate change and variability. For instance, little is known about how farmers cope and adapt to changing climatic conditions in different parts of the country. As such, it is uncertain from a policy perspective how to best enhance national coping and adaptive capacities. This research seeks to provide empirical understanding of the factors and drivers that contribute to risk to climate change and variability in crop food production systems and rural livelihoods in Liberia and thereby provides insights into the processes that are needed to create the capacity to cope and adapt. A better understanding of the risks posed by climate change and variability, particularly delayed rainfall or dry spells will provide guided policy recommendations to improve crop food production, livelihoods and agricultural practices in Liberia.

Mapping climate risk in Liberia is important because the IPCC's regional assessments of climate change impacts for Africa (Boko et al., 2007 and Knox et al., 2012) imply declining grain yields are likely and predict that agricultural production and food security in SSA will be negatively affected particularly relating to increased drought intensity and frequency linked to greater inter-annual rainfall variability. Furthermore, the impacts of climate change and variability on food production in SSA will vary spatially and understanding the complexity of such systems requires further investigation through more detailed assessments of key agricultural regions, such as the central and northern counties of Liberia that this study focuses on.

Liberia is a semi-arid agrarian country in West Africa, is highly exposed and sensitive to climate change and associated hazards (Mechiche-Alami and Abdi, 2020; Quenum et al., 2020; Wuokolo, 2022). Increased warming trends, prolonged dry spells, frequent floods are examples of physical climate risks, which can aggravate the risk of communities to food insecurity and poverty in the country (EPA, 2021). Particularly in central and northern Liberia, temperatures and rainfall are dramatically changing and such changes are becoming more severe with intensified extreme events, which may partly be due to the influence of the Saharan climate and weakness of the South-West Monsoon Winds from the Gulf of Guinea (Asare-Nuamah and Botchway, 2019). By taking into consideration the choices of farmers at the rural levels, there is a need to understand how they will be affected by climate change and variability, how they might respond with the resources they have, and how these conditions can be replicated and built upon for successful coping and adaptation strategies. The results of study will have significance for the agricultural crop production systems in Liberia and the West African region more widely.

1.2 Aims and Objectives

The overall aim of this study is to assess climate risks in central and northern Liberia and improve the understanding of the links between Liberia's crops production system, climate change and variability. This is achieved through the following specific objectives:

1. Assessing historical patterns and dynamics of climate between 1981-2020 and how modelled future climate (2020-2100) will impact rice and cassava production in Liberia.
2. Assessing rice and cassava exposure to climate change and its induced hazard.
3. Exploring the nature of vulnerability and risk to climate variability at the district levels.
4. Assessing the different coping and adaptive strategies that have been adopted by the farmers to cope with climate change and variability.
5. Identifying policy recommendations to reduce climate risks of food production systems at the district, county, and national level.

1.3 Justification and Contribution to Knowledge

The overarching aim of this study is to assess climate risks in central and northern Liberia that will improve the understanding of the links between Liberia's crops production system, climate change and variability, particularly rural farming districts. By adopting a mixed method, multi-scale research approach that addresses each of the objectives, this study provides several important academic and policy contributions, namely by:

a) contributing to scientific debates or discussion on the development of integrated risk and vulnerability assessments that can be applied in geographical areas where more detailed data may be lacking. This is especially important for Africa and Liberia in particular, where appropriate climate data are lacking. few climate projections due to lack of appropriate climate data.
b) contributing to the development of an integrated risk assessment that can be applied in geographical areas that are data scarce. This is also important for SSA and Liberia in particular that is dependent on rainfall for crop production.
c) providing theoretical and conceptual understanding of crops production and rural livelihood risk that guides more general discussions on the sorts of livelihood systems that should be able to adapt to future climate change. This would be significant for geographical areas where the theoretical and conceptual understanding are lacking in SSA, particularly Liberia.
d) contributing to scientific discussion by increasing our understanding of how small-scale farmers in the rural communities can cope with the challenges posed by climate change and variability.

e) providing insights into the difficulties or barriers faced by small-scale farmers' adaptation pathways in the context of rain-fed agriculture, thereby providing guided policy recommendations to help enhance food production and reduce livelihood risk in Liberia and beyond.

f) increasing understanding of the drivers of exposure and vulnerabilities to climate change variability in agriculture-dependent households in Liberia to enhance the design and implementation of specific climate adaptation policy.

1.4 Terminology and Concepts

Definition and interpretations of key terminologies such as vulnerability, adaptation, and resilience are yet to have universally agreed definitions. Given that definitions of these terms and concepts are often contested, the working definitions provided here will be applied throughout this research. Justifications for the chosen definitions are provided to frame the analysis and discussions.

Climate Change: this thesis will adopt the United Nations framework Convention on Climate Change (UNFCCC) definition of climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (Kuyper et al., 2018). Natural processes within the climate system, such as changes in ocean circulation, human activities that change the atmosphere's composition through burning fossil fuels and land surface changes through deforestation, reforestation, urbanization, desertification.

Risk: is defined as the possibility of something bad happening. Risk involves uncertainty about the effects/implications of an activity with respect to something that humans' value (such as health, well-being, wealth, property, or the environment), often focusing on negative, undesirable consequences. The international standard definition of risk for common understanding in different applications is "effect of uncertainty on objectives" (IPCC, 2022).

Hazard: is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact-drivers (IPCC, 2022).

Exposure: defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected (IPCC, 2022).

Vulnerability: defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2022).

Adaptive Capacity: the ability of a system (household, or environment) to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2014). Adaptive capacity is "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."

Coping Capacity: coping capacity and adaptive capacity are mostly distinguished with reference to timescale. Adaptive capacity is linked to long-term strategies whilst coping may include short-term strategies (IPCC. 2022). In this thesis, coping capacity refers to short-term strategies taken by farming households and districts to counteract the immediate negative impacts of climate change and variability.

Climate Model: a numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties. The climate system can be represented by models of varying complexity; that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. Coupled Atmosphere - Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near or at the most comprehensive end of the spectrum currently available. Climate models are typically applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal and interannual climate predictions.

Climate Variability: variations in the mean state and other statistics (i.e., standard deviations, occurrence of extremes, etc.) of the climate across all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Drought: this thesis will adopt the IPCC (2020) definition of drought as a "phenomenon that exists when precipitation is significantly below normal recorded levels causing serious hydrological imbalances that adversely affect land resource production systems." This thesis is concerned with meteorological drought, which refers to lack of precipitation over a particular period, and agricultural drought, which refers to "periods of declining soil moisture and consequent crop failure" (Mukherjee et al., 2018).

Dry Spell: dry spell is a period where the weather has been dry, for an abnormally long time, shorter and not as severe as a drought (Mathugama and Peiris, 2011).

Livelihoods: "a livelihood comprises the capabilities, assets (stores, resources, claims and access) and activities required for a means of living" (Guo et al., 2022). An assessment of livelihoods offers the opportunity to highlight the various adaptations that might be available to determine how rural communities can cope with declining crop yields due to drought.

1.5 Structure of the thesis

This thesis is structured into eight chapters that are connected to the study objectives. Following this introductory chapter, is chapter two, which reviews the relevant literature on climate change and variability and the impacts of these on agricultural crop production and livelihoods with reference to Sub-Sahara Africa (SSA). Additionally, chapter two explores literature on various frameworks that have been used to assess climate risk to agricultural crop production and livelihoods of rural households, discusses the evolution of vulnerability and risk assessment, and incorporating developments in climate adaptation in SSA.

Chapter three illustrates the study country (Liberia) emphasizing land tenure system and the nature of rice and cassava farming system in Liberia. The research design and methodology are also discussed in this Chapter, portraying the study locations and the range of quantitative and qualitative methods used to collect and analyze data. The relevance of participatory approaches for this study is discussed in this Chapter. Besides, Chapter three also investigates the strengths and limitations of the research instruments used for data collection. Finally, issues relating to positionality and ethical considerations are explored in Chapter three. In Chapter four focussed on the application of multi-scale, multi-indicator method used to assess climate risk and identify counties that are risk due to climate change and variability. Chapter four also explores districts that are exposure to climate induced risk, within which household, experts and stakeholders' interviews were used to compliment climate data at the local level where the study was carried out. The Chapter also assesses the extent of climate change and variability in the study areas by obtaining the perception of rural farmers on the impact of climate variability and change.

In chapter five explores the nature of district vulnerability and risk to climate variability in the study areas. Chapter five also discusses, crop production (yield, poverty, and population) in the identified counties and districts is characterised. Applying the sustainable livelihoods approach, this chapter builds on chapter three (national and regional level assessments) by developing and applying a household livelihood exposure and vulnerability index at district levels to characterise and explore the nature of climate risk. In chapter six, the main coping and adaptation strategies used by households in the farming districts are identified and evaluated. This chapter also assesses the socioeconomic factors that may influence households' choice of specific coping and adaptation strategies.

Chapter seven analyses the various policies aiming to tackle climate change and variability. It also analyses policies on agricultural production and food security in Liberia. The possible policy interventions identified in this thesis that can be used to reduce the adverse impacts of climate change and variability on agricultural production and rural livelihoods are also presented. Chapter eight summarises the main conclusions and provides a synthesis of the key findings, exploring the implications for agricultural production and food in Liberia. Chapter eight also provides interdisciplinary, mixed methods and approaches to address the aims and objectives of the study. Finally, priorities for future research are presented.

Chapter 2 Literature Review

2.1 Introduction

The previous chapter set the background that underpins this research and also introduced some of the core factors that underpin this study. This chapter reviews relevant literature on risk and vulnerability assessments to establish the conceptual and theoretical frameworks for the study. It identifies gaps in the literature that inform the appropriate research design and methods outlined in Chapter 3. This chapter begins by examining literature on the extent of climate change and variability with specific reference to Sub-Sahara Africa (SSA) and Liberia. The chapter afterward examines the implications of climate change and variability on Liberia rice and cassava production. The chapter highlights the impacts of climate change and variability on different components of food security: food availability, accessibility, utilization, and stability. The chapter provides a review of the relevant frameworks that have been recommended to assess risk to climate change and variability. It then highlights appropriate literature on climate adaptation measures with reference to SSA. Finally, the chapter concludes with a synthesis and reflection, highlighting the main research gaps that the thesis addresses.

2.2 Climate Change and Variability in Sub-Saharan Africa

Climate change is one of the most serious challenges facing the global community and as such has been given different definitions by different authors according to their perception and the way it affects them. The intergovernmental panel on climate change (IPCC) defines climate change as statistically significant variations that persist for an extended period, typically decades or longer. It includes shifts in the frequency and magnitude of sporadic weather events as well as the slow continuous rise in global mean surface temperature. Ozor (2009) defined climate change as change in climate over time, whether due to natural variability or as a result of human activity and is widely recognized as the most serious environmental threat facing our planet today. This definition elicits the seriousness of the threat posed by climate change and variability and the urgency of the need for countries to rise to this urgent clarion call of combating the negative effects of climate change. Over the years, climate change and variability has posed a big challenge globally, and it is important to reduce its impact on improving the quality of life (Abbass et al., 2022). Worldwide observed and anticipated climatic changes for the twenty-first century and global warming are significant global changes that have been encountered during the past 65 years (Leal Filho et al., 2021). They also emphasize that climate change is a global inter-governmental complex challenge with its influence over various components of the ecological, environmental, socio-political, and socio-economic systems (Leal Filho et al., 2021; Feliciano et al., 2022).

Although Africa is considered as a minor player in terms of total global greenhouse gas (GHG) emissions, contributing less than 4% of the World's total emissions (Etim et al., 2020). Studies by Attoh et al., (2023) and Choi et al., (2023) suggest that Africa is the most vulnerable continent to climate change and variability. This vulnerability has been attributed to the continent's low adaptive capacity and its over-dependence on rain-fed agriculture (Attoh et al., 2023; Choi et al., 2023). Rain-fed agriculture is one of the major economic activities and provides the backbone of most African countries' economies, employing about 60% of the workforce (Asare-Nuamah and Amungwa, 2021; Annex 2012). Attoh et al. (2023) and Choi et al. (2023) confirmed that within Africa, Sub-Sahara Africa (SSA) is considered as the most vulnerable to the adverse impacts of climate change and variability.

Bedair et al. (2023) indicated that Africa is warmer than it was 100 years ago, with greater warming occurring since the 1960s. Many studies have established that there have been rapid changes in rainfall, temperature as well as increased incidence of extreme weather events across Africa, particularly SSA (Bedair et al., 2023; Hessebo et al., 2021; Bandh et al., 2021). Decadal warming rates of 0.29°C have been observed for Africa in general (Zhang et al., 2023). In terms of future trends, Almazroui et al. (2020), Amosi and Anyah, (2024) and Lee et al. (2023) projected changes in temperature and precipitation changes by computing two future time slices, 2030-2059 (near term) and 2070-2099 (long term), relative to the present climate (1981-2010), for the entire African continent and its eight subregions. The CMIP6 multi-model ensemble projected a continuous and significant increase in the mean annual temperature over all of Africa and its eight subregions during the twenty-first century. The mean annual temperature over Africa for the near (long)-term period is projected to increase by 1.2 °C (1.4 °C), 1.5 °C (2.3 °C), and 1.8 °C (4.4 °C) under the Shared Socioeconomic Pathways (SSPs) for weak, moderate, and strong forcing, referenced as SSP1-2.6, SSP2-4.5, and SSP5-8.5, respectively. SSA has experienced both seasonal and annual rainfall variability (Bedair et al., 2023). Several studies investigating rainfall variability have noted a decline in annual precipitation in SSA, especially West Africa, and particularly in the Sahel (Bedair et al., 2023; Hessebo et al., 2021). The El Niño phenomenon, sea-surface temperatures and the feedback between land and the atmosphere have been identified as important influences on rainfall variability (Bandh et al., 2021). Liberia like many other West African countries has experienced considerable variations in temperature and rainfall patterns over the past four decades (EPA, 2019; Tore et al., 2021; Mechiche-Alami and Abdi, 2020). Several studies have projected that temperature will increase and rainfall will decrease in all the country's agro-ecological zones (e.g., EPA, 2019; Tore et al., 2021; Mechiche-Alami and Abdi, 2020). Therefore, Liberia provides a useful case study country in which to explore the links between climate risk to climate change, food production and livelihoods. The next section examines how the components of food security could be adversely impacted by climate change and variability. Since this thesis is primarily concerned with food production aspects of the food system, emphasis is placed on food availability as this is the aspect to which food production is most closely linked.

2.3 The Impact of Climate Change and Variability on Food Security in Sub-Saharan Africa

Greenhouse emissions have become a global issue that has attracted the aggressive attention of policymakers and global world leaders in recent times. Ambitious efforts towards significant reduction of CO2 emissions globally started in 2015 after the Paris accord agreement. As the United Nations concluded its Climate Change Conference (COP 26) meeting in 2021, countries set aggressive and determined targets towards transitioning to cleaner and green energy (United Nations Climate Change Conference, UK, 2021). These efforts are very important, necessary, and are expected to be timely in order to see a shift to a world free of greenhouse emission.

Climate change affects several aspects of livelihood, which includes food security, environmental degradation, poverty, etc. Climate change and its variability are significant drivers of the global rise in hunger (FAO et al., 2018). Food security is indispensable to survival, while food insecurity reflects a dysfunctional food system (Capone et al. 2019; El Bilali et al., 2020). Food security is often perceived as a multidimensional and flexible concept that gained prominence since the World Food Conference in 1974. According to report by the Food and Agriculture Organization (FAO), food security is described as a situation where there is physical, social, and economic access to sufficient, safe, and nutritious food for all people at all times to have an active and healthy life (Mahmah and Amar,2021). Food security addresses goal 2 and 3 of sustainable development goals (SDGs), which is zero hunger and good health and mental wellbeing. Achieving food and nutrition security has remained a major health challenge in developing countries, particularly in regions like SSA. Mahmah et al. (2021) noted that climate change influences food security on several fronts, which includes a direct and indirect impact on several aspects of food security, particularly in the agricultural and livestock sectors. Food insecurity increases the risk of malnutrition and contributes to poor health particularly in the vulnerable children and women. This in turn negatively affects their educational performance and yields poor productivity (Mahmah et al. 2021).

The 2009 declaration of the World Summit on Food Security defines food security as follows: "Food security exists when all people at all times have physical, social and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (Khalid, 2018, p 2). This definition of food security leads to the identification of four pillars or dimensions: availability, access, utilization, and stability (Khalid, 2018). Food availability pertains to the supply side of food security and the physical existence of food in a sufficient quantity and of appropriate quality, whether derived from domestic agri-food production, domestic stocks, food imports, food aid, or a combination thereof. Once the food is available, households and individuals must have sufficient access to that food (FAO et al., 2019). Sekyi-Annan et al. (2017) and Thornton et al. (2018) postulate that more countries in SSA will experience a substantial reduction due climate change and variability.

The impacts of climate change on human health may also indirectly affect agriculture (Sirba et al. 2021). In SSA where temperatures are already high, any further increases can be very dangerous for human health, increasing the incidence of diseases such as diarrhea, and malaria (Asmall, et al. 2021; Funna, 2020). For instance, Kiehbadroudinezhad et al. (2024) project increases of 12% of diarrhoea cases by 2050 due to climate change in low-income countries. Increased incidence of malaria due to climate change could also potentially affect labour availability for agriculture (Kiehbadroudinezhad et al. 2024), with considerable implications for food availability (Kiehbadroudinezhad et al. 2024). Under the HadCM2 climate scenario, Kiehbadroudinezhad et al. (2024) estimates an additional 55-65 million people are likely to suffer from hunger by the 2080s. The distribution of food is essential if food is to be made available, especially in developing countries that lack the infrastructural capacity to store and transport food from production centers to other areas. Food needs to be moved from areas of production to consumption through various transport systems. In this regard, increased incidences of extreme events such as flooding, rainstorms and heat stress due to climate change across Africa (IPCC, 2014) could have devastating effect on food availability by disrupting road infrastructure, making food distribution quite challenging.

Another essential determinant of food security is food accessibility. Food accessibility depends on dynamics like that of income, income supply containing remittances, disproportionate income, real prices of food, landlessness, gender literacy and the standing of employment (FAO, 2008). Sufficient food supply does not guarantee food security for either households or individuals, because food access is often more problematic than availability, especially for the most malnourished people (World Bank, 2007). Provided that food is available, and households have adequate access, then food security requires that households can consume adequate nutrients and energy (FAO et al., 2019). Climate change and variability may trigger the already high prices crop food production cost, thereby increasing prices for consumers (Omotoso et al. 2023). This will affect food access by households in SSA (Lefe et al. 2024). It is estimated that by 2080 climate change could reduce agricultural GDP in SSA by 8% compared with a decline of about 4% in Asia (Shah et al., 2008). This will greatly affect the capacity of people to access food as a reduction in GDP will seriously compromise the ability to finance food exports for most countries in this region (Pickson and Boateng, 2022). Reduced income for farmers in SSA due to reduced crop yields may affect the ability of most households in SSA to purchase food, even when food is available on the market. (Wudil et al., 2022).

Food utilization refers to the way in which the body extracts and uses the nutrients found in food, and is rooted in nutritious food selection, a diverse diet, sound eating habits, proper food preparation and hygiene practices, and intra-household distribution of food. Increasing temperatures associated with climate variability could affect the quality of food in storage, thereby affecting local food supplies, particularly in SSA (Kızıldeniz et al., 2023). This will be especially significant for vegetable crops, which have a short shelf life. Developed nations may be able to invest heavily in storage facilities that will reduce these impacts on food quality (FAO, 2027). However, this is likely to present serious challenges for developing countries (including those in SSA), which already have lots of developmental issues with which to contend. It has also been observed that climate change and variability could directly adversely affect the nutrient contents of food such as grains, as well as increase toxins in food as a result of increased incidences of diseases, plagues and pests (Krishna, 2023). Food utilization may also be related to the impacts of climate change on the ability of individuals to utilize food due to increased incidence of diseases.

Finally, food stability indicates the consistency of achieving the pillars of availability, access, and utilization over time. Stability concerns both short-term instability that may cause acute food insecurity and medium- to long-term instability that may cause chronic food insecurity. Stability may be adversely impacted by a range of factors including climatic, economic, social, and political factors (FAO et al., 2019). The impacts of climate change and variability on food stability relate to the increased incidence of extreme events such as cyclones, droughts and floods that will ultimately affect the stability of local production and supplies

(IPCC, 2014). Food instability due to drought has also been reported to result in a dramatic reduction in agricultural production (including livestock) with SSA and parts of South Asia two of the poorest regions in the world predicted to experience the highest degree of chronic malnourishment (Gashu et al. 2019; Bruinsma, 2017). The on-going discussions show that all components of food security will be negatively affected by climate change and variability. In SSA, this challenge is further complicated by a lack of institutional and scientific capacity to address the problems presented by increased temperature and reduced rainfall on the livelihoods of rural households and communities. Food security in many SSA countries will, therefore, be placed under considerable stress due to climate change and variability. Thus far, this review has established the extent of food systems' risk to climate change and variability with reference to SSA. Achieving food security requires that all four pillars be met simultaneously (FAO, 2008).

In SSA, food insecurity is more exacerbated by climate change and its variability. It is expected that mean and annual peak temperatures will continue to rise, despite overall higher average rainfall. Several temperature observations collected in SSA show substantial evidence of global warming between 0.5 °C and 0.8 °C between 1970 and 2010 over Africa (Onyutha, 2021; Muthoni, 2020). SSA is one of the most vulnerable regions to rising temperatures and unpredictable wet weather (Mohammed et al., 2020). For example, rainfall in West Africa's semi-arid and sub-humid zones was 15-40% lower on average over the previous 30 years (1968-1997) than between 1931 and 1960 (Nicholson et al., 2013; McCarthy et al., 2021). There was a 2.8-fold decrease in water availability throughout Africa and a 40-60% decrease in the average river discharge in West Africa (Madhi, 2023; Berrang-Ford et al., 2021). By 2025, up to 370 million people in Africa will be under water stress (Madamombe et al., 2024). The Central and Eastern African regions are the most vulnerable (Williams et al., 2018). Studies in Chad revealed a strong diminishing trend of rainfall for three decades, especially during the dry season, causing drought conditions for many years. As for temperature, each of the three decades has witnessed a rise of 0.15 °C from 1950 to 2014 (Maharana et al., 2018). Both rainfall and temperature fluctuations were unequally distributed across the country (Pattnayak et al., 2019; Affoh et al., 2022).

Agriculture is the economic backbone of most SSA economies, accounting for up to 14% of gross domestic product (GDP) (FAO, 2021; Bin Rahman and Zhang, 2023). In 2019, it employed 52.9% of the workforce in the sub-region (Horne, 2024; Affoh et al., 2022, World Bank, 2019). However, agriculture is still traditional and very sensitive to climate change. Rainfed agriculture is prevalent in most countries. Increasing temperatures and shifts in rainfall patterns have affected agricultural production with significant drops in crop and livestock production, thus impacting food distribution (Field and Barros, 2014). From this, it can be deduced that food systems are central to achieving food security within a region. Failure in one of these components can result in a household becoming food insecure (Javadi et al., 2023). Much of the literature suggests that food security could be threatened by climate change together with other factors such as increasing population, consumption patterns and urbanization (Kennard, 2023, Onwunali et al., 2024). Food security is influenced by the interplay of a complex set of economic and sociopolitical factors including poverty, lack of markets, accelerated population growth, poor infrastructure, conflicts, and a high disease burden-aspects that characterise most economies in SSA (Onwunali et al., 2024; Javadi et al., 2023). Climate change and variability will add to these factors. Climate change has been described as a new security threat to Africa (Kennard, 2023), suggesting increased incidences of civil wars during the last decades due to climate change and a strong correlation between historical civil wars and warmer years (Linke and Raleigh, 2023). Climate change and variability will adversely affect all four components of food security, highlighting the need for policy makers to implement appropriate measures to mitigate these impacts (Chakravarty et al., 2020). Therefore, this study is needed to assess how detrimental is the impact of climate change and variability on agricultural crop production in Liberia. Unearthing the questions in this study is very important for Liberia and the SSA region because the climate variability has induced hardship and worsened food security in the already plagued African nations. West Africa is one of the most affected regions in the continent with about 28.8% of its population (115.7 million) exposed to food insecurity in 2020 from 8.6% in 2014 (Otekunrin et al. 2021; FAO et al. 2021).

2.4 The Impact of Climate Change and Variability on Agricultural Crop Production in Liberia

Agricultural production risks, such as climate change, are dominant in developing nations with most farmers in these countries experiencing them, even though the major origin and implications might be different across nations (Hammer et al. 2014). Agriculture has been an important sector of sub-Saharan Africa (SSA) countries which serves as an incentive for accelerating poverty reduction and also in improving food security. Some of the causes of food insecurity and poverty is traceable to the vulnerability of agriculture to production hazards, which ultimately affect farmers' income (Ngozi et al. 2020; Sanogo et al. 2020). As the African populace strive to outstrip poverty and improve economic growth, these production risks portend the deepening of vulnerabilities, and seriously undermine the prospect of development (Jadhav, 2024). Agricultural production activities in Africa, as opined by Bedeke, (2023) and supported by Adimassu and Kessler, (2016), are mainly more susceptible to climate change in comparison with other economic sectors. Smallholder farmers in SSA are likely to be more susceptible to climate change, most especially due to increasing incidences of poverty, inadequate technological advancement and over-reliance on rain-fed agriculture (Bedeke, 2023; Mulwa et al. 2017). Studies by Ibrahim et al. (2020) shows that more than 95% of agricultural activities in SSA are rain-fed. According to Kotir, (2011), the projection for crop yield in Africa could be as low as 10%-20% by 2050, or even more than 50% because of the effect of variability in climate change and variability.

There are indicators of climate change and variability include irregular rainfall, mostly with continuous salt stress, drought, prolonged delayed rainfall or dry spells, incidence of flood and temperature changes, had been reported in empirical literatures, with a varying impact in different regions of the world (Adebisi-Adelani and Oyesola, 2014; Camarasa-Belmonte et al. 2020; Shawul and Chakma, 2020). Smallholder farmers may perceive climate change, but the degree of their perception of its source and implications may vary among farmers. Farmers' low level of perception of climate change could manifest as a result of age, inexperience, a lack of information and/or a lack of credit facilities (López, 2024; Java-Indonesia, 2020). Several studies, such as Mundial, (2023), Oyelere et al., (2020), and Yakubu et al., (2021) had examined the effects of climate variability on crop production, including rice and other crops, and different adaptation practices employed by farmers in SSA and beyond. Despite the significant climate risks in SSA countries, including Liberia, it is still possible to reduce their negative impact by responding through adaptation practices. Adaptation strategy means an adjustment in natural or human systems in reaction to actual or expected climate change and can be remarked as a policy implication to mitigate the destructive effects of climate change (Ali et al. 2020; Nkoana et al. 2021).

One area that will be strongly impacted by the inadequate rainfall and high temperature is agricultural production, mostly the interior counties such as Bong and Lofa Counties (Figure 2.1). These counties were once considered as the primary agricultural areas (food basket of the nation) before the civil conflict. During these periods (1989-2003), economic activity came to a virtual standstill; the production of food mainly rice and cassava dropped to less than 50% of pre-war levels and by 1995 production levels of these crops dropped further to about 19% for rice and about 53% for cassava (MOA, 2008). The intra-annual rainfall variability and increased temperature are also situated in a host of other political, economic, social, and environmental challenges has adverse consequences on Liberia's development because the economy is dependent on rain-fed agriculture (EPA, 2007). This illustrates that Liberia's agricultural sector is extremely sensitive to the adverse impacts of climate variability (Stanturf et al., 2011), hence the need to explore the extent of vulnerability and provide appropriate policy interventions.

Further, despite the projected decrease in rainfall and increase in temperature, data on the nature and extent of vulnerability of Liberia's food systems and rural livelihoods to climate variability and change are lacking and this hampers the development of effective policy to reduce the adverse impacts of climate variability change. For instance, little is known about how farmers adapt to changing climatic conditions in different parts of the country. As such, it is unclear from a policy perspective how to best enhance national adaptive capacity. This research seeks to provide empirical understanding of the factors and drivers that contribute to vulnerability to climate variability and change in food production systems and rural livelihoods in Liberia and thereby provides insights into the processes that are needed to create the capacity to adapt. A better understanding of the risks posed by climate variability and change (particularly dry spells) will provide guided policy recommendations to improve food production, livelihoods, and agricultural practices in Liberia.

2.5 Impact of Climate Change and Variability on Rice and Cassava Production in Liberia

2.5.1 Rice (Oryza sativa L.) Production in Liberia

Rice, being one of the most important staple foods for Liberia's 5.2 million people, its economic activities in relation to production and consumption are being extensively regarded a panacea for economic development and poverty reduction (Momolu, 2023; HIES, 2016). Rice consumption has outpaced domestic production, accounting for approximately 50% of adult caloric intake with an annual per capital consumption estimated at 133kg (Momolu, 2023; HIES, 2016). At the nation level, rice crop is widely grown in almost every region in due to the role it plays as a staple food crop and is widely grown in almost every region in in the country (Saysay et al., 2018; see Figure 2.1).

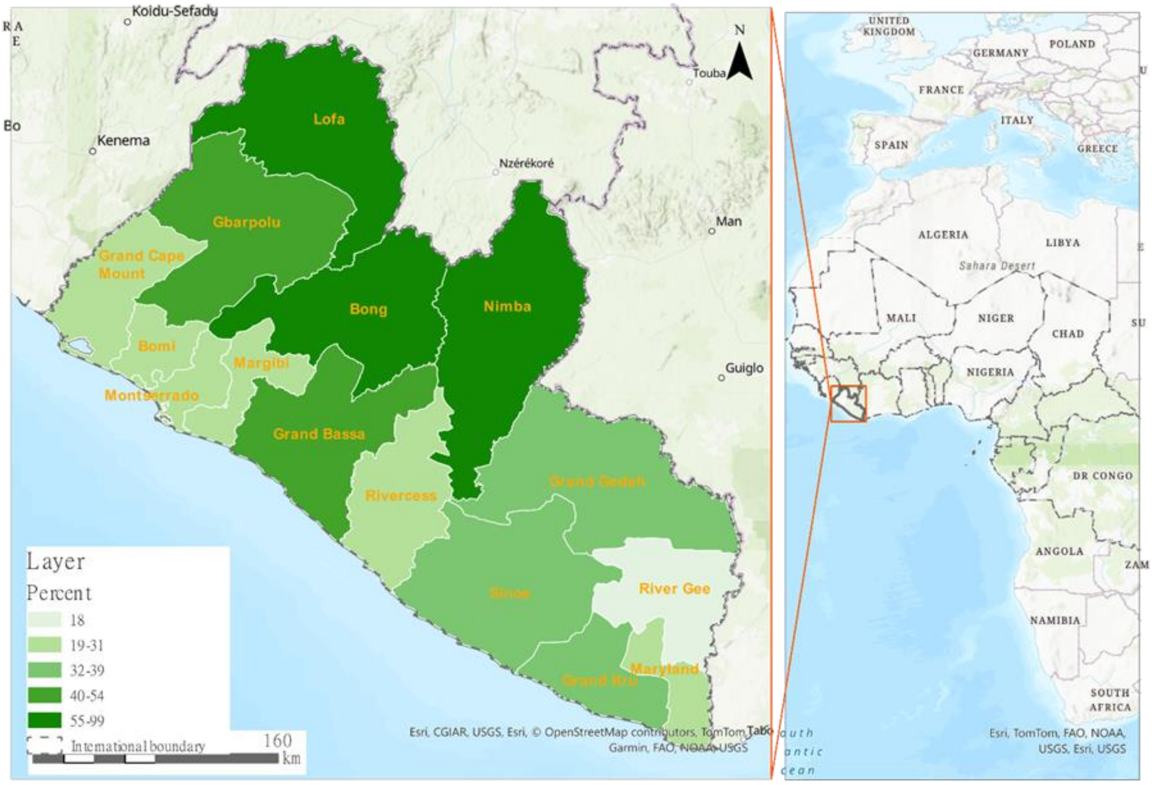

Figure 2.1 Map of Liberia showing the percent rice production per county. Source: LISGIS' Annual Agricultural Survey, 2019

Despite rice being widely cultivated and the role it plays as a staple food crop in the country, a total annual rice output of about 290,600 metric ton has not kept pace with the growing demand of over 400,000 metric tons, largely due to low productivity and the large deficit is met through importation (NIC, 2015). The average yield in Liberia is just about 1.2 t/ha (Saysay et al., 2018; HIES, 2016); which is low compared to other West African countries with 2.7t/ha in Ghana, 3.0 t/ha in Côte d'Ivoire, 3.4 t/ha in Mali and 4 t/ha in Benin (Donkoh and Awuni, 2011; Oladele et al., 2011; Donkor and Owusu, 2014). The low productivity at the farm level is a pervasive problem, which impends not only the economic well-being of the farmers but also the efforts by the government to ensure food security. The implication is that if no special attention is given to reverse the situation, the country stands a chance of increasing its importation bills, facing severe food insecurity and negative outcomes from poverty reduction efforts. In recent past, the Liberia government has actively intervened in the rice production through the development of various national documents such as Agenda for Transformation (AfT), the Pro Poor Agenda for Prosperity and Development (PAPD). These national documents aimed at increasing the current number of operational rice farms and encourage its development partners to support the initiatives in the country in order to accelerate crop production and alleviate poverty. These efforts have made many people engage in rice farming activities thereby employs more than 51% of the Liberian population

(Knoema, 2019). In recent years, concerted efforts of the government, the World Bank, and non-governmental organizations have seen the rice sector receive support in the form of agriculture equipment and inputs such as fertilizers and improved varieties (MOA, 2014). The efforts indicate an acknowledgment from the stakeholders of the role of rice in national food security. Nevertheless, rice production has continuously declined compared to the area under cultivation, despite the synergies created by value chain stakeholders and farmers' increased involvement (MOA, 2014). Henceforth, it is essential to have clarity on questions like what are the causes of low productivity of rice in Liberia? What are the factors affecting rice production in the study areas and how can these factors be mitigated? These are important policy issues that need to be understood by planners and policy makers.

Available literature suggests that temperature and rainfall variations have a detrimental effect on rice growth stages, leading to decreased rice production (Parry et al., 2013; Hussain et al., 2020). Crop production declines primarily due to shorter growth phases, increased heat stress during critical reproductive stages, decreased photosynthetic capacity, improved respiratory processes, and increased water demands for rice production (Abbas and Mayo, 2021; Ullah, 2017). The temperature thresholds at which spikelet fertility occurs, depends on the ambient temperature and the air humidity (Van Oort and Zwart, 2018). In dry conditions, this threshold level will be higher than in humid conditions (Van Oort and Zwart, 2018). On the other hand, increased night-time temperatures may reduce assimilate accumulation (Ullah, 2017). According to Chary et al. (2021) and Gora et al. (2019), climate change through irregular rainfall, mostly with continuous salt stress, delayed rainfall or dry spells, flood and increase in temperature, are factors that affect agricultural productivity. Adoption of adaptation strategies therefore remains an imperative option to abate the effect of climate change, also addressing the prevailing challenges on rice production (Reddy et al. 2022; Viswanathan et al. 2020). Climate change adaptation has a laudable importance to the maintenance of food security of developing nations if well planned in terms of an extensive policy among smallholder farmers (Reddy et al. 2022; Viswanathan et al. 2020; Karki et al. 2021).

Previous studies by Ray et al. (2019), Diallo et al. (2022), Islam et al. (2020) and Deressa et al. (2008) analysed the climate change impact on food production, but the analytical understanding of different adaptation strategies used by rice farmers is yet to be investigated. An empirical study conducted by Mansaray and Jin, (2020) showed that climate variability has significant effects on the yield of rice production in Liberia, implying that climate change primarily affects rice farmers' production system. Sufficient literature also exists on climate change adaptation strategies of farmers in developing countries such as Nigeria (Nnadi et al. 2021), Nepal (Khanal et al. 2018), Bangladesh (Alam, 2015) and Kenya (Mulwa et al. 2017), but relatively little attention on rice farmers in Liberia. However, one of the major concerns in studying adaptations among smallholder farmers is the identification of compactible adaptation strategies, as many changes in agricultural management and technology vary across agro-ecological zones (Naazie et al. 2023; Tessema and Simane, 2021). As postulated by Tessema and Simane, (2021) and Mwinkom et al. (2021), different adaptation strategies are practiced by farmers depending on the variability of climatic factors, socio-economic and institutional factors. In order to understand the impact of climate risk in Liberia, it is imperative to have information on the causes and consequences of actual climate change impact on rice farmers. It is against this backdrop that this study attempts to assess and provide critical information on the impact of climate change and variability on crops production, focusing on Liberia's major rice and casava-producing counties.

2.5.2 Cassava (Manihot esculenta) Production in Liberia

Cassava is both a food and a cash crop. It is the only crop of the root and tubers group that is cultivated in all tropical regions of Latin America, Africa, and Asia. More than 450 million Africans consume cassava daily as a staple (Konan et al. 2020). In Liberia, more than 74% of the agricultural households in Liberia cultivate cassava, see Figure 2.2 (MOA, 2010).

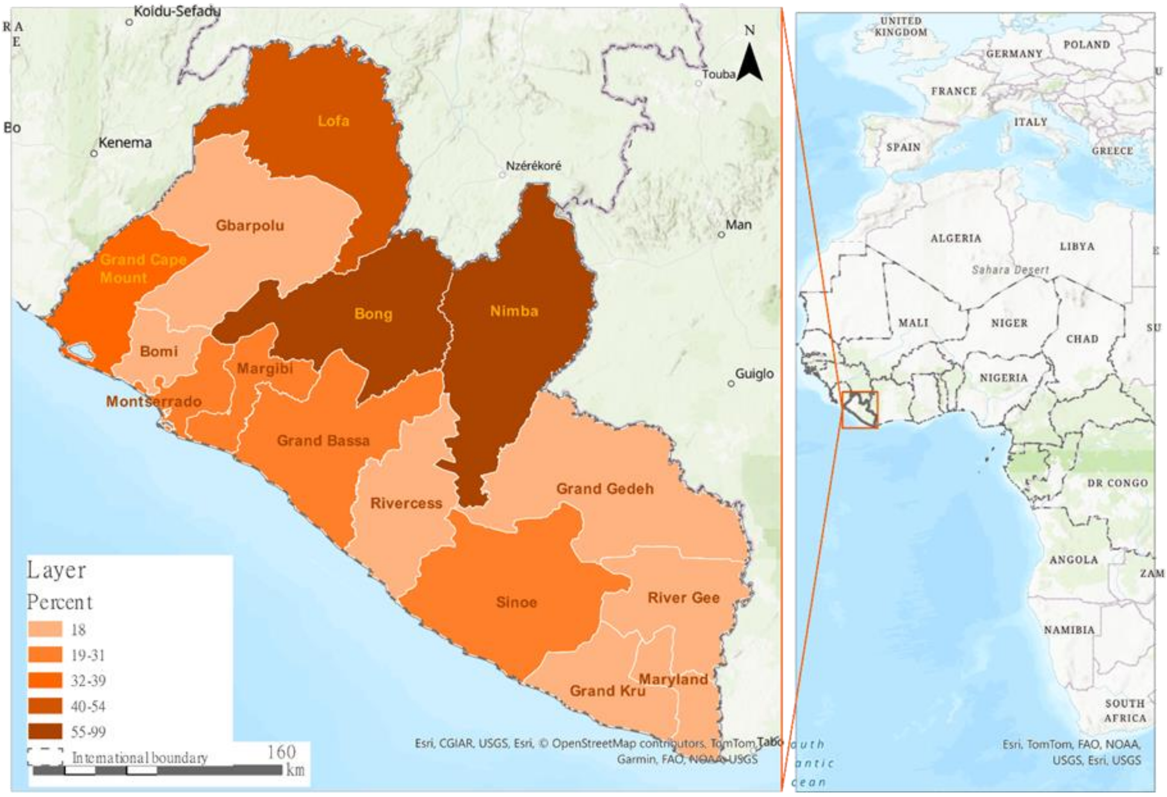

Figure 2.2 Map of Liberia showing the percent cassava production per county. Source: LISGIS' Annual Agricultural Survey, 2019.

Yet, there is still low domestic food production. The mean supply of cassava output is short of the regional average of 10 metric tonnes per hectare. And there are knowledge gaps and dearth of empirical studies to inform stakeholders about the efficiency of cassava production (FAOSTAT, 2020). Throughout the humid lowland tropics, cassava (*Manihot esculenta*), also known as manioc, tapioca, muhogo, and yuca produces carbohydrate-rich storage roots, which is a staple food crop for approximately 800 million people worldwide (FAO, 2015). It is also considered as a famine resilient crop that is regarded as one of the food crops expected to support global food security and increased income especially for smallholder farmers in sub-Sahara Africa. Compared to other root and tuber crops, the demand for cassava is estimated to provide food and income to more than two billion people in Africa, Asia, and Latin America by 2050 (Konan et al. 2020).

In Africa, cassava is the second most important staple food in terms of per capita calories consumed (Nweke, 2004). Storage roots are used as a fresh carbohydrate source and can also be processed into flour, which may be consumed by the grower's family, sold in local markets, or used to produce several industrial food products (Bechoff, 2017). Subsistence farmers rely on cassava for a vital energy source, as it can be planted and harvested throughout the year, tolerates periods of unpredictable drought, and grows on marginal soils (Hillocks and Thresh, 2002). Crop modelling carried by Jarvis *et al*., (2012) suggested that cassava may be highly resilient to future climate change and could provide Africa with adaptation opportunities, which are not offered by other staple food crops. Moreover, Africa produces over one-half of global cassava (57%) (Bennett, 2015); however, the continent's average fresh yield (9.9 tonnes/ha) lacks behind potential yields (15 - 40 tonnes/ha) achieved under experimental conditions (Fermont et al., 2009). There are many reasons behind the reduced yields, including restricted access to labour, poor soil quality and premature harvesting (Fermont et al., 2009). Productivity in East and Central Africa is significantly constrained by two viral diseases, cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), which together are estimated to cause annual losses worth US$1 billion (International Institute of Tropical Agriculture (IITA), 2014a) and adversely affect food security in the entire region (Patil et al., 2015).

However, a high number of climate impact and yield response studies in Africa and other developing countries predict declines in the yield of major staple crops by the late 21st century due to climate change, but a more resilient response of cassava to future climatic shocks (e.g., see Sultan and Gaetani, 2016; Zhang et al., 2019, Vanli et al., 2019). This indicates a high potential for cassava to adapt to a harsh future climate and serve as a food security crop under such conditions, thereby minimizing the national food insecurity burden. Cassava is known for its low input requirement and high resilience to unfavourable production conditions and has a high output of energy per area cultivated. This makes cassava a strategic crop for overcoming hunger (FAO, 2015), and it is easy to cultivate on marginal lands (Delaquis et al., 2018; Jiang et al., 2019; Shan et al., 2018). In addition, cassava has a lower risk of crop failure (compared to crops like rice, maize, groundnut, tomatoes, peppers, and other vegetables), and serves as a potential feedstock for many industries (through the use of starch for pharmaceutical, textile and adhesive purposes), a famine reserve (flexibility in harvesting) and a cash crop (Uarrota et al., 2017). As a beneficiary to China's preferential free trade agreement to developing countries, Liberia benefits 99% tariff-exemption on exports to China: an opportunity to optimize trade of cassava tubers and cassava products to one of the largest cassava consuming markets of raw and processed cassava tubers (MCI, 2017). Despite this opportunity, there is a dearth of information concerning the productivity of cassava crop in Liberia.

2.6 Definitions and Concepts of Vulnerability and Risk

The United Nations International Strategy for Disaster Reduction defined vulnerability as the condition determined by physical, social, economic, and environmental factors, or processes, which increases the susceptibility of a community to the impact of hazard (UNISDR, 2007). This definition incorporates four (physical, social, economic, and environmental) factors into the discourse. It suggests that these factors are what contribute to the susceptibility of a people or system during event of stress. The definition also suggests that all shocks are triggered by these pre-existing factors, and it is the combination of any of these factors with the conditions that triggered the shocks that make it difficult for systems or people to withstand conditions of impact.

Vulnerability emerges as a central concept that has gone on to feature in research on risks, hazards, famine and food security, and the impact of climate change (Adger, 2006; Cutter, 1996; Watts and Bohle, 1993; Wisner et al., 2004; Lin & Chang, 2013). As a key pointer in the evolution of vulnerability theories, Alwang, et al (2001) presents a selective review of the framing and definitions of the concept of vulnerability from the following five different perspectives: economic; sociological/anthropological; disaster management; environmental and health/nutritional. Attempt has been made to establish the relationship between environmental risk and socioeconomic vulnerability with intentions of identifying the different theoretical approaches involve in undertaking vulnerability research (Brouwer, et al (2007). Brouwer, et al (2007) suggests that environmental risk exposure also goes hand in hand with income inequality and access to natural resources, while higher exposure levels are associated with higher inequality and less access to land. Sarewitz, Pieke and Keykhah (2003) questioned the meaning of vulnerability as a risk-based approach. They have a different view on framing vulnerability exclusively as risk based. They argue that by doing so, would only succeed in undermining other prospects of assessing or measuring vulnerability. They contend that vulnerability is best understood when it not exclusively related to a specific occurrence, but rather when it is approached from a wide range of standpoint so as to make the right judgement on the appropriate balance between risk and vulnerability-based approaches.

On the other hand, risk is defined as a function of hazard, exposure and vulnerability, which is in turn divided in susceptibility or sensitivity and in coping and adaptive capacity. In this context, risk also refers to a particular group of people or biophysical unit of exposure especially to the structures and institutions and socioeconomic that govern human lives (Vincent, 2004). It is a degree of susceptibility to the effects of events of shocks, of processes of change or of a combination of factors, including stress, which is sufficiently offset by capacities to resist negative impacts in the short, medium to long term and to maintain levels of overall well-being (Allen, 2003). It therefore involves a combination of hazard/exposure, social response and the susceptibility of places (Eakin 2005). In the case of the climate risk in central and northern Liberia, a combination of these (risks) factors discussed above informed the decision to give attention to biophysical and socioeconomic circumstances that produced the climate hazard. Exploring the strategies implemented by the rural farmers in the study areas in the face of crops failure or reduction in yield, it is imperative to understanding community adaptation strategies used to mitigate the impact of climate variability.

The theory of climate risk provides a framework for identifying and assessing risk across all lifeline sectors (Andersson-Sköld et al. 2022). In this regard, climate change environment has additionally shifted from vulnerability toward risk in terms of conceptual understanding and responding to climate change (IPCC, 2014; IPCC, 2012; Caggiano et al. 2022). The concept as described by the IPCC Fifth Assessment Report (Oppenheimer et al, 2014) and updated in recent Special Reports on 1.5 C (IPCC, 2018), on climate change and Land (SROCC; IPCC, 2019) and the Ocean and Cryosphere in a changing climate (SROCC; IPCC, 2019b. According to SROCC, risk is as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards such as extreme temperatures and rainfall variability with the exposure and vulnerability of the affected human or ecological system to the hazards.

2.7 Conceptual and Theoretical Frameworks for Assessing Climate Risk

2.7.1 The Conceptual Evolution of "Vulnerability" and "Risk" within the IPCC

Climate change vulnerability and risks assessment is one way to provide policy makers with the necessary information to reduce the risks associated with climate change and variability. Identifying and assessing climate risk is common across all lifeline sectors (Andersson-Sköld et al., 2015). The climate change community has additionally moved from vulnerability toward risk in terms of conceptual understanding and responding to climate change (IPCC, 2012; IPCC, 2014; Carter et al., 2015; Connelly et al., 2015).

The impacts of future extreme events on humankind are particularly uncertain (IPCC 2021). This is partly due to lack of confidence in the evolution of extreme weather resulting from climate change, and on the evolution of societal adaptation. In the first case, the low confidence is mainly due to a mismatch between the larger spatial and temporal scale of climate and the local occurrence and short lifetime of some weather extremes. These uncertainties represent an important challenge for all the decision makers that want to mitigate the risks and vulnerabilities due to climate change (Eiser et al., 2012). At the same time, there is a lack of coherence over the definition of risk across disciplines, sectors, and organizations (Wolf, 2011). Given that risk is such a well-established concept across a number of domains, from health to information systems, the International Standards Organization (ISO), with the International Electrotechnical Commission (IEC), provides a series of principles and a framework for risk management. These are housed in a family of documents under ISO 31000 "Risk Management" (ISO/IEC 31000, 2019).

Over the past decades, conceptual approaches to design vulnerability and risk assessment have been widely used in different disciplines, because of the differences in their objectives and knowledge background (e.g. Hagenlocher et al., 2017; Hagenlocher et al., 2018; Asare-Kyei et al., 2017; Hashempour et al, 2020; Ali, 2017). However, the understanding and definition of vulnerability and risk assessment can be very different. Originally, vulnerability was used in the field of disaster studies to represent the extent of the injury (Füssel and Klein, 2006). Later, with the growing influence of climate change and variability issues, the concept was introduced to the field of climate science, which led the IPCC to develop the First Assessment Report, which provided a preliminary explanation of vulnerability. In 1996, the IPCC Second Assessment Report gave the definition of sensitivity and vulnerability. Füssel and Klein (2006) identified three main conceptual frameworks of vulnerability assessment. The first is the risk-hazard framework, characteristic of technical assessments of risk and disaster management. This type of approach emphasizes the activities and techniques that a technical team can implement to assess and reduce vulnerability (Downing et at., 2005; Fakhruddin et al., 2020). The second is the social-constructivist framework, which focuses on human vulnerability (Füssel and Klein, 2006). In this framework, the social approach to vulnerability, both individual and collective, is a crucial dimension to study vulnerability to climate change, where social, economic, and institutional factors, in addition to biophysical ones, are considered (Adger,1996; Kelly and Adger, 2000). In this sense, vulnerability is always linked to a specific hazard or set of hazards, which creates a close link between vulnerability and hazard (Kelly and Adger, 2000).

The third is the IPCC's Fourth Assessment Report (AR4) framework focuses on vulnerability to climate change which is defined as the "…degree to which a system is susceptible and cannot cope with the adverse effect of climate change, including climate variability and extreme, which is in function of the character, magnitude and rate of change and climatic variation to which a system is exposed, its sensitivity and its adaptive capacity" (IPCC, 2007: 883). Between 2001 and 2007 IPCC reports, the definition of vulnerability has remained same except that the word 'or' is substituted by 'and' in the first part of the definition in 2007 report. This has been in order the 'sensitivity' and 'lack of adaptability' are considered as co-factors of vulnerability and not as its alternative definitions (Füssel and Klein, 2007). Vulnerability assessment based on this definition considers indicators representing exposure, sensitivity and adaptative capacity, which is now considered as old paradigm. This is represented by the following equation:

$$Vulnerability = f(Exposure, Sensitivity, Adative\ capacity) \tag{2.1}$$

Vulnerability, therefore, refers to the degree to which a system is susceptible to or unable to cope with adverse effects of climate change (including climate mean, variability, and extremes), and it is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007).This general definition has been accepted by the academic community such as Editorial Committee of China's National Assessment Report on Climate Change (ECCNARCC, 2007, p. 182-200).

In 2014, the fourth framework known as IPCC's Fifth Assessment Report (AR5) was adopted. In the AR5, vulnerability was redefined as “…the propensity or predisposition to be negatively affected” (IPCC, 2014, Annex II), being a function of sensitivity and adaptive capacity. This report defines sensitivity in the same way as indicated in the AR4, with the difference that, in addition to systems, ecosystem can also be affected; and adaptive capacity also includes institutions, humans, and other organisms. In this approach, vulnerability remains an element of risk. Risk, being defined as the “…potential consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values…it is the result of the interaction of hazard, exposure, and vulnerability” ({IPCC, 2014: 1772).

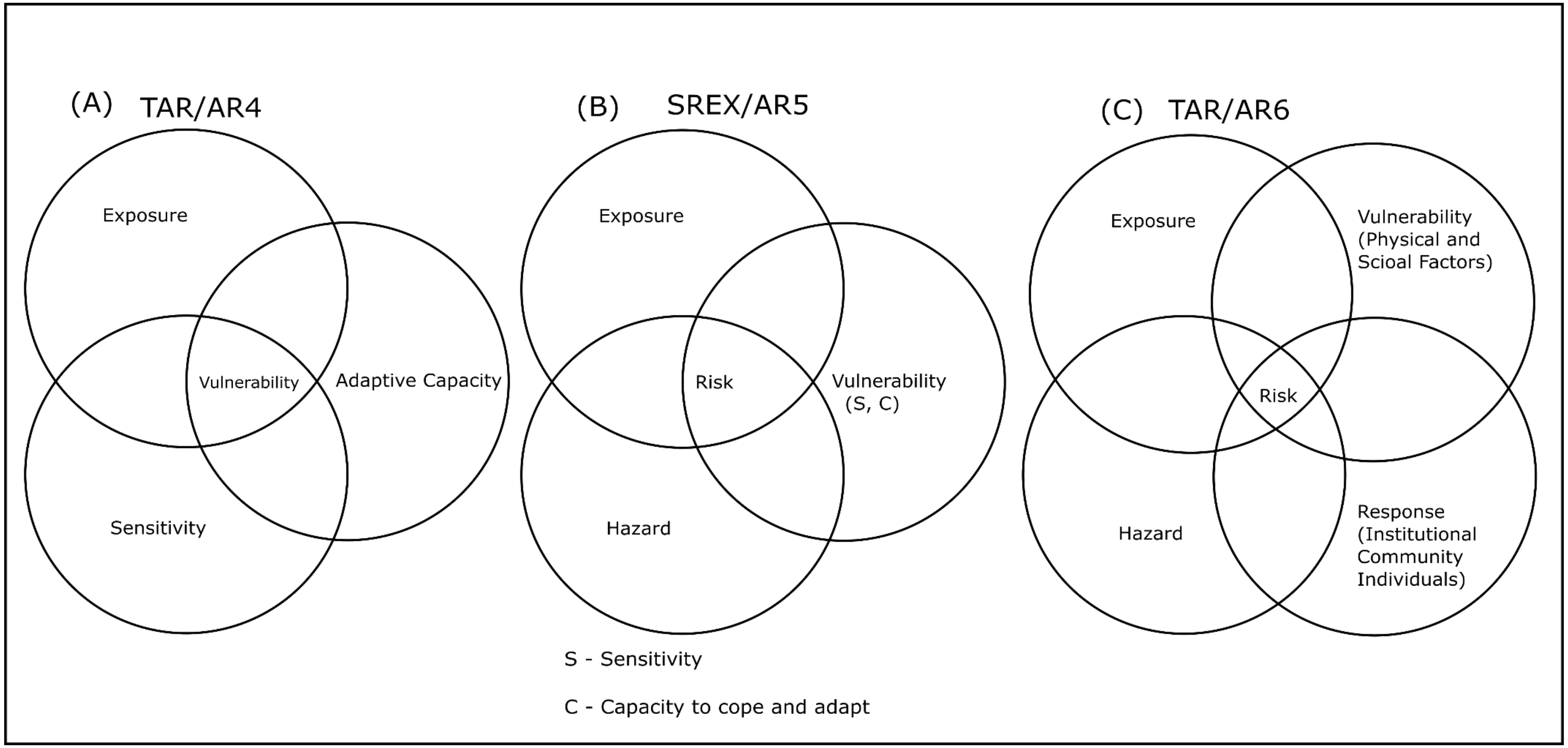

Figure 2.3 Climate related impact assessment framework based on The IPCC's perspective. (A) The vulnerability (V) assessment framework with respect to TAR/AR4, (B) the Risk (R) assessment framework with respect to the SREX/AR5 and (C) the Risk (R) assessment framework with respect to the TAR/AR6. The diagrams are drawn to illustrate the concepts based on the definition of vulnerability in the TAR (IPCC 2001) and AR4 (IPCC 2007), the definition of risk and SPM.1 as indicated in the AR5 (IPCC 2014), SREX (IPCC 2012) and the definition as indicated in the AR6 SPM. Source: Foden et al. (2019).

In this sense, the exposure refers to “the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural assets in places and environments that could be negatively affected” (Ibid: 1765). Thus, the equation that determines the AR5 approach is:

$$Risk = f(hazard, exposure, vulnerability[f(sensitivity, adaptive\ capacity)]) \qquad (2.2)$$

Risk is a social construction derived from the production and reproduction of conditions of vulnerability and inequality (García, 2005). In this regard, the impact-risk framework presented in the Intergovernmental Panel on Climate Change (IPCC) Working Group (WG) II Report (2014) in figure 1 shows that the risk of impact from climatic and non-climatic hazard(s) is caused by the interaction of hazard, exposure and vulnerability. Separating hazard and exposure from the concept of vulnerability in the IPCC 2014 report is a paradigm change from IPCC 2007 report. This paradigm change in 2014 report presents vulnerability as a characteristic internal property of a system delinked from exposure to hazard (IPCC, 2014).

Subsequently, in 2022, the fifth framework from IPCC's Sixth Assessment Report (AR6) was adopted, which vulnerability was redefined as “…the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2022: SPM-5). In this report, sensitivity is defined as indicated in the AR5, with addition to systems, ecosystems can also be affected; and adaptive capacity also includes institutions, humans, and other organisms.

In this new approach (AR6), vulnerability remains an element of risk as defined in AR5. AR6 reports maintained the AR5 definition of risk as the “…potential for adverse consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values… it is the result of the interaction of vulnerability, exposure, and hazard” (IPCC, 2022: SMP-4). In this sense, exposure is defined as “the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural assets in places and environments that could be negatively affected” (SMP-5). Though, the IPCC AR6 framework is yet to clearly specify how to operationalize a climate risk assessment. Therefore, there is no one standard approach or formula for assessing risk resulting from the consequences of climate change. That is why there are numerous approaches to risk assessment. Nevertheless, risk can be considered as a dynamic process with respect to time, and it can be derived basically from the convolution of three main components (IPCC, 2022; UNDRR,2019; UNISDR, 2016; IPCC, 2014). This Equation is derived on the IPCC, 2022 definition.

$$Risk = f(Propbabilty\ of\ a\ Hazard(P), Exposure(E),$$
$$Vulnerability\ [sensitivity, adaptive\ and\ coping\ capacities]) \qquad (2.3)$$

Hazard is considered as “the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Physical climate conditions that may be associated with hazards are assessed in Working Group I as climatic impact-drivers” (IPCC, 2022; Staupe-Delgado, 2019).

Exposure is defined as “the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by natural hazards and climate change” (IPCC, 2022; IPCC, 2014, Annex II). The vulnerability in this report is considered as the “propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2022, 2014, Annex II). The term “risk” has different meanings: (a) as a synonym for probability of a harmful effect occurring and (b) as a synonym for the mathematical expectation of the magnitude of the undesirable consequence (even as a quasi-synonym of consequence, whereby risk has a similar meaning to undesirable outcome) (IPCC, 2022; Fakhruddin et al., 2022). Based on these explanations, it is clear that the concept of climate change vulnerability began in the 1990s, with the sole purpose of understanding the extent and complexity of climate change and its effects, in the context of developing policies and measures to reduce such vulnerability (Hinkel 2011), but vulnerability assessment in Africa is highly challenging.

While Africa is covered by the second highest number of adaptation and vulnerability studies of all world regions, the geographic distribution of these studies within the region is highly uneven (Berrang-Ford et al., 2019, de Sherbinin et al 2019). Uneven geographic coverage of risk assessments may reflect economic characteristics such as countries’ contribution to the region's agricultural output, rather than the distribution of potentially vulnerable groups, with most studies conducted in Western and Southern Africa (William et al., 2018). Although there is a tendency to focus more on vulnerable groups such as smallholder farmers, there is still limited engagement with local perspectives and knowledge (William et al., 2018). While the frameworks have become less hazard-centric, involving greater attention to social aspects (Hagenlocher et al., 2019), there are still deficits regarding the conceptualization of vulnerability and, especially, the empirical operationalization and implementation of this in vulnerability assessments (William et al., 2018).

Integrating multiple dimensions of vulnerability involves attention to the complexity and the differential effects of each dimension on overall vulnerability. Innovation to the IPCC risk framework during the AR6 process now includes the idea of responses (both greenhouse gas mitigation and adaptation) as a determinant of risk (Andrews et al., 2023; Simpson et al., 2021). The new IPCC AR6 risk framework also now gives much greater attention to the aggregating, combining, or cascading interactions of multiple drivers of vulnerability (Simpson et al., 2021). This innovation is particularly important to advance the understanding of vulnerability and overall risk as common understanding of vulnerability includes the idea of adaptive capacity as a dimension of response and important for risk reduction, however, there has been a failure to integrate responses in climate risk assessment and management. While exposure is commonly considered a determinant of vulnerability (Adger et al., 2018), prior to this new risk framework it has been ambiguous within the IPCC risk assessment as to the specific nature of interaction between multiple exposures and multiple vulnerabilities particularly when the two concepts are disaggregated (Simpson et al., 2021). It is also important because inappropriate responses can increase vulnerability and lead to maladaptation (Schipper 2022). Finally, in contrast to its previously limited scope within the agenda of Working Group II, this innovation now extends vulnerability to all three Working Groups of the IPCC by including the potential effects of GHG mitigation responses on vulnerability, independent of a proximate climate hazard (Andrews et al., 2023). The new risk framework makes explicit how each dimension of vulnerability affects and is affected by other determinants of climate change risk (including exposure, hazards, and responses to climate change) and therefore which dimensions of vulnerability should be targeted for the most effective and feasible climate risk assessment and management.

2.8 Conceptual Framework for Climate Risks Assessments

Conceptual approaches to design vulnerability and risk assessment have been widely used in different disciplines, because of the differences in their objectives and knowledge background (e.g. Hagenlocher et al., 2017; Hagenlocher et al., 2018; Asare-Kyei et al., 2017; Hashempour et al, 2020; Ali, 2017). However, since the overall aim of this study is to assess climate risks in central and northern Liberia and improve the understanding of the links between Liberia's crops production system and climate variability, the study decided to use the definition proposed by IPCC in the Fifth Assessment Report (AR5) of 2014, which specifically refers to the risks deriving from climate change (IPCC, 2014). The framework proposed by IPCC, (2014) estimates the climate risk as a combination of hazard (H), exposure (E), sensitivity and adaptive capacity (see equation 2.3). In this context, hazard refers to the probable occurrence of climatic events that could have adverse impact on food crops (rice and cassava) and compromise its production. The exposure component refers to the population engaged in farming and the amount of rice and cassava production in the districts that may be affected by major hazard events. Vulnerability refers to susceptibility (physical and socioeconomic) is intended as the degree to which the system is positively or negatively) affected by a certain climate exposure (Zebisch et al. 2017), while coping and adaptive capacities refer to the ability to adapt to the consequences of climate variability and change. Based on these concepts, the risk assessment framework was built as follows: First, the defined climate hazards affecting food crops (rice and cassava) production in the study areas, here divided as mean average monthly and annual temperatures (1981-2020; 2020-2100), average monthly and annual rainfall (1981-2020; 2020-2100), and drought indices (1981-2020, 2020-2100). Each hazard specific indices were selected to analyze the variations in frequency and intensity of high impact events. Then, the study also identified the exposure samples, here defined as two major fields related to percentage of the population engaged in farming in the study areas and percent total of rice and cassava production. Finally, the study selected specific susceptibilities (physical and socioeconomic such as access to farmland, soil and water quality, percent of population educated engaged in farming percent of sex engaged in farming etc.) and adaptive capacity (e.g., policy documents developed in Liberia to mitigate the adverse impact of climate change and variability on agricultural production) indicators based on the exposure sample under analysis. Details of selected indicators and calculation of risk index, and normalization these indicators are explained in Chapter 3.

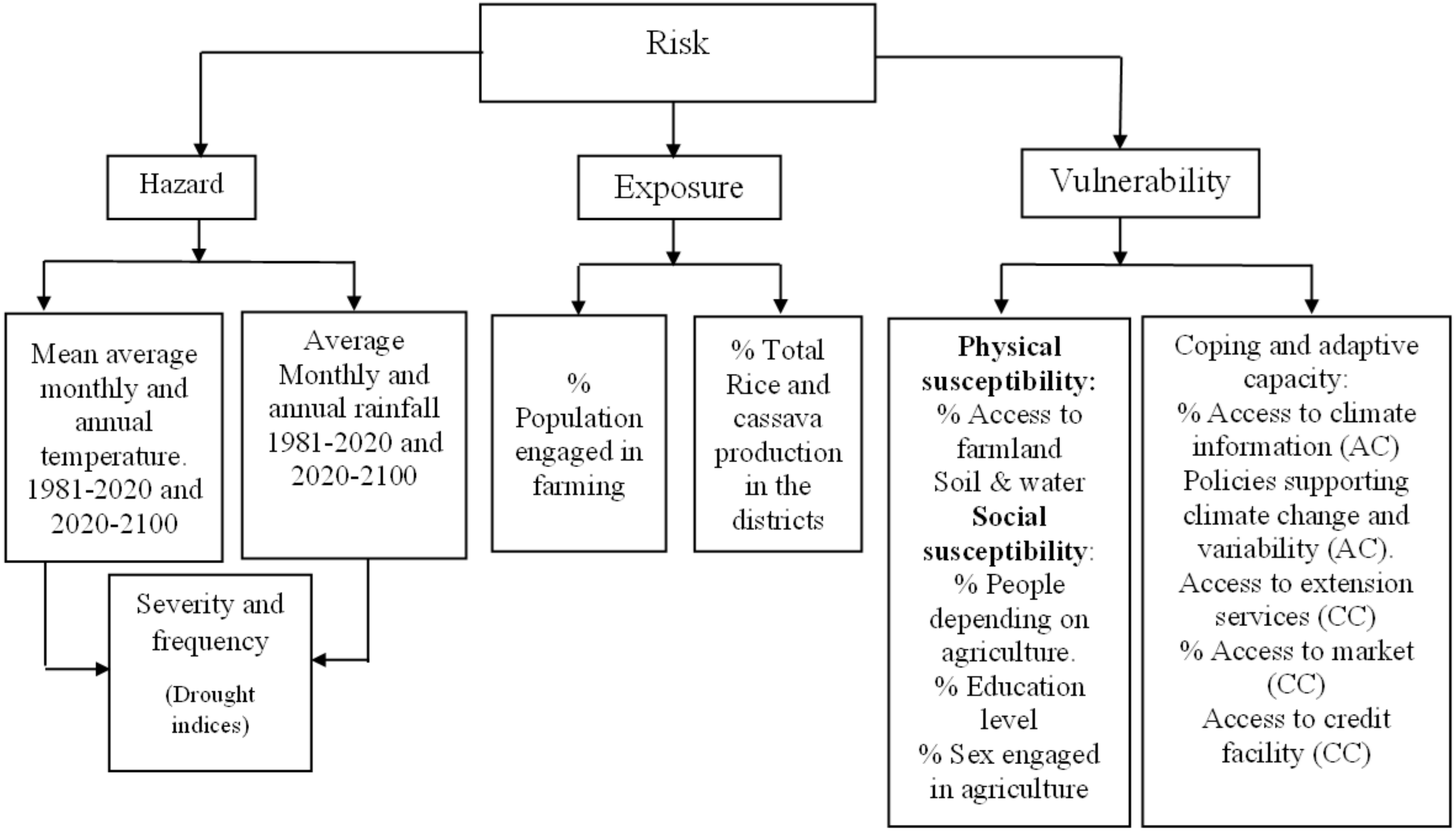

Figure 2.4 Drought risk assessment scheme concept for hazard adopted from Hagenlocher et al. (2018). This figure illustrates climate risk assessment using the IPCC 2022 definition of climate risk assessment. This framework is based on the different underlying elements, such as climate risk, hazard, exposure, and vulnerability (coping and adaptive capacities). This *assessment* the assessment incorporates both physical and social information.

Generally, the aim of risk assessment research is to provide a full comprehensive analysis of the causes of risk in order to enhance the identification of various opportunities that could be used to cope with and adapt to such underlying causes (Schipper, 2020). Such an understanding will help to develop appropriate prevention, adaptation and mitigation strategies to reduce the risks posed by climate change and variability (Fakhruddin rt al. 2020). Further, assessing climate risks has mostly been difficult because of its dynamic nature relating to its spatial and temporal dimensions (Adger et al., 2018). However, a number of studies have proposed different theoretical frameworks for the assessment of vulnerability and risks as a result of climate change and variability (e.g. Hagenlocher et al. 2018; Fakhruddin et al, 2020).

2.9 Theoretical Frameworks for Climate Risk and Vulnerability Assessment

Different types of methods and tools have been used to assess climate risk as a result of the multiplicity of interpretations and concepts. The various methodological approaches used in assessment of climate change and vulnerability in agricultural sector ranges from experimental, modelling, meta-analysis, and survey based. There are two well-known methodologies for estimating vulnerability and risk in the literature, the risk variable assessment method and the indicator technique. The risk variable assessment procedure is based on the econometric technique of determining welfare loss of variables of interest (e.g., household food consumption, income, agricultural crop yields, etc.) as they relate to a particular set of stressors, for instance, climate change (Tesfaye and Tirivayi, 2020; Drozdowski, 2021). Tesfaye and Tirivayi, (2020) and Drozdowski, (2021) emphasized that this approach can provide a risk index for a particular area; however, this does not adequately reflect all three components of risk. These approaches include the entitlement-based and Sustainable Livelihood Approach (SLA), which are discussed further below.

2.9.1 Entitlement-based Approach

Entitlement-based approach is one of the variable assessment approaches based on the development economic literature to explain how food insecurity occurs. This approach was first introduced in the early 1980s following the initial work of Sen (1981) on "poverty and famine". This marked the starting point of a paradigm shift to the body of food insecurity research as an innovation based on Malthusian theory, by shifting the emphasis away from mere availability to accessibility of food by individuals or household (Devereux, 2001). Therefore, entitlement theory displaced the prior notion that a shortfall in agricultural production was the main cause of food insecurity, arguing that people's access to food depends on their entitlement packs. It therefore uses economic and institutional factors to explain risk to food insecurity. Entitlements are “the set of alternative commodity bundles that a person can command in society using the totality of rights and opportunities that he or she faces” (Sen, 1984, p. 497).

Entitlements include the resources which could be actual or potential comprising of mutual arrangements (reciprocal), production as well as productive assets that may be available to a given individual or household at the time of difficulty (Sen, 1984). However, a household’s level of entitlements determines the extent of its risk to a specific food (Sen, 1981). Food insecurity may occur when households or individuals are not able to access food through their entitlements even when there are adequate food supplies (Devereux, 2001).

Based on this theory, Sen (1981) identified four types of relationship involving entitlements which include production, trade, labour and inheritance or remittance. The theory suggests that individuals or households will have food access directly or otherwise via these four means. Three fundamental types of food entitlements may be identified:

i. direct entitlements in which the household produces its own food.
ii. indirect entitlement whereby the members of the household buys food from the market; and/or
iii. households or individuals are provided with food through charity, non-governmental organization (NGO) or remittance from family and friends, this is a transfer entitlement (Fraser et al., 2005) or through transfer of money from family and friends, which constitute transfer entitlements (Fraser et al., 2005).

When households experience disruption in their entitlement bundle, they became susceptible to food insecurity as they do not have the capacity to change their strategies for food entitlement (Fraser et al., 2005).

This theory was criticized as it gave too much emphasis on economic market-based causality (Antwi-Agyei, 2012). By focusing exclusively on economic factors, this approach fails to appreciate bio-physical and socio-political factors that could greatly influence food insecurity in a particular region as well as the way in which people construct their livelihoods to withstand the impacts of such situations (Burchi & De Muro, 2016). For instance, the outbreak of diseases and widespread epidemics may account for most people who die during periods of food insecurity instead of a lack of appropriate food (de Waal, 1990). Further, the entitlement approach may be too narrow by focusing only on food as the outcome (Yaro, 2004). Indeed, achieving food security may not necessarily imply livelihood security since food security is just a part of livelihood security (Davies, 1996). Additionally, Devereux (2001) practically criticized entitlement approach when he argued that Sen's ideas of entitlement had four shortcomings. First, in connection with the idea of endowment, in reality, people choose hunger instead of selling their assets. Second, based on De Wall's health crisis model, death is not caused by the right, but is more due to the pattern of migration and exposure to new diseases. Thirdly, criticism also focuses on entitlement rights, in many cases, in relation to individual as a unit of analysis, in developing countries, the right to poverty is owned by society not by individuals. Finally, the shortcoming of this theory is due to extra-entitlement transfer problems. Hunger problems are not just problems with individuals but also problems with institutions, social contexts, and political crises.

Further, the entitlement approach may be too narrow by focusing only on food as the outcome (Yaro, 2004). Indeed, achieving food security may not necessarily imply livelihood security since food security is just a part of livelihood security (Davies, 1996). In this case, since the entitlement theory is about individual food security, applying this concept to the larger population may be difficult (Yaro, 2004). Moreover, by focusing only on an individual's endowment and entitlement sets to analyse their food security, it is possible to miss several critical variables that could potentially influence food security at the macro-societal level (Yaro, 2004). Certainly, decisions at the household level regarding production and purchases may be greatly influenced by major economic and social factors prevailing at the community and regional levels and these should be considered in a holistic understanding of food insecurity assessment.

By focusing on market-based economic failures, the entitlement approach fails to account for the role of government policies in food insecurity. Political theory argues that food insecurity may occur as a result of bad agricultural policies and the failure of the international community to provide adequate aid (Devereux, 2001). By favouring exchange failures instead of production failures, this approach also downplays the significance of a decline in food availability in causing food insecurity and famine (Swift, 1993). For instance, in Mali, the 2015 drought resulted in the starvation of more than 300,000 people due to food insecurity (Giannini et al., 2017, Bhaga et al., 2020). In South Africa, the 2014-2016 drought resulted in vegetation and wildlife loss in protected areas, although the impacts were not catastrophic (Swemmer et al., 2018). Recently, the 2017-2018 drought in the Western Cape Province of South Africa resulted in water restrictions which, in turn, resulted in knock-on effects on the economy, human health, and sanitation (Parks et al., 2019; Sousa et al., 2018). A decline in food production could lead to higher food prices beyond the reach of poor and marginalized households. Despite these criticisms, the entitlement approach offers a valuable lens through which we can assess how the various bundles that a household may be entitled to can be used to explain how they buffer against the negative impacts of drought on their livelihoods. In this thesis, the entitlement approach allowed a broad conceptualization and exploration of the different capital assets that households and districts can access to reduce the adverse impacts of climate variability (particularly drought and dry spells) on their livelihoods.

2.9.2 Sustainable Livelihood Approach

This section reviews literature on sustainable livelihoods approaches (SLA) linking them to climate risks. It reflects the complex factors that shape how households sought livelihood approaches in the face of the impact of climate shocks. Livelihood approaches share many of the concerns addressed in climate risk analysis, whilst livelihood approaches place emphasizes on the ways in which households and communities draw on their assets and capabilities to build livelihoods, risk highlights the conditions that hinders the livelihood approaches.

Sustainable livelihoods approach (SLA) is an analytical framework that emerged from social science which has been widely used among international development agencies (Davies et al., 2008; Navila Ulfi and Dyah Rahmawati, 2020). SLA emerged from poverty reduction discourse in 1980s as a conceptual framework to understand how people manage poverty and develop poverty reduction strategies (Gutierrez-Montes et al., 2009). SLA was later utilized during the 1990s as sustainable rural livelihoods framework (Scoones, 2013). The framework was then adopted and further developed by the UK Department for International Development (DFID) (2001) as sustainable livelihoods framework which incorporates most of what is considered to be the best practice in development. The SLA was intended to be applied for analyzing the rural context which aims to design and support development programs to help rural poor and vulnerable population (Davies et al., 2008; Serrat, 2017).

Indeed, Chambers and Conway (1992, p. 7) emphasized that:

> “A livelihood comprises the capabilities, assets (resources, stores, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the [current and] next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long-term.”

Similarly, it is used to assess communities' capacities to withstand conflicts and other climate and non-climate stresses. Awazi and Quandt, (2021) used the SLA to identify a range of stressors that either reduce adaptive capacity or increase risk to climate variability in Kenya and Cameroon. They argue that agriculture-dependent households may be able to reduce their overall risk to climate variability and change by diversifying the strategies within their livelihood portfolios or specializing to take advantage of a niche (Awazi and Quandt, (2021).

The SLA has two major components: livelihoods and sustainability. Its main features are highlighted in Figure 2.5. Livelihood capital assets consist of tangible resources and intangible assets (including claims and access) that people use to construct their livelihood outcomes. Livelihood strategies generally refer to the combination of activities that people embark on in order to achieve their livelihood outcomes (Chambers and Conway, 1992).

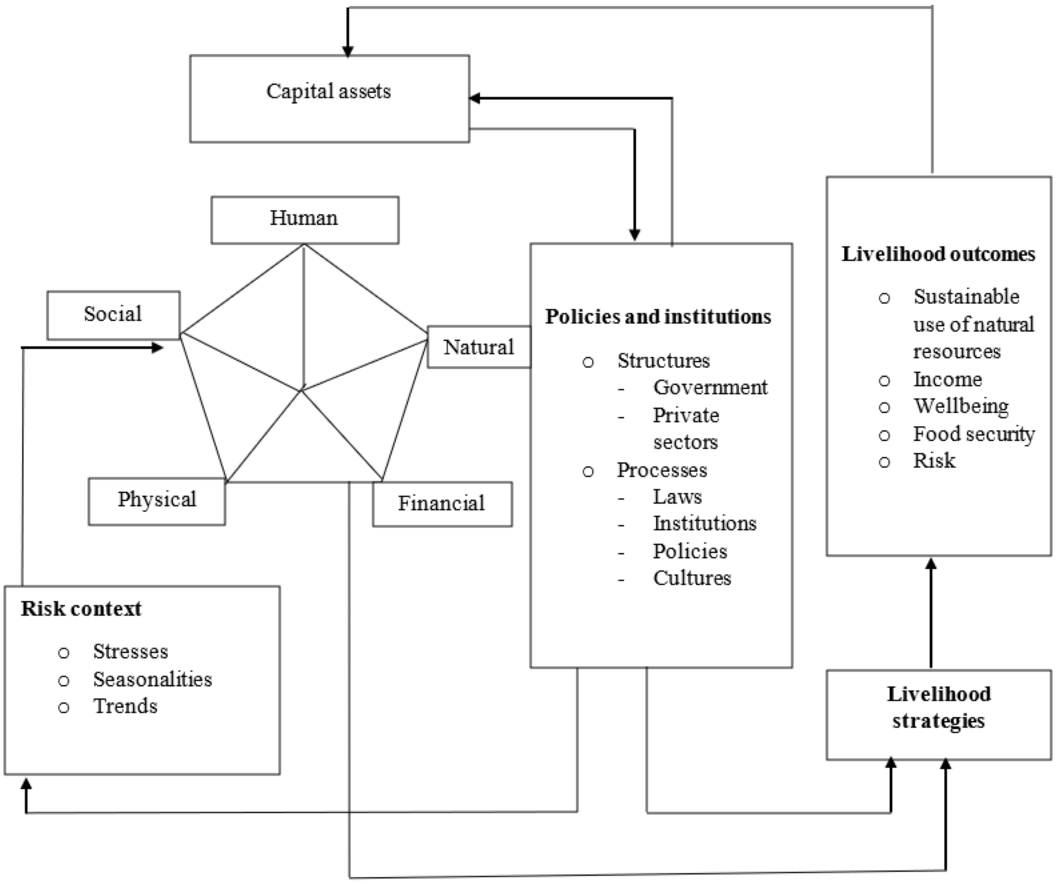

Figure 2.5 Sustainable livelihoods approach, Source: DfID, 2001.

Livelihood outcomes generally refer to outputs such as more income, increased well-being, reduced risk, improved food security, more sustainable use of the natural resource base, and recovered human dignity, between which there may again also be conflict (Chambers et al. 1992). In this regard, livelihood outcomes are greatly influenced by the risk context, which refers to the external environment in which people or households exist (DfID, 2001). Within the SLA, risk assessment considers the stresses, seasonalities and trends that communities or local people may be exposed to and their capacity to withstand such stresses (Birkmann, 2006). Such stresses consist of seasonal rainfall variability, poor soil fertility, frequent conflicts because of inadequate access to water and prolonged illness caused by disease epidemics, all of which contribute to climate risk. Climate risk also includes long-term trends such as migration, recurring seasonal changes, changes in the natural resource base as well as short-term changes such as conflict, illness and natural disasters (DfID, 2001). In Indian and Pakistan, Newman et al. (2020) and Shahzad et al. (2021) applied SLA to assess a range of social and biophysical stresses linked to population pressure, land degradation and droughts that increase farmers' exposure to climate change risks whilst reducing their adaptive capacity.

Similarly, in South Africa Tshikolomo th Africa, Tshikolomo et al., (2020) SLA was applied to assess a vary of social and biophysical stresses linked to population pressure, land degradation and droughts that increase farmers' exposure to climate change risks whilst reducing their adaptive capacity. Reed et al., (2013) also used SLA stressed that improved access to livelihood capital stocks such as soil, land, water, forest and household income may help farmers develop adaptive capacity by reducing their susceptibility to climate change. In Ghana, Antwi-Agyei et al., (2017) used the SLA to identify social and physical factors, including plot size, access to micro-finance service, educational levels and access to information on seasonal rainfall patterns that influence climate risk. Their report further indicated that the use of fertilizers and high-yielding crop varieties in combination with diversification of off-farm income sources helps farmers ensure livelihood security. Hence, a household at risk, according to this research, is one that is unable to sustain livelihood activities to cope with the shocks imposed by environmental shocks including climate variability (Osman, 2021).

Sustainable livelihood approach states that livelihood should be considered in terms of people's access to capital assets (financial, physical, natural, human, and social), their livelihood strategies and outcomes are governed by the prevailing policies as well as institutions (both formal and informal) (Pellowe and Leslie, 2020). Sustainable Livelihood Approach (SLA) further highlights the various interactions that govern households' or individuals' abilities to withstand shocks and stresses (Johansson, 2015). Previous studies have shown that smallholder farmers in SSA are more at risk due to their lack of access to resources and assets (Jin et al., 2015b; Baffoe and Matsuda, 2018). Unfortunately, livelihood risk will make it more difficult for farmers to obtain the support of resources and assets. In the long run, farmers will fall into a long-term vicious circle (Van Den Berg, 2010), which seriously threatens the sustainability of their livelihoods. The agricultural decisions of farmers are a response that occurs after farmers comprehensively weigh their own livelihood asset endowments (Scoones, 1998; Baffoe and Matsuda, 2018). According to the sustainable livelihood framework (Chambers, 1987; Scoones, 1998), farmers' livelihood assets consist of natural, financial, human, physical and social assets. For example, financial and social assets have been proven to be the main factors affecting the adaptation of farmers to climate change in the Nile Basin of Ethiopia (Deressa et al., 2009; Chen et al., 2014). García de Jalon et al. (2018) found that investing in all five types of assets, especially human or social assets, helps farmers adopt adaptation measures. Of course, farmers suffering from livelihood risks and adopting adaptation strategies will have a livelihood outcome, which will also have an impact on livelihood risks. This section is focused on the role of livelihood assets in farmers' climate risks and adaptation strategies and what policy measures can be taken to avoid climate risks and to promote the adoption of adaptation strategies as much as possible. What follows next is an exploration of the links between access to livelihood capital assets and risk to climate variability.

2.9.3 Sustainable Livelihoods Capital Assets and Risk to Climate Change and Variability

It is important to highlight the fact that individuals become at risk to climate variability whenever their means of livelihood is at stake. The theory of SLA approach is anchored on the belief that local farming communities have numerous capabilities that need to be considered. Basically, the Sustainable Livelihood Approach is useful in the understanding of the way individuals or communities use a combination of diversity of capital endowments including tangible capital asset, example land asset, and intangible capital asset such as the level of education or farmers experience, claim and access, etc. individuals possess and have control over to use it in achieving livelihood goals within the existing social, economic and political milieu (Carney, 1998; Yaro, 2004). Usually, the sustainable livelihood approach is used by taking into consideration the five capital assets i.e. the human, physical, financial, social, and natural assets as well as their links to an overall risk context, processes, institutions and policies and livelihood outcomes (Scoones, 1998).

Human capital assets refer to the quality and quantity of labour. At the household level, this is reflected in the household size and composition, and it is characterized by e.g. educational level, training and skills levels, and the health status of the household members (Sharaunga and Mudhara, 2021; Adhikari, 2020). Sharaunga and Mudhara, (2021) observe that basic education is regarded as important in breaking the cycle of intergenerational poverty. It is assumed that households with lower human capital must allocate a substantial amount of their scarce resources to educate themselves and member of their family. Using part of the households' limited funds to fund education will erode their financial asset base, thereby reducing capacity to withstand the impacts of climate change and variability. Since food production is labour intensive in the study communities, linked to climate change and variability could adversely affect farm labour (Labiru et al., 2023) because households with few numbers of labour force during the farming season could miss crucial timelines that render crops more susceptible to drought and dry spell. To assesses educational levels, seven categories were used; no formal education, pre-primary, primary, junior, senior, vocational and degree for households that had tertiary education. Furthermore, household were asked the number of people actively going to school. Natural capital assets consist of natural flow and stocks, land, and biological resources such as trees and biodiversity (Gbayisemore et al., 2022). They also include the quality and quantity of land, pasture, water, agro-ecological conditions such as soil quality, slope and topography of the land, forest resources (Gbayisemore et al., 2022) and that these resources may be improved or degraded by the actions of human beings. In most rural communities in many parts of SSA, natural capital in the form of land is a crucial asset for many livelihoods and therefore can greatly influence the other capital assets (Murken and Gornott, 2022). Financial capital includes income, savings, credit, and other savings in liquid form (Scoones, 1998). It also includes remittances and easily disposable assets such as livestock and poultry (Hesselberg and Yaro, 2006; Gbayisemore et al., 2022,). Physical assets refer to non-land assets including infrastructure (markets, roads, electricity, and irrigation facilities) (Gumel, 2022). It also includes the type of housing, machinery, and equipment (Scoones, 1998). Finally, social (including political) capital assets highlight the various rights and claims due to membership of recognized groups or associations (Gumel, 2022). It includes networks and connectedness, social relations, as well as relationships of trust and reciprocity (Scoones, 1998). Social Capital entails the various rights and claims arising from membership of recognized groups or associations (Gumel, 2022). Farming communities draw on such capital assets to pursue their livelihood activities (mainly agriculture) (DfID, 2000). Social capital includes collaboration, membership of voluntary organizations, community groups, professional union, social or political networks as well as reliance on family and relatives as well as friends at the time of need (Ellis, 2000).

Several studies have used this SLA framework (e.g. Gumel, 2022; Bedeke, 2023; Ngwenya, 202; Etana et al., 20201). In general, these studies enhance our understanding of how communities or local people have responded to past environmental shocks by deploying the capital assets that they can command to withstand climatic shocks. Building on previous research on livelihoods diversification (Musumba et al. 2022; Ayana et al., 2021; Little, 2021; Melketo et al., 2020) and livelihood capital assets (Wong, 202; Berhanu et al. 2022; Gunarathne et al., 2020; Dharmawan et al. 2020), this thesis adopts the SLA as an assessment of livelihoods offers the opportunity to highlight the various adaptations that might be available to determine how rural farmers can cope with declining crop yields due to drought, and also how such declining yields can affect livelihoods (Ubisi et al. 2017; Aniah et al. 2019). In this study, the SLA is used to frame how rural livelihoods, including crop production systems in Liberia, can be at risk through the identification of the various capital assets. These capital assets are employed by households to varying degrees to mitigate the effects posed by climate change and variability (Savari and Zhoolideh, 2021; Ahmad and Ma, 2020; Rodriguez et al., 2017). Therefore, accessibility to capital assets is a defining factor that greatly influences the ability of a household to cope with climate change and variability (Gallo et al. 2020; Mekonen and Berlie, 2021).

Despite its utility and widespread use, the SLA has been criticized as an analytical tool in terms of its difficulty to address temporal dimensions, power dynamics as well as multiple scales. For example, it may only offer a snapshot of the vulnerability of the household or local people in a particular point in time and may not reflect the temporal changes associated with these shocks (Scoones, 2013; Toner, 2003). The vulnerability context as well as the policies and assets portfolio are dynamic and in constant state of flux. Therefore, there is the need to include a temporal dimension into the framework to strengthen its analytical value (Scoones, 2009 and 2013).

The SLA has also been criticized for failing to explicitly include political capital (Scoones, 2009; Toner, 2003; Baumann, 2000). By failing to do this, it downplays the significance of power and politics in influencing the vulnerability of farming households to climate variability. Baumann and Sinha (2009) argued that the inclusion of political capital would greatly enhance the analytical value of the SLA. Moreover, the assessment of the possible impacts of transforming structures and processes on rural livelihoods is made difficult by the lack of inclusion of political capital.

Another shortcoming with the SLA is its failure to capture the dynamics of livelihoods analysis across multiple scales (Scoones, 2013). Whilst claiming to link micro to macro, Scoones (2009, p. 187) argues that such claim “is often more of an ambition than a reality.” For instance, the SLA fails to address wider global processes and how such processes impact livelihood activities and outcomes at the household level (Scoones, 2013). Globalization affects households' decision making and livelihood choices at the local level.

Although assets are mediated by various transforming structures including policies, practices and institutions that are embedded in the SLA, such transforming structures and processes have been deemed too general to be useful for empirical work (Birkmann, 2006). These transforming structures and processes are important in defining the various opportunities and constraints available to an individual or a particular household in pursuing their livelihoods outcomes (Appiah et al. 2021; Thanh et al. 2022). The SLA has further been criticized for failing to acknowledge distributional issues (Swift et al. 2001). For instance, even though it highlights the importance of increasing the opportunities available for the poor to achieve their livelihoods, it fails to promote issues of equity (Appiah et al. 2021; Thanh et al. 2022), which are central to coping and adapting to climate variability.

While offering a people-centred approach to the understanding of livelihood vulnerability and inequalities that confront various households and thereby shaping development objectives (Natarajan et al. 2022), the focus on the household has been deemed to result in methodological individualism (Fairbairn et al. 2021). Moreover, livelihood assessments only superficially evaluate the capital assets that may be available to the households. For instance, livelihood analysis of a household may only provide assessment of the availability of natural capital to cope with drought, but such assessments fail to provide valuable "insights into whether specific agro ecosystems are likely to be sensitive to environmental change" (Fraser, 2007, p. 497). The SLA also fails to consider the physical and ecological environments (Gumel, 2022). For instance, Scoones (2013) argues that the SLA fails to vigorously incorporate practices to deal with changes in environmental conditions. Finally, the SLA has been criticized for conceptualizing poverty as a lack of capital assets instead of a lack of entitlements (Natarajan et al. 2022; van Dijk, 2011).

This thesis addresses these shortcomings by adopting a multi-scale climate change climate risk assessment: mapping exposure and vulnerability as well as climate risk at the district levels. Concerns relating to temporal dimensions and power dynamics were taken into consideration in the choice of research methods. For instance, participatory methods were used to explore the temporal dimensions of livelihood vulnerability to climate change and variability as well as the influence of power relations within the study communities.

2.9.4 Assessing the Temporal Dimension of Vulnerability

Several researchers (e.g. Borras et al., 2022; Choden et al., 2022; Grigorieva et al., 2023) have used a combination of social and ecological theories to explain how food systems may be vulnerable to environmental (including climate) change. For instance, Choden et al. (2022) uses historical case studies to explain how food systems may be vulnerable to climate change and variability. First, he finds that changes in agro-ecological settings influence how agricultural productivity and food systems were sensitive to environmental changes. Second, sensitivity of people or communities depends to a greater extent on their ability to switch from agricultural-based livelihood systems to other livelihood strategies that depend less on the climate. Finally, he notes that local, regional, and international institutions play a critical role in either reducing or exacerbating the vulnerability of communities to climate variability. These observations led Choden et al. (2022) to propose that vulnerability of food systems to environmental change such as climate change can be assessed at the agro-ecosystem, community (livelihoods) and institutional levels. Hence, food systems within agroecosystems that are fragile with few livelihood options and social networks together with weak institutional arrangements are more likely to be vulnerable to environmental and climate change (Choden et al., 2022). Their approach has been applied by several scholars (e.g. Ranasinghe et al., 2023, Bedeke, 2023; Meza et al., 2021, Garschagen et al., 2021; Frischen et al., 2020) to assess the climate risk of food systems or rural economies to environmental change. This thesis builds on this by combining livelihood theory with a temporal element through local level participatory approaches.

2.9.5 Quantitative Indicator Approach to Climate Risk Assessment

Mostly, one of the classical approaches for quantification of climate risk is the indicator method of climate risk assessment which employs the use of a set or collection of some proxy indicators, and assess risk by calculating indices, averages or weighted averages for the selected variables or indicators (Kinnunen et al., 2022; Chepkoech et al., 2020). Therefore, indicators referred to as quantitative measures normally in form of single values employed as a representation of phenomenon of interest concerning a given community, household, or a particular system (Kumar et al., 2021). A chosen indicator is meant to simplify useful information which can be measured and quantified, rather it makes the phenomenon perceptible (Gumel, 2022). The process of aggregating diverse indicators as a representation of a single value to be used in characterizing particular households, community or a system of interest usually proves cumbersome. It shows more tasking where the assessments are carried out in a very large spatial area as the indicators used may appear different in different areas (Kumar et al. 2021). Therefore, it is desirable to clearly comprehend the methodology involve in the measurement of the indicators needed in vulnerability assessment (e.g. Khan et al. 2021; Sperstad et al. 2020). The advantage of this method is that it can be applicable in any scale of analysis, such as household level, district, or national level. The disadvantage of the indicator approach is that applying indices may be marred by subjectivity in variables selection but could be very useful in observing trends and discovering conceptual frameworks, multiple indices can accurately measure the multiple dimensions of vulnerability (e.g. Choudhary et al. 2022; Lanlan et al. 2023; Gumel, 2022). Therefore, other studies may consider an integrated vulnerability assessment approach to construct vulnerability index for the identification of the most vulnerable to climate change variability among farmers' households, villages, and communities.

Moreover, substantial literature has been published on the use of quantitative indicator approaches to assess risk to climate change and variability at the global scale (e.g. Saikia and Mahanta, 2023; Hagenlocher et al. 2019), regional scale (e.g. Ricart et al., 2023; Birkmann et al., 2022), as well as national and district scales (e.g. Ye et al., 2021; O'Neill et al., 2020). This allows the comparison of the relative vulnerability of different nations, regions, or districts to the adverse impacts of climate change and variability and provides valuable insights to policy makers and development partners regarding the current challenges confronting vulnerable groups and how these could be addressed through appropriate policy interventions (e.g. Gumel, 2022; Bedeke, 2023).

For example, Shah et al. (2020) and Beccari, (2016) conducted studies where they developed a Vulnerability-Resilience Indicator approach to assess vulnerability and resilience in the context of natural hazards and review of hydro-meteorological hazard, vulnerability, and risk assessment frameworks and indicators in the context of nature-based solutions. They used indicators relating to settlement sensitivity, hazard, water availability, food security, human health sensitivity, ecosystem security and availability to explore the main environmental and socioeconomic factors that could influence the ability of these different groups of farmers to withstand the stresses imposed by climate change and variability. Whitney et al., (2017), Erdiaw-Kwasie et al., (2019) and Beccari, (2016) used adaptive capacity to capture both coping and adaptive capacity in their assessment. Whitney et al, Erdiaw-Kwasie et al. and and Beccari's works have been criticized by several writers (e.g. Choden et al., 2020) who highlight that by not distinguishing between coping and adaptive capacity, this assessment fails to capture the main factors that might influence the way people use their livelihoods to manage risk associated with climate variability.

In another study, Tofu et al. (2020) used the indicator approach to assess climate vulnerability and adaptive capacity in Ethiopia by examining the link between national-level socioeconomic data and climate-related mortality to highlight the main factors that correlate with past extreme weather events. They concluded that there was a strong correlation between socioeconomic indicators with aggregated mortality and that countries in SSA and those experiencing crop failure might be the most vulnerable. Whilst making significant contributions by identifying socioeconomic factors that may be lacking in typical quantitative crop modelling studies (Niu et al., 2021), this study used direct impact of rising temperature on human health which has resulted into the increase in heat-related mortality and morbidity worldwide as dependent variables and failed to account for other variables such as the size of the environmental anomaly that might have resulted in such mortality (Simelton et al., 2009). Although the results of Tofu et al.'s study provides useful insights into the critical factors that could influence sensitivity of a particular country to climate variability, it should nevertheless be interpreted with caution as it provides an insufficient basis to inform policy because it lacks policymakers' awareness about climate variability and change (Huyer et al. 2021; Manevska-Tasevska et al. 2023).

Several researchers have also used a quantitative indicator approach to assess and mapped climate risk at the regional and global scales (Macharia et al. 2020; Xenarios et al. 2014). Similarly, Macharia et al. (2020) mapped hotspots of climate change and food insecurity in the tropics, conceptualizing risk as a function of hazard, exposure, and vulnerability (physical and socioeconomic susceptibilities, and coping and adaptive capacities). The study revealed that the most vulnerable areas were characterized by high exposure and susceptibility or sensitivity to climate change coupled with low coping and adaptive capacities (Macharia et al. (2020). Midgeley et al. (2011) conducted vulnerability assessments for Southern Africa to highlight "hotspots" of current and future (2050) vulnerability to climate change. This study showed that areas that relied significantly on rain-fed agriculture and characterized by high population growth were more vulnerable. Using Principal Component Analysis techniques, Wanyama et al. (2021) and Medina et al. (2020) created spatially explicit socio-ecological vulnerability maps for the Southern Africa Development Community. This study produced information on rich vulnerability maps suggested that different parts of the region demonstrated different types of vulnerability to environmental (including climate) change. Such studies contribute to the understanding of the extent of vulnerability of different regions as well as enhancing the understanding of the various factors driving vulnerability. Vulnerability assessments relying on census data at the national level could mask significant local level variability in terms of access to assets and entitlements (Dumenu et 2020; Khadka, 2022)) because of the problem of aggregation that makes particular poor regions seem less vulnerable than they really are (Poudel et al. 2020). This leads to loss of vital information relating to 'hotspots' of vulnerability at the local level (Dumenu et al. 2020). The development of such climate risk indices rarely acknowledges the participation of communities regarding what is perceived to influence vulnerability to climate variability at the local level (Ceci et al., 2021; Barua et al. 2020). This thesis addresses these challenges by adopting a participatory approach to identify and unpack the extra information that can be obtained from rural level risk analysis that is lacking in these counties and district level assessments (Chapters 5-7).

2.9.6 Effectiveness and Criticisms of the Indicator Approach

Building on the previous section of this thesis, the indicator approach has shown to be an extremely useful tool for monitoring and studying trends to guide policy formulation (Corlet Walker et al. 2020). Equally important is the fact that the indicator approach is also applicable at any scale. Thus, this thesis uses a mixed-method approach that incorporates different aspects at different phases, creating a risk index to identify key districts in Liberia where crop production systems and livelihoods are most vulnerable to climate variability. This could guide policy formulation and advance appropriate interventions, helping to reduce the risks of groups for whom risk has been projected to increase due to extreme events associated with climate change and variability.

Notwithstanding, the use of an indicator approach has been highly contested by several scholars such as Wanyama et al. (2021); Medina et al. (2020) and Macharia et al. (2020). For example, there are serious contentious methodological issues regarding the selection, standardization, and weighting of the various indicators (Medina et al. 2020). These difficulties may be attributed to the complex and interconnected nature of the various processes that influence climate risk (Macharia et al. 2020; Bedeke, 2023). One major weakness of indicator approach was mentioned by Zellner et al. (2022), Villamor et al. (2019) and Newman et al. (2020), in which according to them relates to the difficulties in simplifying the complex interactions that occur within a socio-ecological system to a single variable that may not be representative enough. Another drawback is that it is difficult to meaningfully compare results from risk indices resulting from an indicator approach from one region to another, due to differences in the sets of variables used (Edmonds et al., 2020; Al Mamun et al., 2023; Wu, 2021). For example, Edmonds et al. (2020) examined five national level and risk and vulnerability studies that sought to compare the vulnerabilities of different regions based on the indicator approach. They observed that the results of these country-level risk and vulnerability assessments could not be compared. Whilst three of the studies ranked country vulnerability, two studies displayed vulnerability of such countries in the form of maps instead of an explicit ranking. Edmonds et al. (2020) observed that "a lack of clear theoretical and conceptual framework for the selection of indicators has hampered the robustness, transparency and policy relevance" of such studies (p. 496). They went on to highlight that even amongst the three studies that performed country risk and vulnerability assessment by ranking, there were considerable differences regarding the selection and number of countries in such studies, making it tough to compare results (Edmonds et al., 2020).

However, to address some of these deficiencies in the application of the indicator approach for risk and vulnerability assessment, Edmonds et al. (2020) have suggested that the selection of indicators for the risk and vulnerability assessments should be representative and robust. This relates to scale issues that are critical in risk and vulnerability assessments (Zellner et al. 2022). This thesis adopted a multi-scale approach by assessing climate risk at the national, county and district levels and drilling down to the household levels. Secondly, there should be a well-defined and transparent conceptual framework that recognizes the multivariate character of the processes interacting to influence climate risk. Thirdly, the processes that shape climate risk in the vulnerability assessment should be verifiable. Zellner et al. (2022) maintained that there should be an appropriate relationship between the theoretical assumptions and the empirical evidence. These points are taken into consideration in the research methodology (Chapter 3).

The next section of this thesis is focused on the concept of adaptation with reference to some of the key strategies used by households in SSA to adapt to climate change and variability.

2.10 Adaptation to Climate Change and Variability

Adaptation to climate change and variability refers to the process of adjustment to climate change and associated effects to moderate the negative effects of climate change or exploit the beneficial opportunities (IPCC, 2014). The 2015 Paris Agreement recognizes adaptation as a key goal towards strengthening resilience and minimizing susceptibilities to climate change, with a view of contributing to sustainable development (UNFCCC 2015). Considering that agriculture remains the major source of livelihood for most rural communities in sub-Saharan Africa, adaptation plays an important role in enhancing resilience of the agricultural sector, protection of livelihoods and minimizing vulnerabilities associated with food insecurity posed by climate change (Sultan and Gaetani, 2016). As such, IPCC (2014) reported that most African governments have initiated governance systems for adaptation, such as disaster risk management, modifications of technologies and infrastructure, ecosystem-based approaches, and livelihood diversification strategies. Similarly, the IPCC report of 2018 identifies a range of adaptation options to reduce risks to livelihood, water, and economic growth, among these are efficient irrigation, disaster risk management, risk spreading and sharing and community adaptation (IPCC, 2018). Since the Fourth Assessment report of the IPCC, livelihood-based approaches towards managing risks to food production have been reported to increase in Africa (IPCC, 2007). However, such efforts may not be sufficient for managing climate-related risks in the long term. For example, in ecology, adaptation ultimately underpins the resilience of Earth's complex systems; species, communities, and ecosystems shift and evolve over time. Other words, adaptation refers to the ability of an organism to adapt to changes in its environment (Burtscher et al., 2022). In the context of climate change research, various definitions of adaptation have been formulated as indicated in Table 2.1. This thesis adopts IPCC (2014) definition of adaptation to climate change as the process by which rural farmers reduce the adverse effects of climate on their livelihoods. This conceptualization allows a better understanding of how households and districts use their adaptive capacities and various assets in reducing the adverse impacts of climate variability on food crop systems and livelihoods. This will help in assessing how such households and districts could be assisted by various stakeholders to withstand climatic stresses.

Table 2.1 Various definitions of adaptation in the climate change literature

Authors	**Definitions**
(IPCC, 2014)	Adaption refers to the process of adjustment to climate change and associated effects in order to moderate the negative effects of climate change or exploit the beneficial opportunities. It is also defined as adaptation is the ability of a system to respond or adjust to risks or potentials effects of climate variability and change conditions.
Sebos et al., 2023	Adaptation to climate change involves adjusting systems to climate events, including building sea walls and developing drought-resistant crops and early warning systems, aiming to increase resilience.
(Smit and Pilifosova, 2001, p.881)	Adaptation to climate change is defined as "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"

Ackerl et al., 2023	Adaptation implies adjustments not only to actual climatic impacts but also to expectations of future climate change to avert potential harm.
Khanian et al., (2019, page 187).	‘‘adjustments in individual groups and institutional behaviour in order to reduce society’s vulnerability to climate change”

Even though agriculture is one of the most widely studied sectors with respect to the impacts of climate change, until recently, efforts have neglected the possible role of adaptation by farmers (Dang et al., 2019). In 1992, the term adaptation was considered a restriction and rarely used in relation to climate change policy (Khan and Munira, 2021). The focus of the international community was on mitigation, which involves reducing the emissions of greenhouse gases (GHG) and increasing carbon sinks, thereby slowing the rate of global climate change (IPCC, 2022). The attention of the international community was on setting targets and schedules for emissions reductions to slow down the rate of global warming (Abbass et al., 2022). Certainly, Abbass et al. (2022) emphasize that “…proponents of adaptation were viewed as rather defeatist and were thought to demonstrate a lack of faith in countries’ abilities to limit emissions” (p. 750). The world will likely continue to warm at a significant rate for many decades whatever targets may be agreed to reduce emission (IPCC, 2022). Therefore, adaptation is necessary to reduce the harmful impacts of climate change and variability on agriculture (Gbadebo et al., 2020; Gnanasubramaniam and Hemachandra, 2020; Sivakumar, 2021). Failing to implement appropriate adaptation strategies for the most vulnerable groups could lead to serious problems including significant deprivation, social disruption, and population displacement, and even morbidity and mortality (Ullah et al., 2021).

The fundamental issues to the understanding of climate adaptation strategies in agricultural systems and rural livelihoods are coping and adaptive capacities. The Intergovernmental Panel on Climate Change (IPCC) (2007:118) defines adaptation as the ‘‘adjustment of natural or human systems in response to actual or expected climatic stimuli, or their effects, which moderates harm, or exploits beneficial opportunities’’. Two types of adaptation to climate change are differentiated. On the one hand, adaptation strategies are longer-term in nature (Thomas et al., 2007) while coping strategies, on the other hand, consist of household strategies that are short-term in nature, and which are meant to minimize the impacts of hazard (Thomas et al., 2007). Coping and adaptive capacities are widely used terms in climate adaptation literature (Gumel, 2022; Serdeczny et al., 2024). Several scholars such as Gumel (2022); Thouret et al. (2022); Susilo et al. (2021) recognize that coping strategies and adaptive capacity are situated within wider socio-cultural and religious processes happening within such communities. Hence, efforts should be made by policy makers to take cognizance of such processes and factors when designing climate adaptation strategies intended at enhancing the capacities of rural farmers to withstand the negative impacts of climate change and variability on their livelihoods.

2.10.1 Types of Adaptation to Climate Change and Variability

Studies have identified various types of adaptation but the fundamental forms of adaptation to climate change and variability can be classified either as planned adaptation or as autonomous adaptation (Khanal et al., 2019; Smith and Malik 2021). Autonomous adaptations are coping strategies which are mostly temporary and reactive in nature and can be implemented by individuals, agents, and institutions (Smith and Malik 2021). For example, in response to a changing precipitation pattern, a farmer may decide to change the crops or use different harvest and planting dates (Kumi et al., 2023). Hence, the effectiveness of autonomous adaptation strategies depends on the availability and accessibility of resources to cope with sudden climate changes (Smith and Malik 2021; Sivakumar, 2021). In contrast, Ojemade et al. (2020) and Rivas et al. (2022) stressed that planned adaptation measures are conscious policy options or response strategies, often multi-sectorial in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptations. Indeed, planned adaptation seeks to address future climate stresses and could be based on predicted future climate adverse impacts or past experiences (Rahman et al. 2021; Seidl et al. 2021; Fischer Denny, 2024). While there is a distinction between planned and autonomous (reactive) adaptation, in practice the line between these two is blurred (Green et al. 2021). Therefore, this thesis explores both autonomous and planned adaptation strategies employed by farming households and districts to reduce the adverse impacts of climate change and variability on their livelihoods. For instance, a reduction in food consumption by the households because of climate related food insecurity could be considered as coping strategy while resorting to planting drought-resistant and early maturing varieties of crops are examples of planned adaptation (Chapter 6).

2.11 Level of Adaptation to Climate Change and Variability

In the context of agriculture, Mitter et al. (2018) classified the process of adaptation into three types of implementations, namely: (i) incremental, (ii) transformational or (iii) systemic separated. Albert et al. (2021) draw attention to the temporal scale of adaptation, and they found that 70% of the adaptation studies focus only in one of these time scales of adaptation (day, or season or long-term), highlighting the need to integrate these dimensions in a multi-temporal scale approach. Some authors developed more specific frameworks for the agriculture sector. Grigorieva et al. (2023) and Ahmed (2020) characterized the adaptation measures according to aim, timing and duration, scale, responsibility and form and organized adaptation measures into the following types: (i) technological developments such as satellite-based early warning; (ii) government programs and insurance (subsidies and technical assistance); (iii) farm production practices/ adapting farm management practices; and (iv) farm financial management/ assisting farmers in accessing credit, capital and risk-insurance. Categories (i) and (ii) involve strategies pursued by public institutions and organizations (Grigorieva et al. 2023; Ahmed, 2020). Examples of Category (i) pathways include the development of new crop varieties, development of early warning systems that provide weather predictions and seasonal forecasts and the development of irrigation techniques to address moisture deficiencies. Examples of Category (ii) pathways include agricultural subsidy support programmes, the development of private insurance to reduce climate related risk, and the development of policies to influence farm-level production. On the other hand, Categories (iii) and (iv) are undertaken at the level of the individual farmer or farmers' group. Examples of Category (iii) pathways include diversification of crop types/varieties and livestock types, changing land use practices to address environmental variations and changing timing of farm operations such as planting and harvesting dates (Vignola et al., 2015). Using crop insurance, participation in appropriate income stabilization programmes and diversification of household income are examples of Category (iv) pathways. Similarly, Vizinho et al. (2021) developed typologies more related to the time when the effects of the adaptation measures will be observed: (i) short term adaptations; (ii) long term adaptations; and (iii) adaptations irrespective of the temporal dimension of climate impacts. Hernández-Morcillo et al. (2018), prioritized the agroforestry measures for adaptation and mitigation according to their perceived performance. Focusing on mitigation, they proposed several measures for sequestering carbon or reducing greenhouse gases, whereas focusing on adaptation they proposed measures for enhancing resilience or reducing threats.

In terms of Level of agricultural adaptation, Marie et al. (2020) distinguish farm-level adaptation from regional and national level adaptation. Regional- and national-level adaptation involve changes in infrastructure as well as support systems whereas farm-level adaptation covers the range of farm management practices undertaken at the farm or field level by the farmer in an attempt to moderate the adverse impacts of climate variability

(Marie et al., 2020; Jia et al., 2021). Adaptation may also be characterized by timing (anticipatory), duration (short or long term), as well as its spatial occurrence (localized or widespread) (Spence, 2022). The success of agricultural adaptation to climate variability should not be measured only by economic outputs in terms of yields but also by ethical considerations relating to distributional and social issues such as equity and fairness (Marie et al., 2020; Jia et al., 2021). This thesis adopts a multi-scale approach by exploring adaptation measures at the national, county, district, and household levels.

2.12 Climate Adaptation Strategies in Sub-Saharan Africa

Numerous researchers have documented adaptation measures that are initiated and implemented by households across SSA to mitigate the adverse impacts of climate change and variability on their livelihoods (Afokpe et al., 2022; Mohammed, 2021, Amare and Balana, 2023). Rural households in dryland farming systems simultaneously respond to other social-economic and political stressors in addition to climate change, thereby making it difficult to assess the impacts of climate variability in adaptation responses (Quandt, 2021; Etana et al., 2022). At the micro-level, the major adaptation measures that have been employed by households in SSA include, but are not limited to, livelihood diversification, crop diversification, migration, planting early maturing varieties of crops, planting drought-tolerant crops, selling farm labour and using agroforestry practices (Afokpe et al., 2022; Mohammed, 2021; Afokpe et al., 2022).

Extensive literature has been published on the use of livelihood diversification as an adaptation strategy to reduce the production risk associated with climate variability across many parts of Africa (see Table 2.2)

Table 2.2 Diversification of livelihood climate adaptation strategies in sub-Saharan Africa

Country	Contextual	Author(s)
South Africa	Farmer in South Africa (Western Cape) employed different strategies such as off-farm income, seasonal migration, change in consumption pattern, taking credit, land renting, and remittance to diversify and adjust to the impacts associated with climate uncertainties.	Amoah and Simatele, (2021)
Uganda	Rural farmers in Soroti District in Uganda have employed coping strategies including selling household assets, wage labour, petty trading, and reducing consumption.	Ogallo et al., (2022)

	Furthermore, shifting planting dates, off-farm jobs, planting different crops, diversifying crops, and diversifying from farm to non–farm activities as their adaptation strategies to reduce the impact of climate change and variability.	
Tanzania	Farmers in Bariadi District, Tanzania diversified livelihood sources by getting assistance from relatives, getting relief food; selling livestock to buy food, selling other household assets to buy food, working for food; borrowing food. reducing the number of meals; migration to other places; and storage of dried food (locally known as michembe) and vegetables. This is done to reduce the impact of climate change and variability.	Cyrilo and Mung'ong'o, (2020)
Ghana	Rural farmers in Northwestern region in Ghana diversify their household sources of income by cultivating more than one variety of crops in a farmland to decrease the pressure of climatic extremes	Mohammed et al., (2021)
Kenya	Households in Northern Kenya diversify their livelihoods activities by involving in arable/crop agriculture; engage in business; receive remittances from family members; receive relief supplies; informal employment and selling wood fuel to reduce the adverse impact of climate change and variability.	Gikonyo (222)

Diversification of livelihood strategies have also been reported elsewhere including Egypt (Helmy, 2020), India (Kadfak, 2020), Wang et al., (2021) and Nepal (Khatri et al., 2023). Farming households in the rural areas may be able to reduce their overall vulnerability to climate variability by diversifying the strategies pursued within their livelihood portfolios or specializing to take advantage of a niche (Sewando, 2022). The essence of livelihood diversification is to create portfolios of activities that have varying risks associated with them (Peng et al., 2022). For example, Brandi and dos Santos (2020) show that Modern Portfolio Theory can be used to reduce investment risks to allow investors to achieve higher returns on their investments with less risk. Similarly, by diversifying their livelihood portfolio (i.e., augmenting the number of livelihood activities and/or strategies pursued), the smallholder farmer will inevitably be reducing the risks of an overall adverse livelihood outcome.

Though, Various studies (e.g. Habib et al., 2023; Kassegn and Abdinasir, 2023; Hoq et al., 2022) have highlighted the potential drawbacks with livelihood diversification as an adaptation strategy. For instance, it has been argued that specializing in one livelihood activity could yield higher economic returns than the engagement of the household in several livelihood activities (Hoq et al., 2022). Further, Mohammed et al. (2021) challenged the assumed positive relationship between livelihood diversification and poverty reduction, and by agricultural extension, climate adaptation. Another potential drawback with livelihood diversification is the loss of productive labour. For example, migration of male labour due to livelihood diversification into distant markets could result in depletion of the local productive labour force (Habib et al., 2023), that could consequently reduce economic returns.

In most parts of Africa, temporary migration has been used as both a reactive and anticipatory response to drought-induced food insecurity (Vogel and van Zyl, 2016). Vogel and van Zyl (2016) highlight that temporary migration is not an uncommon adaptation strategy in response to changing weather patterns (particularly drought) within subtropical Africa. In another study, Kidane et al. (2022) observed that labour migration was one of the principal strategies indicated by rural households in Ethiopia as both a past and present climate adaptation strategy. In Liberia, a report by Okorn and Egbe (2023) shows that households in the rural districts migrate to the city because of food insecurity linked closely to climate variability. People who solely depend on rain-fed agriculture for their livelihoods (as in many SSA countries) may have their livelihood activities jeopardized by increasing droughts and dry spells as a result of climate change. Hence, such households may have few options other than to migrate to find alternative livelihoods elsewhere. This is even more serious in situations where such households cannot switch their livelihood activities in their present communities and districts.

The importance of agro-forestry practices as a climate adaptation strategy has been widely emphasized in many parts of the world (e.g. Dagar et al., 2020; Raj et al., 2020; Saha et al., 2022; Buxton, 2020). For example, designing agroforestry systems with better complementarity in resource use between trees and organic crops and selecting crop cultivars and animal breeds especially suited for organic agroforestry systems, may improve gains in productivity. In another word, the incorporation of agricultural systems with trees on the same piece of land can ensure the complementary use of environmental resources that can enhance productivity (Rosati et al., 2021). In east and central Africa regions, agro-forestry provides opportunity for low-income farmers to enhance their livelihoods by selling small timbers, medicines and food (Mushashu, 2023; Yirga et al., 2024; Abdu, 2021). Agroforestry systems provide both mitigation and adaptation measures to reduce the threats of climate change and variability (Awazi et al., 2022; Awazi et al., 2022; Bogale and Bekele, 2023). In drought prone regions, agro-forestry practices have the potential to improve the microclimate through the reduction of temperature maxima which consequently reduces heat stress and evapotranspiration and can yield positive benefits for food production (Soni et al., 2017; Amrutha et al., 2023).

Most farming households also depend on non-timber forest products such mushrooms and snails to cope with climate change and variability to deal with food insecurity (Raneri et al., 2023; Atampugre et al., 2022). The extent of reliance of farming households in Nigeria on these forest resources is greatly influenced by the characteristics of the households (Fadairo et al., 2020). These rural households were headed by people with little or at least primary education with good human capital were less likely to rely on non-timber forest products to cope with crop failure due to climate variability. In Ethiopia, Gezie, (2019) confirmed that farmers used different methods such as by planting different crop varieties, tree planting and changing the timing of planting were some of the key adaptation strategies in response to climate change and variability. Though at early developmental stages, the use of weather-based index insurance schemes has also been explored in many countries in Africa including Ethiopia (Robles, 2021) and Malawi (Munkombwe et al., 2022; Kajwang, 2022). The key principle underlying weather-based index insurance is that the government through its principal agencies provide insurance against specific climate events like droughts that could destroy crops (Kajwang, 2022; Munkombwe et al., 2022). These events could be recorded at local weather stations or at the regional level (Kajwang, 2022; Munkombwe et al., 2022). Hence, farmers who purchase this weather-based insurance are given specific payments to offset losses incurred from such droughts. Weather-based insurance schemes hold great prospects for climate adaptation in many parts of Africa. Such schemes could provide significant solutions to reduce climate vulnerability, especially when combined with existing practices and local indigenous knowledge.

It is important to emphasize that most of the adaptation measures highlighted in this study are used by farmers in SSA as risk dispersal measures to reduce the negative impacts of climate change and variability, but that they fail to take advantage of the opportunities presented in relatively good farming seasons (Ziro et al., 2023). Such measures are more coping strategies (rather than adaptations) that reduce present risks without necessarily accounting for future climate change. In this regard, adaptation practices should be compatible with national developmental agendas (Asmare and Alemu, 2021; Okitasari and Katramiz, 2022) and be mainstreamed into developmental programmes (Pardoe et al., 2020).

The implementation of the various adaptation strategies may be impeded by several barriers such as unreliability of weather forecast information, lack of access to agricultural extension services, and lack of access to water for irrigation. Other barriers were lack of financial sources, lack of access to affordable credit institutions, lack of framesets and cost of agricultural inputs. Klasic et al. (2022) define barriers as "obstacles that make adaptation less efficient, less effective or may require changes that lead to higher costs". Generally, barriers to adaptation are defined as challenges, obstacles, constraints or hurdles that impede adaptation. Some scholars such as Ahmad et al. (2021) and Kihupi et al. (2020) use the term 'limits' and 'barriers' interchangeably. But more often limits and barriers have different meanings. Barriers are considered surmountable or mutable while limits are seen to be absolute or unsurpassable. In the IPCC fifth assessment report characterizes adaptation barriers (synonymous with adaptation constraints) as "factors that make it harder to plan and implement adaptation actions or that restrict options" (Klein et al., 2014). Several studies have documented that agricultural adaptation to climate change and variability could be impeded by economic, cultural and social barriers including land tenure insecurity (Sanga et al., 2021; Osumanu, 2022; Batung, 2021). Whilst making useful contributions by enhancing understanding of the adaptive measures that have been used by households in SSA and more widely to cope with and adapt to climate change and variability, most of these studies fail to highlight the behavioural and socioeconomic factors that may influence the choice of these adaptive measures, although recent progress in this area is acknowledged (Osumanu, 2022; Batung, 2021). This has resulted in the development of one size fit all adaptation strategies that may not respond to the crisis faced by certain social classes. Therefore, there is the need to carefully explore how farmers' choice of adaptation measures is influenced by socioeconomic as well as political characteristics to enable region-specific adaptation policies to be designed and implemented. By adopting a starting-point interpretation approach of risk, this study seeks to investigate suitable adaptation measures that may be used to reduce the vulnerability of farming households to climatic stresses.

2.13 Synthesis and Conclusions

This chapter has established that increasing temperatures and rainfall variability associated with climate change and variability could have a devastating effect on livelihoods as well as all four components of food security (availability, accessibility, utilization, and stability) in SSA (Tofu and Wolka, 2023). However, these impacts will vary spatially. Thus, understanding the complexity of climate impacts on agricultural production systems requires further investigation through more detailed assessments of key regions in West Africa. Although climate risk and vulnerability as concepts are difficult to measure and describe, this review has provided useful insights into climate risk assessments by establishing that several authors have proposed different theoretical and conceptual frameworks to assess the vulnerability of food systems and that such frameworks could be considered in relation to climate change and variability. Further, this chapter also provided the conceptual transition of the conceptual framework from AR4 to AR5 and AR6, which provided a shift from a predominantly biophysical approach to more comprehensive one. These climate risk assessments may be used to identify exposure and vulnerable groups within a particular geographical area and can inform policy regarding resource allocation in such areas. Even though contributing to the understanding of the factors that may cause vulnerability, many of these studies (Dang et al., 2019; Ullah et al., 2021; Ahmadalipour et al., 2019; Brügger et al., 2021; Hagenlocher et al., 2018; Mac Gregor-Gaona et al, 2021) use provincial, national level data and indicators that have been selected somewhat subjectively from the literature. Although such provincial and national-levels theoretically driven risk and vulnerability assessments provided a strong foundation from which more detailed work can take place, their importance at the local level may be inadequate. Based on the inadequacy of such national and regional-level assessments to inform policy at the local level, this study seeks to use climate data and empirical data based on the factors that farmers perceive to influence their risks to climate change and variability. Besides, most of the vulnerability assessments have been conducted at specific scales - notably at the global resolution (Meza et al., 2020; Li et al., 2019; Ngegba et al., 2022; Anwana and Owojori, 2023; Bosco-Abiahu et al., 2021; Feldmeyer et al., 2021), regional scale (Kundzewicz et al., 2019; Ramli et al., 2020; Bullock et al., 2022; Azzarri et al 2020; O'Neill, et al., 2020) and national scale (Ahmadalipour et al., 2019; Xu et al., 2020; Bedeke et al., 2023; Vittal et al., 2019; Wang and Sun, 2023) focusing on past and current climatic evets. Further assessments have been undertaken at the household level without considering the wider processes operating at the societal and regional levels that can influence the vulnerability of people in households. Whilst these allowed comparison of the relative vulnerability of different nations and regions to the adverse impacts of climate change, they failed to consider the multi-scale nature of vulnerability by concentrating on only one scale. Climate change at the global level produces cross-scale interactions that provide impacts at different geographical scales, which are not discrete but, on a continuum, (Dressler et al., 2022; Robbins, 2022). Adopting a multi-scale approach to climate risk assessments provides a significantly richer understanding of the different dimensions of the problem through its exploration across scales. By using a multi-scale approach (national, counties, districts and households), as widely called for in the vulnerability literature (Dressler et al., 2022; Robbins, 2022), this study avoids the danger of narrowly focusing on one scale of climate variability problems. Though sub-Saharan Africa is projected to be severely affected by climate change, specific case studies in this region highlighting the extent of vulnerability of food production systems and livelihoods to climate change and variability are lacking. This knowledge gap hampers proper understanding of the drivers and barriers of climate risk of food production systems and livelihoods in this region to climate change and variability. For instance, the specific adaptive capacity that farming communities in this region might have been often ignored in risk assessments. There is, therefore, the need for specific case study research to be conducted to clearly understand the extent of vulnerability of food production systems and livelihoods in this region to climate change and variability. This study addresses these research gaps by integrating different participatory methods and household surveys to assess the extent of crop production system and agricultural livelihoods' risks to climate change and variability in Liberia.

Chapter 3 Study Area, Research Design, Materials and Methodology

3.1 Introduction

This chapter describes the research design, and the methods used to collect data to achieve the objectives of the research and address key gaps identified in the literature. It explains how the farming counties and districts in the study areas were selected and provides a description of these districts. The chapter highlights the sampling approach and describes how the quantitative and qualitative data were collected and analysed. The relevance of participatory methods for this thesis is also explored. The strengths and limitations of the various research methods used for data collection are then discussed and the basis for qualitative and quantitative approaches in climate science research are explained. Also, the chapter describes the study country (Liberia) highlighting the nature of its farming and land tenure system. Lastly, issues relating to positionality and ethical considerations are explored.

3.2 Study Area

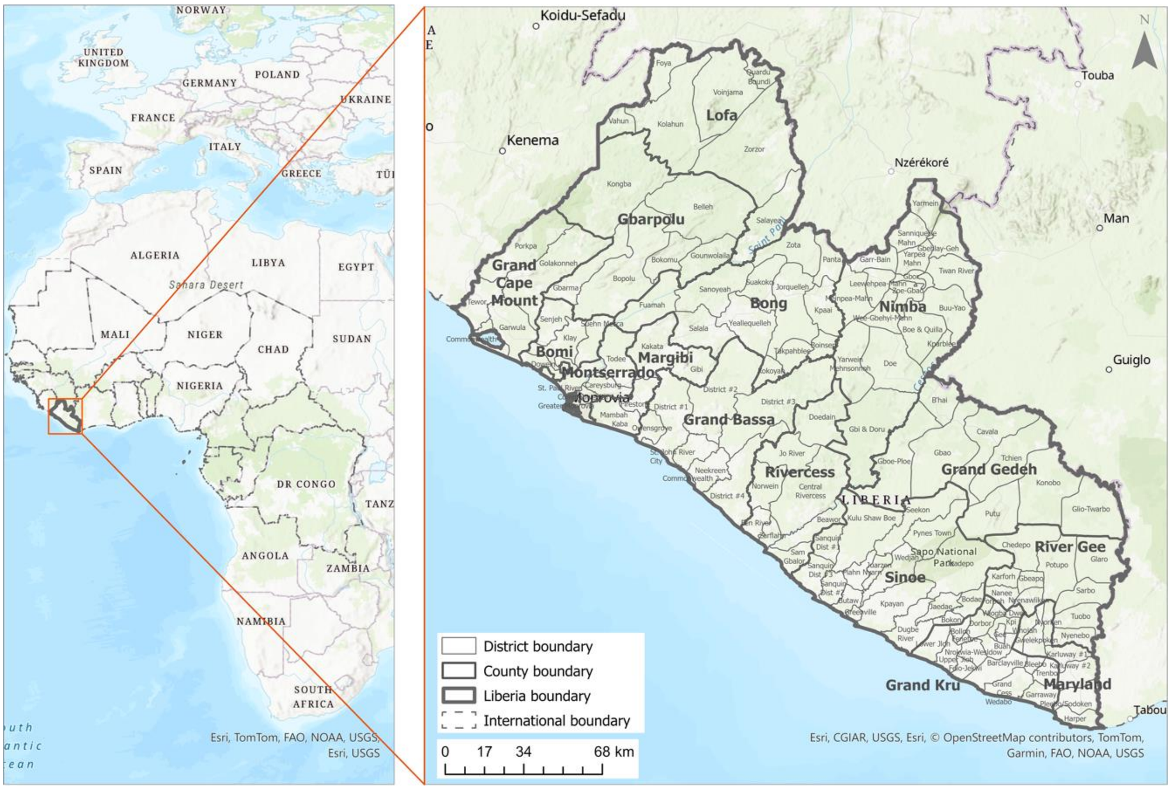

Figure 3.1 The political map of Liberia.

The study was conducted in Liberia (Figure 3.1), which is situated on the Coast of West Africa, between latitudes 6° 26' 1.32" N and longitudes 9° 25' 18.31" W. Liberia is bordered by Guinea to the north, Cote D'Ivoire to the east, Sierra Leone to the west and the Atlantic Ocean to the south. Liberia is divided into 15 administrative counties which is sub-divided into 136 districts. The agro-ecological zones of Liberia are rainforest, coastal savannah, semi-deciduous forest, transitional zone, Guinea savannah and Sudan savannah zones (Figure 3.2). There are two distinct seasons in Liberia, the rain and dry seasons. The average annual rainfall ranges between 800 mm and 2400 mm, generally decreasing from north to central (EPA, 2019). Temperatures in most parts of the country are high, with a mean annual temperature of above 24 °C (EPA, 2019). The temperature in Liberia is strongly influenced by season. Temperatures during the rainy season are relatively low because of near-complete cloud cover, and slight diurnal variation occurs. From the 1980s to 2020, temperatures typically ranged from 24.0 to 25.0 °C during the wet season and 24 to 28 °C during the dry season. These temperature ranges are consistent with those reported in this study of 24 to 26 °C and 24.5 to 29.0 °C during the wet and dry seasons, respectively. Temperature trends are similarly difficult to discern from the observational record. From 1981to 2020, the mean annual temperature increased by 0.18 °C per decade. In term of Liberia's rainfall, the country receive rainfall year-round. As indicated earlier, most of Liberia experiences two seasons due to the movement of the inter-tropical convergence zone (ITCZ): a wet season usually falls between May and October and a dry season between November and April, when the dry and dusty harmattan winds blow off the Sahara Desert (USAID 2017). Also, in the southern zone, the rains have a relative break from the middle of July up till late August (EPA, 2018). According to the 2023 National Population and Housing Census results, Liberia has a population of 5.2 million people which represent an increase of the population size of the country from 3.5 million in 2008 (LISGIS). Liberia has a total land area 9.8 million hectares (ha), of which 4.02 million ha (representing 41%) is agricultural land. Of this arable land space 600,000 hectares is lowland (MOA, 2015, HIES, 2016).

Liberia being a semi-arid agrarian country in West Africa, is at risk to the impacts of climate variability and change, such as warmer temperatures, increases in annual rainfall, and increases in the frequency of heavy rainfall events. These climate change impacts present serious challenges to the country's socio-economic development. Liberia's low adaptive capacity to respond to climate change is partially due to the detrimental effects of the 1989-2003 civil war. Since the war, the government, along with various international and national institutions and organizations, has been taking actions to better understand and address climate change challenges throughout the country. Remaining needs include data on short and long-term climate change impacts and risks within the country, as well as the financial, technological, and human resources to identify adaptation priorities and implement appropriate adaptation plans and strategies (EPA, 2019, EPA, 2021). Particularly in central and northern Liberia where this study was conducted (Figure 3.1), temperatures and rainfall are dramatically changing and such changes are becoming more severe with intensified extreme events, which may partly be due to the influence of the Saharan climate and weakness of the South-West Monsoon Winds from the Gulf of Guinea (Asare-Nuamah and Botchway, 2019).

According to Antwi-Agyei et al. (2018), climate change and variability affect agricultural production levels and disrupt the livelihoods of many farmers. Agriculture is the largest sector in the Liberian economy and contributes 30% of Gross Domestic Product (GDP) and sustains the livelihoods for ~60% of the population (MOA, 2010; HIES, 2016). However, future agricultural growth is threatened by climate change and variability due to high dependence of rural populations on natural resources and rain-fed agriculture for their livelihoods. Variations in rainfall patterns and increases in temperatures are projected to bring considerable additional challenges to the sector that is already experiencing the severity of impacts associated with climate change (EPA, 2019).

3.2.1 Topography, River, and Land Use

Liberia's topography features coastal lagoons and mangrove marshlands, rain forest and mountainous plateaus. Liberia's coast runs 906.496 km^2 and is home to some of the country's largest cities (such as Monrovia, Buchannan, Sinoe and Greenville) and conducive to fishing and tourism (Figure 3.2). Liberia's land surface notably holds the most forested land in West Africa. As of 2015, forests make up 6.5 million hectares, equating to 68% of Liberia's land surface, including tree crops such as palm oil, rubber, and cocoa. Of this, about 4.3 million hectares are categorized as tropical forest with over 80% canopy cover. While, about 975,000 hectares are classified as degraded land (that is canopy cover under 30%) (USAID/Liberia, 2020). Liberia has the largest remaining part of the Upper Guinean Forest ecosystem, with an estimated 42% of the remaining forest. The rest of the Upper Guinean Forest is in Côte d'Ivoire (28% of the remaining forest), Ghana (16%), Guinea (8%), Sierra Leone (5%), and Togo (1%). Just an estimated 40-45% of Liberia's original forest cover remains, and less than 30% of its area is covered by natural forests. It is home to many rare and endemic species and listed as one of 34 global biodiversity hotspots. Its tracts of forest were once continuous but are now fragmented into blocks that are isolated from each other because of human pressure: logging, road construction, agriculture, and human settlements.

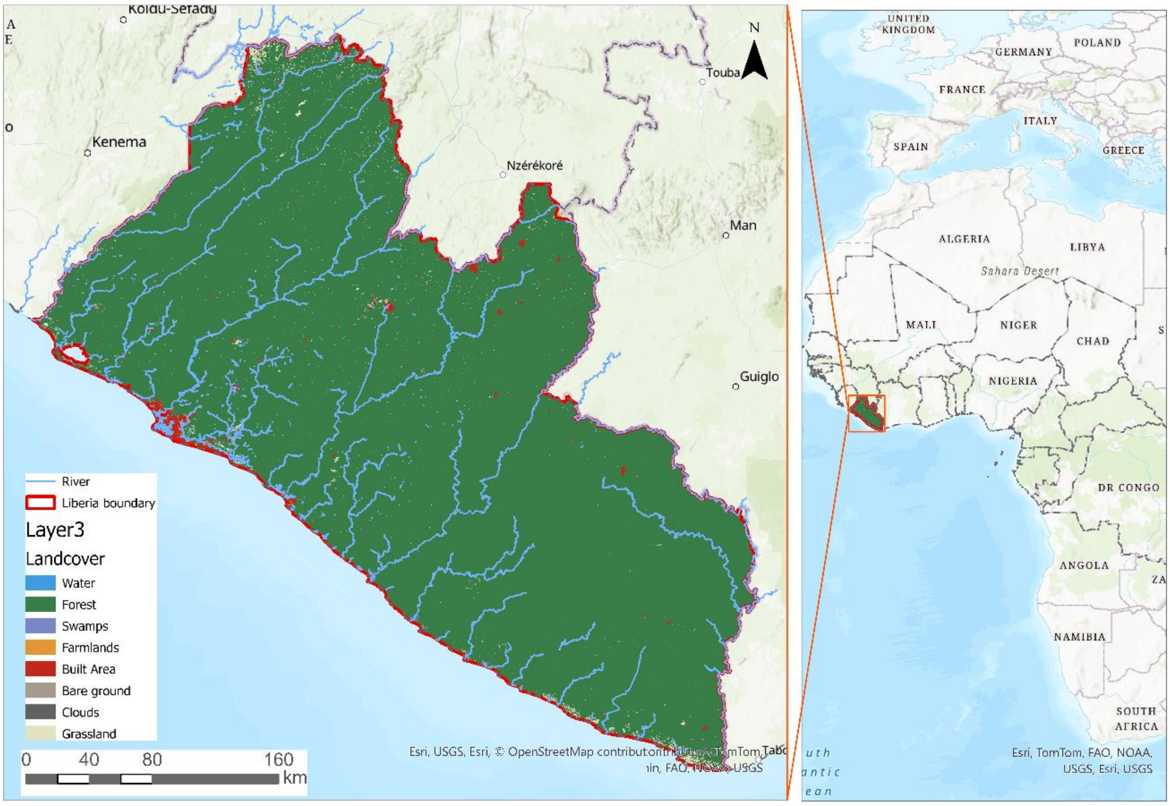

Figure 3.2 Map showing the topography, river, and land use of Liberia.

The plateaus are cultivated for agriculture (27% of land) and the mountains (including Mount Nimba and Putu Mountain) are home to mineral resources - especially iron ore, gold, and diamonds. The mining and quarrying sector contributed 7% of GDP and employed around 10% in 2017, with an increasing rate experienced over the last 5 years. Liberia also has significant hydraulic resources including the Cavalla River, the St John River, and the St Paul River, conducive for the development of hydroelectricity (Figure 3.2) (EPA, 2019; NPRSCC, 2018). Crops that are socioeconomically important include rice, cassava, plantain, potatoes, yam, eddoes, and banana. But rice is considered the most important food crop in terms of hectarage under cultivation with an estimated 58% of farmers cultivating it. It is also widely consumed as a staple almost in every part of the country (HIES, 2016). Cassava, yam and plantain are mostly cultivated by farmers in the central and northern savannah and transitional agro-ecological zones (Figure 3.2). Climate change related problems such as dry spells, floods and soil erosion have often resulted in severe food insecurity (HIES, 2016).

Despite of this vast arable land area, Liberia can produce only 20% of its rice needs. The production of roots, such as cassava, sweet potatoes and vegetable crops are highly variable depending on the vagaries of the weather (MOA, 2012). Liberia is unable to produce enough to feed its citizens due to the fact that some proportion of agricultural land has poor soil properties making both crop and livestock productivity very low (MOA, 2012, HIES, 2016). Furthermore, many of the rural farmers lack access to basic infrastructure and social services, and poor roads leave many areas inaccessible (HIES, 2016). It is estimated that 80% of agricultural production in Liberia is produced by smallholder farmers, who use rudimentary technology such as hoes and cutlasses (HIES, 2016). Therefore, conducting this study, and subsequently mapping climate risk in Liberia is important because the IPCC's regional assessments of climate change impacts for Africa imply declining grain yields are likely and predict that agricultural production and food security in SSA will be negatively affected particularly relating to increased drought intensity and frequency linked to greater inter-annual rainfall variability (Borona, M., Mbow and Ouedraogo, 2021). Furthermore, the impacts of climate change and variability on food production in SSA will vary spatially and understanding the complexity of such systems requires further investigation through more detailed assessments of key agricultural regions, such as the central and northern counties of Liberia that this study focuses on. By taking into consideration the choices of farmers at the rural levels, there is a need to understand how they will be affected by climate change and variability, how they might respond with the resources they have, and how these conditions can be replicated and built upon for successful coping and adaptation strategies. The results of study will have wider significance for the agricultural systems in Liberia and the West African region.

3.2.2 Selection of Study Counties and Districts

Selection of study site is a vital component of the research design, and this process describes how the study districts were selected. Prior to Liberia's civil crisis, Bong, Lofa and Nimba Counties were the unquestionable leader in food production, feeding itself and harvesting enough for the rest of the country. The dogged determination of the people to toil the soil with added assistance from such Liberian institutions as the Bong County Agriculture Development Project, Lofa County Agriculture Development Project (LCADP), Nimba County Rural Development Project (NCRDP) and the Liberia Produce Marketing Corporation (LPMC). These counties soared to the top as the nation's primary producer of food. Farmers in these counties produced rice, cassava, fruits, vegetables, sweet potatoes, and other cash crops including oil palm fruit (from which palm oil is extracted), coffee, cocoa, and sugar (MOA, 2019).

Liberia experienced some of the worst cases of the conflict which paralyzed every aspect of the country, from infrastructure to human capacity to agricultural activities among others.

The once booming agriculture base, known as the 'Breadbasket of Liberia' dropped far behind in food production due to several constraints, including limited access to technology, inefficient farming practices, low public and private investments, erratic rainfall and increase in temperature as a result of climate change and variability and a fragmented value chain, among other factors that have kept productivity low (World Bank, 2017). Nimba County is much more improved in terms of crops production and yield compared to Bong and Lofa Counties. The agricultural dream of Bong and Lofa Counties of regaining its “breadbasket” status is still far from reality due to some proportion of agricultural land having poor soil properties making both crop and livestock productivity very low (MOA, 2012, HIES, 2016). Based on this, Emran et al. (2021) and Khan et al. (2020) emphasized that major policy interventions to manage climate change and variability may be taken at the national and county level, hence there is need to explore the interaction of climate and farming systems at these levels. Therefore, this research develops and applies an innovative multi-scale approach by exploring climate risk of crop food production systems to climate variability (particularly drought and/or delayed rainfall) in dryland farming systems at the national, district, and household levels.

Findings of the stakeholder interview and review of literature highlighted Salala, Suakoko and Zota districts of Central (Bong) and Salayea, Foya and Zorzor of Northern (Lofa), Liberia respectively as the districts mostly at risk due to climate change and variability (Figure 3.3). These six districts represent a range of different agro-ecological and socioeconomic factors. These districts were selected for this research based on available literature together with appropriate guidance from experts and stakeholders in the study country. During discussions and interviews, the experts and stakeholders provided valuable information that was used to select these farming districts. Three districts were eventually selected from each county to allow comparisons to be made among districts within the same counties without sacrificing the opportunity for in-depth qualitative analysis; hence, three districts were deemed a suitable number of districts. These districts (Figure 3.3) lie within the transitional ecological zone and experience seasonal rainfall patterns with the major rainfall season from June to September and the minor rainfall season from November to April (Chapter 4). Findings in Chapter 4 show that the average monthly rainfall in these counties ranges from 150mm - 400mm with average minimum temperatures of 25 °C and maximum 29.0 °C respectively (Chapter 4). The transitional zone is characterized by potential evapotranspiration of about 1230 mm per annum and relative humidity of 75% (EPA, 2013). The major crops grown include annual crops such as rice (Oryza sativa), cassava (Manihot esculenta), plantain (Musa spp.), yam (Dioscorea spp.). About 70% of the population in the district are involved in agriculture (HIES, 2016). In terms of socioeconomic characteristics, the economy of these districts is based on commercial farming including crop production and livestock rearing, whilst that of the vulnerable district is mainly subsistence farming (HIES, 2016).

Figure 3.3 Map of Liberia, showing the counties of study (Bong and Lofa respectively).

3.2.3 Identified Research Districts in Liberia

Having identified the research counties, an investigative study was undertaken to select specific farming districts by conducting a literature search, expert, and stakeholder interviews. Upon arrival in each study district, an initial meeting was held with the district chiefs and some stakeholders. During these meetings, the researcher and the purpose of the study were introduced to the experts and stakeholders. Altogether, nine experts (including officers at the EPA, Ministry of Agriculture, and the Statistics Office) and three key informants in each district were interviewed during the investigative fieldwork from December 2021 – March 2022.

Based on the literature, the following criteria were identified for the selection of specific farming districts.

1. Farming districts must be accessible by road.
2. The districts must be willing to participate in the study during its entire period.
3. The districts should have been exposed to some type of climate anomaly (particularly drought or delay rainfall and increase temperature).

4. The district should have characteristics that could be researched with respect to the study’s objectives, and

With these criteria, several farming districts in both counties were eligible to be included in the research. Based on consultation with local experts and advice provided by the National Statistics Office, an officer from the EPA and MOA, and local census data where this exists, three farming districts were selected from each county. These districts were selected because, according to the experts and stakeholders, they were exposed to some degree of climate change and variability and decrease in crop yield (i.e. delayed rainfall and increase in temperature) and have either developed appropriate state-of-the-art strategies to deal with these or have not been able to deal with this climate negativity. Based on the expert interviews Salala, Suakoko and Zota, Bong County and Foya, Salayea and Zorzor, Lofa County were selected respectively (Figure 3.3). These districts represented a range of agro-ecological zones, environmental and socioeconomic conditions that provided valuable context for in-depth analysis. These districts, therefore, constituted unique and manageable units, due to their small sizes, that allowed investigation into the complexity of climate risk of farming systems and rural livelihoods to climate variability.

3.2.4 Land Tenure System in Liberia.

Land tenure defines access to land resources and considers the ways in which land is held or accessed (Sawyer, 2005). In Liberia, like in most parts of Africa, land resources are controlled under complex customary systems, which are managed by a set of social norms and cultural rules (Sawyer, 2005). Prior to colonisation, land ownership, rights and tenure in Liberia were customarily controlled, invested, and administered under the spiritual or traditional head of a clan or a family (Blanco-Ward, et al 2021). During colonisation, the land tenure system included both the customary system and the British conveyance system. The structural adjustment programmes and economic reforms of the World Bank and the International Monetary Fund embarked on by the government of Liberia in the late 1980s included institutional reforms that reverted control over land back to the traditional authorities (Unruh, 2009).

Former American slaves were settled on the Liberian coast beginning in the 19th century. With the arrival of the settlers, a statutory system of land tenure was established for areas under their control. The settler society was exclusive and resided within an array of indigenous African coastal communities. All these communities possessed land tenure systems that held land to be inalienable (Sawyer, 2005). Nevertheless, settlers interacting with indigenous communities pursued alienation of land (instead of use) made possible by a mix of violent conflict and alliance-making (Sawyer, 2005). Settler acquisition of lands was supported by a variety of laws, including an early constitution (Sawyer, 2005; Wiley, 2007). While the indigenous lands on the coast appear to have been purchased, in the interior or 'hinterland' indigenous land was acquired through an extension of the 1847 constitution into the interior, together with its enabling laws (Wiley, 2007). Customary law, based on usufruct rights, continued in interior areas inhabited by indigenous communities, and administered as provinces by the Liberian state. The initial decades of the 20th century saw often brutal subjugation of parts of the interior, with the resulting tensions between the Americo-Liberian settlers and indigenous inhabitants still reflected in current land issues. When the provinces became counties in the mid-20th century, the customary tenure system continued and was sanctioned as a distinct system by the state (GRC, 2007). Some aspects of the customary tenure system were supported and changed to suit the state, while other aspects were neglected or declared illegal. The land law of 1956 primarily attends to Americo-Liberian settlers in areas they occupied. This was complicated by the emergence of what was known as the Kwi, indigenous Liberians regarded as 'civilized' who enjoyed special social status and property rights. All other land in the interior was, and continues to be, primarily occupied by indigenous Africans under customary land tenure; but is legally considered the property of the state and therefore public land (World Bank, 2007).

The 1986 Constitution of the Republic of Liberia recognises two forms of tenure systems - public and customary. Public lands are acquired through the invocation of legislation according to the Lands Commission Act of 2010 (Act 458) and invested in the President of the Republic in trust for the people of Liberia (Land commission, 2010). Customary land is held and administered by the traditional or spiritual head of the family with state agencies such as the Lands Commission of Liberia, providing services for land transaction (Sawyer, 2005). Customary land tenure systems are recognised and observed as an institution governed by customary law (Unruh, 2007b; GRC, 2007). In accordance with article 258 of the 1986 Constitution of the Republic of Liberia, the Land Commission Act of 2010 (Act 483) stipulates that 78% of all land is held under customary system. Of the remaining 22%, 20% is held for the government for developmental projects whilst 2% is held in a dual ownership between the government and customary owners (MOFA, 2003).

In Liberia, access to land for farming and other developmental projects by individuals is mainly through the traditional customary land ownership system (MOFA, 2003). Members of a particular clan or community can acquire land for farming and other developmental ventures preceded with the presentation of customary gifts to the traditional or spiritual leader (Kasanga, 2001). However, people from outside the community do not have rights to communal land and may acquire land for farming by entering into a contractual agreement with the chief or the traditional head for a specific period of time (Richards et al., 2004). The belief underpinning the customary land system is that land is an ancestral trust and should, therefore, be utilised judiciously in order not to jeopardise the chances of the generations unborn to use such resources (ICG, 2004; Unruh, 2005a). For this reason, land rights are held as leasehold and not freehold in Liberia.

Ownership of customary land differs remarkably across the different parts of the country. Within Liberia, inheritance of communal land is based on the system of property inheritance, which is matrilineal in southern Liberia and patrilineal in northern Liberia. In southern Liberia, ownership of land is not gendered, meaning that both male and female of a particular clan can access and own land. However, in rural areas in Liberia, there are complex land tenure issues and land ownership. In these areas, it is the chief who represents his people that owns rights to all lands in the community and who is therefore entitled, under the customary system, to grant usufruct rights to families and individuals within the community (Toe and Stevens 2014). The Land holds rights on the behalf of the community and for that matter when individual's usufruct rights to a particular land is terminated the land reverts to the constitution (Richards, 2005).

In Liberia, land inheritance is through the male heir, and female right of usufruct is not recognised under the customary law. In another words, women tend to have less rights in land under customary law than under statutory law (Alden, 2007). The cultural discrimination against females relating to land ownership increases women's vulnerability and food insecurity. Agricultural activities in most parts of Africa are beset with various challenges including lack of markets, poor rainfall, lack of financial resources, and lack of infrastructure. However, unequal access to land and its associated land insecurity have been identified as one of the most important factors that negatively impact on the livelihoods of smallholder farmers in Africa (Hohe, 2005; Junne and Verkoren, 2005; Kamphuis, 2005; Sorensen, 1998).

3.3 Research Design and Approach

The research design developed to address the research objectives used an integrated range of methods including quantitative assessments of climate and crop cultivation information; participatory methods to assess indicators of risk, exposure, and vulnerability; expert interviews to assess institutional capabilities. The research design develops and applies a multi-scale integrated suite of analysis approaches for climate risk assessment, adaptation strategies and policy support. The household data collection is divided into four interlinked phases throughout the study periods to achieve the research objectives.

i. Phase one of this study is sub-divided into two stages.
   a. Using relevant literature together with experts' knowledge in Liberia to identify counties and districts that are mostly at risk as a result of climate induced hazard in Liberia.
   b. Selection of specific farming districts within the counties identified in Stage ia) through literature and experts' interviews during fieldwork.
ii. Phase two involves the collection of all necessary data meteorological and the main fieldwork. This is further sub-divided into two stages.
   a. Collection of all necessary climate data (meteorological) through the Climate Research Unit (CRU) of the University of East Anglia, UK.
   b. Categorization of these climate data into specific counties of studies based on the data available.
iii. Phase three: the main fieldwork is further sub-divided into four stages.
   a. This stage uses quantitative and qualitative methods to characterize and explain the nature of farming districts that are at risk as identified in phase ib.
   b. This stage uses both qualitative and quantitative methods to determine coping and adaptation strategies used to manage climate variability in study districts.
   c. Additionally, the study employed participatory methods to identify barriers to adaptation strategies in the study districts.
iv. Phase four involved the use of expert and stakeholder interviews, as well as policy analysis, to assess institutional capabilities and policy arrangements at the local, counties and national levels.

Although they have different epistemological and ontological backgrounds, quantitative and qualitative methods are combined, and this allowed deepening of understanding through cross-validation of data (Sniukas and Sniukas, 2020). Quantitative methods tend to allow generalization of results and predictions (Whitmarsh and Speed, 2021, Winchester, 2023). Sniukas and Sniukas (2020) argued that mixed-method enquiry is like combining two different and separate paradigms of research methods. They argued that quantitative and qualitative procedures have their epistemological implications (such as “positivism' i.e. scientific and objective”, and “non-scientific and subjective”) and should not be seen as complementary. Climate change is a complex problem, and the use of different approaches helped to bring a better understanding of the different dimensions of the problem. Whilst it is true that qualitative methods are flexible and allow a deeper and better understanding of the extent of risk of households and districts to climate change and variability (Winchester, 2023), but it may be difficult to generalize from the findings gained through such methods. Qualitative methods such as key informants interview allowed the construction of meaning and incorporation of different perspectives regarding climate risk and how households and districts respond to climate variability. Quantitative approaches such as farmers’ perception on climate change, impact of climate change and variability on crops yield were useful in measuring the intensity of cases and extent of climate risk.

3.3.1 Sample Size Selection

This study employed a multi-stage sampling technique. The first stage, a systematic and random sampling procedure was used to select rice and cassava farmers (households) from available (sampling frame) farmers’ list in the districts (Suakoko, Salala and Zota, Bong County, and Salayea, Foya and Zorzor, Lofa County) representing agricultural households. These agricultural households were defined based on the data collected from the 2014 National Agricultural and 2016 Household Income and Expenditure Surveys (2016 HIES), respectively. A total of 2,400 rice and cassava farmers in both counties (1,600 in Bong and 800 in Lofa) was contained in the sampling frame. Out of the total number of farmers, 5% (n = 80) sample was randomly drawn from the population of Bong and a 10% (n = 80) sample was drawn from Lofa county respectively. This approach was necessary to have an equal number of households selected for the two counties for comparative purposes and the sample size selected was also necessary based on the number of resources (time and money) available to the research.

3.4 Materials and Method

3.4.1 Climate Data Approach

One of the major problems in climatological investigations for Liberia is the lack of long-term reliable and sequence records of climate observations. One of the reasons for the country’s lack of such a record is because of the civil and political crisis which the country was plunged into for 14 years. The results of this crisis were devastating, most and/or all infrastructures were destroyed, many lives lost, and properties destroyed. Therefore, assessing climate change and variability, this study source meteorological data, mainly temperature and rainfall from the Climate Research Unit time series (CRU TS v4.05), (https://climateknowledgeportal.worlbank.org/download-data), that exist on a coarse 0.5° latitude by 0.5 longitude grid globally except for Antarctica. This data is derived by the interpolation of monthly climate anomalies from extensive networks of weather station observations. Importantly, it is a gridded dataset derived from observational data which provides quality-controlled rainfall and temperature values from thousands of weather stations worldwide, as well as derivative products, including monthly climatologies and long term historical climatologies (CRU TS (1901-2020). Moreover, these observed datasets are resolved only to monthly and annual time steps. This study, therefore, undertakes original analyses of observed monthly and annual climate variability and change (1981-2020) and use GCMs outputs from (CRU TS v4.05) of the University of East Anglia to project future (2020-2100) climate (mean annual temperature and annual rainfall) under four Representative Concentration Pathways (RCPs): RCP2.6, RCP4.5, RCP6.0, and RCP8.5 representing low, moderate, moderate to high and business as usual emission scenarios for the period 2020-2100, which are compared with baseline (1986-2005) simulations. The comparison is based on determining the departure of future climate to the end of centuries from the baseline (1986-2005). These climate model outputs, are derived from the Coupled Intercomparison Project, Phase 5 (CMIP5) collections (Sperber et al., 2013) and is a standard experimental framework for studying the output of coupled atmosphere-ocean general circulation models, overseen by the World Climate Research Programme. CMIP5 is designed to improve the understanding of past, present, and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context (Sperber et al., 2013). This understanding includes assessments of model performance during the historical period and quantifications of the causes of the spread in future projections. Previous studies evaluated CRU GCMs across the world including African countries, using different variables, and has found the CRU dataset to be reasonable and useful for climate analysis (Oguntunde et al., 2020; Nikiema et al, 2017; Dutta and Maity, 2022).

3.4.1.1 Hazard Calculation

Consistent with Figure 3.4, two separate data are acquired in this study- climate (meteorological) data and field survey data. The data for each component was controlled and edited, thereafter several statistical analyses carried out as explained in detail in the next section. To carry out the analysis of the study, forty years (1981-2020) of historical climate data and 81 years (2020-2100) of GMC’s model output (mainly temperature and rainfall) were extracted from the CRU TS dataset. The 40-year and 81-year time periods were chosen since they provide more accurate meteorological data that are utilized for drought analysis (Jabal et al., 2022). Drought/hazard risk projections for near and distant future (2020-2100), CRU SPEI model outputs for 12- month period is used to determine future drought extend, frequency and intensity at the national and county levels. Secondly, these datasets are then analyzed to find monthly sums and averages to indicate annual rainfall and mean annual temperature for Liberia and the study areas using Mann-Kendall trend analysis. These cleaned datasets were imported into R software v 4.2.1 for analysis into 10-year (observed period) and 81-year (GCMs future projection), using Mann-Kendall trend analysis (Hamed, 2008).

3.4.1.2 Mann-Kendall Test (Non-Parametric)

The Mann-Kendall (M-K) test is a statistical nonparametric test widely used for trend analysis in climatological and hydrological time-series data (Shiru et al., 2019; Ayugi and Tan, 2018; Dassou et al., 2016). The test was suggested by Mann (1945) and has been extensively used with environmental time-series. There are two advantages to using this test (Shah and Kiran, 2021; Proutsos et al., 2022; Kendall, 1948). First, it is a nonparametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. Trend analysis is the technic used to observe the past trend of climate and to predict outcomes by using both the historical and future results. Increasing or decreasing trend of all the independent weather parameters (e.g., monthly, and annual temperature and rainfalls, etc.) are statistically examined in two phases. The first phase uses the non-parametric Mann-Kendall test and second one, descriptive statistics to evaluate the perception of the household involved in agricultural production from the survey data (Shah and Kiran, 2021; Proutsos et al., 2022; Kendall, 1948).

Many studies have applied M-K test to assess the SPEI trend either locally or globally. For instance, Vicente-Serrano et al., (2015) used M-K test to assess trends in the seasonal SPI and SPEI time series representative of different regions obtained through principal component analysis in Bolivia. Similarly, Li et al., (2015) combined M-K trend test of SPEI time series and an analysis of the average variation of dry episodes duration in a region of South Tibet. In SSA, Byakatonda et al., (2018) used M-K test to analyze long term drought severity characteristics and trends across semiarid Botswana using two drought indices (SPI and SPEI), and Tan et al., (2019) used M-K test for Malaysia drought trend assessment where droughts are identified by means of SPI. About SPI, which is straightforward comparable to SPEI being built in a very similar methodological framework, several studies have used a parametric approach to evaluate the change in time of droughts. Based on this this study, use Mann-Kendall (M-K) test to detect trends in time series of SPEI values at a time scale of 3, 6, 12, and 24 months from 198-2020 as observed and 2020-2100 for future drought detections.

The test statistic *Z* was computed as follows:

$$Z = \begin{cases} \frac{s-1}{\sqrt{Variance\ (s)}} \quad if\ S > 0 \\ 0 \quad if\ S < \ 0 \\ \frac{s+1\ if\ S < 0}{\sqrt{Variance\ (s)}} \end{cases} \tag{3.1}$$

where *S* was calculated with the following equation:

Where:

$$S = \Sigma\Sigma\ sgn(X_i - X_j) \tag{3.2}$$

$$sgn(X_i - X_j) = \begin{cases} 1, if\ X_i - X_j \ > 0 \\ 0, if\ X_i - X_j = 0 \\ -1, if\ X_i - X_j < 0 \end{cases} \tag{3.3}$$

A positive value of *Z* shows an upward trend, while a negative value shows a downward trend. | *Z* | > 1.96 denoted the confidence level of 95%. The trend's slope gives the annual rate and direction of change.

3.4.1.3 Standardised Precipitation Evapotranspiration Index (SPEI)

The Standardised Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardised Precipitation Index (SPI), developed by Vicente-Serrano et al., (2010). It is designed to take account of both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months. At longer timescales (>~18 months), the SPEI has been shown to correlate with the self-calibrating PDSI. Based on the analysis of SPI, SPEI and PDSI indices, there exists a strong correlation between SPI and SPEI (Ajayi and Ilori, 2020). The SPEI is however, frequently used index, as it requires more single variables (such as Precipitation, Maximum Temperature, Minimum Temperature), and latitude to compute the Potential Evapotranspiration values, using an approved Hargreaves equation, which is represented by the following equation:

$$ET_{0,Harg=}HC.R_a\ .(T_{max} - T_{min})^{HE\left(\frac{T_{max}+T_{min}}{2}+HT\right)} \tag{3.4}$$

Where $ET_{0,Harg} = ET_0$ estimated by Hargrave equation $(mm\ day^{-1})$; R_a = extra-terrestrial radiation (mm day^{-1}); T_{max} = dairly maximum air temperature (°C), T_{min} = daily minimum temperatue (°C), HC = emprical Hargraves coefficient; HE = empirical Hargraves exponent, and HT = empirical temperature coefficient

$[HC = 0.0023\text{HC} = 0.0023,\ \text{HE} = 0.5, \text{and HT} = 17.8\ (Hargraves, 1994)\ ]$

Several studies have shown the Hargreaves equation may provide reliable estimates of reference evapotranspiration for five days or longer time steps. In cases where more data are available, a more sophisticated method is required to calculate PET is to make a more complete accounting of drought variability. However, these additional variables can have large uncertainties (Vicente-Serrano et al., 2012). As potential evapotranspiration measures are influenced by temperature changes, SPEI yield more accurate results regarding the assessment of drought as compared to SPI. The interannual variation of rainfall over Liberia are yet to be accurately captured by existing climate models, and majority of the models result predict an intensification of rainfall over most parts of Liberia, even though the frequency and intensity remain uncertain (EPA, 2019). Therefore, analysing drought by incorporating the changes in PET rates yield a better sense of the drought condition that can ensure in the future. SPEI calculation is like SPI with one difference that works on the principle of "Climate Water Balance", as it takes the difference between precipitation and the reference evapotranspiration as the input, instead of precipitation (Begueria et al., 2014). The "Climatic Water Balance" is taken for each month and can be computed over different time scales (1 month, 3 months, 6 months, 12 months etc) and they are converted into standardised values by fitting them to a log-logistic distribution. Climatic Water Balance equation is given as:

$$D_i = P_i - PET_i \tag{3.5}$$

Where i represents the month, and the log-logistic distribution,

$$F(D_i) = \left[1 + \left[\frac{\alpha}{D_i - \gamma}\right]^{\beta}\right]^{-1} \tag{3.6}$$

Where $\alpha, \beta\ and\ \gamma$ are the scale, shape and location parameters calculated from the climatic water balance (D_i) and the SPEI index is also obtained as the standardised values of F (D_i).

Other drought indices that need to be mentioned in this analysis are the Standardized Precipitation Index (SPI; McKee et al. 1993) and the Palmer Drought Severity Index, PDSI, Vicente-Serrano et al., 2012). These indices have been used to evaluate drought frequency and intensity both at the local and the global level (Mishra and Singh, 2010; Raziei et al.2009; Dai 2013; Sheffield et al. 2012; Vicente-Serrano et al. 2014; Guenang and Kamga 2014; Ajayi and Ilori 2020). These indices are explained in the next section.

3.4.1.4 Standardized Precipitation Index (SPI)

The Standardised Precipitation Index (SPI) is a multi-scalar and a widely used index to characterise meteorological drought. It is designed to quantify the precipitation deficit for multiple timescales. On a short timescale, the SPI is closely related to soil moisture, while at longer timescales, it can be related to groundwater and reservoir storage. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. The SPI can be created for differing periods of 1-, 3-, 6-, 12-, 24, and 48 months, using monthly input data. The SPI is compared across regions with distinctly different climates. It quantifies observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The raw precipitation data are typically fitted to a gamma or a Pearson Type III distribution, and then transformed to a normal distribution. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean (Hayes et al., 2007). On other hand, Positive values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; accordingly, wet periods can also be monitored using the SPI. Hayes et al., (2007) also used the classification system shown in the SPI value table below (Table 2) to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude". The Standardised Precipitation Index (SPI) as a drought index hardly identify the role of temperature in future drought conditions and the independent of global warming scenarios cannot explain the influence of temperature variability and the role of heat waves.

For operational purposes, the SPI has been recognised as the standard index that is available worldwide for quantifying and reporting meteorological drought (Santiago and Begueria, 2016). There have been concerns raised about the utility of the SPI as a measure of changes in drought associated with climate change, as it does not deal with changes in evapotranspiration. Therefore, alternative indices that deal with evapotranspiration have been suggested as the SPEI (Santiago and Begueria, 2016).

3.4.1.5 Palmer Drought Severity Index (PDSI)

The Palmer Drought Severity Index (PDSI) is the drought index that uses readily available temperature and precipitation data to estimate relative dryness (Vicente-Serreno, Begueria et al. 2012). It is a standardized index that generally spans -10 (dry) to +10 (wet). The PDSI has been reasonably successful at quantifying long-term drought (Wang et al., 2022; Temam et al., 2019; Zhao et al., 2017). As it uses temperature data and a physical water balance model, it can capture the basic effect of global warming on drought through changes in potential evapotranspiration. Monthly PDSI values do not capture droughts on time scales less than about 12 months; more pros and cons are discussed in the Expert Guidance. Though, PDSI lacks the multi-scalar character which is essential for the assessment of both drought in relation to different hydrological systems and different drought types. Therefore, the SPEI has the ability to combine the sensitivity of PDSI to changes in evaporation demand with the specificity of calculation and the multi-temporal nature of the SPI (Vicente-Serreno, Begueria et al. 2012). Based on the analysis of the three drought indices, there exists a strong correlation between SPI and SPEI (Ajayi and Ilori, 2020). However, SPEI is the most frequently used index, as it requires more single variables (such as rainfall, Maximum Temperature, Minimum Temperature), and latitude to compute the Potential Evapotranspiration values. Therefore, this study adopts the SPEI index to assess drought extent and frequency over Liberia and the research counties. Since the study used an integrated research approach i.e., quantitative, and qualitative approach, the collected data is analysed using both quantitative and qualitative methods.

3.4.1.6 General Circulation Models (GCMs)

To perform climate change projections, the geographical or seasonal pattern of change are collected from the General Circulation Models (GCMs) simulations. The magnitude of the pattern can be scaled with respect to the specificities, such as the amount of forcing for specific temperature changes or particular emission scenarios (Harris et al., 2014). GCMs also represent physical processes in the atmosphere, ocean, cryosphere, and land surface, and are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. The simpler models of GCM have also been used to provide globally or regionally averaged estimates of the climate response. Moreover, the General Circulation Models (GCMs), in concurrence with the nested regional models, may possibly have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis (IPCC, 2013). Furthermore, Harris et al. (2014) discovered that the GCM approach is derived from pattern scaling which is efficient in terms of time and effort it requires to generate future projection for specific profile. Since this study is to determine the intensity and frequency of drought in Liberia because of rising global temperatures, with limited detailed studies in the past, the research will adopt future projection by using the dynamical scaling approach. This approach led to the extrapolation of the effects of large-scale climate processes to regional or local scales of interest.

3.4.2 Estimation of Drought Hazard and Exposure and Vulnerability

Following the description of hazard component, this study adopted an integrated hazard exposure and vulnerability assessment approach using a diverse set of biophysical and the socioeconomic indicators listed in Table 3.1 that reflect the three risk components: hazard, exposure, and vulnerability (susceptibilities, coping and adaptive capacities). Therefore, based on the modular scheme of drought risk assessment, hazard and exposure indicators were identified. These identified indices (i.e., Physical biophysical, and socioeconomic vulnerability) reflect the three risk components (hazards, exposure, and vulnerability (sensitivity, coping and adaptive capacities) that were selected and used in this study. A combination of quantitative and qualitative methods was used for the collection of relevant data from both primary and secondary sources. As primary sources of information, quantitative and qualitative information about the general information of the farmers, farming activities, perception of climate change exposure and impacts, irrigation, and access to communication facilities, and identification of adaptation strategies used by the farming communities to cope with the effects of climate variability and change were collected through sample household surveys. In addition, qualitative information was obtained using inter-personal interview techniques such as key informants' interviews and direct observations during the field surveys.

Table 3.1 Key indicators of drought hazard each risk components in Liberia. Bong and Lofa Counties

Scale	Components of Risks	Indicator	Description of indicators	Source of data
National	**Hazard**	Change in mean average monthly annual temperature and average monthly and annual rainfall of past 40-year.	Trends analysis of historical climate data for 40 years (1981-2020)	CRU Ts 4.02 grided set of global climatic data
		Changes in mean average annual temperature and annual rainfall GCMs future projected.	Trends analysis in temperature and precipitation 81 years (2020-2100) using model outputs.	CRU Ts 4.02 grided set of global climatic data
		Number of drought and dry spell events and intensity.	Drought analysis, using SPEI values to determine drought frequency and intensity and /or dry spell based on a 10-year average period (1981-2020) and 2020-2100 in the future.	CRU Ts 4.02 grided set of global climatic data
Sub-national	**Hazard**	Change in rainfall and mean temperature	Trends analysis of mean temperature and precipitation for 40 years (1981-2020) in the past.	CRU Ts 4.02 grided set of global climatic data
		Changes in mean temperature and rainfall GCMs projected.	Analysis of drought, using SPEI values to determine drought frequency and intensity and /or dry spell based on a 10-year average period (1981-2020) and 2020-2100 in the future.	CRU Ts 4.02 grided set of global climatic data
		Number of drought and dry spell events and intensity.	Drought analysis, using SPEI values to determine drought frequency and intensity and /or dry spell based on a 10-year average period (1981-2020) and 2020-2100 in the future.	CRU Ts 4.02 grided set of global climatic data

	Climate information	Percentage of farming population observed climate change	2021/22 Survey data
Exposure	Population	Number of people living in the area	2021/22 Survey data
	Number of households fully engaged in agriculture	Percentage of households fully engaged in agriculture (rice and cassava) production)	2021/22 Survey data
	Population density of the districts	This indicator is determined based on the population density living in the district.	National Population Census (2021)
Vulnerability	Access to extension services	Percent of farming population that has access to extension services (CC)	2021/22 Survey data
	Accessibility/ infrastructure	Percentage of farming population that has access to market (CC)	2021/22 Survey data
	Climate information	Percentage of farming population that has access to climate information (AC)	2021/22 Survey data
	Policy documents	Availability of policies supporting climate change and variability (AC)	EPA, LC
	Access to farmland	Number of farmers that have access to farmland (Physical susceptibility)	2021/22 Survey data
	Gender	Proportion of gender participation in farming activities (Social susceptibility)	2021/22 Survey data

	Literacy rate	Number and percentage of farming population that can read and write (Social susceptibility)	2021/22 Survey data
	Counties population below poverty line	This indicator is identified by the percentage of population below poverty line to the total population of the counties.	Liberia Statistics Office (2016 HIES)

CC: Coping Capacity**.**

AC: Adaptive Capacity.

EPA: Environmental Protection Agency of Liberia.

LC: Land Commission, Liberia

3.5 Survey Data Collection and Analysis Approach

Concept and quantitative approaches to risk assessment are continually evolving. A broadly acceptable holistic concept integrates and links all dimensions associated with risks such as natural, physical, social economic and environmental aspects (Hagenlocher et al., 2018). The IPCC sixth Assessment Reports defines risk is defined as a function of the hazard, exposure, and vulnerability (susceptibility, copping and adaptive capacities). While risks are commonly thought of as natural, they can be exacerbated by human-induced variables that speed up or increase the scale of occurrences or processes, or lessen them through interventions and adaptations, such as agricultural production and climate change. Overall, the study first describes how variables are characterized in each component of hazard, exposure, and vulnerability at the national and county levels (see Table 3.1). Consistent with vulnerability and risks assessment, previous studies have employed a wide range of methods based on IPCC contributing components such as hazard, exposure, and vulnerability (sensitivity, coping and adaptive capacities) to quantitatively assess risk at different scales (Nguyen, 2015; Fritzsche et al., 2017; Žurovec, et al., 2017). In this chapter, an integrated meteorological approach is adopted. This approach provides both the breadth and depth of data required to address the aims of this study, which encompass both description and explanation of public understanding of and response to climate risk assessment. In addition to the integrated approach, the study also adopted a mixed method research design and utilized household surveys for data collection and analysis. This approach was useful for assuring complementarity and synergy of results (Creswell et al., 2017). Besides, it is an approach that has been extensively used and applied to a range of situations including climate risk disaster risk in Liberia (EPA, 2019).

The integrated meteorological and mixed method approaches are widely used in climate risks assessment research (Ani et al., 2022; Nadeem et al., 2022) because they have the potential to accommodate a range of units of analysis together and enable comparative analysis of the impact of climate change on agricultural production (Guo et al., 2022; Zubieta et al., 2022). When the results are analysed, they are a useful tool to communicate findings to a wider audience including policy makers and can be used as a basis for deeper analysis (Zubieta et al., 2022; Wiréhn et al., 2017). The procedure used to assess the influence of risk with respect to climate change and variability during period 1981-2020, and 2020-2100 for Liberia is presented using a flowchart given in Figure 3.4.

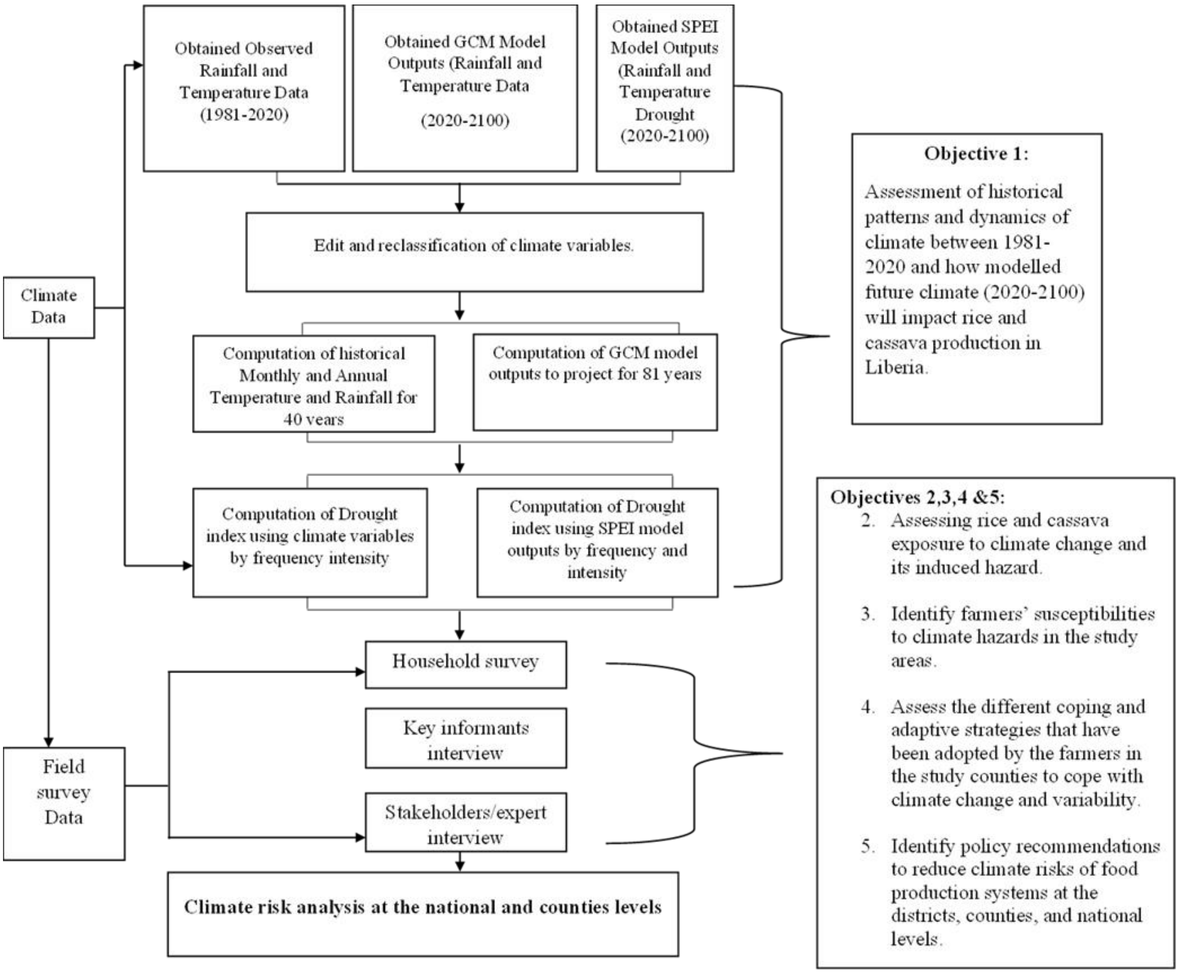

Figure 3.4 Data collection and analysis workflow of climate risks assessment in Liberia.

Consistent with the objectives of the study, Figure 3.4 shows that the study obtained two separate types of data, climate (meteorological) data and field survey data. The meteorological data considers temperature and rainfall occurrence for the past forty years (1981-2020) and analyses eighty-one years (2020-2100) of GCM's model output, extracted from the CRU TS dataset. The decision to select 40-year and 81-year time periods for this study was chosen because they provide more accurate meteorological data that are utilized for drought analysis (Jabal et al., 2022). Drought/hazard risk projections for near and distant future (2020-2100), CRU SPEI model outputs for 12-month period are used to determine future drought extent, frequency and intensity at the national and county levels. After obtaining these datasets, they are then analyzed to find monthly sums and averages to indicate annual rainfall and mean annual temperature for Liberia and the study areas using Mann-Kendall trend analysis. These cleaned datasets were imported into R software v 4.2.1 for analysis into 10-year (observed period) and 81-year (GCMs future projection), using Mann-Kendall trend analysis (Hamed, 2008). Furthermore, the study also used empirical data i.e., household survey comprising of semi-structured questionnaires, administered to the rural farmers, key informant interview administered to prominent people in each district and experts’ interview with selected staff from the ministry of agriculture, the Liberia Statistics Office (LISGIS) and the Environmental Protection Agency of Liberia (EPA). The field survey lasted for three consecutive and intensive months of fieldwork from November 2021 - March 2022. Table 3.2 shows which research methods are used to achieve the research objectives. The strengths and limitations of these research methods are flagged up later in this chapter in Table 3.3.

3.5.1 Research Method

In this study, both primary and secondary data were used. The primary data were collected from the socio-economic, institutional and biophysical situation of the sample respondents using field observation, semi-structured questionnaires, and a key informant interview at the household and district levels. Three data collection instruments were used in order to capture the data from different sources and triangulations were carried out to confirm and clarify the research issues. Field observation was conducted throughout the whole course of the research in order to ensure the validity of the information obtained. It was done with the purpose of getting guidance for the development of the formal question and to be familiar with the values of local people. The key informants' interview (KII, see 3.12.2) was conducted with purposely selected eighteen selected individuals composed of district chief and community’s leaders from each district about the history of climate change, kind of adaptation strategies and factors that influence farmers' adoption of adaptation strategies. Experts interview (see 3.12.3) was conducted with nine selected experts from the Ministry of Agriculture, Environmental Protection Agency of Liberia, and the National Statistics of Liberia (LISGIS). The semi-structured interview was used because it ensures each key informant has equal opportunities to provide information and was assessed accurately and consistently. In this work, both closed and open-ended questionnaires were applied (see 3.12). The majority of the survey questionnaires were closed-ended questions. The remaining small number of questionnaires were open-ended. The survey questionnaire covered a wide range of information which included household characteristics, farming system, farmers' perceptions about climate change, and determinants of their adoption of adaptation strategies. The questionnaires were administered by trained data collectors who were university graduate students and staff from the National Statistics Office (LISGIS). The researchers played the role of supervisory. A brief orientation and training for 10 enumerators were given (see section 3.12.1). Prior to implementing the survey, the questionnaire was briefed and piloted its clarity for data collectors. Besides, secondary data were collected from documents such as journal articles, books, annual reports, Intergovernmental Panel on Climate Change (IPCC) report, and other related resources. This study was conducted with full consent of the respondents and ethical approval was obtained from the Ethical clearance committee of the University of Glasgow (see Appendix).

Table 3.2 Research methods used during household survey to achieve the research objectives.

	Research objectives			
Research method	Exploring and characterising the nature of district vulnerability and risk to climate variability	Identify farmers' vulnerabilities to climate hazards in the study areas.	Accessing adaptation strategies for managing climate variability	Policy documents available to mitigate the adverse impact of climate change and variability in Liberia
Questionnaire survey	✓	✓	✓	
Key informant		✓	✓	
Expert interviews			✓	✓
Policy analysis			✓	✓

3.5.2 Significance of Participatory Methods in Research

Interdisciplinary research requires participatory approaches, which allow local people the opportunity to participate in the research by sharing their experiences and knowledge, to find solutions to issues in their local environment (Chambers, 2021). These approaches/methods involve sharing knowledge and expertise between scientists and non-scientists (with the local people) in a collaborative fashion (Ballard and Belsky, 2010). In this respect, researchers act as facilitators and learners to seek assistance from the local people in the choice and use of appropriate participatory methods (Kanyamuna and Zulu, 2022). This allowed indigenous communities to own the information generated. Mwangi, et al. (2021) mentioned that participatory approaches/methods have certain advantages that can be originated if well performed. Ziervogel and Calder (2003) categorized the advantages of participatory methods as follow:

The active participation of indigenous people or social actors in the research process can encourage social interaction or change, and in addition, by using participatory methods such as key informant interview (KII), help to build local capacity to manage problems such as climate variability and change. This has the potential to increase their self-belief and confidence in their own capabilities.

Despite the usefulness of this method, the use of methods in this study encounters some limitations. For example, the involvement of local people in this study was time consuming and expensive. To address some of these challenges, discussions at key informant interview and household surveys levels were moderated by the researchers to ensure that discussions were relevant to the scope of the research and digressions by participants. Serious methodological concerns have been raised in relation to the extent to which findings generated from context–specific participatory approaches such as key informant interview can be generalized (Banks and Brydon-Miller, 2018 and Jellason, et al., 2021). To address such shortcomings, participatory approaches were complemented by quantitative approaches such as crop failure assessment and time series analysis that allowed the intensity of cases and extent of risk to be measured, thereby providing scope for generalization. Additionally, participatory approaches/methods used in this research allowed the researcher to gain indigenous perceptions into the complexity of climate change and variability, and how it affects agricultural crop production systems and rural livelihoods in the research areas. For example, using participatory approaches/ methods provides valuable insights into how livelihood activities of rural people in the study districts have been adversely affected by climate variability. Households have used native knowledge to construct districts climate models and develop innovative strategies to cope with climate variability. In conclusion, it is therefore necessary that this knowledge is recorded and synthesized to explore the nature and extent of climate risk and coping measures used by these farmers.

3.5.3 Household Questionnaire Survey

A semi-structured household questionnaire was used to gather quantitative data from the rural farmers to complement the data obtained from the KIIs, and experts discussion and interview. The household questionnaire was prepared after a review of relevant literature followed by expert meetings with local officials such as experts from the Environmental Protection Agency of Liberia (EPA), the National Statistics Office (LISGIS) and the Ministry of Agriculture (MOA) to finalize the interview questions list. This helped to target suitable questions relevant to the case study region. The interview questionnaire was developed focusing on past and current climate change perception in the study districts, climate change adaptation, implementation actions, success of climate change adaptation, perspective on policy, rules and regulations related to climate change adaptation, short term and long-term strategies, and resource constraints.

Although random sampling was used, factors such as age, gender, and wealth group of the farmers were representative of the various social groups within each district. The questionnaire consisted of both closed and open-ended questions (Appendix). It was conducted in the respondents' homes, and this allowed the research team to make a preliminary assessment of their socioeconomic conditions (Lottering, et al., 2021 and Orlove et al., 2010). The study adopts the most common definition of household used by the Liberia Institute of Statistics and Geo-Information Services (LISGIS). The household is defined "as a group of people who own the same productive house, live together and feed from the same pot" (LISGIS, 2008). In this respect, the household is deemed to comprise of a family with a man, wife, and children.

To describe households and farming localities, the study followed the framework proposed by Derbile et al. (2022) who suggests that climate risks can be assessed by looking at the household, localities (livelihoods) and institutions (at the local, regional, and national levels). This framework was slightly modified to consider local aspects such as socioeconomic factors that can potentially influence agricultural production systems' risk to climate variability and change, especially in developing countries. At the household level, participatory methods were used to determine locally relevant indicators. At the local level, households were asked to indicate some of the factors that make them at risk to climate variability. This information was used to assemble the household and localities livelihood that are at risk as a result of climate change and variability. The study collected information on the kinds of crops cultivated as well as the land tenure system assessed. Information on gender issues, cultural values, and road networks which may affect their capacity to adapt to climate change and variability were collected and evaluated.

In Liberia, traditional knowledge has, in most cases been used by farmers to solve varied issues including climate variability related problems (Nyadzi et al., 2021). An assessment was undertaken to determine the effectiveness of institutional arrangements at the local, counties, and national levels. Data on governmental assistance in the form of subsidies and the type and roles of the various institutions involved in agricultural development and environmental protection in Liberia were collected. This is necessary because these organizations are often used as indicators for the presence of good governance (Vernon, 2022). The household questionnaire survey also assessed the adaptation and coping responses used by the farmers in the research localities. The research also collected data on the availability of, and accessibility to, government subsidies, and general government policies and programmes particularly on land tenure systems and land use. Additionally, the research further collected data on timing of farm operations.

Information such as barriers to climate adaptation strategies including access to information on early warning systems for farmers, financial constraints, availability of, and accessibility to, extension advice, illiteracy and how it affects accessibility to information, technological constraints were collected during the survey. Moreover, traditional belief systems and norms which sometimes serve as barriers to the adaptation strategies were identified and evaluated. This information provided insights into the difficulties confronting farmers in their attempts to implement appropriate strategies to cope with and adapt to climate variability and change. The household survey was also used to assess the perception of farmers regarding rainfall and temperature patterns in the research counties. To complement the information obtained from the quantitative household surveys, key informant interviews was conducted: three key informant interviews were conducted in each district. Three key informants were selected from each district purposively, and in-depth interviews were also carried out with a district chief, youth agriculture leader (male), youth agriculture leader (female). In addition, field observation and document review were used to augment the data.

3.5.3.1 Training of Research Assistants and Pre-Testing of Questionnaire

Climate change is a challenging problem which is not widely known by the different terms used to describe it in different parts of Liberia. Therefore, it was necessary to run a training programme for research assistants who were recruited to help the researcher with data collection. Ten research assistants (RAs) were recruited based on their technical competencies in the Statistics Office in Liberia, including their communication and writing skills, as well as their ability to act objectively within interview situations. These research assistants were originally from the research areas and spoke the local dialects of the farmers. Six of them were graduates in the social sciences while four were senior students at the University of Liberia, specialized in sociology, demography, and economics. The RAs were thoroughly prepared by the principal investigator on the nature and significance of the research through a five -day training workshop held at the National Statistics Office of Liberia’s (LISGIS) training room, December 13-17, 2021. This was done to ensure a standardized process that all interviewers asked questions in a similar fashion to reduce any ambiguity (see Figures 3.5 and 3.6). The questionnaire for the household survey (see Appendix 1) was tested on the fifth day (December 17, 2021) in ten randomly selected rural households in the peripheral of the capital city of Liberia. Residence in these locations is also involved in agricultural activities, which is similar to the study areas. The pre-test was done to evaluate the kind of responses that could be anticipated in the actual field survey. Two key informant interviews (KII) were also conducted to reflect the applicability of using KII for research of this nature. After the trial and analysis of the responses, the questionnaire was modified by deleting unrelated and ambiguous questions for both questionnaire and KII. During the main fieldwork, the research team met at the close of work every day to discuss the day’s work and deliberate on any issues arising. Figure 3.3 shows the districts that were visited during the field data collection.

Figure 3.5 Photo of the researcher assistants training session in Monrovia, Liberia (December 2021).

Figure 3.6 Photo displaying principal investigator (standing in blue T-shirt) monitoring a mock interview being conducted by two of the research assistants, Monrovia (December 2021).

3.5.3.2 Key Informant Interviews (KII)

In addition to sample household surveys, ten qualitative information surveys were collected regarding key issues in farming and the associated impacts of climate variability and change on major crop such as rice and cassava production systems and adaptation measures being applied by local communities. Key Informants' Interviews were conducted with 18 selected individuals across the research areas (three from each county) who were considered knowledgeable about the issues on farming and climate variability and change and its impacts on the agricultural production system in their respective districts in terms of general and adaptation practices. The responses and views expressed by the key informants were analysed using content analysis.

3.5.3.3 Expert Interview and Policy Analysis

During the field survey, some staff from the Liberia Environmental Protection Agency (EPA) and the Liberia Institution of Statistics and Geo-Information Services (LISGIS) who exhibited significant knowledge on climate variability and change and agricultural activities were selected for experts' interviews. Interviews with experts were accompanied by visits to their respective points of interest (offices), where appropriate. This interview allowed in-depth discussion and validation of the main issues that were highlighted in the household questionnaire survey. Experts' interviews took place on a one-to-one basis to ensure confidentiality of responses and lasted between thirty and thirty-five minutes.

Results from the experts' interviews determine the different adaptation and or mitigation strategies to manage the impacts of climate change and variability in vulnerable districts and counties. Experts who participated in the research included the National Focal person, the United Nations Framework Convention on Climate Change (UNFCCC), the National Focal person, the United Nations Convention to Combat Drought (UNCCD), and National Focal person, National Disaster Relief Agency, all based at the Environmental Protection Agency, Liberia. Other experts were from the national statistics office and the ministry of Agriculture. These experts were purposefully selected.

In addition, specific policies were analysed to determine the effectiveness of these policies in terms of food security. These include the Food and Agriculture Sector Development Policy, National Climate Change Policy Framework, Liberia National Adaptation Programme of Action (NAPA), National Action Plan for Disaster Risk Reduction, National Policy, and Response Strategy on Climate Change, National Environmental Policy of Liberia, and Intended Nationally Determined Contribution. Table 3.3 presents the strengths and limitations of the main study methods that were used to collect data for this study.

Table 3.3 Strengths and limitations of the research methods (source: Adopted from Warrick, (2009)

Method	**Strengths**	**Limitations**	**Practical solutions**
Questionnaire survey	Allowed exchange of knowledge between researcher and participants. Relatively cheaper, flexible, and adaptable	Sometimes, time consuming	Researcher kept respondents on the topic under discussions and avoided unnecessarily digressions that did not add to the interview responses.
Experts and stakeholders' interview	Provided expert opinion on vulnerability of farmers in the study area.	Difficult to get stakeholders to be interview	Used personal contacts in the various ministries to link up with experts. Booked interview appointment to suit experts and stakeholders.
Key Informant Interviews (KII)	This process allows an in-depth discussion from on main issues from prominent people in the community.	Sometimes difficult to identify the appropriate key informants	Relied on opinion Leander in district such as chiefs, community representative, religious leaders and head of farmer association.
Policy and institutional analysis	Allowed the targeting of specific policies to enhance the relevance of research.	Difficulty in getting access to policy documents from governmental agencies and institutions.	Used personal contacts in the ministries to get access to policy documents. Also, during expert interviews, request was made for policy documents and other secondary data.

3.5.3.4 Data Collection for the Household Survey

The Household survey used a face-to-face interview approach, but it deviated from the traditional pencil and paper process to a newer approach of Computer Assisted Personal Interview (CAPI) method (https://www.csprousers.org/help/CSPro/what_is_cspro.html). Each Supervisor and Enumerator had a tablet and with the software application installed which could load the questionnaire. The Enumerator then asks questions as in the questionnaire from the respondent and then records the responses using drop down menus, alphabetical and numerical filed in the application. The skip patterns, range and consistency checks are already programmed into the application that guide the interviewing process and put in quality controls.

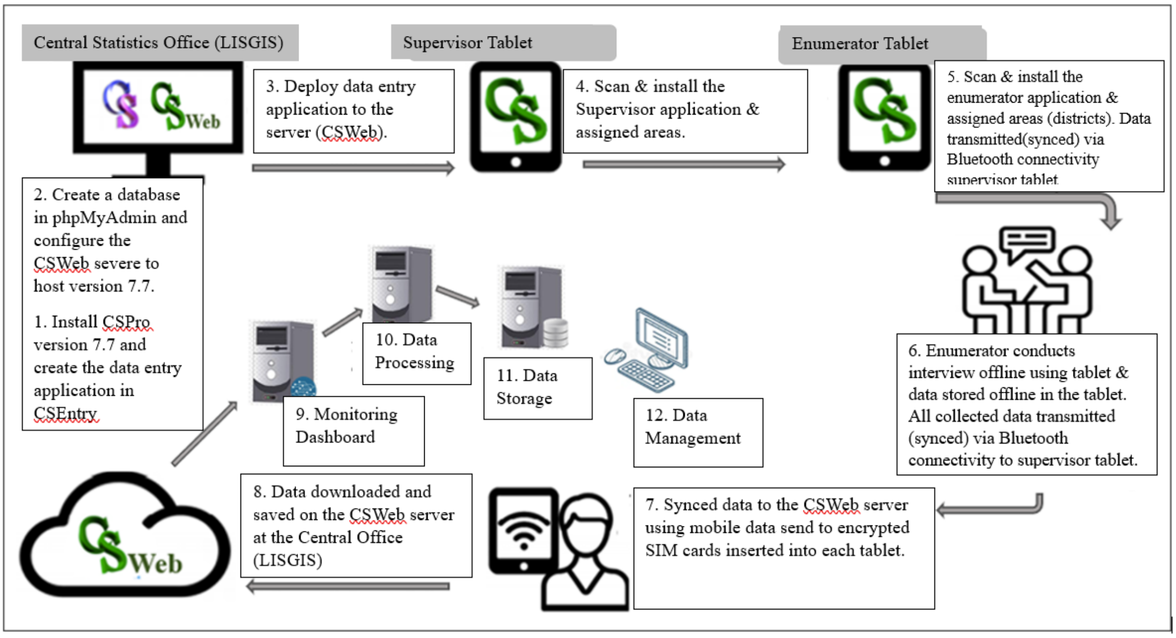

Figure 3.7 CAPI workflow architecture, showing data collection process, synchronization between interviewers, supervisors and central server at the National Statistics Office (LISGIS).

3.5.4 Data Collection Instruments

The approach utilizes three data collection instruments: Tablets, Dashboard platform, and Offline dynamic base maps application (CSPro). All data were collected electronically (Tablets) and sync to Supervisor tablet and a dashboard at central statistics office LISGS) using CSWeb Dashboard platform with electronic form, pictures, GPS features that allows community's assets on a map to capture data at the individual level. The advantages of this mode of data collection are to get data in real time, accurately track locations of Enumerators using the GPS technology to control curb-stoning, avoid the pitfall of missing or mutilated paper surveys, and transmission of data to a central server immediately upon completion of each interview, which safeguards the integrity of the data. Data analysis forms the core of any study, as it clearly shows the accurate trends and patterns of data for real time programing. Under this assessment, SPSS v20 and CSPro batch in-build plug-ins were used to manage the data. This allows statistical tests appropriate to the levels of data to be obtained, in order to identify both trends and correlations between variables. Meanwhile, CSPro qualitative data analysis application was deployed to track and manage the qualitative data for accuracy and precision.

3.5.4.1 The Functions and Relevance of Dynamic Offline Maps During Data Collection

The role of maps in the data collection process is to support interviewers in locating their area of assignment. In general terms, map serves several purposes in data collection process, as follows:

i. Maps ensure coverage and facilitate data collection operations.
ii. Maps support data collection and can help ensure that interviewers easily identify their assigned geographic areas, in which they will interview households.
iii. Maps can thus also play a role in supervising the progress of data collection operations. This allows supervisors to strategically plan assignments, identify problem areas and implement remedial action quickly.
iv. The data collection team needs to have a set of unique offline dynamic maps covering the entire district of assignment that accurately define the boundaries within which each interviewer must work during the data collection phase.

Therefore, the quality of maps used in data collection has a major influence on the quality Control measure and reliability of data synced to central office.

3.6 Quantitative Data Analysis Approach

After determining the data collected based on the indicators of each component mentioned in Table 3.1, the data is processed, then exported from CSpro to SPSS where frequency test was applied to ensure consistency and finally exported to R Software Package (version 4.21) and an ArcGIS desktop, cleaned and further analyzed.

The non-gridded data (field survey) are arranged at the administrative units, i.e., counties and districts levels, and produced tables and graphs using R Software Package before transforming into the map format by using ArcGIS desktop The key informant and experts' interviews were analysed by transcribing all the responses.

The quantitative data was analysed using descriptive statistics such as frequencies and percentages to summarise the information on climate change perceptions, impacts, coping and adaptation strategies and barriers to adaptation strategies. The descriptive statistics was analysed for farmers' demography and climate change perceptions using SPSS version 20 and R software package version 4.2.1 and results presented using tables and graphs. This method was used to identify the determinant factors affecting farmers' choice of coping and adaptation strategies to climate change and variability. Besides, the study also used

Pearson's correlation coefficient was applied to examine the associations between climate variability and households' food security status. Correlation measures the linear relationship between two variables. A correlation coefficient has a value ranging from -1 to 1 i.e., a value closer to one indicates the presence of strong relationship between variables and value closer to 0 shows little or no linear relationship between the variables being correlated. Likewise, a positive correlation coefficient confirms a positive linear relationship between the variables and negative coefficient denotes an inverse relationship (Rahman and Muktadir, 2021; Şahin and Aybek, 2019).

For paired measurements (X_1, Y_1), (X_2, Y_2) …, (X_n, Y_n), the study expresses a simplified Pearson product moment correlation:

$$r = \frac{\sum XY}{\sqrt{\sum X^2 \cdot \sum Y^2}} \tag{3.7}$$

Where $X = x - \bar{x}$ and $Y = y - \bar{y}$ are the differences between the measured value and the mean value.

The factors affecting farmers' coping and adaptation strategies to climate change and variability were related to socio-demographic, economic, institutional, and infrastructural characteristics of households and their locality. The socio-demographic and economic variables included gender of house heads, education, age of household heads, farm size and off-farm economic activities. The variables in the biophysical category included perception of climate change and variability. Access to credit, extension service, on-farm activities, perception of land tenure system, access to information on climate change, and access to market were from the institutional and infrastructural factors (Kogo et al. 2022; Sohail et al. 2022).

3.6.1 Standardization and Calculation of Exposure and Vulnerability Components

The purpose of the normalization is to adjust different factors with different units to the same dimensionless unit. As a result, the values of the indicators range from 0-1.

It is necessary to standardize the indicators in a comparable range. Among the studies related to exposure vulnerability assessment, normalization is used to represent the indicators in one single functional form (Osei-Amponsah et al.2023). The normalization has been calculated using the following equation:

$$Y_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})} \tag{3.8}$$

On the contrary, if the variable is with a negative relationship in the value of the indicator, then the normalization has been achieved using the following equation:

$$Y_{ij} = \frac{Max\left(X_{ij}\right) - X_{ij}}{Max\left(X_{ij}\right) - Min\left(X_{ij}\right)} \tag{3.9}$$

Where Y_{ij} is the normalised score for the ith indicator related to the district. X_{ij} is the actual value of the ith indicator for ith district. $Max\ (Xij)$ and $Min\ (ij)$ are the maximum values of jth indicator among all the districts. Weighted index was another method is applied to integrate the component of exposure and vulnerability indexes.

The survey included weights to the different factors and indicators that are key to developing composite exposure and vulnerability indices. There are different approaches to how to apply weighting to different factors and indicators. For example, Wilhelmi and Wilhite (2002) assigned the weights based on the relative contribution of each factor to overall vulnerability. Based on this, Chen et al. (2013) applied statistics using principal component analysis (PCA) to evaluate the weights of factors in social vulnerability assessment, while Yuan et al. (2015) assigned weights based on expert opinions and employed accelerating genetic algorithm-based analytic hierarchy process (AGA-AHP) to quantify the opinion of the respondents. On the other hand, Murthy et al. (2015) indicated that weighting may be assigned to selected indicators to reflect their relative importance. However, the most common approach of weighting as indicated by Tate (2012) is the use of equal weights to all variables. This method is therefore applied and used in this study. The reason for the adoption of equal weight is that it is the method that is used by the National Statistics Office of Liberia in all national surveys, such as the 2013 Liberia Demographic and Health Survey (LDHS, 2013) and the 2016 Household Income and Expenditure Survey (2016 HIES). Additionally, by using this method in this study, it will make the study to be compatible with national approaches. The equation used to calculate weight is given as:

$$\bar{X} = \frac{\sum W_i X_i}{\sum W_i} \tag{3.10}$$

$where\ \overline{X} = weighted\ sample\ average$

$W_i = weight\ of\ value\ i$

$X_i = individal\ value\ to\ be\ weighted$

Following equal weighting, indicators were aggregated for the development of respective component indices. Additive aggregation (summing) of normalised indicators is nearly universally used (Nadeem et al., 2022) and was applied here. All normalised indicators of exposure and vulnerability were aggregated to form the overall indices of risk. Finally, quartile analysis has been carried out to classify districts based on exposure and vulnerability.

3.13.6 Qualitative data analysis

Qualitative data were collected through a mixture of household questionnaire surveys, key informant interviews, and expert interviews. Digital recordings of KIIs from each district were listened to repeatedly to ensure accuracy. Qualitative data were coded and indexed through intensive content analysis and the major themes that emerged analyzed (Sheydayi, and Dadashpoor, 2023; Kumar et al., 2022). These major themes were triangulated through a more in-depth agro-ecological survey and any contradictions were clarified through key informant interviews (Grey and Manyani, 2020; Murray et al., 2023; Shackleton et al., 2021). Structuring qualitative data into various themes allowed the categorization of the responses and identification of those that diverged from the common themes. Appropriate quotes from farmers and experts were used to provide more emphasis to enrich the discussions.

3.7 Policy Analysis

The study used content analysis of the key policy documents (Nicmanis, 2024) that relate to climate adaptations and food security in Liberia was undertaken (including analysis of the Liberia National Adaptation Programme of Action (NAPA), National Action Plan for Disaster Risk Reduction, National Policy, and Response Strategy on Climate Change, National Environmental Policy of Liberia, and Intended Nationally Determined Contribution) to the UNFCCC, the National Action Plan to combat drought and desertification (NAP), and Food and Agriculture Sector Policy (FAPS) to highlight the key themes covered by such policies. These policy documents were carefully read to fully understand the contents and the main message covered by these policies. Also, a discourse analysis of each policy document was undertaken by examining the dominant narratives covered in each policy document. The main subjects that emerged from the content analysis of a particular policy document are then checked against other policies to highlight any similarities or contradictions of various policies that were meant to address similar concerns, in this case climate variability and food security.

3.8 Basis for Using Quantitative and Qualitative Approaches in Climate Science Research

Climate science research links the natural and social sciences. The problems it addresses, likewise, are capable of being tackled through both scientific and social research methodologies. Many climate scientists, however, have been educated largely in one or the other discipline, and are likely to favour one area of quantitative, numerically based, 'scientific' or qualitative, value-based, 'social' methodologies. Quantitative research is popularly associated with the rational and objective, while qualitative research concerns itself with meaning and values (Blaikie and Priest, 2017). There is, however, a growing body of literature (Collins, 1982; Golinski, 1998) calling for an integrated approach in which the two research paradigms are perceived as being complementary to each other. Collins (1982) and Golinski (1998) pointed out that 'humanness' of scientific inquiry, for instance, depends on implicit knowledge and represents institutional values, which in most cases are clearly exposed in sociological studies by social scientists. Conversely, the use of measurement in social science research does not automatically indicate a commitment to positivism (Bonaccorsi, 2022). For example, Coleman (2022) and Hendren et al. (2023) argued that quantification (ideally, based on respondents' own categories) can give greater confidence in the accuracy of conclusions derived from qualitative data.

Therefore, the difference between quantitative and qualitative methods can be understood as mostly technical, and not necessarily philosophical. Certainly, many social studies have combined quantitative and qualitative methods of data collection and analysis in different ways, and have achieved different ends (Coleman, 2022; Wayessa et al. 2023; Hirose Creswell, 2023). This combined approach (quantitative and qualitative) offers different understandings into the social dimensions of climate change, and each is better suited to answering different types of research question. Therefore, Wayessa et al. (2023) revealed that the rationale to combine these methods stems from "the basic and plausible assertion that life is multifaceted and is best approached by the use of techniques that have a specialized relevance". Adopting an integrated methodological approach in this study provides both the breadth and depth of data required to address the aims of this study, which encompass both description and explanation of public understanding of and response to climate risk assessment.

3.9 Positionality Statement

Positionality is an important consideration when carrying out research involving human subject. I am an experienced researcher undertaking PhD research in Climate Change

Vulnerability Assessment in Liberia. I come to this research with the understanding that conventional research in climate science along with agricultural production faces many challenges (both public discourse and in scientific literature) debates (Sumberg and Giller,2022). I have existing views and experience of environmental and climate science. In addition, I am passionate about the previous study on climate vulnerability assessment and believe it improves the understanding on the subject matter.

My previous academic and professional experiences have guided the choice of my research topic and research question. When returning to the field after an extended time off researching at the university of Glasgow. I frequently contacted staff at the National Statistics Office (LISGIS) and EPA, Liberia about consistent climate data on Liberia. Locally, there were no data to support my research. I also often resorted to informally seeking help from colleagues from LISGIS and EPA, Liberia. I worked on my research making calls and encouraging them to help with the provision of data on Liberia. With time, I became frustrated with what I perceived to be inadequate help which led me to visit Liberia twice. and I pursued a PhD to explore this topic, with the aim to enhance my understanding of critical environmental and climatic issues and thereby improve how to effectively demonstrate the relevance of environmental and climatic issues at the national and global level. I ended up by obtaining meteorological data from the World Bank Climate Change website and conducted a household survey in Liberia to support my climate data.

My academic and professional backgrounds in environmental and climatic issues have continued to shape the research I have undertaken as part of my PhD. Specifically, it has informed my qualitative interview topic guide, interview technique and data analysis, due to having an in-depth personal understanding of the contextual elements mentioned by participants. For quantitative aspects of my PhD, it has shaped my research questions and study design elements, such as selecting multiple short electronic diary entries-rather than one long survey or using a paper survey as well as piloting my survey items with research colleagues to ensure readability and understanding. My insider positionality meant I was familiar with stakeholders such as the study areas, KII and experts' consultation. It has also allowed me to plan for wider impact beyond these obvious dissemination strategies, such as the development of a best practice guideline for vulnerability assessment of a personal toolkit for front line researchers on how to seek and use setting. Without this insider knowledge, I may not have recognised the need for activities beyond conference presentations and journal articles to ensure that my research findings influence climate vulnerability research.

3.10 Conclusion

This chapter has described how the study districts that participated in this research were selected. The research design as well as the use of participatory methods in this study has been justified. This chapter contributes to wider academic debate in relation to how different methods (i.e. quantitative and qualitative approaches) at different levels can be integrated to assess climate risk of dryland farming areas. Climate change and variability is a complex problem interacting with different processes at different levels (Ishtiaque, 2021; Chen et al. 2023). The use of a mixed-method approach allowed validation and deepening of understanding of the main issues involved in climate risk assessment of farming systems and livelihoods to climate change and variability through triangulation, thus providing a significantly richer understanding of the different dimensions of the problem through its survey across scales. Combining different methods with valuable insights from local farmers provided local insights that enhanced learning by the researcher and members of the study districts. Having described how the various data were collected and analyzed, the next chapters (Chapters 4-7) present the findings, discussions and implications from the study.

Chapter 4 Assessment of Historical Patterns (1981-2020) and Modelled Future Climate (2020-2100) and Identification of Exposure to Climate Induced Hazards

4.1 Summary

This chapter outlines the results and data collected in identifying hazards and exposure in the study districts in Liberia (objective 1 and 2). Particularly, this chapter illustrates how a quantitative and qualitative regional assessment is a critical first step in identifying differences in climate sensitivity of agricultural production systems. It shows how such an assessment enables the formulation of more targeted district level research that can investigate the drivers of exposure to change on a local scale. Finally, the chapter proposes methodological steps that can improve climate risk assessments in dynamic farming systems where there are multiple drivers of change and thresholds of risk that vary in both space and time. This will help to improve climate risk assessment in Liberia and more widely as it shows the additional information that can be obtained from local-level exposure and vulnerability assessments that may be lacking at the national and county levels for analysis.

The chapter is organized as follows: the next describes the introduction, materials and methods are discussed in section 4.2, highlights the approach and explains how all the necessary data (climate data-i.e., rainfall, temperature, and household survey data such as qualitative and quantitative) were collected and analyzed, while section 3.6 presents results of both meteorological and survey data, and the next two sections (i.e., 4.7 and 4.8) present discussion and conclusions of the chapter. Issues involving positionality and ethical considerations are explained in the next chapter in this chapter.

4.2 Introduction

The long-term patterns of weather that distinguish the different parts of the world are changing due to global climate change and variability. Climate change is very real, as it is subject to various external forcing, mainly natural and anthropogenic. The effects of these external forcings have led most climate scientists to confirm that man-made activities are contributing to changes in global climate (Fawzy et al., 2020). These include greenhouse gas-producing industrial operations including mining, deforestation, the production of petrochemicals and refineries, and fossil fuel burning. The greenhouse effect traps the heat emitted from the Earth’s surface temperature (EST), raising by around 30 °C (Akanwa et al., 2019). An annual 13 million hectares of forest are lost due to mining and agricultural operations (Akanwa et al., 2017). According to the 2018 report of “Intergovernmental Panel on Climate Change" (IPCC), if the emissions of greenhouse gases (GHG) are not decreased within the succeeding 30 years, the Earth would suffer disastrous impacts (IPCC, 2018a). Around 63% of the global GHG emissions are produced by developing nations, yet 98% of those nations are severely impacted by climate change (Javadinejad et al., 2019). The most dangerous effects of climate change and variability will be experienced by these nations, which also have the least ability to adapt their combat mechanisms.

In Africa, climate change impacts are widely observed, where it has directly affected climate-dependent activities such as agriculture and indirectly impacted on social aspects such as poverty, conflict, education, and health (Adu et al., 2019). According to the IPCC (2022), Africa is one of the most exposed and vulnerable continents to climate change and variability because of multiple stresses and its low adaptation capacity. Ziervogel et al. (2022) report that agricultural production and food security in many African countries are likely to be severely compromised by climate change and variability. The implications of climate change and variability on agriculture cannot therefore be overemphasized especially for agrarian economies. Various climate change scenarios indicate that water stress will increase in the future (Boazar et al., 2020; Rahimi-Feyzabad et al., 2020), and as the agricultural sector is considered as the largest consumer of water, it is likely that the area of agricultural land will be drastically reduced, especially in arid and semi-arid regions (Delfiyan et al., 2021; Savari and Zhoolideh, 2021).

The IPCC (2022) noted that yields in agricultural production are generally expected to decline most severely in countries at lower latitudes. The projected impacts of climate change and variability are threats to crop production in regions that currently experience food insecurity (Oluwatimilehin and Ayanlade, (2023). In Africa and south Asia, major grains including wheat, maize and sorghum and rice are projected to suffer mean yield losses of 8% by 2050 with some crops, notably wheat in Africa, expected to experience a yield change of -17% (Leal Filho et al., 2020; Oluwatimilehin and Ayanlade, (2023). Notwithstanding, the impacts of climate change and variability have already been felt on the agricultural sector in Africa, and climate change induced disturbances to the monsoon recorded between 1966-2002 are estimated to have reduced yields of rice by 4% (Auffhammer et al., 2012). These changes have impacted national and global industries (Gomez-Zavaglia et al., 2020), as well as the marginalized and impoverished rural areas in developing countries whose livelihoods are dependent upon small scale agriculture (Mkonda et al., 2018; Kreft et al., 2017). Agronomic studies suggest that yields could fall quite dramatically in the absence of costly adaptation measures, as current farming technology is basic and incomes low, suggesting that farmers will have few options to adapt. Without adaptation, climate change is generally problematic for agricultural production and for agricultural economies and communities, although risk can be reduced with adaptation-related activities.

Across SSA, crops yield, and production quality are negatively impacted by rainfall variability and increase in temperature (Kangalawe et al, 2017). Bedeke, (2023) and Neupane et al. (2022) revealed that decreases in rainfall are leading to significant crop yield declines in the dryland areas of SSA and subsequent rises in food prices in the local market. Seasonal rainfall patterns across SSA are expected to show high levels of spatial and temporal variability (Mwendwa et al., 2022; Serdeczny et al., 2017), which could adversely affect the length of plant growth period, the cropping calendar and crop water requirements (Pereira et al., 2020). Climate scenarios for the West Africa regions indicate that climatic conditions are expected to change considerably until the end of the 21st century, involving, for example, earlier onset of dry season, higher mean temperature and extreme weather condition, and more precipitation (Kangalawe et al, 2017) which could increase food insecurity. These changes and variability are often thought to negatively impact agricultural production in the region (IPCC 2014). The IPCC fifth Assessment Report (AR5) however, presents a more critical report of climate change and variability impact for West African agriculture. It states that ‘there is unpredictable evidence concerning future impacts’ of climate change on agricultural production in West Africa (Fitzpatrick et al. 2020). For example, increased precipitation complicates the conditions for both sowing and harvesting (Rötter et al. 2018; Sime and Demissie, 2022) and increased variation of temperature and precipitation could cause yield variability and loss. Accordingly, climate change in Liberia is likely to imply both challenges. Regardless of climate impacts, adaptation policies and mitigation measures are essential to limit risks to climate change.

Climate change scientists worldwide have been involved in several climate change impacts and drought risk assessments at the regional and global levels, undertaken in the framework of several schools of thought and disciplines including geography, agricultural science, water resource analysis, climate research and social sciences (Asare-Kyei et al 2017); Kamali et al 2018). These studies have led to a growing awareness about the importance of shifting from crisis mode - a reactive approach - to a proactive risk management approach in dealing with hazards. The severity of drought risk and its impacts on livelihoods have provoked researchers to contribute to the awareness and the need of improving drought risk management systems worldwide. These types of systems are especially relevant to Liberia because they will enhance the essential climate change policy and its associated response strategies in key sectors such as agriculture, fisheries, forests, mining, coastal area and cross-sectorial policies and interventions.

Liberia like many other countries in the tropics is affected by several climate-related hazards, the most common being floods, tropical storms, coastal erosion, changes in seasonal rainfall patterns and rising temperatures, which occur during rainy seasons, and are costly in terms of both human and economic loss (EPA, 2020). The risk and severity of these natural hazards is expected to increase with climate change (World Bank, 2021). In 2017 alone, more than 100,000 people were affected by floods in the country (EPA, 2020). Given the importance for crop production and rural living standards more broadly, this study focuses on rice and cassava production with reference to Bong and Lofa. Bong and Lofa, including Nimba (not considered in this study due to limited funding and time) counties are known as Liberia's 'breadbasket', simply these counties account for more than 60% of agricultural production in Liberia. According to Stanturf (2015), these counties have been predicted to experience increased environmental stress in the coming years due to climate change and variability (National Disaster Risk Management Policy, 2012, EPA, 2019). Therefore, Liberia is a useful case study context in which to undertake more detailed risk assessments, in which the findings could have significance not only on dryland farming systems in Liberia but also more widely across the West African region.

Moreover, mapping climate-induced events for Liberia is also important because the IPCC's regional assessments of climate change impacts for Africa imply declining grain yields are likely and predict that agricultural production and food security in SSA will be negatively affected particularly relating to increased drought intensity and frequency linked to greater inter-annual rainfall variability (Mumo et al., 2018). However, the impacts of climate variability on agricultural production in SSA will vary spatially and understanding the complexity of such systems requires further investigation through more detailed assessments of key regions such as that provided in this thesis. This chapter aim is to assess how climate change and variability have impacted agricultural production in two counties in Liberia, i.e., Bong and Lofa and to also identified districts more exposed to climate hazards. The specific objective of the research is:

1. Assessment of historical patterns and dynamics of climate between 1981-2020 and how modelled future climate (2020-2100) will impact rice and cassava production in Liberia.
2. Assessing rice and cassava exposure to climate change and its induced hazard,

In addressing these, this chapter accesses meteorological and household survey data that offer important methodological approaches for this study. This chapter also has potential policy implications as it provides appropriate information on the impact of climate change and variability of agricultural production (i.e., rice and cassava) in Liberia.

This chapter uses Mann-Kendall Test (Non-Parametric) to analyse meteorological data, descriptive statistics for household survey data and content analysis for KII. Detail explanation of this section is contained in chapter 3.

4.3 Results

4.3.1 Hazard

The present study performed a trend analysis of temperature and rainfall data to identify changes in the weather pattern of Liberia and the study areas. Based on the historical records available for Liberia and the study areas, from 1981 to 2020 at the Climate Research Unit (CRU), the average, mean monthly temperature and average monthly rainfall from 1981-2020 are shown in Figures 4.1 and 4.2 for Liberia and the study counties (Bong and Lofa). The analysis show that September (Figure 4.1) has the highest amount of average rainfall for Liberia in September with a decline in October and reaches a low in December across Liberia. The variations in rainfall are high in the rainy months of June, July, August, and September, and low in the dry months, November, December, January, February, March, and April for Liberia. On the other hand, the overall mean monthly temperature for Liberia is at its highest peak in March with more than 27 °C and 24.5 °C, the lowest recorded in August from 1981 to 2020. Likewise, the pattern of rainfall in the study counties ranging from 400 mm in September for Bong being at its highest as indicated in Figures 3.2A and the highest rainfall for Lofa being in August (4.2B), almost the same temperature recorded for both counties which have impacted crop production in the study areas.

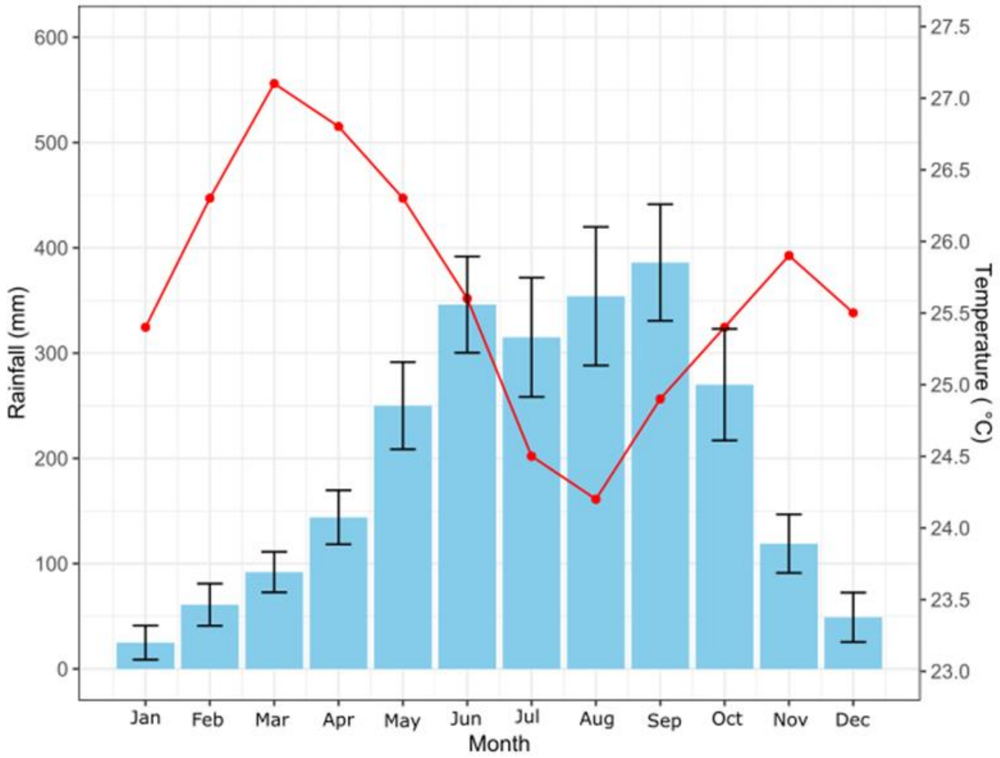

Figure 4.1 Climograph of Liberia showing rainfall (blue bar) and temperature (red line), 1981-2020.

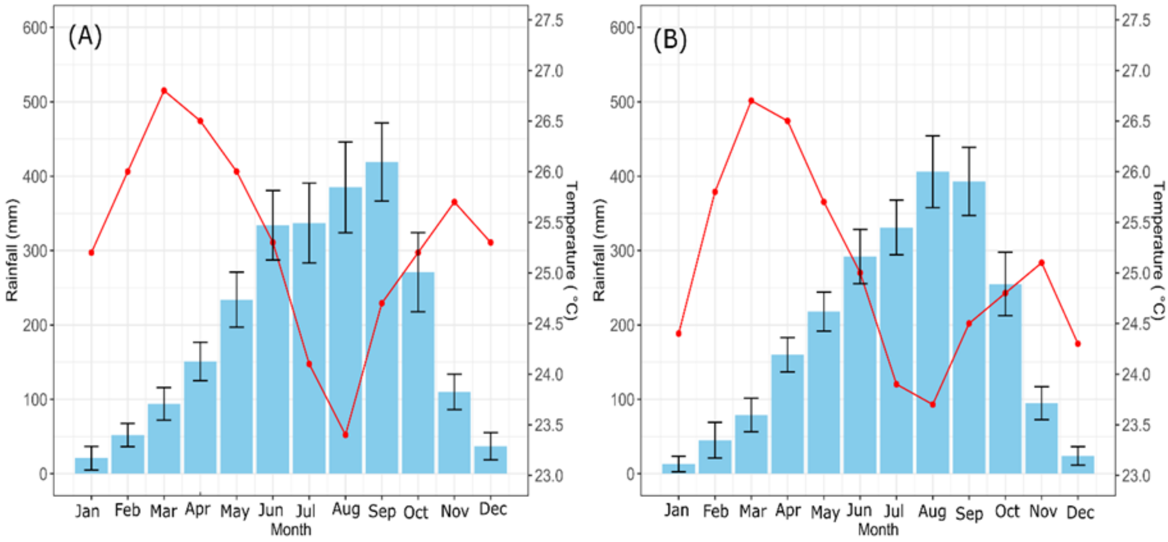

Figure 4.2 Climograph of Bong (A) and Lofa (B) showing rainfall (blue bar) and temperature (red line), 1981-2020

4.3.2 Determination of Farming Season and Months of Planting

The period of farming and months of sowing/planting were in general supplied by the collaborating institutions, the Ministry of Agriculture (MOA) and the National Statistics office (LISGIS) along with the climate information for crops production. Farming periods and months of sowing/planting are indicated in Table 4.1.

Table 4.1 Farming season in the study areas (source: LISGIS; MOA, 2016)

Activities	Months
Bushing of farm site	December - January
Burning and clearing of farm site	February - March
Planting of crops	April - May
Harvesting of crops	September – October

Table 4.1 illustrates the farming season in the study areas for rice and other crops production. This information was confirmed by the farmers across all six districts during the household survey. Based on the information, it is assumed that the planting months across all districts are in April-May every year, which according to the meteorological analysis (see Figures 4.1 and 4.2), the rainfall during these months range from 150 mm-240 mm. According to the reports from the Ministry of Agriculture (MOA) and the National Statistics Office (LISGIS), a total of 300 mm - 400 mm rain is needed for crops production (rice), most especially at the beginning of the planting season (LISGIS, 2016). Cassava is somehow drought resistant crop but requires water at the early stages of planting for germination (MOA, 2010). The monthly rainfall from 1981-2020 as indicated in Figures 4.1 and 4.2 show a low level of rainfall from April-May as against the water requirement stipulated by MOA and LISGIS. During these months, the water is lower (150 mm -240 mm; see Figures 4.1 and 4.2), which normally lead to crops failure when the crops could not receive adequate water at the early stage of planting for germination.

4.3.3 Mean Annual Temperature and Annual Rainfall (1981-2020)

The mean annual temperature over Liberia as illustrated on Figure 3.8 shows the lowest mean annual temperature values of 25.1°C in 1982 and 1986. The trend line shows an increase in temperature during these periods (1981-2020). The mean annual temperature has increased by 0.8°C between 1981 and 2020 (Figure 4.3), an average rate of 0.18°C per decade. There is insufficient data to determine trends in daily temperature extremes for all seasons. The EPA in Liberia confirmed that the average of daily temperature per year increased to above 31°C from 2009-2012 (EPA, 2019).

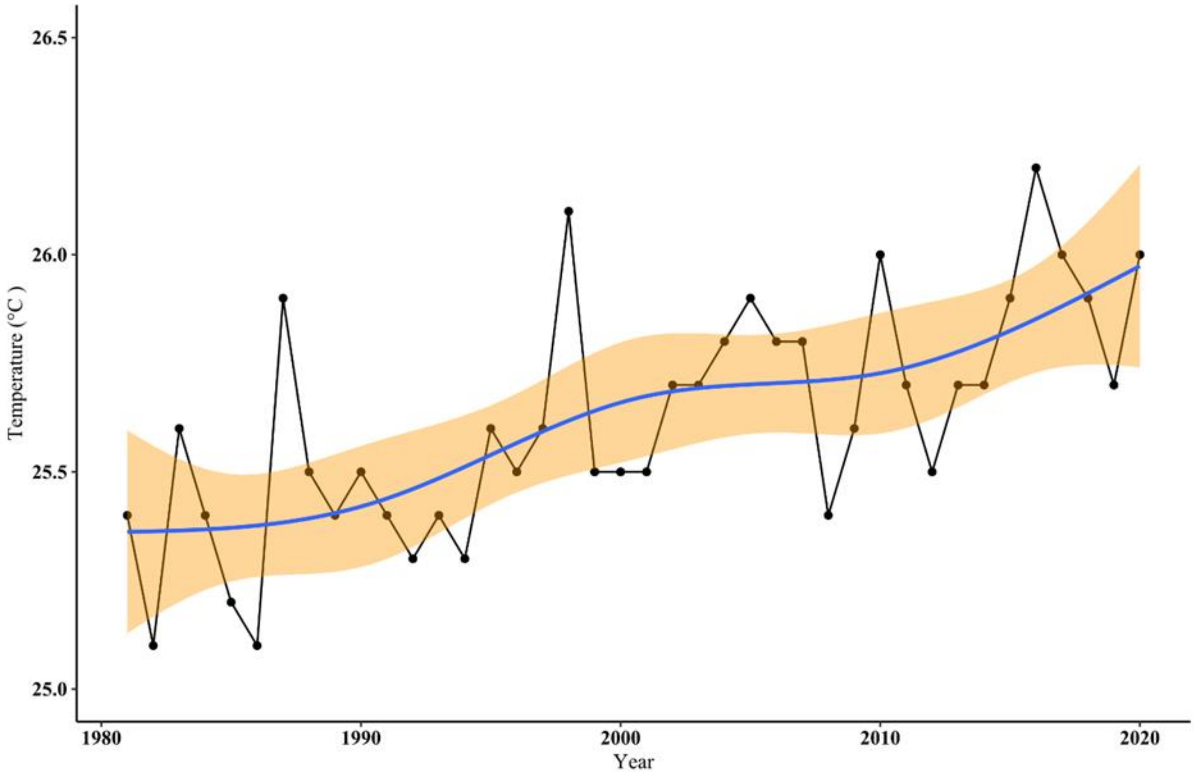

Figure 4.3 Mean annual temperature for Liberia, 1981-2020

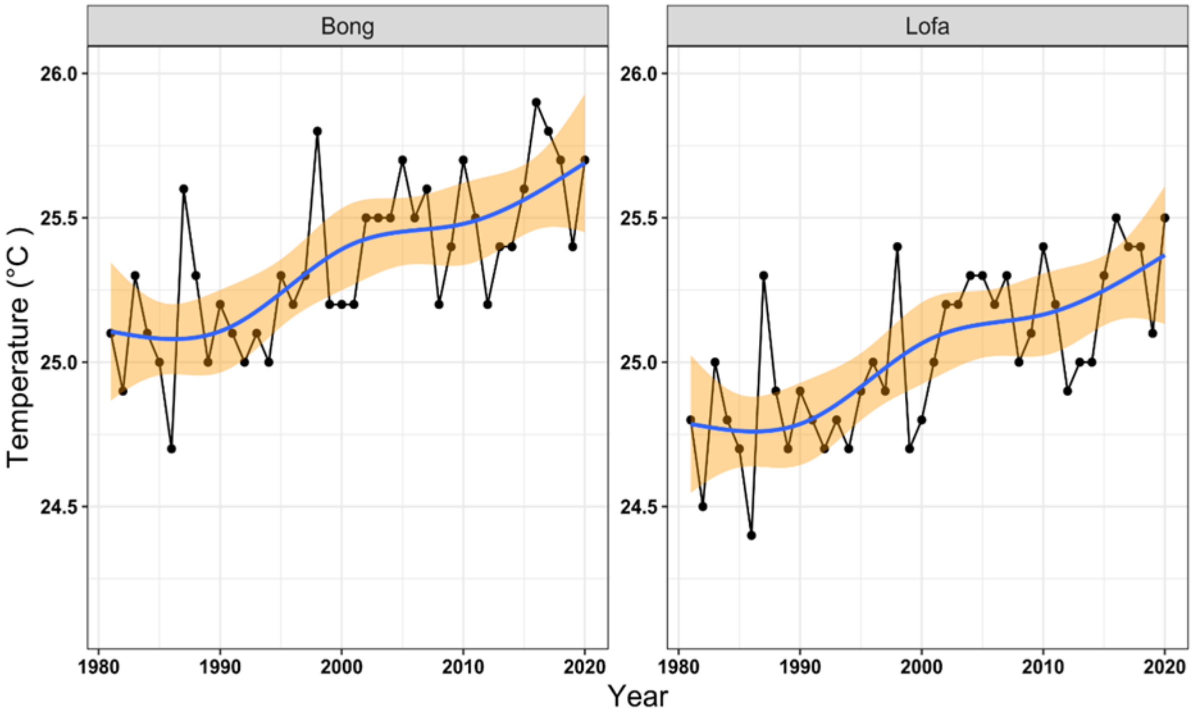

Figure 4.4 Mean annual temperature for Bong and Lofa, 1981-2020.

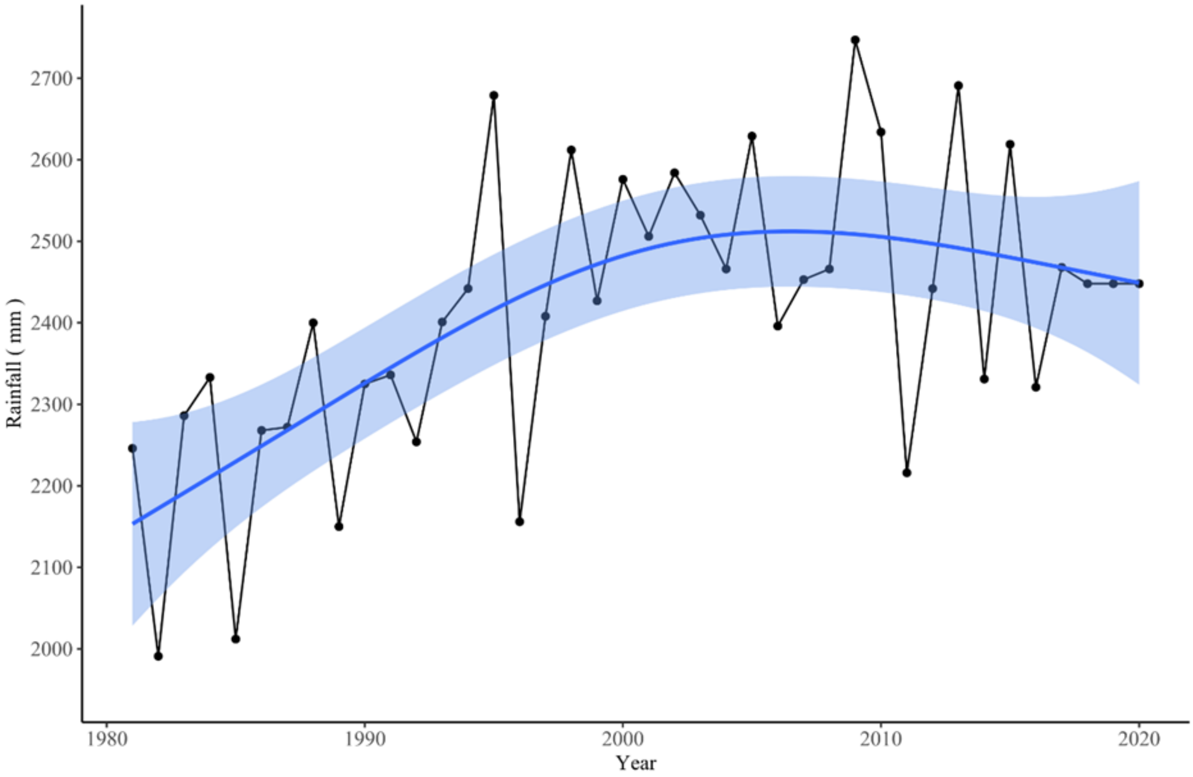

Figure 4.5 Mean annual rainfall for Liberia, 1981-2020.

As indicated at the national level, the trend lines in Bong and Lofa (Figure 4.4) indicate that the mean annual temperature has also increased during this period (1981-2020). The results also show that there has been an increase in the mean annual temperature over the period from ca. 25.0°C in 1981 to ca. 25.7°C in 2020 over Bong County, while Lofa County, has recorded a mean annual temperature with 24.5°C in 1981 to 25.5°C in 2020. This represents an increase in the mean annual temperature of ca. 0.7°C in Bong, and ca. 1.0°C in Lofa from 1981 to 2020.

The annual rainfall for Liberia with a 10-year moving average reveals a persistent high variability in annual rainfall during the past 40-years (1981-2020). The moving average (blue line) revealed an upward trend from 1981-2002, later stabilized from 2002-2010, and began to decline after 2010. The black line is marked by a series of negative trends between 1981-2020 (Figure 4.5). The lowest annual rainfall for Liberia was 1991 mm in 1982, followed by a series of inconsistent patterns until 2009 when the country recorded its highest annual amount of rainfall of 2747 mm in 2009.

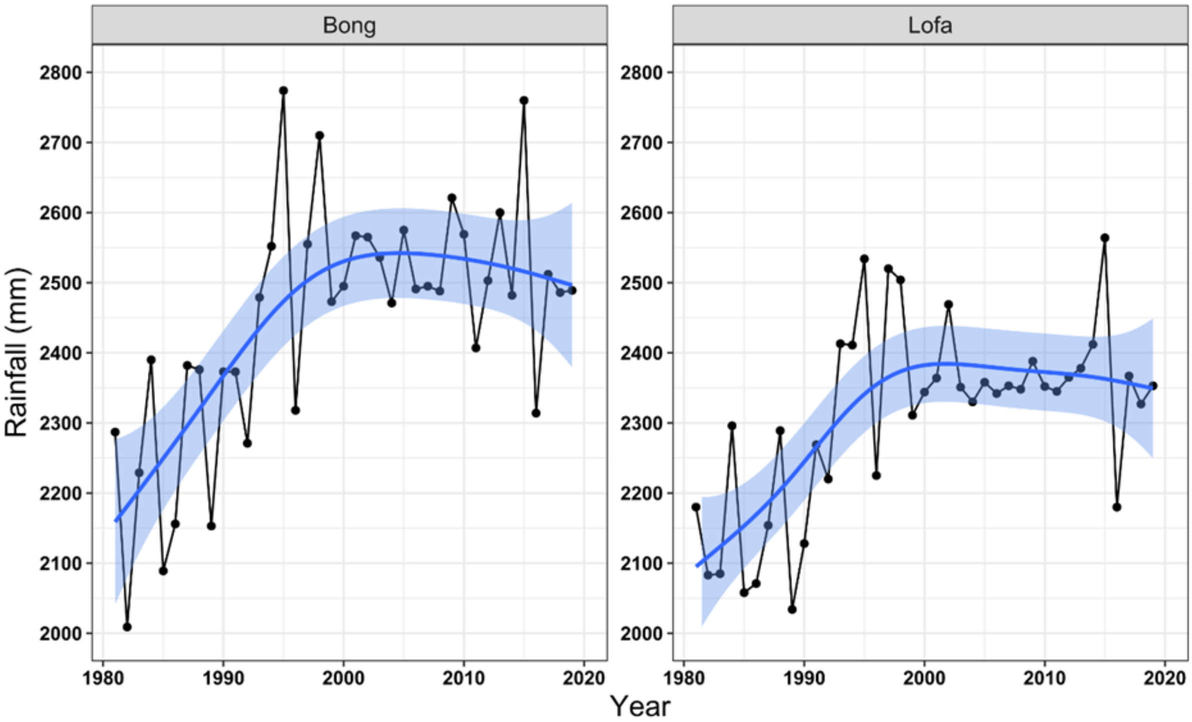

Figure 4.6 Annual rainfall for Bong and Lofa Counties, 1981-2020.

Equally, the annual rainfall variability can be observed in Bong and Lofa (Figure 4.6). The trend lines show an increasing trend for both counties from 1981 through 2000 and later a subtle decrease from 2000 to 2020. The black line in both counties also indicate a series of negative trends from 1981 to 2020. The highest amount of annual rainfall recorded for Bong County was above 2700 mm in 1995, while the highest annual rainfall for Lofa County was recorded in 2018 (2550 mm) and low annual rainfall following the years after. Mean annual rainfall over Liberia has decreased since 1981, however, it remains unclear if this is a long-term trend are due to the variability in rainfall for the region. However increased frequency of intense rainfall is expected, and these event occurrences are also expected to increase in unpredictability. Increasing sea levels may also result in additional vulnerability to coastal areas during heavy rainfall. The observed changes in climate have a grave impact on rural agricultural system in Africa (IPCC, 2018). This is largely due to overdependence on agriculture, which is sensitive to climate change.

Furthermore, to support the results from the meteorological analysis, the study explores the farmers' perception farmers to establish the impact of climate change and variability in their districts. A closed ended question was posed to the farmers as to whether they have been experiencing any changes in rainfall and temperature within the past 5-10 years. Figure 4.7 shows that farmers in the study districts have observed changes in the trends in local climate, which is characterized by an increase in temperature across all six districts, decline in rainfall and increase in evaporation for the past 5-10 years.

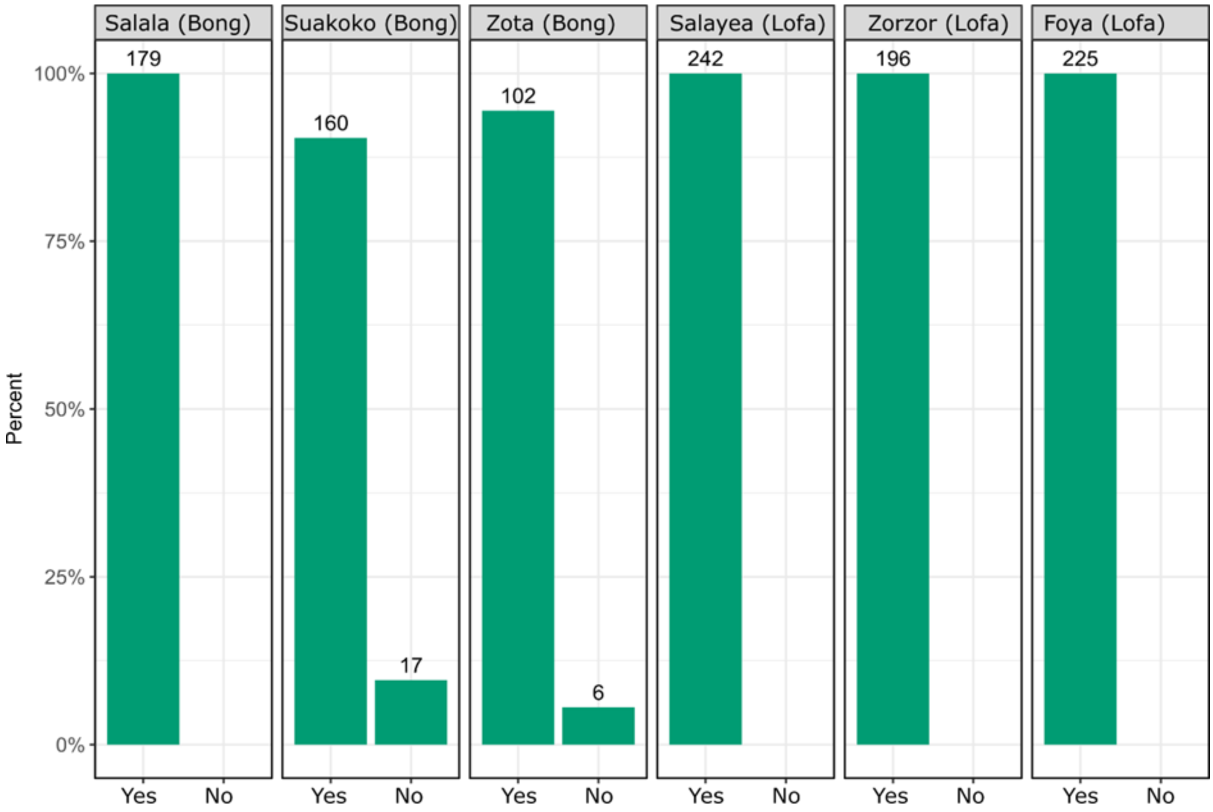

Figure 4.7 Observed any changes in monthly and annual temperature and rainfall in the past 5-10 years.

The reasons for the notable variability in rainfall and increase in temperature in recent years were due to the several dry spells during the rainy season, most especially during farming periods, and pronounced dry season. This demonstrates that farmers in the study areas have good perception of climate change in their respective districts. Though, historical crop yield and production data were not available for analysis, farmers' perception were also solicited on the impact of variability such as rainfall and increase in temperature on their crop yields during the past 5-10 years. As indicated in Figure 4.8, climate change impact on farmers' agricultural yield included crops failure, 30 and above farmers (more than 17%), crops reduction, more than 36 farmers (more than 20%) and both crops failure and reduction more than 40 farmers (more than 50%) across the study districts. See below the explanations for these occurrences that were provided by the district's chiefs during the Key informant interview and open-ended analysis. This indicated that the majority of farmers have observed crop failure within the past 5-10 years.

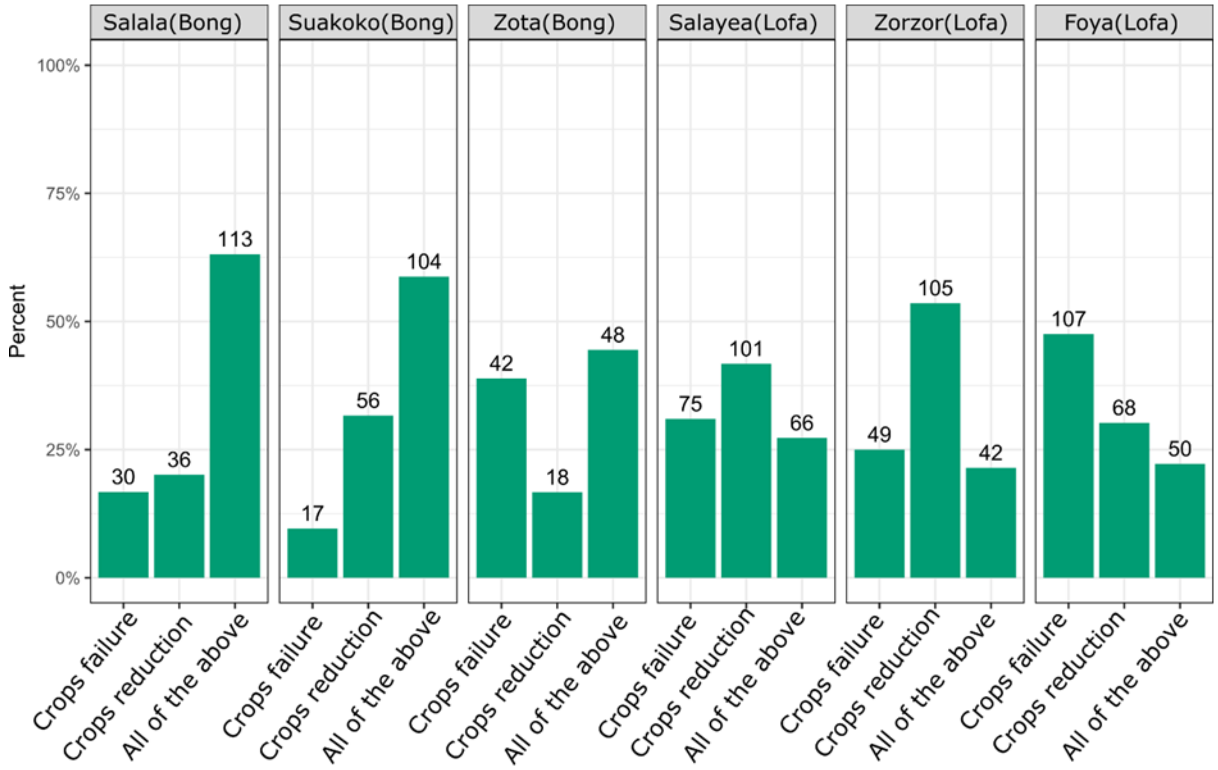

Figure 4.8 The impact of climate change on crops yields in the past 5-10 years.

Similarly, a key informant account in the district Salala district in Bong County explained that "*crops failure and crops reduction during the years have been caused by insufficient rainfall most especially at the early stage of the farming season.*" (December 2021). Furthermore, a chief in Foya district also stated that *"about five years now, our district has been facing serious problems of crops failure due increase in sunshine and no early rain for our crops to grow to bear fruits. Additionally, we are seriously facing food shortages and government is not helping us except for those who have families in Monrovia (capital of Liberia) and oversea can received money for their upkeeps."* (December 2021).

Based on the finding of this study, Borhara et al. (2020) conducted a study to investigate trend in monthly and annual rainfall and temperature over Togo for the period 1977-2012 using the Mann-Kendall (MK) test and Sen's slope (SS) method to evaluates the significance impact of rainfall and temperature variability for maize, sorghum and millet yields in northern Togo. Their result found that rainfall and temperature variability affect rainfed cereal crops production, but the effects vary across crops. The findings of this investigation is similar to the results of this study with revealed variability of rainfall and increase in temperature leading to crop reduction and failure in the study districts.

4.3.4 Future Climate Change

The global-average temperature trend is an important indicator of global climate change. Substantial attention has been focused on temperature trends; whereas trends in precipitation have received less attention in public discussions of climate model results (Srinivasa et al., 2017; Kumar, 2013; Kitoh et al., 2013). Significantly, precipitation drives the hydrologic cycle, including regional flood and drought conditions. In this study, one of the objectives is to assess temperature and precipitation trends using the CMIP5 climate models to understand the impact of climate change and variability. The impacts of climate variability and change are predicted to compromise socio-economic development in developing countries. Adaptation is the only alternative to reduce the impacts. However, before starting to determine any adaptation strategies, it is important to conduct scientific research to understand potential pathways of future climate change under different emission scenarios. This gave rise to the use of model outputs to estimate future climate change impacts on agriculture and drought hazard, for different time periods 1981-2020 (observed) and 2020-2100 (future scenarios), using meteorological outputs from five Global Climate Models (GCMs), for four representative concentration pathways (RCPs) which represent scenarios of future concentrations of greenhouse gases (RCP 2.6, RCP4.5, RCP6.0 and RCP8.5, respectively). This is essential for having facts to guide the formulation of effective mitigation and adaptation strategies. In this section, the annual temperature and rainfall records of over 80 years (2020-2100) have been analysed based on CRU CMIP5 model outputs data for Liberia and the Central and North-Western (Bong and Lofa) part of Liberia.

4.3.5 Projected Temperature Over Liberia (2020-2100)

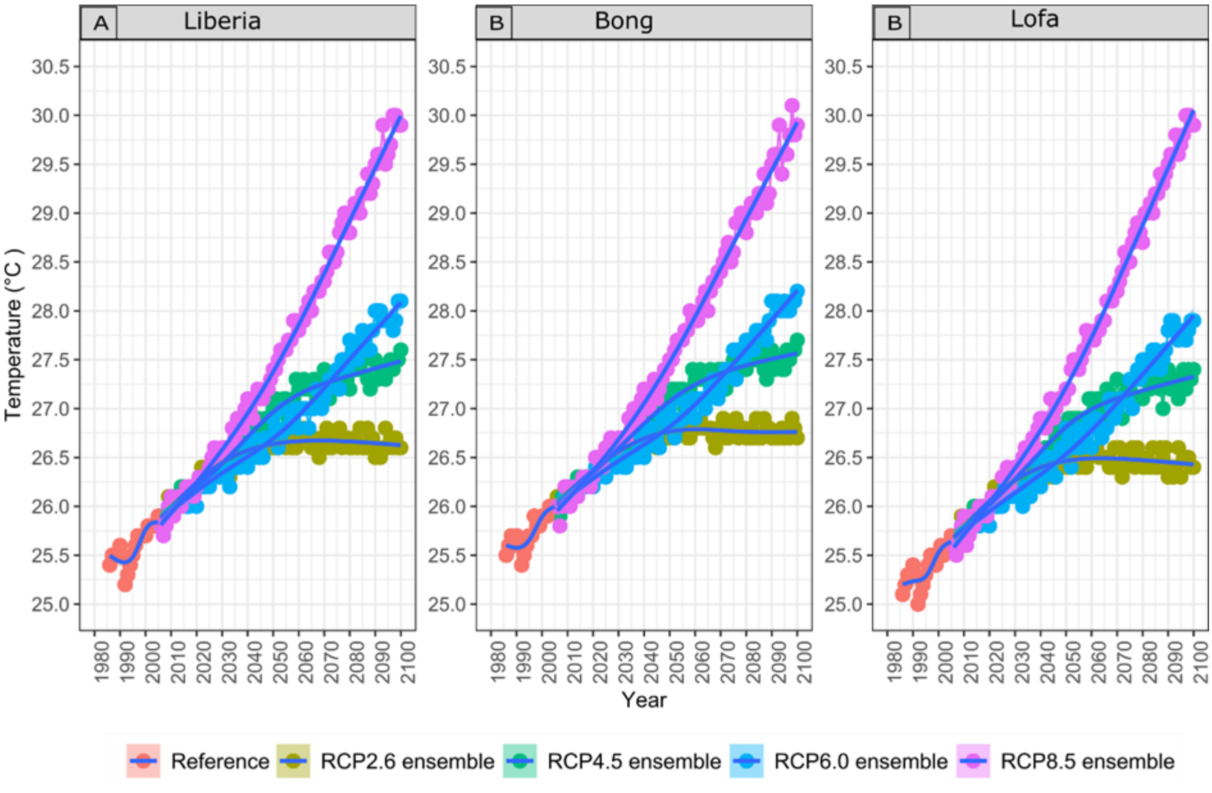

Figure 4.9 Changes in Average Annual Temperature Scenarios comparative to observational period (1986-2005) over Liberia, Bong and Lofa, an average over 80 years (2020-2100).

Climate projection (see Figure 4.9) show changes in future temperature scenarios comparative to the observational period (1986-2005) over Liberia and the research counties and averaged over 80 years. Figure 4.9 shows that for both the observational period and future scenarios, the models indicate a rise in temperature. There is a substantial rise in temperature over the country for the rest of the century for all scenarios. Additionally, the model also revealed that temperature is likely to increase under a high emission scenario. For example, Liberia today is 25.7°C and will increase to 26.5°C (low) or up to 30.0°C (high) - so this means an increase over the period of somewhere between 0.8 °C up to 4.3°C degrees in the worst-case scenario. Similarly, for example, Bong, currently is 26.0°C, and will rise to between 26.7-30.0°C, so an increase of 0.7°C possibly up to 4.0°C, similarly, Lofa is currently 25.5°C, so an increase to 26.5°C possibly up to 30.0°C, so 1.0 to 4.5 degrees. The model also projected an increase in temperature across all emission scenarios throughout the end of the century (Figure 4.9). This increased heat condition will result in significant implications for human activities such as agriculture and ecosystems.

The increase in temperature under all the emissions scenarios could accelerate evapotranspiration and reduces crop growth that could lead to the reduction of crop yield in the future. Crop production in a rainfed agriculture is highly influenced by temperature.

Therefore, deviation from the optimum temperature will likely affect crop (i.e., rice and cassava) productivity and yield. High temperature could affect many physiological processes in plants, such as rate of photosynthesis, respiration rate, crops evapotranspiration processes etc which could affect growth, development, and yield of crops. Therefore, future climate could affect crop (rice and cassava) production in the study areas unless adaptation measures are developed to reduce the impact. The projected increases in temperatures by the GCMs are in agreement with those reported by Hamed et al. (2022); Reboita et al. (2022) and Hassan et al. (2020) for Egypt, South America and Nigeria respectively. Changes in the projected total rainfall varied both in magnitude and direction among the GCMs for both study locations. The inconsistencies in the direction of change in projected rainfall amounts by GCMs in this study has also been reported by other studies (e.g. Hassan et al. 2020; Shiru et al. 2020) for rainfall in West Africa.

4.3.6 Projected Rainfall Over Liberia (2020-2100)

The amount and distribution of rainfall is projected to change across the different RCP scenarios (Figures 3.15, Liberia, Bong and Lofa). The model indicate that Bong has the overall highest values for annual rainfall, but variability around the average looks similar to Lofa and slightly reduced for Liberia (probably due to averaging across a broader region). Despite the high rainfall and inter-annual variability, under the medium to high-emission scenario (RCP 6.0), the models project that annual average rainfall at the national scale is projected to increase within the next eight decades (2020-2100). Similarly, Liberia's First National Communication (2013) pointed out that increasing temperatures and high variability of rainfall will impact the country's water balance in the country which could create a more difficult agricultural scenario due to soil runoff and intense rain (EPA, 2013). Even though, the increase in future rainfall as indicated in the model (Figure 4.10) might improve soil moisture availability that is required for crop production, the overall increase in temperature (Figure 4.9) could lead to reduction in crop yield in Liberia, most especially in the study counties that are sensitive to climate change and variability.

Figure 4.10 Changes in Average Annual Rainfall Scenarios comparative to observational period (1986-2005) over (A) Liberia, (B) Bong and (C) Lofa, an average over 80 years (2020-2100).

Akinyoola et al. (2021) carried out a study to examine the trend and future projection in precipitation and temperature events for Nigeria the period 2020-2099. By adopting three statistical change point detection techniques to identify changes in precipitation and temperature trends at 5% significant level, the study found significant change in temperature is expected to occur for all zones under RCP4.5 and RCP8.5 for future period 2020-2099 with increase in mean annual temperature trend 0.026-0.38°C and an increase in precipitation amounts under RCP4.5 but significant decrease in magnitude under RCP8.5 in near and far-future. Similarly, Sharma et al. (2023) explores the spatio-temporal variations of aridity across the Sabarmati River basin (SRB) of India, using rainfall and temperature datasets for the baseline (1951-2019) and future (2020-2100) periods. Using GCM5 with two RCPs, the study confirmed projected increased rainfall and temperature at the end of the 21st century. These results are similar to this study. Therefore, the results will benefit policymakers in a position to reduce future climate vulnerabilities and can be used for building local adaptation strategies in response to long-term climate change.

4.3.7 Drought Analysis

Drought frequency and intensity are defined as the number of events and extreme degree of strength in each period. Two periods were investigated, 40-year and over 80-year periods in this study, 1981-2020 (representing the observed period) and 2020-2100 (representing the future scenario). The severity of an event is estimated as the sum, in absolute values, of all the monthly indicator values between the start and the end of the event. Since the study is focused on drought frequency and intensity between these two periods, here drought severity (DS) refers to the average severity not the total severity of drought events in the selected period. To conduct drought analysis, the study selected the entire country (Liberia) and the study counties (Bong and Lofa) for the analysis of drought severity (i.e., frequency and intensity), using the SPEI values provided. The SPEI values of -1 to -1.5, -1.5 to -2.0 and below -2.0 means moderate, severe, and extreme droughts, respectively; and -0.99 to 0.99, 1 to 1.49, 1.5 to 1.99, and 2.0 and above are considered as near to normal, moderate wet, very wet, and extreme wet respectively (Table 4.1).

Table 4.2 SPEI values and corresponding event probabilities. Source: Mckee et al. (1993); Lloyd-Hughes and Saun-ders, (2002).

Class	Description of State	SPEI values	Probability (%)
1	Extreme drought	$SPEI \leq -2$	2.3
2	Severely drought	-2$< SPEI \leq -1.5$	4.4
3	Moderately drought	-1.5 $< SPEI \leq -1$	9.2
4	Near normal	-1 $< SPEI < 1$	68.2
5	Moderately wet	$1 \leq SPEI < 1.5$	9.2
6	Severely wet	$1.5 \leq SPEI < 2$	4.4
7	Extremely wet	$SPEI \geq 2$	2.3

Figures 4.11 and 3.12 show the evolution of SPEI over 1-, 3-, 6-, and 12-month intervals from 1981-2020 for Liberia and the two counties where the research was caried out. Short timescales showed a high temporal frequency of dry and moist periods. With increasing timescales, drought and moist periods showed a lower temporal frequency and a longer duration. Two contrasting periods were evident between 1981 to 1990 (Figures 4.10 and 4.11). Wet and dry conditions dominated from 1981-2020 for the short timescales, whereas persistent drought conditions occurred from 1981 to 2006 for the long timescales and were particularly moderate to severely dry during the period 1981- 1997 for Liberia and the research counties (Bong and Lofa). The index identified very wet, moderately wet conditions from 2000 to 2011 with an interlude of dryness in 2012. The SPEI also identified near normal from 2015 to 2020. This was related to the very warm temperatures during those decades.

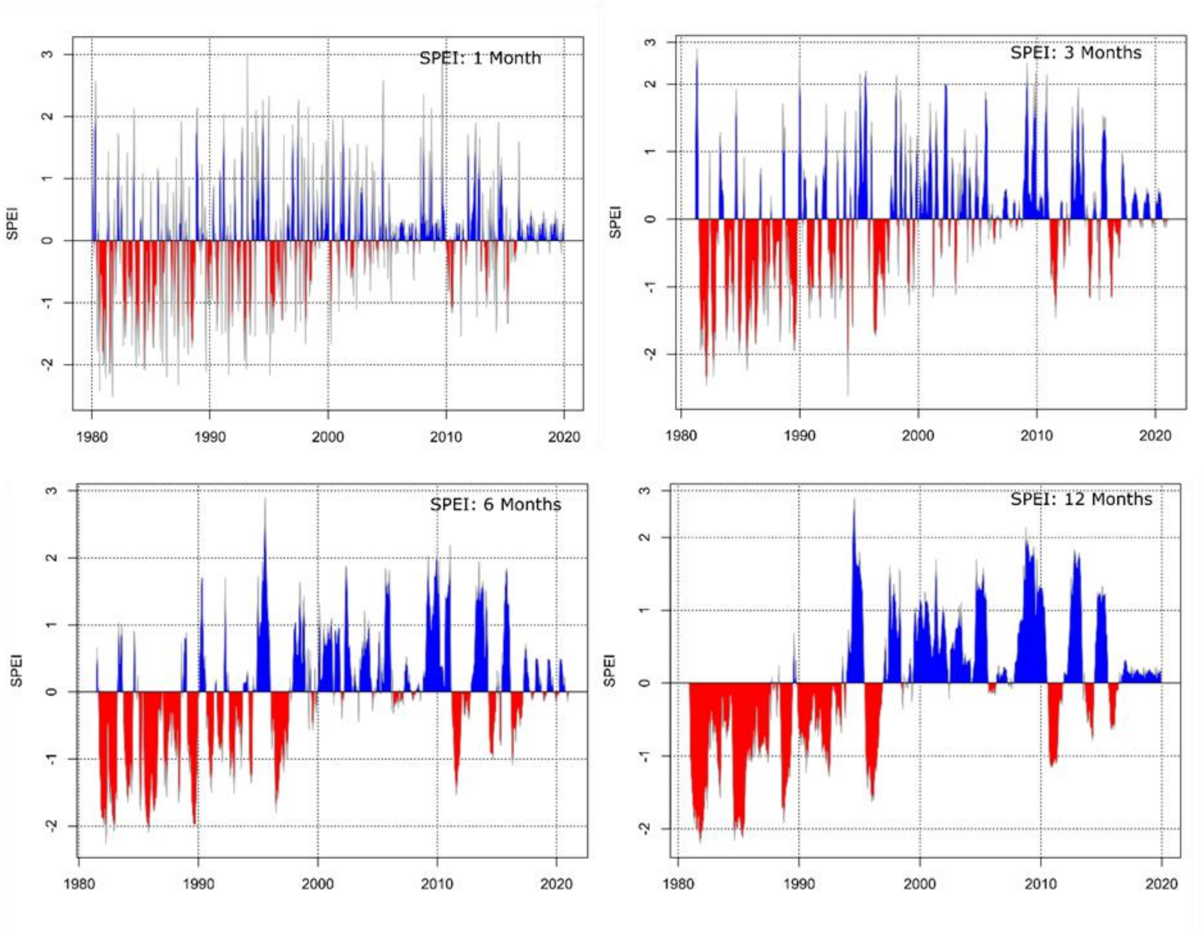

Figure 4.11 The evolution of SPEI at 1-, 3-, 6- and 12-month timescales for Liberia, 1981-2020

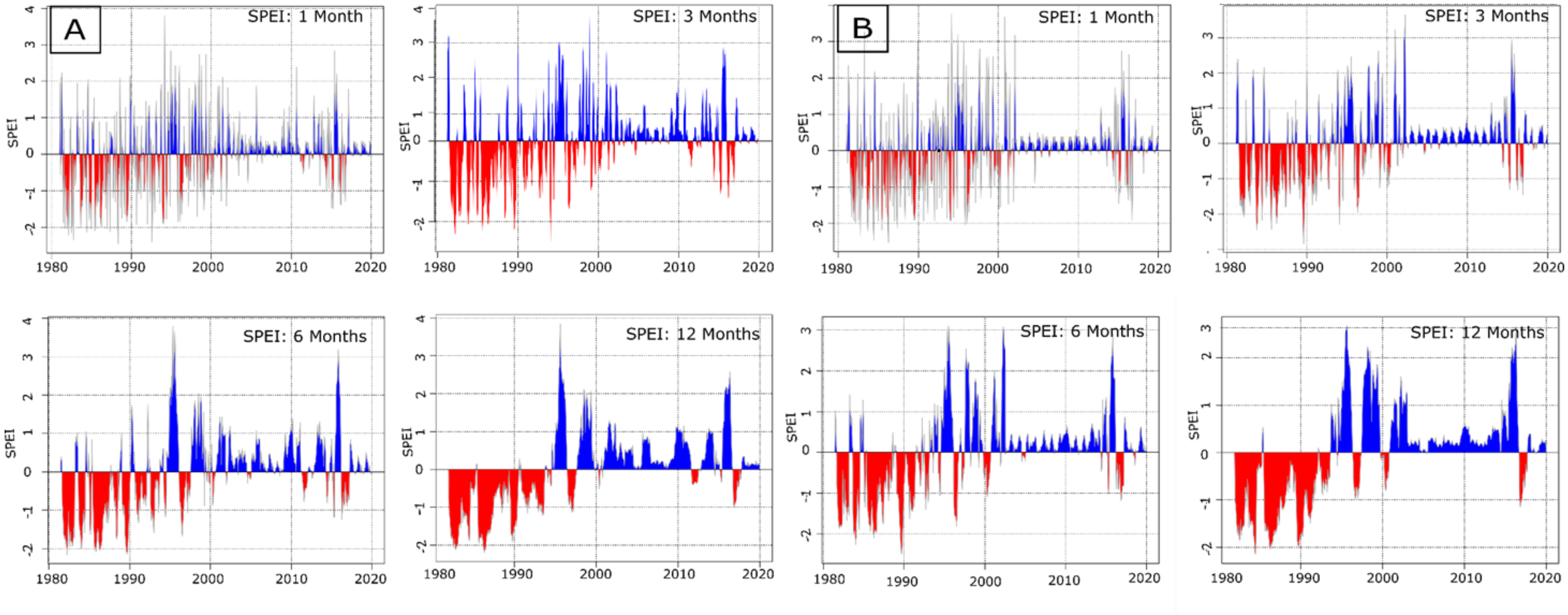

Figure 4.12 The evolution of SPEI at 1-, 3-, 6- and 12-moth (s) for (A) Bong and (B) Lofa Counties, timescale Liberia, 1981-2020

Thus, the evolution of the drought indices is related to the observed changes of precipitation and temperature. The temperature and precipitation show a positive trend throughout the past four decades (1981-2020). This occurs from the lack of water in a certain area, especially the northern part of the country. This is caused by the absence of rain, moisture, and low dew points (National Plan of Liberia, NDPL, 2019).

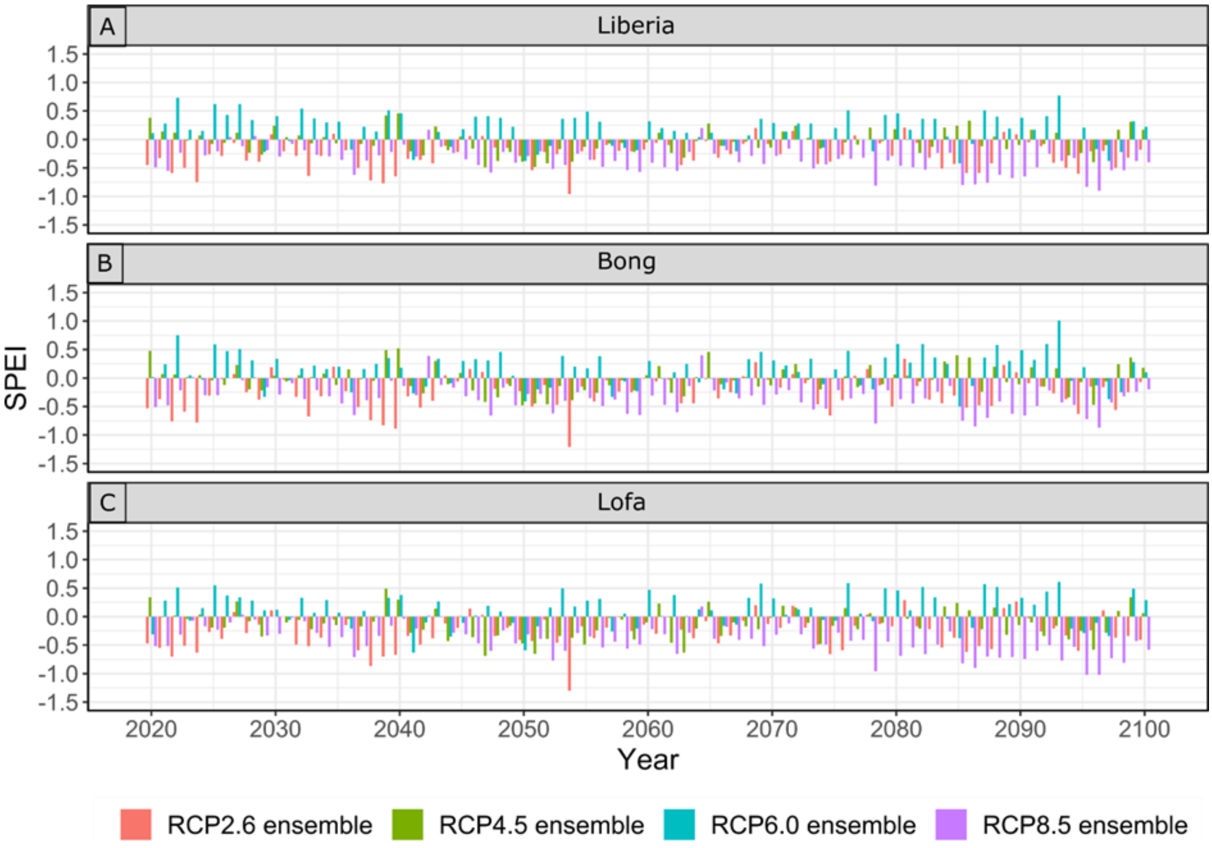

Figure 4.13 Long-term results of SPEI-12 months during the period of 2020-2100 for each GCM in RCP2.6 (Orange), RCP4.5 (Yellow green), RCP6.0 (Aqua) and RCP8.5 (Magenta) for (A) Liberia, (B) Bong and (C) Lofa.

The long-term future trend of SPEI 12-months is calculated and plotted for each GCM during the period of 2020-2100, and the results are indicated in Figure 4.13. The Figure shows the mean decadal changes of SPEI for all the emission scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). A negative value is indicated at the national scale, using CRU TS v. 4.05 gridded data, time-series analysis to understand the long-term SPEI for the next eighty (80) years. In general, the evolution of SPEI according to the model, the pattern of drought is projected to be near normal to moderately dry condition with respect to RCP2.6 and RCP 8.5 emission scenarios respectively while RCP 4.5 and RCP 6.0 with the values of 0.3, 0.4, 0.5, and 0.6 are projected to be near to normal throughout the eight decades (2020-2100). During these decades, the indices of different emission scenarios are negative (mostly RCP2.6 and RCP8.5), indicating near normal to moderately dry condition for Libera, and RCP4.5 and RCP6.0 indicate positive with wetter events. Overall, these results show more humid periods than drought periods, which are like the results of Sylla et al.; (2016) between 1981 and 2020 in Liberia. This pattern also corresponds to what that is expected at the local level (Bong and Lofa) counties.

4.3.8 Exposure Index for Both Counties

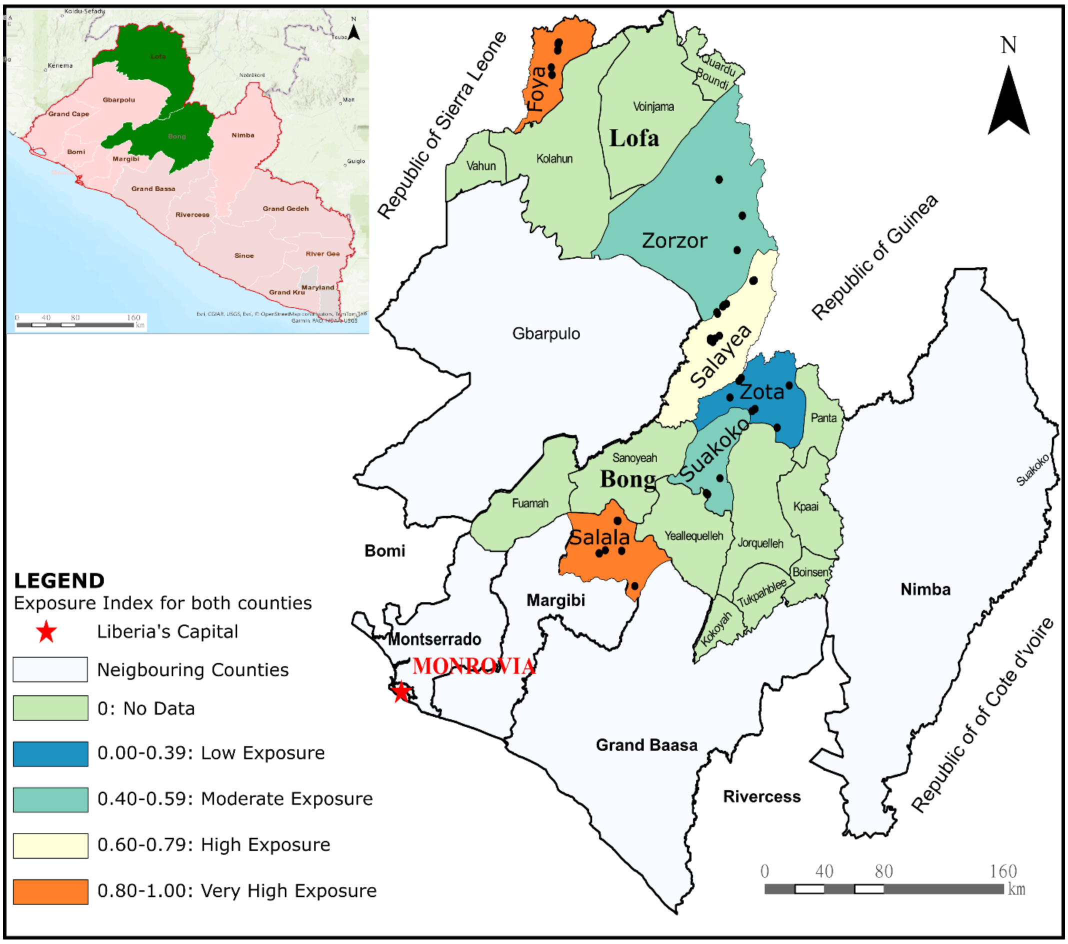

Figure 4.14 Exposure index for both counties.

Exposure as one of the components of risk refers to the presence of people, livelihood, species, or ecosystems, environmental functions, services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by climate hazards Oppenheimer et al (2014). In this study, exposure was assessed based on population density, rice, and cassava fields in the study districts. Based on the analysis, exposure index values were visualized as a map of exposure for Bong and Lofa Counties. The exposure mapping separated districts of Bong and Lofa Counties into very high and to the lowest exposed categories. Figure 4.14 presents population, rice, and cassava production field in the north and central districts of Liberia to be more exposed to climate risk than other districts. Very high (0.80-1.00) and high (0.60-0.79) categories of exposure are mostly observed at the northern (Foya, Lofa) and central part (Salala, Bong, and Salayea, Lofa) of the country due to high population density, rice, and cassava production, whereas moderate

(0.40-0.59) and low (0.00-0.39) exposures are mostly in Zorzor (Lofa), Suakoko and Zota Bong County

4.4 Discussion

The increasing frequency and intensity of temperature and precipitation events as a result of changing climate and its devastating impacts are being reported from different part of the world. This has led to crop destructions, environmental damages, and economic losses of several billions of dollars across the globe (Clarke et al., 2022). Understanding of droughts together with temperature and rainfall characteristics is fundamental to planning adaption measures to mitigate the impacts of climate change and variability (Tran et al., 2020). The assessment of the trend of annual rainfall shows the highest amount of average rainfall for Liberia in September with a declines in October and reaches a low in December across Liberia and Bong while in August for Lofa (see Figure 4.2B). The variations in rainfall are high in the rainy months of June, July, August, and September, and low in the dry months, November, December, January, February, March, and April for Liberia and almost the same for the study counties (Bong and Lofa, see Figure 4.2). The increase in the amount of rainfall for the Liberia and the study counties could be attributed to Liberia's geographic location in West African Atlantic coast, at latitudes of 4 to 8 degree south of equatorial climate where the northern regions are tropical and strongly influenced by the West African Monsoon (Ekwezuo, 2016). Rainfall amount and timing can influence the yield of crops. Low rainfall amounts can be detrimental to crop yield, especially if the dry periods occur during critical developmental stages (O'Neil et al. 2022; Fosu-Mensah, 2012). Erratic rainfall pattern can also activate severe climatic events including droughts, prolonged delayed rainfall or dry spells and floods, which can have unfavourable impacts on the yields of food crops (Mainuddin et a. 2022; Rahman et al. 2017). Additionally, the result also showed the rainfall onset, cessation and length of rainy season varied in the years and for Liberia and the study counties from 1981-2022. This variation could be explained by latitudinal differences among the districts as well as the complex series of atmospheric and oceanic interactions that have increased as a result of climate change and variability (Bessah et al. 2021; Atiah et al. 2020).This finding is supported by previous studies (e.g. Thierfelde et al 2017; Davis et al. 2017; Okigbo, 2020) suggesting that variation in the onset of rains and cessation trends could significantly affect the length of the rainy seasons. Furthermore, results also indicated variation in the number of dry days per season in the districts over the study period. The occurrence of dry days decreased from April to September but increased from November to April (see Figures 4.1 and 4.2). Increase in the number of dry days accompanied with high evapotranspiration could result in the reduction and failure the yields of crops (MacCarthy et al. 2021).

Regarding temperature, Liberia and the study counties experienced increase in temperature This could possibly be due to natural processes including solar variability, wind, vegetation cover and waterbodies (Mares et al. 2022; Singh and Bhargawa, 2020). Temperature increase reduces the yields of crops and quality of food crops through faster development of a crop thereby resulting in a shorter crop growth duration (Tariq et al. 2020; Acosta-Motos et al. 2024) and increasing the photosynthetic and respiratory cycles of crops (Neupane et al. 2022; Sabagh et al. 2021). Increase in temperature can also lead to an exponential increase in the saturation vapour pressure of air and directly damage their plant cells (Tariq et al. 2020). Rise in temperatures has also been reported to affect crops development due to environmental stress which is the principal reason for more than 50% global losses in yields of majority of crops (Tariq et al. 2020; Acosta-Motos et al. 2024) exacerbating the vulnerability of food supply (Pour et al. 2020). Furthermore, alterations in rainfall and temperature rise could eventually result in dry spells and reduce the maturity period of crops (Mwinkom et al. 2021). This agrees with previous studies conducted by Kelly et al. (2022); Bessah et al. (2021); Togbah, (2024) suggesting that rainfall has been variable whereas temperature has been increasing in northern Ghana and in most part of northern Liberia.

The study result (see Figures 4.9 and 4.10) show changes in future temperature and rainfall scenarios comparative to the observational period (1986-2005) over Liberia and the research counties and averaged over 80 (2020-2100) years. For both observational periods and future scenarios, the models indicate a rise in temperature and overall highest values for annual rainfall, but variability around the average looks similar to Lofa and slightly reduced for Liberia. The projected increases in temperatures by the GCMs are in agreement with those reported by Hamed et al. (2022); Reboita et al. (2022) and Hassan et al. (2020) for Egypt, South America and Nigeria respectively. Changes in the projected total rainfall varied both in magnitude and direction among the GCMs for both study locations. The inconsistencies in the direction of change in projected rainfall amounts by GCMs in this study has also been reported by other studies (e.g. Hassan et al. 2020; Shiru et al. 2020) for rainfall in West Africa.

During the past decades, various methods have been developed for this purpose, amongst which the SPEI is one which incorporates evapotranspiration, an important variable for the assessment of water stress particularly in semi-arid and arid environments. It is important to mention that SPEI has been widely used in different parts of the world for droughts assessment. However, in Liberia, SPEI has not been widely used for the purpose of meteorological droughts assessment compared to other drought indices. Therefore, this research utilizes the SPEI due to its strength in drought analysis.

The result for the short timescales for Liberia shows a high temporal frequency of dry and moist periods. With increasing timescales, drought and moist periods showed a lower temporal frequency and a longer duration. Two contrasting periods were evident between 1981 to 1990 (see Figures 4.15and 4.16). Wet and dry conditions dominated from 1981-2020 for the short timescales, whereas persistent drought conditions occurred from 1981 to 2006 for the long timescales and were particularly moderate to severely dry during the period 1981- 1997 for Liberia and the research counties (Bong and Lofa). The index identified very wet, moderately wet conditions from 2000 to 2011 with an interlude of dryness in 2012. The SPEI also identified near normal from 2015 to 2020. This was related to the very warm temperatures during those decades. Thus, the evolution of the drought indices is related to the observed changes of precipitation and temperature. The temperature and precipitation show a positive trend throughout the past four decades (1981-2020). This occurs from the lack of water in a certain area, especially the northern part of the country. This is caused by the absence of rain, moisture, and low dew points (National Plan of Liberia, NDPL, 2019).

The result for the long-term future trend of SPEI 12-months during the during (2020-2100) for each GCM (Figure 3.18) shows the mean decadal changes of SPEI for all the emission scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5). A negative value is indicated at the national scale, using CRU TS v. 4.05 gridded data, time-series analysis to understand the long-term SPEI for the next eighty (80) years. In general, the evolution of SPEI according to the model, the pattern of drought is projected to be near normal to moderately dry condition with respect to RCP2.6 and RCP 8.5 emission scenarios respectively while RCP 4.5 and RCP 6.0 with the values of 0.3, 0.4, 0.5, and 0.6 are projected to be near to normal throughout the eight decades (2020-2100). During these decades, the indices of different emission scenarios are negative (mostly RCP2.6 and RCP8.5), indicating near normal to moderately dry condition for Libera, and RCP4.5 and RCP6.0 indicate positive with wetter events. Overall, these results show more humid periods than drought periods, which are like the results of Sylla et al.; (2016) between 1981 and 2020 in Liberia. This pattern also corresponds to what that is expected at the local level (Bong and Lofa) counties.

Several studies have been conducted in the African region to assess the impacts of climate change on droughts. The studies suggested an increasing trend in the intensity and frequency of droughts in different parts of Africa (Ayugi et al. 2020; Masih et al. 2014; Lottering et al.

2021; Adaawen, 2021; Schilling et al. 2020) reported that changes in climate have increased the frequency and severity of droughts in different African countries. Shiru et al. (2020) and Ayugi et al. (2020) reported the significant increase in drought frequency, duration, and severity in Africa. More recently, Haile et al. (2020) assessed climate changes in precipitation and temperature on drought characteristics over East African region during 1989-2099 using the SPI and SPEI indices to measure future drought in the region. They results confirmed that precipitation and temperature will increase over East African region with temperature having dominant impact leading to droughts, which is (drought) likely to increase at the end of the 21st century by 16%, 36%, and 54% under RCP 2.6, 4.5, and 8.5, respectively, with the areas affected by extreme drought increasing more rapidly than severe and moderate droughts. Uwimbabazi et al. (2022) used both SPI and SPEI to access meteorological drought events over Rwanda at seasonal and annual time scales from 1981 to 2020, using the Man-Kendal test to evaluate the trends in rainfall, temperature. Their analysis found nonsignificant trends in annual in rainfall, while an apparent significant increasing trend in surface air temperature. The SPEI characteristics indicated that Rwanda is more prone to moderate drought events than severe and extreme drought events during March- May and October-December seasons. This study also suggests that the frequency of droughts in Liberia is not increasing similar to the drought events Rwanda and different to the East African region (Uwimbabazi et al. 2022).

Finally, all the residents of the districts are highly dependent on agricultural activities. As a result, the fluctuation of rainfall and increase of temperature has exposed the district farmers to climate induced hazards which adverse impacts on the livelihoods of the districts as well as biophysical environment. The frequency and severity of seasonal delay in rainfall have seriously impacted the productive activities in the counties. The periodicity of rice and cassava in yielding good produce further complicates the hardship. The worst situation happens when poor rice production coincides with poor rainfall conditions.

4.5 Conclusions

This Chapter concludes that rice and cassava production are highly sensitive to the impact of rainfall variability and increase of temperature particularly dry spells or delayed rainfall contributing to reduction in crop yield. Inter-annual variability in rainfall and temperature increase creates uncertainty in available water for agriculture (Figures 4.1 and 4.2). Future projections across the country and the study counties using four climate models predict change in rainfall across the different RCP scenarios (Figures 4.10), with Bong County showing the overall highest values of annual rainfall but variability around the average looks similar to Lofa and slightly reduced for Liberia over the next eight decades. Furthermore, the results also indicate an increase in temperature over the period of somewhat between 0.8°C up to 4.3 °C in the worst-case scenario for Liberia. Similarly, in the study counties of Bong, an increase in temperature will be between 0.7 °C possibly up to 4.0 °C, while for Lofa, it is expected to increase between 1. 0 °C to 4.5 °C over the same decades (i.e., 2020-2100). It is certain that the six districts will bear the brunt of these climate events, likely to manifest in the form of long-term dry spells and occasional delayed rainfall. Consequently, an increase of temperature in recent years is the main cause of increasing severity and frequency of dry spell for the different crop growing seasons in Liberia, particularly the study counties. It is not possible to make a concrete conclusion based on the findings of the present study as the increases in rainfall due to climate change and variability may lead to droughts occurrences in some seasons, particularly in the northern part of the country where rainfall is the declining and temperature is increasing. This change is associated with the global and West African Climate change and variability. However, the local climatic changes have resulted the deterioration of livelihood (prevalence of poverty) and further degradation of natural resources.

The implication of the results presented in this chapter indicate that there is an urgent need for policy approaches that deal with climate risks within a larger context of development towards empowering rural districts in Central and Northern Liberia that are largely dependent on rain-fed agriculture, a key livelihood activity that is very sensitive to climate change. Policy makers need to formulate more specific and targeted climate adaptation policies to reduce the negative impact of dry spells or delay rainfall of farmers whose livelihoods depend largely on rain-fed agriculture. Ultimately, this will enhance dry spell or delay rainfall preparedness within dryland farming counties and districts. Most importantly, effective implementation of these policy strategies at the national and district levels is critical towards addressing the long- term impact of climate variability on smallholder agriculture across Central and Northern Liberia. The approach outlined in this section is particularly useful in evaluating the climate risk of a particular county or district to dry spell or delay rainfall in developing countries. The next phase of this research is to characterise and explain the nature of exposure and vulnerability in the districts and determine the adaptation pathways of individual district to climate variability and change.

Chapter 5 Exploring the Nature of District Vulnerability and Risk to Climate Variability

5.1 Summary

This chapter presents results on identifying vulnerability (physical and economic susceptibilities) and risk to climate variability in the study districts in Liberia (objective 4). The results show that farmers in the study areas are highly vulnerable (susceptible) to climate change and variability. Specifically, the indices of vulnerability components showed that farmers have a high level of susceptibility to the climatic uncertainties. Further, the vulnerability analysis across different rice and cassava growing districts showed that farmers, particularly in the low-yield districts, are more vulnerable than the farmers in the high-yield districts. In other words, the results show that within the same agro-ecological zone, farmers and districts experience different degrees of drought exposure and vulnerability. These differences can be largely explained by socioeconomic characteristics such the poverty line by the county. To sustain and enhance the living standard of vulnerable households and districts, policymakers need to identify and facilitate appropriate interventions that foster asset building, improve institutional capacity, as well as build social capital.

5.2 Introduction

Climate change is a global phenomenon, and its adverse impacts vary across geographical areas (Cianconi et al., 2020; Bedeke et al., 2020). Sub-Saharan Africa (SSA) is particularly vulnerable to the negative impacts of climate change and variability because a major part of its land surface covers the tropics which are warm-to-hot year-round (Cianconi et al., 2020) and the population depends largely on climate-sensitive sectors such as agriculture for their livelihoods (Dendir and Simane, 2021). Climate crop modelling studies indicate that agriculture will be disproportionately affected SSA by climate change compared with other sectors (Mekonnen et al., 2021; Mensah et al., 2022). Therefore, there is an urgent need for interdisciplinary work that combines insights into food production with socioeconomic evaluations of farming communities to better understand how climate change and variability may affect agricultural production systems and rural livelihoods (Cinner et al., 2022). An interdisciplinary approach allows different dimensions of climate change and variability and their potential impacts on social and ecological systems to be explored. By bringing together different disciplines such as climate modelling, agricultural science, ecology and environmental sustainability, a more comprehensive explanation of climate change and its impacts on people can be achieved (Khanal et al., 2021; Sam et al., 2020).

Africa, mostly semi-arid countries of SSA, has been dealing with risks resulting from climate change and variability, such as drought events and dry spells. These climatic events are exacerbated by deep rural poverty, limited government capacity, and exposure to additional shocks (IPCC, 2022). Such climatic risks particularly affect poor countries, and it is a growing concern that climate change will worsen these events through rainfall variability (IPCC, 2022). These changes represent a severe problem in some geographical areas, especially in developing countries such as Liberia that are generally considered more at risk to the effects of climate change because of their lower capacity to cope and adapt (Fitzpatrick et al.2020; Kangalawe et al., 2017).

Sultan et al. (2019*)* revealed that climate change has affected West African agriculture through changes in rainfall patterns, characterised by strong inter-annual rainfall fluctuations, increased frequency of rainfall extremes and prolonged droughts. Agriculture in West Africa is predominantly rain-fed and thus highly at risk to climate change and variability, making crop production uncertain (Sultan and Gaetani 2016, *Z*ougmoré et al., 2018). Uncertainty about future crop production creates uncertainty for the food system, with consequences for economic, health and socio-cultural systems (van Mil et al., 2014*).* Asare-Kyei et al.; (2017) and Kamali et al. (2020) confirmed that West Africa is considered as a hotspot of climate change. In this region a temperature of 3-6° C above the late 20th century baseline is "*very likely"* to materialize within the 21st century and is expected to occur one or two decades earlier than other regions (IPCC, 2022). This makes the region even more susceptible to climate variability resulting in hazardous conditions. The frequency of occurrence of extreme events is expected to increase and the interaction of climate variability with non-climate stressors will aggravate vulnerability of agricultural systems in semi-arid Africa, such as, the West Sudanian Savanna region of Burkina Faso, Ghana, and Benin (IPCC, 2014). Since Liberia is within this region, it is likely to be affected if no action is taken. There is also medium confidence that projected increases in extreme rainfall will "contribute to increases in rain-generated local flooding" (Kundzewicz et al, 2014, p. 24). For West Africa, a decrease in the absolute number of extreme events is projected, but an increase in the intensity of very wet events, which combined would lead to increased drought and flood risks towards the late 21st century (Sylla et al., 2015).

Limited financial capital, lack of access to physical infrastructure such as roads and public health services, poor access to information on weather forecasts and a paucity of improved technologies are exacerbating the SSA's climate change vulnerability by reducing capacity to cope with climate risks (Bedeke, 2023; Mensah et al., 2022; Mall et al., 2017). Severe land degradation and widespread deforestation because of human pressure are leading to agro-biodiversity loss and ecosystem service depletion, and subsequently contributing to climate change vulnerability (Pereira, 2017). Additionally, climate change and its impact on food security and agricultural sectors in Africa has been cited by many researchers (e.g., Ofori et al, 2021; Alves et al., 2022; Amin et al., 2023).

Liberia is an appropriate place to investigate these issues because agriculture is the backbone of its economy, contributing up to 76.9% of national Gross Domestic Product (GDP) (Moore, 2017). In addition, it is the main source of income for many low-income Liberian families, employing about 75% of the population (of those in employment) (HIES, 2016), while the sector contributes significantly to the foreign exchange earnings of the country. It is also important to note that the agricultural sector contributes to the development of Liberia through the provision of raw materials (e.g., rubber, oil palm, etc) to local industries (Duku and Hein, 2021). Despite its socioeconomic importance, Liberia's agricultural sector is arguably one of the most climate sensitive sectors because of its dependence on rain-fed cultivation. The amount and pattern of rainfall plays a key role in determining agricultural productivity (Sohoulande Djebou et al., 2017; Duku and Hein, 2021). Rice and Cassava yields in Liberia are projected to decrease by 18% by 2050 due to projected decreases in rainfall and increases in temperature linked to climate change and variability (EPA, 2018). This has the potential to severely affect food security because rice and cassava are grown and consumed in every part of the country, with the present population of 5.2 million and projected to increase 10.3 million by 2058 (EPA, 2019). Moreover, it is also reported that climate change will raise sea levels and increase the frequency and intensity of storms and storm surges, threatening the lives and livelihoods of the country's residents especially in the central, northwest, and southern regions. Due to these different climatic events, farmers in these counties (such as Bong and Lofa) have begun to engage in various measures such as gold and diamond mining, dry businesses (such as selling goods such as clothes, and other essential commodities in the market), etc. in response to the current adverse consequences of climate change and variability. This chapter explores the district and explains the nature of vulnerability (susceptibilities) and risk of farmers at the district level. Practical evidence on the generic attributes of agriculture-dependent districts that have proven resilient or vulnerable to past climate-related problems is lacking at these scales. Addressing this gap will increase our understanding of how communities cope with the impacts of climate-related risks, providing useful insights into the structure and drivers of vulnerability (Leal Filho et al., 2019; Abbass et al., 2022). This will provide valuable lessons for the management of climate variability in agriculture-dependent communities in developing countries such as those in SSA more widely. The primary aim of this chapter is to explore the nature of district vulnerability particularly farmers' susceptibilities and risk to climate hazards in the study areas. To achieve this overarching aim, the specific objective is to identify and categorize districts that are vulnerable to climate induced hazards. By meeting this objective, this chapter develops geographical analysis tools that provide an empirical understanding of crop production and rural livelihood vulnerability at the district levels. This chapter also has policy implications as it provides policy makers with relevant information on vulnerability to climate change and variability to feed into a more targeted climate adaptation policy in Liberia. The materials and methods used to collect all information are discussed in Chapter 3. Though, vulnerability indicators were calculated into an index scored representing vulnerabilities of climate hazard. Ultimately, the following modular framework, hazard, exposure and vulnerability to climate risk were considered in a multi-hazard risk index through multiplicative aggregation, where both risk components were weighted equally (see chapter 3). Aggregation of indicators and domain were in excel and result visualized in GIS Pro. Results are presented in Figures in 5.1 and 5.2 respectively.

5.3 Results

As described in data collection and processing section, exposure and vulnerability indices are classified into four categories of exposure and vulnerability, very high (0.80-1.00), high (0.60-0.79), moderate (0.40-59), and low (0.00-0.39) categories and mapped by districts within Bong and Lofa Counties based on quartile method. The normalisation of aggregate scores brought values within a common range (of 0-1). Accordingly, the districts of Bong and Lofa Counties are ranked into respective exposure and vulnerability classifications.

5.3.1 Vulnerability (Physical and Socioeconomic Susceptibility)

In the context of climate change and variability, agricultural susceptibility shows that farmers' assets and resources, is exposed to hazard of temperature, rainfall, and its associated biophysical and biological hazards. The calculated index score of physical susceptibility indicator of (0.80-1.00) for Zorzor district represents a critical value of very high susceptibility (see Figure 5.1). High susceptibility is observed in Salala (0.60-0.79). For instance, districts with very high and high susceptibility have considerable proportions of their farmers as smallholders, leased farmers, and tenants with no access to farmland.

Besides, the findings further show that the soil type and groundwater are major components in term of physical susceptibility to climate risk. These districts have saline soil and poor quality of groundwater with low yield (rice and cassava) in the district. Moderate (0.40-59) and low (0.00-039) levels of physical susceptibility are mostly observed in Salayea and Foya districts in Lofa County and Suakoko and Zota districts in Bong County, respectively.

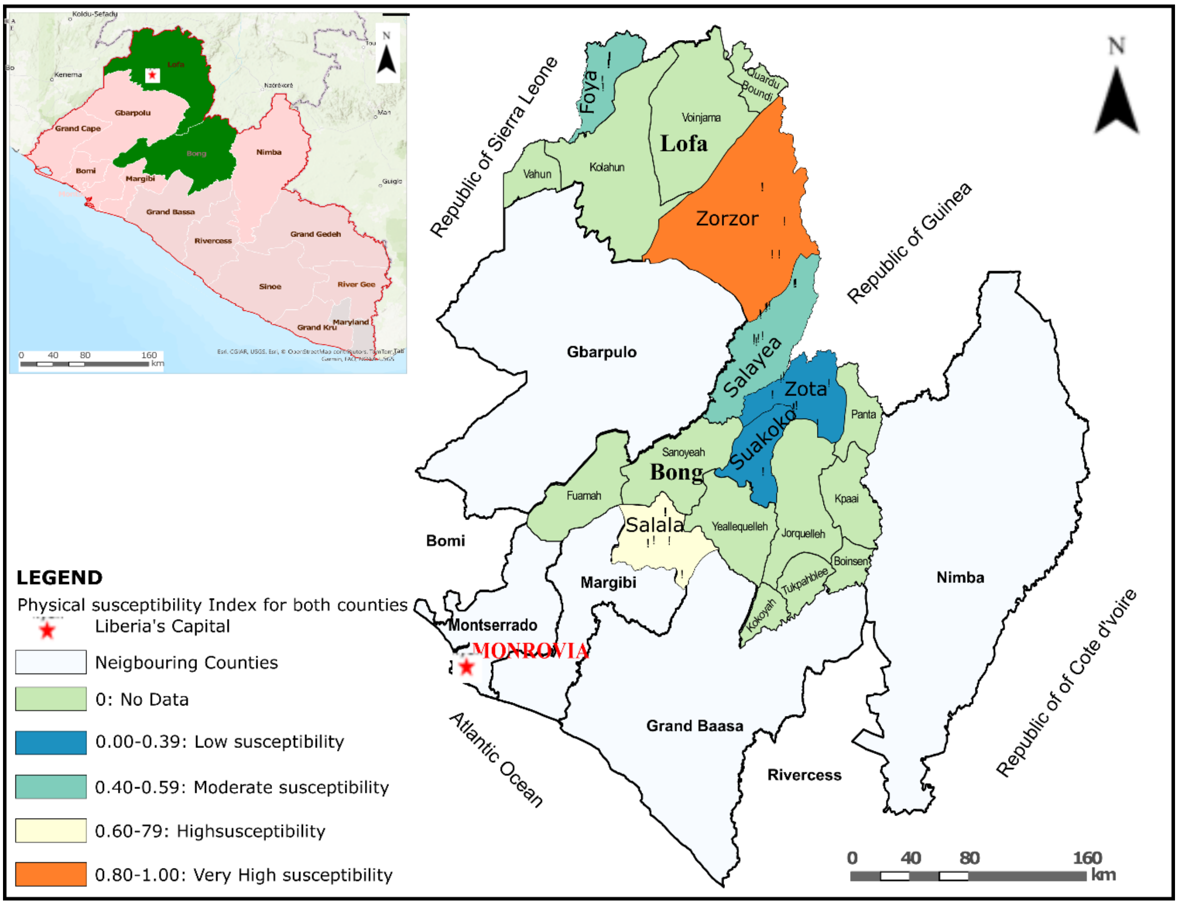

Figure 5.1 Physical susceptibility index for both counties.

In terms of socioeconomic susceptibility, the poverty data of the counties are used to determine the socioeconomic susceptibility in the study areas. The socioeconomic susceptibility would be higher if the poverty ratio of the farmer was used in socioeconomic factors. However, comprehensive data to examine the distribution of poverty within and across all farmers in areas was not available for this analysis. The poverty data used for this study is based on the Liberia Household Income and Expenditure Survey (HIES, 2016) reports, which contained the population of Liberia, urban, rural and at the county levels. In the Liberian context, poverty is categorized in three dimensions (absolute poverty, food poverty and extreme poverty). Absolute poverty is defined as a situation where individuals cannot meet their food and non-food minimum needs. The benchmark for those needs is established through an overall or absolute poverty line and is defined as the line below which individuals cannot meet their food and non-food minimum needs. Food poverty on the other hand, is defined as a situation whereby individuals cannot meet their basic food needs. The minimum benchmark for those food needs is also established through a food poverty line. While extreme poverty is observed when the individuals' total food and non-food consumption falls below the minimum food requirements of 2400 kilocalories. Therefore, for this study, one poverty line (i.e., Absolute poverty) is used in this analysis, socio-economic susceptibility. Table 4.1 revealed the trend of the national poverty line for Liberia from 2007-2016, which shows only a little improvement as indicated.

Table 5.1 Poverty Trend for Liberia (2007-2016); Source: Liberia Statistics Office, HIES, 2018

Category	Absolute Poverty (2007) (%)	Absolute Poverty (2010) (%)	Absolute Poverty (2014) (%)	Absolute Poverty (2016) (%)
Liberia	63.8	56.3	54.1	50.9
Urban	55.1	55.1	43.3	31.1
Rural	67.7	59.4	70	71.5
		Study Counties		
Bong		70.7		71.3
Lofa		61.8		68.7

Though, almost a decade ago, more than half of the population of Liberia was poor and living in absolute poverty. This also means that more than half of the population in these poverty brackets [(63.8% in 2007), (56.3% in 2010), 54.1% in (2014), and (50.9% in 2016)] could not achieve the minimum expenditure to acquire basic food and non-food items for themselves. It appears that there is a trend for the rural areas to be increasing in poverty overtime, which the urban areas are areas declining. At the county level where the research was conducted, poverty is higher in Bong County (70.7% and 71.3%) compared to Lofa County (61.8% and 68.07). Generally, the majority of the rural population (i.e., farmers) earn lower incomes than the population in the urban areas in Liberia. In addition, farmers produced rice and cassava primarily for consumption because the income from this production is insufficient to cover their household expenses or provide working capital for next growing season. In terms of socioeconomic susceptibility, Bong County is more susceptible to climate risk than Lofa county. Very high (70.7% and 71.3%) and high (61.8 and 68.7) levels of susceptible are found, respectively.

5.3.2 Climate Risk Index for Both Counties

Climate risks assessment in this study adopted equation 2.2 indicated in Chapter 2, which considered rice and cassava cultivation periods based on monthly hazard (hazards and exposure) in Chapter 4, and total vulnerability indicated in Chapter 5. The risks in May and April follow a similar pattern as the hazard as explained in Figures 4.6 and 4.7, and Table 4.3 in Chapter 4, which show delay and decrease in rainfall and increase in temperature for Bong and Lofa Counties. In most of those months, the risk is mostly very high (0.80-1.00) and high (0.60-0.79) only two districts (Foya, Lofa) and Salala (Lofa) are at very high risk and Zorzor with high risks. June, July, and August present moderate and low risks (0.40-

0.39) and (0.00-0.39) because of high rainfall. Salayea and Suakoko are at moderate risk while only Zota is at the low risk due to its geographic position.

This overall perspective is significantly different from the month-to-month perspective, in which one can see that some specific dry periods can coincide with vital growth stages, leading to serious reduction of crop yields. If the study only considers the total rainfall, it can alter the rainfall and may result in improper decision-making in certain places. Moreover, two important stages are considered, flowering, and grain filling, both of which influence the crops yield, occur from June-July. If the initial planting is delayed, delaying the onset of the growing season, these vital stages could be postponed to May, putting them at risk of serious water shortage.

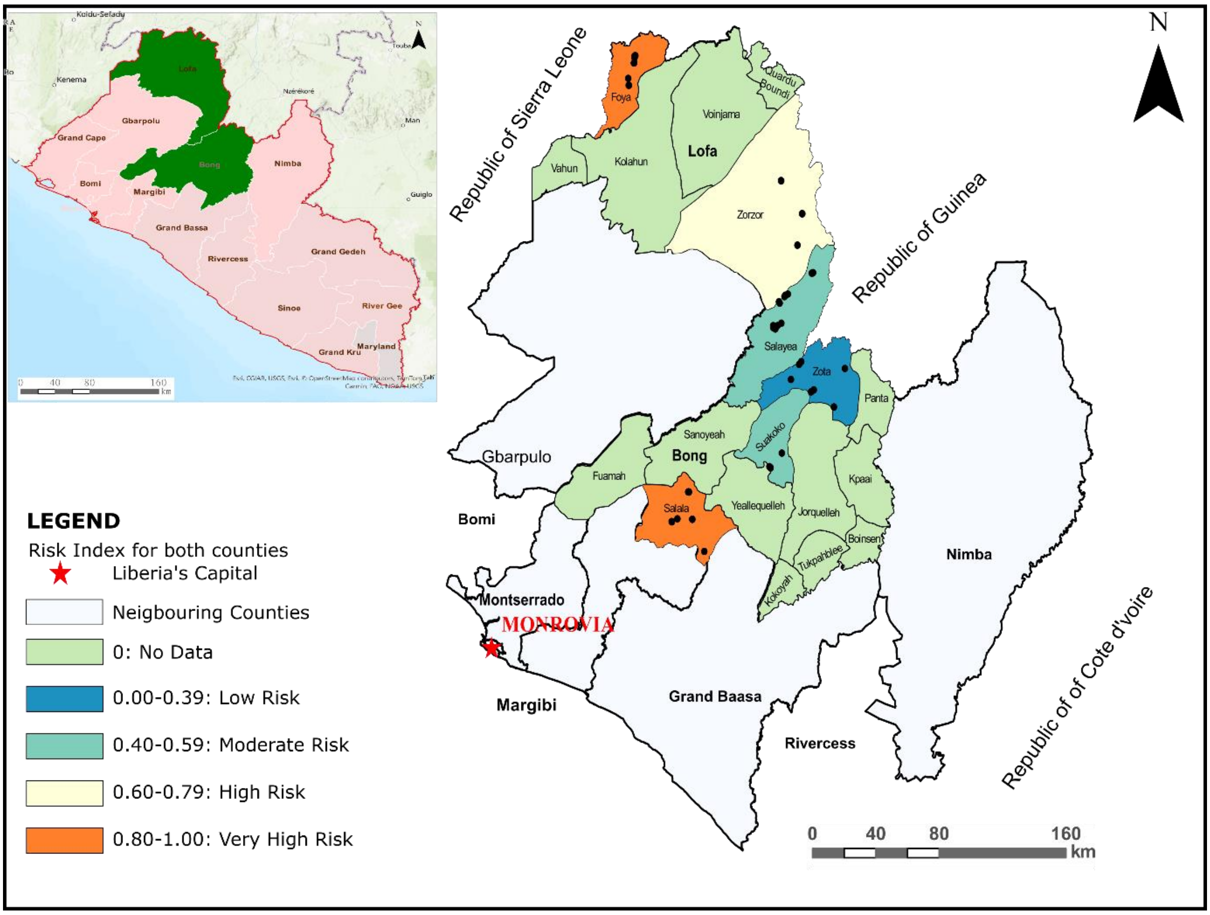

Figure 5.2 Risk index for both counties.

5.4 Discussion

Climate risk assessment at the local level presents specific challenges related to lack of data (e.g., physical, and socioeconomic data at the lowest level of aggregation) and the highly complex and dynamic interplay between exposure and vulnerability of the elements at risk.

Across all the districts studied, rural farmers live in an unsafe condition and are basically exposed and vulnerable to climate induced hazards that affect their agricultural production.

Agriculture being considered as the mainstay of the rural farmer livelihoods, serving both as the primary source of household food consumption.

In Liberia, rice and cassava farmers are particularly vulnerable to reductions in crop yield for a variety of reasons. First, the farmers cultivate very small parcels of land (less than 2 ha), dedicate most of their land to crop production for household consumption and obtained low crop yields, which are insufficient to meet their household needs, let alone provide surplus for sale. During the field survey and key informant interview, community leaders and farmers reported obtaining rice and cassava yields of only 0.4 - 0.7 tons/ha, which is even lower than the national (low) average of 1.5 tons/ha (HIES, 2016). The declining yields in the study districts are due to the decline in rainfall and increase in evaporation for the past 5-10 years (see Figures 4.12 and 4.7; Chapter 4). The reasons for the notable variability in rainfall and increase in temperature in recent years were due to the several dry spells during the rainy season, most especially during farming periods, and pronounced dry season.

5.4.1 Vulnerability (Physical Susceptibility)

Access to farmland by the farming population is one of the major factors in physical susceptibility to climate-induced hazards. Figure 5.1 represents a very high susceptibility in the study county. This is because access to farmland, soil type and good quality of water are major factors in Zorzor which have made this district physically susceptible to climate-induced risk. The area with high susceptibility primarily has poor-quality of soil, adequate groundwater, and limited access of farmland with low expected yield. Rice and cassava production require an appreciable amount of water during growth and persistent delays in rainfall, especially in the most district (Zorzor and Salala) have often resulted in low yield from such crops. Indeed, soils in these districts are known as haplic and xanthic ferralsols, which cover almost 70% of the territory and have low fertility. Ferralsols are typically associated with tropical conditions, high rainfall and very old (Tertiary) land surfaces. Because of intense weathering over protracted time periods, they have lost nearly all the weatherable minerals they had inherited from their parent rock and are now dominated by stable products such as aluminium oxides, iron oxides and kaolinite. Moreover, ferralsols are acidic and have low nutrient availability. Their ability to hold nutrients (i.e., from fertilizer or released from decomposing organic materials) is low and mostly tied to their organic matter. Continuous cropping of farmlands in Zorzor, Salala, Suakoko, and Foya districts without the addition of appropriate soil amendments has also left the soil with low fertility and highly unproductive and thereby susceptible to climate-induced risks. This result is supported by Diop et al. (2022) who confirmed that Africa’s lands are largely vulnerable and threatened by soil degradation and low water availability, especially in semi-arid and arid regions as is limits crop and livestock productivity and farmer livelihood options. Therefore, in African agricultural lands, adopting/improving measures that conserve soil and water resources is crucial. In addition, Arjwech et al. (2019) also confirmed that Soil and groundwater salinity poses a serious problem in Khon Kaen Province of Thailand and causes major reductions to crop productivity.

On the other hand, rural farmers' inability to access farmland due to the bureaucracy to acquire farmland is another factor that contributes to susceptibility in the districts. In Liberia, lands are private, state and community owned. A rural farmer that has no farmland on his own must negotiate to acquire farmland on an annual basis through the respective ownership (i.e., private owner, state, or community). The process of acquiring such farmland also requires the verification of a deed from the Liberia Land Authority per the Land Authority Act, which in most cases take a long period. Furthermore, customary land is primarily accessed through group claims held by families, quarters, or towns. Within these claims, individuals may acquire seasonal or permanent rights, for example for crops, trees, or house plots (Richard, 2005). Paramount and Clan Chiefs decide whether a request is granted or not. This system mostly makes the acquisition of farmland very challenging. In addition, the limitations on who can own farmland in Liberia and the uncertainty about land titling both add to the costs and risks of agricultural production in a wide range of activities and create prohibitive barriers to agricultural and other development in some cases (Richard, 2005). Therefore, access to land and its resources and security of tenure are essential for agricultural and economic development, growth, and poverty reduction. Smallholder farmers, who make up the majority of Liberia's rural population, require access and security of tenure to move beyond subsistence farming into more profitable and sustainable livelihoods that will achieve food security and increased export crop production.

5.4.2 Vulnerability (Socioeconomic Susceptibility)

Farmers' socio-economic attributes, in this study, are poverty, population depending on agriculture, education level, and gender. These indicators hold fundamental significance in determining resilience against catastrophes (Onoja et al. 2022).

The poverty ratio used in this study is based on the total population of the county, not only farmers. In Liberia, farmers, particularly the smallholder farmers, generally earn lower incomes than people in other occupations. In Liberia the average wage in the agriculture sector is usually the lowest (less than LRD$ 15000.00/month in 2016 – i.e., 160 = 1USA$) (HIES, 2016). In addition, for small farm holders, rice and cassava production are primarily considered only for self-consumption because the income from rice and cassava cultivation are insufficient to cover household expenses or to provide working capital for the next growing season (LISGIS, HIES, 2016). The total susceptibility integrated both physical and socioeconomic factors is depicted in Figure 5.1 and Table 5.1. Very high and high susceptibility levels appear mostly in Zorzor, Bong and Salala, Lofa counties. This is because of the high susceptibility associated with socioeconomic indicators dominates in Bong compared to Lofa. However, in the rest of the districts, particularly in Salala, Suakoko, and Salayea, the susceptibility due to physical indicators is lessened to moderate (0.40-59) and low (0.00-039) because of the low levels associated with socioeconomic indicators in those areas. Besides, poverty, land, and the environment are inseparably linked. The result of this study is supported by Kandasamy et al. (2022) and Piya et al. (2019), who indicated that poverty could lead to marginalisation and limit the capital assets that may be needed to reduce the impacts of climate hazards on livelihoods of farming communities and districts. Though poverty may not be directly equated with vulnerability, it could potentially constrain the capability of districts to cope with the impacts of climate induce risk and this is especially so for rural districts where livelihoods depend entirely on rain-fed agriculture (Dick-Sagoe and Nyamadi, 2022).

Moreover, poverty may compel people to live in environmentally fragile areas which could worsen their vulnerability to climate and other environmental changes (Garba et al., 2022). Hence, high poverty levels in these districts will further inhibit the potential of such small-holder poor farmers to manage the impacts of climate variability. Also, differences in land tenure between northern and southern Liberia could partly contribute to the vulnerability of the districts. The findings also confirmed that majority of the population >68% rely on the farm yield as their primary source of living. The rural poor of Liberia depend almost entirely upon farmland and other natural resources for their livelihoods, including their food, fuel, shelter, water, and medicines. Another critical socioeconomic attribute which is very important is the educational level of the farmer. The finding of the study (Figure 5.7) confirmed that most of the households in all the districts are characterized by low levels of education, less than 30% are without any formal education. This result did not confirm with the finding of Khan et al. (2020) who confirmed that literate farmers are relatively more conscious about the regional climatic variation and are more observant of associated risks, which, in turn, improve their decision-making ability in responding to these risks. The finding of this study revealed that most of the farming households in the six districts are susceptible to socioeconomic risk.

5.5 Conclusions

This chapter's aim was to identify spatial variations in climate induce risks of rice and cassava cultivation in central and northern Liberia, using a comprehensive approach, which includes one key component of risk, i.e., vulnerability. The vulnerability domain consists of physical, socioeconomic, and coping and adaptive capacity units. Coping and adaptive capacities will be analysed in the next chapter.

This chapter provides methodological steps in relation to climate risks assessment that can be used to characterise exposure and vulnerability (physical and socioeconomic susceptibilities) and hence, the vulnerability to climate induces hazards of a particular farming districts. Although it is acknowledged that local-level exposure and vulnerability assessment is very resource intensive, the innovative methodological approach outlined in this chapter is reproducible and will improve climate risk assessments in Liberia and more widely. This chapter has provided a more nuanced understanding of how different households could be impacted by climate variability. Building on previous research on livelihood diversification and livelihood capital assets, a clear need has been identified to support rural households through their participation in non-farm livelihood activities to reduce the negative impacts of climate risks. Findings in this study will help to guide a more general discussion of the sorts of livelihoods that enhance coping and adaptive capacities to future climate changes and thus allow the farming households to maintain suitable agricultural production.

5.6 Implication

The implication of the results is that policy makers need to formulate specific programmes that target areas that are exposure and vulnerability to climate induced hazards. that foster asset building so as to increase the capacity of household that are exposure and vulnerable to climate induced hazards. Exposed and vulnerable households should also be targeted in terms of resource allocations and other interventions aimed at reducing their exposure and vulnerability to climate induced hazards.

Chapter 6 Assessing Adaptation Strategies for Managing Climate Variability: An Empirical Study from Two Counties in Liberia

6.1 Summary

This chapter assesses the different coping and adaptation strategies that have been adopted by farmers in the study areas to address the adverse impacts of climate change and variability livelihoods activities. The study mixes questionnaire surveys and key informant interviews (KIIs) to collect all necessary information during the household field surveys. The results show that rural households' choice of a particular climate adaptation strategy may be partly influenced by different demographic factors including gender, age, educational level, and land tenure system as well as agroecological setting. Additionally, the chapter recognizes that rural households have employed on-farm and off-farm adaptation strategies including crops diversification, changing the timing of planting, planting drought resistant crops, multiple cropping, planting early maturing crops, help from family and friends, temporary migration, other income generating activities, livelihood diversification, reduce number of food as well as reducing food consumption to manage climate variability. The results show that most rural households used coping strategies that are linked to livelihood diversification. Most of these rural households engaged in multiple off-farming livelihood activities in an attempt to avoid destitution as a result of crop failures linked to climate variability (dry spell). The chapter concludes that these sociodemographic and agroecological factors must be taken into consideration by policy makers in the design and implementation of climate adaptation policies. The findings suggest that policy makers need to formulate targeted climate adaptation policies and programmes that are linked to enhancing livelihood diversification, as well as encouraging rural households in different farming districts to share knowledge on climate adaptation.

6.2 Introduction

Climate change poses a significant challenge to food security, particularly in developing countries (Datta et al., 2023). These challenges continue to threaten global economic development and may have an impact on different aspects of domestic life, such as agricultural productivity and diets (Bhuiyan et al., 2017; Bakht et al., 2020). Although climate change is a worldwide concern, rural farmers are highly affected due to their limited coping and adaptive capacities (Kom et al., 2020). Climate change and variability severely affects Sub-Saharan Africa's agricultural sector (FAO, 2016), particularly because of compounding challenges of poverty, low infrastructural and technological developments, and the high dependence on rain-fed agriculture (Joshi, 2021). Likewise, Liberia's agricultural sector is negatively affected by climatic events such as delayed rainfall, frequent dry spells, reduced surface water resources, soil erosion, floods, and variable diurnal temperatures (Kassaye et al., 2021; Yang et al., 2020). These extreme events are Liberia's main drivers of low agricultural productivity (Asrat and Simane, 2017). The performance of the agricultural sector shows strong associations with the rainfall pattern (Tessema and Simane, 2021). Rainfall shortages or changes in seasonal pattern led to food shortages and in the worst cases to famines. The country's dependence on food assistance is partly due to climate related disasters such as drought, dry spells, flood, and rainfall variability. This continues to disrupt society's cohesion and pose a significant threat to agricultural livelihoods in sub-Saharan Africa (SSA), where most households are exposed to food and nutritional insecurities (Bedeke, 2023).

Agricultural productivity in SSA is characterised by complex choices due to an increase in extreme events, population growth, urbanisation, land use pressures, institutional and technical developments which put governments and societies in a position where they must make difficult decisions about agricultural production (OECD/FAO, 2016). Due to this intricacy, decision-makers are confronted with the challenge of defining and prioritizing trade-offs and interactions of climate change relevant to agriculture. Despite this, agriculture is expected to offer more and various food varieties to meet the expanding food needs while guaranteeing ecological sustainability. There is broad consensus that SSA must increase agricultural productivity while reducing the environmental impacts across scales for improved social outcomes (Bedeke, 2023; IPCC, 2021), as this is contingent on achieving the Nationally Determined Contributions (NDCs) and the United Nations Sustainable Development Goals (particularly Goal 1-which indicates no poverty, Goal 2 - achieve food security and improved nutrition, and Goal 13-Climate action) (Yeleliere et al., 2023). However, the IPCC, (2021) revealed that the West Africa enclave of SSA is projected to experience a 10% - 40% decline in crop yields and the growing season will shrink by 20% on average by 2050. This will likely exacerbate food and nutritional securities, cause income and consumption losses, intensify poverty levels, threaten rural livelihoods (von Braun et al., 2023), and, in most rural contexts, cause the depletion of productive assets to control consumption (Yeleliere et al., 2023). In SSA, agriculture is the main source of livelihood for over 60% of the workforce (Shuaibu et al., 2021). These projections, combined with lower crop yields, hinder the region's progress in reducing poverty and ensuring food security. As such, multiple strategies are spiritedly promoted with varying emphasis on responding to current and anticipated changes including the use of conservational agricultural practices, external inputs, and agroecological principles, improved agronomic practices, livelihood diversification, and soil management practices (Yeleliere, 2022). Rural farmers in Liberia are particularly facing different types of climate change related risks, such as reduced or variable rainfall, warming temperatures, crop and livestock pests and diseases, flooding, shortage of water and soil erosion (Munaweera et al., 2022). Current climate variability contributes to reduced agricultural productivity, and the future sustainability of the sector in the area depends on the types of coping and adaptation strategies used by farmers (Kpewoan II, and Elkiran, 2022). Planned adaptation to climate change is urgent in parts of Liberia such as the rural areas were almost entirely rainfall dependent and agricultural production. Reducing exposure and vulnerability along with increasing adaptive capacity and strengthening the adaptation processes through building on adaptation practices are suggested.

As a result of their exposure to multiple climatic stressors and resulting food shortages, rural farmers have developed coping (short-term) and adaptation (long-term) strategies to anticipate and adapt to climatic shocks (Pauw, 2013). Changes in food consumption patterns, selling livestock, selling construction and fuelwood, borrowing grain or money, renting land, and seasonal migration are the most used coping strategies (Alemayehu and Bewket, 2017; Dendir and Simane, 2021). Local people's perception of climate change determines how rural farmers develop adaptation strategies to mitigate the effects on their local environment and livelihoods (Deressa, Hassan, and Ringler, 2011). Previous empirical studies in Liberia have shown that rural farmers widely perceive increased temperatures and a decline in rainfall (Asrat and Simane, 2018; Esayas et al. 2019). In Liberia, the months with high daytime temperatures; the frequent occurrence of heat-induced crop and livestock diseases; an increase in malaria incidences; the emergence of new invasive plant species as weeds; and the quick disappearance of water sources due to high evapotranspiration rates were the main manifestations of temperature rise (Habte et al., 2021; Zeleke et al., 2022).

Considering these climate crises, the Central Government of Liberia through the Environmental Protection Agency (EPA) has championed multiple strategies through policies, programmes, and plans for durable systems (EPA, 2021). Such durable system includes the National Environmental Policy of Liberia, Programmes for implementation (2002-2021), the Liberia's National Adaptation Programme of Action (2009), the National Policy and Response Strategy on Climate Change (2018), the Liberia's National Adaptation Plan (2020-2030), the Liberia's Nationally Determined Contributions 1 &2 (2013 and 2201), the Liberia’s Initial Communication 1&2 (2002, 2021) etc (EPA, 2021). These policies documents /plans are not realising the desired outcomes in tackling climate change in the local context. This could be because of the lack involvement and participation of all relevant stakeholders to incorporate their views and priorities particularly the local people who are the main victims of climate disaster or extremes and are exposed to the local climatic conditions and realities. Adaptation responses that encompass local vulnerabilities, needs, capacities, and actionable evidence and experience tend to be more successful (Jha. 2023). If properly planned and executed, locally led adaptation intervention prioritise farmers’ livelihood by utilizing local resources, expertise, and practises, and provide the local people’s capacity to influence adaptation activities and promote collaborative and participatory action against the brunt of climate variability for resilient agricultural systems (Gidey et al., 2023). Promoting local adaptation action through a participatory and all-inclusive process can produce democratic, equitable, and context-specific solutions to climate crises at all levels.

Thus, empirical evidence on the general characteristics of agriculture-dependent districts that have proven to be at risk as a result of past climate-related problems is lacking at these levels. Addressing this gap will increase our understanding of how districts cope with the impacts of climate-related problems, providing useful insights into the structure and drivers of risk (Eakin and Baeza et al., 2019). This will provide valuable lessons for the management of climate variability in agriculture-dependents communities in developing countries such as those in SSA more widely. The overall aim of this chapter is to explore the characteristics associated with those households and communities that are resilient and vulnerable to climate variability. This will help us to understand the processes and factors that create risk, allow input from the studied districts themselves, as well as providing guidance for the development of effective policies. To achieve this aim, the specific objectives of this chapter are to:

1. Develop and employ a household livelihood risk index in relation to climate variability (particularly drought) in order to compare and contrast the components of risks in different farming districts.
2. Determine different coping and adaptive strategies that have been adopted by the farmers in the study counties, and
3. Investigate the socioeconomic, environmental and districts characteristics associated with climate risk,

4. Use statistical methods to identify correlation between farmers socio-demographic characteristics and strategies adopted.

In this regard, by applying this, the chapter seeks to distribute to empirical understanding of crop food production and rural livelihoods risk at the household and district levels that will help guide a more general discussion of the types of food production systems and livelihoods that enhance coping and adaptive capacities to future climate changes.

6.3 Indicators for Sustainable Livelihood Approach to Climate Risk

In Chapter 3, Table 3.1, indicators for this study are highlighted at the district levels. The study identified five types of livelihood capital assets suggested by DFID, namely natural, physical, human, social and financial capitals assets. These five capital assets represent different shaped asset pentagons to show households' differential access to assets (see 2.8.3).

During key informants' interviews and questionnaire surveys (Chapter 3), households were asked to highlight indicators linked to each form of capital asset (i.e. natural, physical, human, social and financial capitals) (see Appendices I and II). An assessment of livelihood capitals offers the opportunity to identify the various capacities that might be used to reduce rural districts' risk to declining crop yields due to dry spells, and how such declining yields can affect livelihoods (Mekonen and Berlie, 2021; Pagnani et al., 2021; Nidumolu). The key indicators that emerged from this exercise were cross-checked with those mentioned in the literature (Le, 2020; Czúcz et al., 2021; Brookes and Barfoot, 2020; Azócar et al., 2021; Sultana and Luetz, 2022). What follows is a brief description of how the livelihoods assets were characterized in relation to households' ability to adapt to climate variability with a view to using this information to develop a livelihood risk index at the districts levels before results are presented and discussed.

6.3.1 Natural Capital

Natural assets refer to the natural resources and services that people rely on for their survival and development (Pandey et al., 2017). Natural capital is especially important for those who make all or a part of their livelihood from natural resource-based activities (Sharafi et al., 2018). This capital involves resources and elements such as soil, water, mines, livestock and other natural resources, e.g., agricultural land ownership, forests and pastures, water ownership and mineral industries Natural capital and risk have close relationships as many destructive shocks to livelihoods such as drought, delayed rainfall, floods, earthquakes, etc. are natural processes which reduce natural capital (Gai et al., 2020). Natural capital assets were assessed by two indicators. The first was the size of the farmland under cultivation (this was estimated as the average area of cultivated land over the past 10 years). It is assumed that the larger the farmland, the greater the opportunity for the household to have more crops and yield, and hence the lower the risk to climate variability. It is worth stressing that a household with a larger farmland may be more dependent on agriculture and therefore more at risk than someone with a small area of land under cultivation but who works as a motorcycle rider or a businessman.

6.3.2 Physical Capital Asset

Physical capital mainly refers to the basic services and infrastructure that provide convenience to farmers' production and life (Singh et al., 2024). The total value of the farmers' agricultural machinery and tools reflects the input that farmers have made for agricultural production, and it also helps to improve the efficiency of agricultural production (De Jalón et al., 2018). Physical capital also refers to various facilities mostly contributing to the local environment including housing, public places, industries, bridges, dams, harbours, and shelters. Furthermore, it includes vital facilities, such as electricity, water, telephone and gas. Physical capital assets that were assessed included the presence of irrigation facilities and ownership of radios, television or mobile phones by a household. Irrigation facilities are crucial for rain-fed agriculture-dependent districts, as these facilities help farmers to practice dry season farming. It is assumed that households with irrigation facilities will be less vulnerable to changing rainfall patterns.

6.3.3 Human Capital Asset

Human capitals are mainly related to personal knowledge, skills, health and labour potential (Baffoe and Matsuda, 2018). In literature, the quantity and quality of the labour force are two important measurements (Fang et al., 2014). Education is widely recognized as an essential element for farmers successfully pursuing different livelihood strategies. Furthermore, professional training is a way of acquiring knowledge (Jezeer et al., 2019). Therefore, in addition to the proportion of the household labour force and the highest degree of education of the family members, agricultural skill training is also listed as an indicator of human capital assets. Furthermore, economists basically define the concept of human capital as the internalized or accumulated internal capabilities of the (working) age range in the society which allows human capital to work effectively with other types of capital to protect economic production (Cismaș et al., 2020; Buyruk, 2020). Human capital assets are represented in two ways: by the educational level of the head of the household (or the most educated person in the household), by the age of the household head. To assess educational levels, seven categories were used; no formal education was valued as 1, pre-primary 2, primary 3, junior 4, senior 5, vocational 6, and 7 for household head with had a degree. The study could not assess this option due to the unwillingness of the respondent to this option because of there was an embargo on such social across some districts by districts' chief. Some reason given to this embargo were unstable levels of participation by group members, potential for groupthink, and challenges in coordinating schedules and managing diverse personalities. The age range of the farmer plays a pivotal role in participating actively in farms works and understanding the realities of climate issues (Pande et al., 2023). To assess the age range of farmers, seven categories of were also used: 19-25 years was valued 1, 26-32 years 2, 33-39 years was valued 3, 40-46 years valued 4, 47-53 years valued 5, 54-60 years valued 6 and above 60 years valued 7, respectively. These age categories are considered to be the farming population in Liberia that are heavily involved in farming activities (LISGIS, 2016).

6.3.4 Social Capital Asset

Social capital assets are a network of social relations among individuals or groups, such as kinship patronage and neighbourhoods (De Jalón et al., 2018; Baffoe and Matsuda, 2018). This asset is built on a relationship of trust and mutual understanding and support, from formal and informal groups, shared values and behaviours, commons rules and sanction, collective representation mechanism for participation in decision-making leaders (Baffoe and Matsuda, 2018). Most rural farmers in developing countries in SSA including Nigeria, Ghana, and South Africa, in Asia including China, Pakistan and Bangladesh attaches great importance to clan culture, and a family name is one highly important element, especially in the countryside. In addition, farmers usually share their experiences and information on agricultural production through face-to-face communication with friends and relatives (Li et al., 2017, De Jalón et al., 2018). The degree of trust among neighbours should be conducive to the formation of a good environment for communication and interactions in the countryside, which is important for sharing the experience of agricultural crop production. Hence, this study could not access information on this indicator because at the time of the field work, the district chiefs had put an embargo on its due confusion among farmers because of lack of trust among farmers to uphold to their commitment in the study districts.

6.3.5 Financial Capital Asset

Financial capital is defined as financial resources, such as cash, bank accounts, savings, income, investments, credit, current assets, pension rights, allowances, grants, financial remittances, household property, etc. (Udoka et al., 2022). The total household income and the stability of the household income reflect the quantity and the quality of the farmer's income, respectively. The degree of difficulty farmers has obtaining financial support reflects the possibility of farmers obtaining financial credit support in the future and providing good financial support for resisting livelihood risks and adopting adaptation strategies. Obtaining information on financial assets was very problematic because of a lack of records of sales and memory lapses. The study assessed financial capital assets by examining the remittances received by the household from family members or friends over the past 12 months. In rural agriculture-dependent districts, remittances from family and friends play an important role in helping farmers to cope with the livelihood impacts resulting from climate variability. Households that received remittances in the last 12 months were scored 1 and those that did not receive any remittances were scored 2. Access to credit is one of the major challenges confronting rural peasants (Ojo et al, 2021). Access to credit may also influence adaptation to climate change including access to inputs such as improved cultivars of crops (Tilumanywa, 2021). Hence, it is assumed that households that have no access to credit will be more at risk and were captured in the interview with those with access to credit.

6.4 Methodology

This chapter uses quantitative (structured questionnaires) of sample household using semi-structured questionnaires to collect responses from rural farmers across all districts, and qualitative (key informants' interview), with selected individuals composed of district chiefs, and youth leader (both male and female). These categories of individual were important for this study because they represent a specific category of group and are knowledgeable about the history of the district, climate change, kind of adaptation strategies and factors that influence farmers' adoption of adaptation strategies etc. Field observation was also used to acquire all necessary information throughout the research period in order to ensure the validity of the information obtained from the respondents. Details of the methodology are explained in Chapter 3.

6.4.1 Data Analysis

To ensure comparability in the construction of the household livelihood risk index (HLRI), all indicators were standardized and weighted to ensure that all indicators were normalized to have relative position between 0 and 1(Osei-Amponsah et al, 2023), (see Chapter 3.6.1) for details explanation.

6.5 Results

The period for which the farmers have been producing crops (rice and cassava) was an important factor in determining the farmers' experience of climate change and variability in their localities.

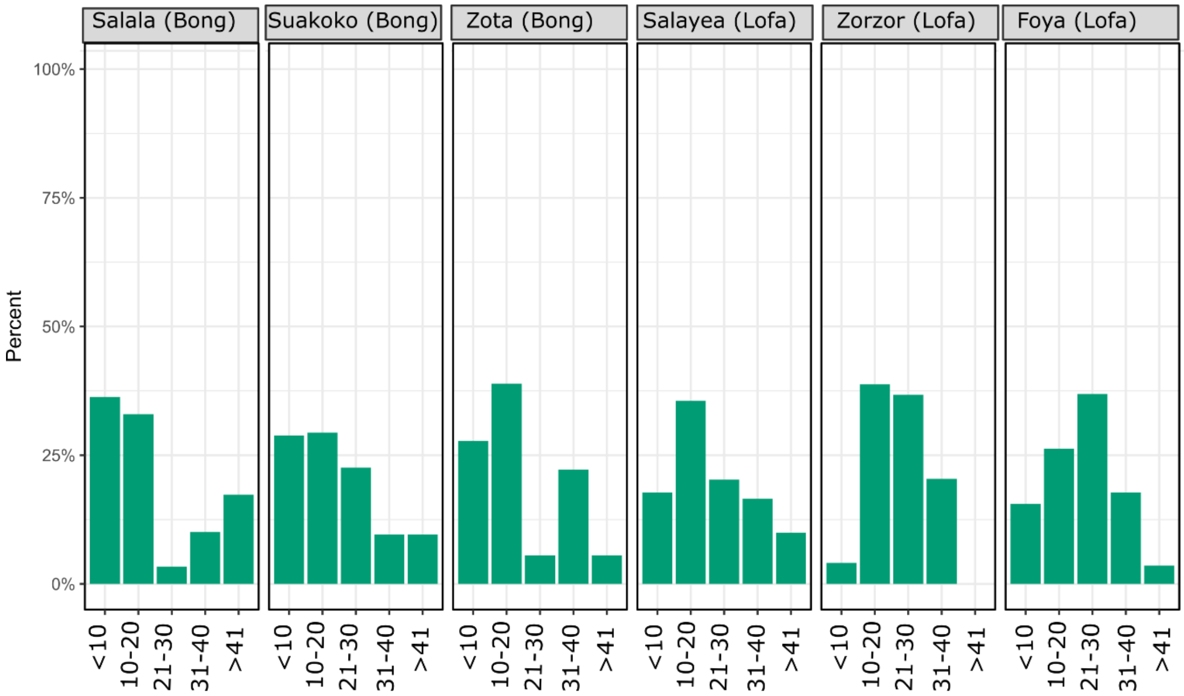

Figure 6.1 The number of years of farming experience.

More than 25% of farmers across all three districts in Bong County have been involved in farming for less than 10 to 10-20 years, while less than 25% of farmers within the same districts in the county confirmed to be involved in farming for 21-41 years and above(see Figure 6.1), For Lofa County, the survey also revealed that more than 40 % of farmer across the three districts indicated to be engaged in farming in their respective districts for 10-30 years. This finding revealed that majority of the farmers interviewed have been farming in this the study area for more than two decades, which indicates that most of them, both male and female have the required experienced in farming in their respective localities.

6.5.1 Farmer`s Perception of Climate Change and Variability

Farmers' perceptions of climate variability are increasingly being used in climate risk assessment and adaptation studies (e.g. Singh et al. 2020; Dakurah, 2021; Ado et al., 2020). This is because farmers' perceptions based on their past experience and future expectations may influence the type of adaptation strategy used in response to climate variability (Singh et al. 2020). It has been suggested that farmers are more likely to adapt to climate change if they can perceive the changes in the climate (Singh et al. 2020). Therefore, it is essential that these perceptions are assessed in a study such as this that seeks to explore the adaptation pathways of Liberian farmers to climate change and variability.

Based on the of the survey, the study confirmed that farmers in the study areas were aware of climate change and its implications for their agricultural and livelihood activities. Both men and women across all districts shared similar perceptions regarding climate change, and respondents identified six major impacts demonstrating evidence of climate change and its contribution to food insecurity (Table 6.1). Particularly, farmers were asked about their observation of changes in rainfall and temperature patterns over the past 5- 40 years (since 1981). The climate time span for perception studies was limited to the 40 years (i.e., from 1981-2020) due to lack of consistent availability of climate data in Liberia (see Chapter 4). However, this length of time is considered adequate to explore how the livelihoods of farming households have been impacted by climate variability (Blackmore et al., 2021).

Table 6.1 Proportion of respondents in the study areas who identified changes in rainfall and temperature.

Variables	**Counties (N=160)**		
	Bong (%)	**Lofa (%)**	**Total (%)**
Increase in rainfall	31.4	22.1	26.8
Decrease in rainfall	68.6	77.9	73.3
Changes in on-set	96.3	98.0	97.2
Decrease in temperature	4.7	6.3	5.5
Increase in Temperature	82.2	79.3	80.8
Temperature the same	12.1	14.4	13.3

Majority of farmers, more than 90% recognised that the weather they experienced has changed. Many reported experiencing multiples shifts. The most commonly described changes related to temperature, with 80.8% of the farmers surveyed raising concern of temperature increases, and that the temperature has become hotter compared with past decades (2001-2020), while 5.5 % of the farmers indicated decreases in temperatures (see Table 6.1). Key Informants Interview in Salala district emphasised that:

"*Sometimes, during the days and nights temperatures have increased making it very hard for us to sleep at night. Now the sun rises very early with high intensity, compared to what we used to experience decades some years ago".* (A district chief, February 2022).

In term of rainfall, whilst 73.3% of the farmers perceived a decrease in rainfall, 26.8% reported increased rainfall over the periods. Most of the farmers are of the view that the rainy season observed in the districts was characterised by intra-annual variability and torrential rainfall, which may not be useful for rain-fed agriculture. Largely, almost all the farmers (97.2% in the study districts) said that there has been a decreasing trend in the amount of seasonal rain which they depend on now as well as delays in the onset of rainfall compared to 20 years ago (2001-2020), all of which contributed to reduced crop yields.

Farmers' perceptions of changing climatic conditions, knowledge of climate change vulnerability, and local adaptation strategies in agriculture production are being used to assess climate risks in various studies (Voss 2022; Anum et al., 2022; Amare and Simane, 2017). Farmers' perceptions are based on their past experiences and future expectations that may influence the type of adaptation strategy used as a response to climatic problems (Voss 2022; Anum et al., 2022). It is also suggested that farmers are more likely to adapt to climate change if they can perceive the changes in the climate (Voss 2022). Accordingly, most respondents claimed that climate change is also linked to the instability of crop yields, leading to conflicts among farmers and prompting some producers to migrate out of the areas. Similarly, observations emerged from Key Informant Interview (KII), in Foya district who highlighted:

"Before, there used to be rainy season for six months, but now, it is no longer six months. Now it is four months (with heavy rainfall). Mostly, the rain stopped with the crops are at the peak of their growth". (District chief, Foya, December 2021-January 2022)

Additionally, a district, 64-year-old key informant interview in Zorzor district was asked to give his perception of climate variability in their respective district, and confirmed that:

"*The change in rainfall is serious. Dry spells (rain not falling on time) have affected our crops yield. Last season, I could not even get a bowl of rice due to the serious dry spells. The lack of rainfall for most of the months exacerbates the dry season which extends to about nine months, and the heat which is accompanied by the dryness is making life difficult for us*." (A district chief, December 2021-February 2022)

This statement reflects respondents' perceptions about changes in rainfall and temperature and corroborates the observed rainfall variation in Liberia and temperature trends (see chapter 3). In addition, the district chief Salala district also maintained that:

"The length of wet or rainy season had not only reduced but had also become unpredictable with a consequence of dry spell. The dry spells in the areas, the farmers indicated, are causing wilting, and drying up their crops." Additionally, the chief emphasized that *"The amount of rainfall we used to receive during the past 10 years was relatively sufficient for*

planting our crops. Besides, the sun was not shining too much at that time (i.e., the increase in temperature was less). However, in recent years, 5 years and more, the duration of rainfall and the intensity of sunshine have changed considerably, thereby making us not plant our crops on time."

Consequently, the farmers hold the view that climatic changes and variability over the years have had adverse impacts on their crops yields most especially rice and cassava which are the staple food crops for Liberia (see Figure 6.2). A 61-year-old farmer in Suakoko district, Bong County revealed that:

"The disease of rice has a close link to weather and other climatic conditions. This usually happens when there is a long dry period from June and August become wet, all because of the climate change". (Suakoko district, Bong County, December 2021).

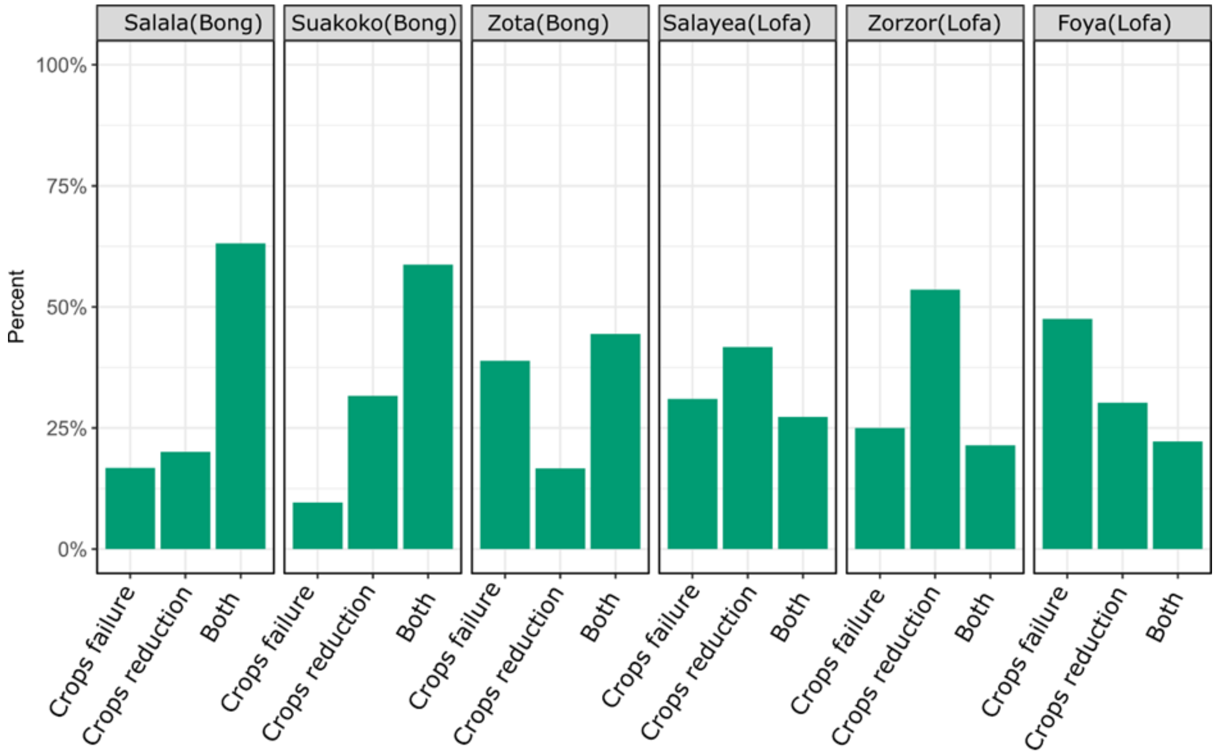

Figure 6.2 Impact of climate change on crops production.

The findings of this study share commonalities with Ojo et al. (2018a) in Nigeria; and Derbile et al. (2022) in Ghana, who indicated that smallholder farmers perceive rainfall as decreasing and average temperatures as increasing in Africa. These observations of changes point to the need for climate information tailored to adequately and timely provision of information to help in adaptation decisions. In Africa, households in dryland are frequently confronted by multiple stressors including lack of markets to sell their farm products, poor educational attainment, droughts, and economic development (Sugden et al., 2022; Voss, 2022) and as reflected in the finding of this study. Even though, adaptation may be prompted by climate events such as floods and droughts, it should be acknowledged that these adaptation strategies are taken in response to the complex interplay of both climatic and non-climatic conditions such as political, economic, and socio-environmental changes (Voss, 2022). The key adaptation strategies adopted by farmers in the study are consistent with studies of Kichamu et al., (2018) in Matungulu Sub-County, Eastern Kenya, Wamalwa et al. (2016) in three Sub-counties in Kisii county, Ochieng et al., (2017) in various agroecological zones in Kenya, Mburu et al., (2015) in Yatta District, Kenya. They identified change of crop varieties, change of planting time, crop diversification and soil and water conservation practices as the most adopted strategies to cope with changing climate.

6.5.2 Local Coping and Adaptation Strategies

Analysis of farmers' coping and adaptation strategies in the study area is reported in this section. To mitigate adverse impacts of climate change and variability, farmers in the study areas used a range of strategies against short term impacts (coping) and long-term impacts (adaptation). These strategies are grouped into four broad categories such as socio-demographic, economic, institutional, and infrastructural as well as land management (planting maturing crops, irrigation, and fertilizer and manure application, crop diversification, chicken manure); crop management (change the timing of planting dates, crop diversification, use of drought tolerant and fast maturing crops, and crop rotation); livelihoods diversification and adjustment (off farm income, help from family and friends, temporary migration, change in consumption pattern, taking credit, getting support from government and NGOs). Onyenekwe et al. (2023) and Fadairo et al. (2020) confirmed that most of these strategies have been in used in different parts of Ghana and Nigeria, and in some West Africa countries for a long period of time in response to historic climate variability. As a result, it can be argued as to whether the strategies are climate change driven or not, but it is evident that the strategies are useful to mitigate the adverse impacts of climate change and variability.

6.5.3 Determinants of Coping and Adaptation Strategies and Access to Capital Asset

The decision to choose a certain coping and adaptation strategies depend on a set of socio-demographic, economic, institutional, and infrastructural, and biophysical factors. In addition, this section also explains the factors contributing to the risk of farmers in the study areas particularly access to capital asset and livelihood diversification. Details of these factors are presented in this section. Firstly, the finding begins with the analysis of coping strategies.

6.5.4 Determinants of Coping Strategies

6.5.4.1 Educational Attainment

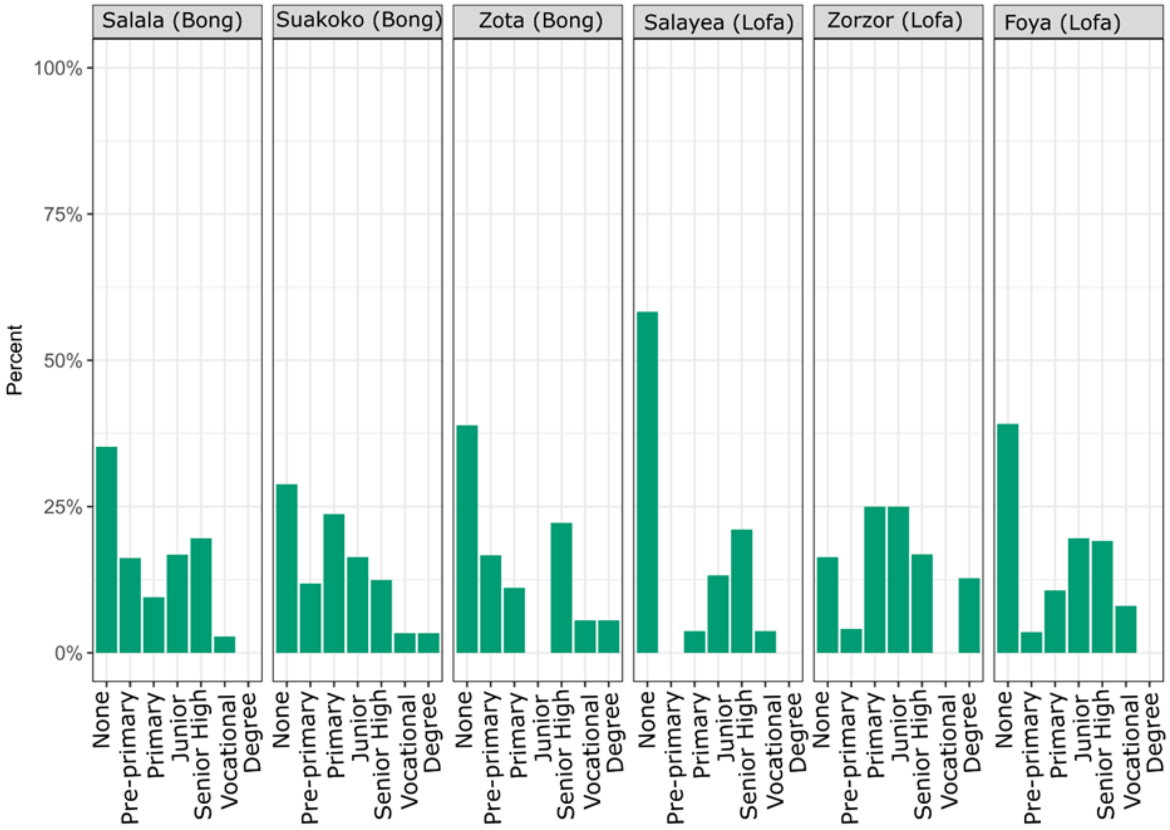

Figure 6.3 Education of the Farmers in the six districts within Bong and Lofa Counties.

Educational attainment of farmers allows them to access appropriate information and encourages the adoption of improved crop varieties (Thinda et al., 2020). In this study, rice and cassava farmers were asked to specify their educational attainment. Figure 5.3 shows that the educational levels of the farmers are low across all districts, as more than 25% of the surveyed household heads did not acquire any formal education in Salala, Suakoko, Zota (Bong County), Salayea and Foya (Lofa County), while less than 20% in Zorzor (Lofa County), respectively. Nearly all the sampled households confirmed to have acquired pre-primary (nursery) and primary education but could not go further due to lack of support. Similarly, the distribution of junior and secondary education was confirmed by the households across all districts except for Zota (Bong County) where there was no single person with junior high education. Except for Zota (Bong County), Salayea and Foya (Lofa County) district, less than 10 % across the rest of the districts in the study counties confirmed to have attained vocational education and university education. In terms of human capital assets and risk to climate variability, the analysis shows low level of education across all districts which demonstrate the district being at risk to climate variability. Increase literacy can increase the capacity of the farmers to access climate information.

6.5.4.2 Identification of Farm Size in the Study Areas

This capital involves resources and elements such as soil, water, mines, livestock and other natural resources, e.g., agricultural land ownership, forests and pastures, water ownership and mineral industries, etc, that are important sources of livelihood and indictor of wealth in rural areas. Therefore, it is assumed that large farm size and access to land enables farmers to produce more and practice different coping and adaptation strategies to climate change and variability.

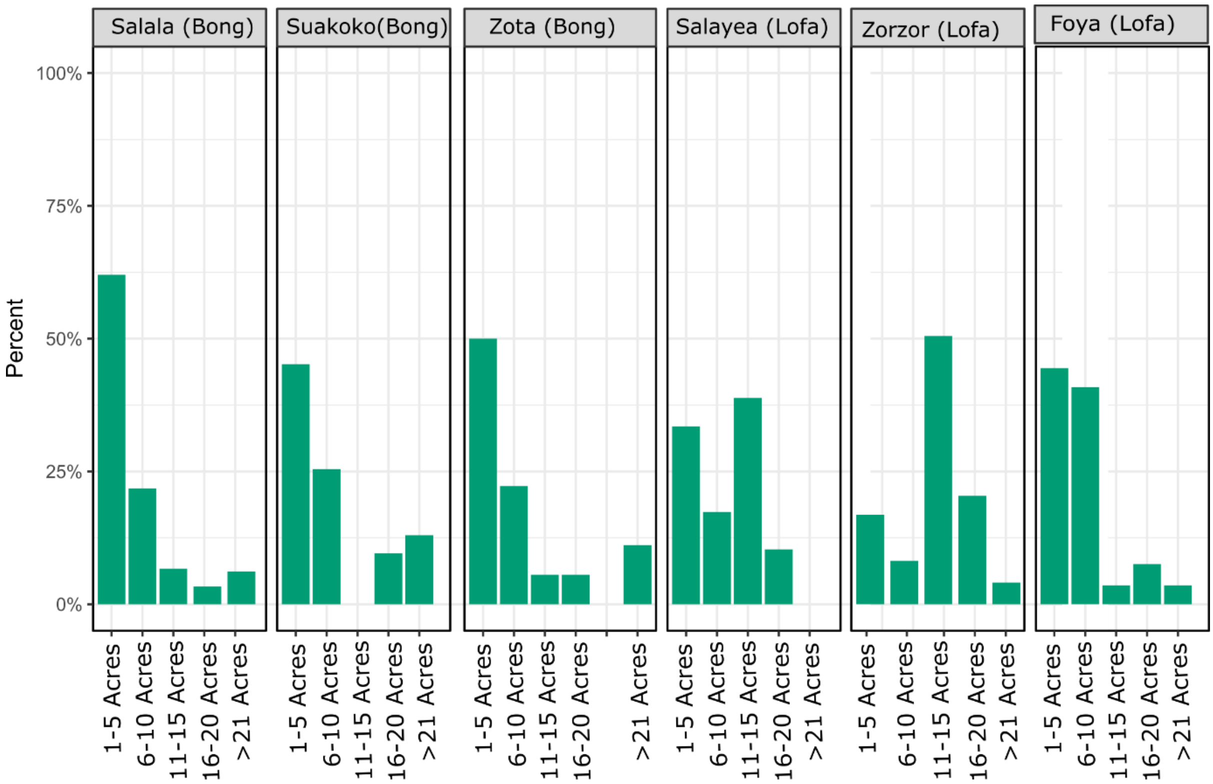

Figure 6.4 Farm size (in hectares) in the six districts within Bong and Lofa Counties

Figure 6.4 displays the size of rural farmers across all six districts. As indicated, more than 48% of the rural farmers across three districts of Salala, Suakoko and Zota in Bong acquired 1-5 hectare of farmland for subsistence farming in the study areas. While farming land acquired by farmers in Lofa varies across the three districts of Lofa. This means a farmer with larger farm size tends to increase their farm products. Moreover, it was observed that farm size was a determinant of use of changes in consumption pattern as a coping strategy. A unit increase in farm size can affects use of changes in consumption. Even though, the major farmers are involved in rice and cassava production in the study areas, but mixed cropping farming are practiced in response to seasonality are key strategies in the study areas. Selling of livestock (i.e., chickens) was a common coping strategy during crop failure periods amongst farmers across the study areas districts. In addition, a farmer in Salala explained that: '*Access to farmland is very challenging in this district. Sometimes, the owner* *of the farmland demands a huge sum of money per farm season, or you share the farm's products with him/her at the end of harvest season.'* [March 2022]. Based on the analysis, farmers' access to natural capital asset are limited which made them to be at risk to climate variability.

6.5.4.3 Farmers' Access to Market

Physical capital mainly refers to the basic services and infrastructure (such as access to market) that provide convenience to farmers' production and life (Singh et al., 2024). Additionally, access to market is also important for coping with climate change by facilitating the flow of inputs and outputs as well as information on coping strategies. Access to market gives the rural farmers the opportunity to purchase and sell agricultural products. Moreover, farmer with good access to markets are more likely to be aware of the changing climatic conditions and strategies to mitigate them. In the study areas, rural households were asked whether they have access to the market to sell their products. As indicated in Figure 6.5, most of the farmers (more than 58%) across all districts revealed that they do not have access to markets due to poor road conditions. While those (less the 42%) indicated 'yes' to having access to roads are those that are farming within the periphery of major roads which make it easier for them to transport their farm products to the market.

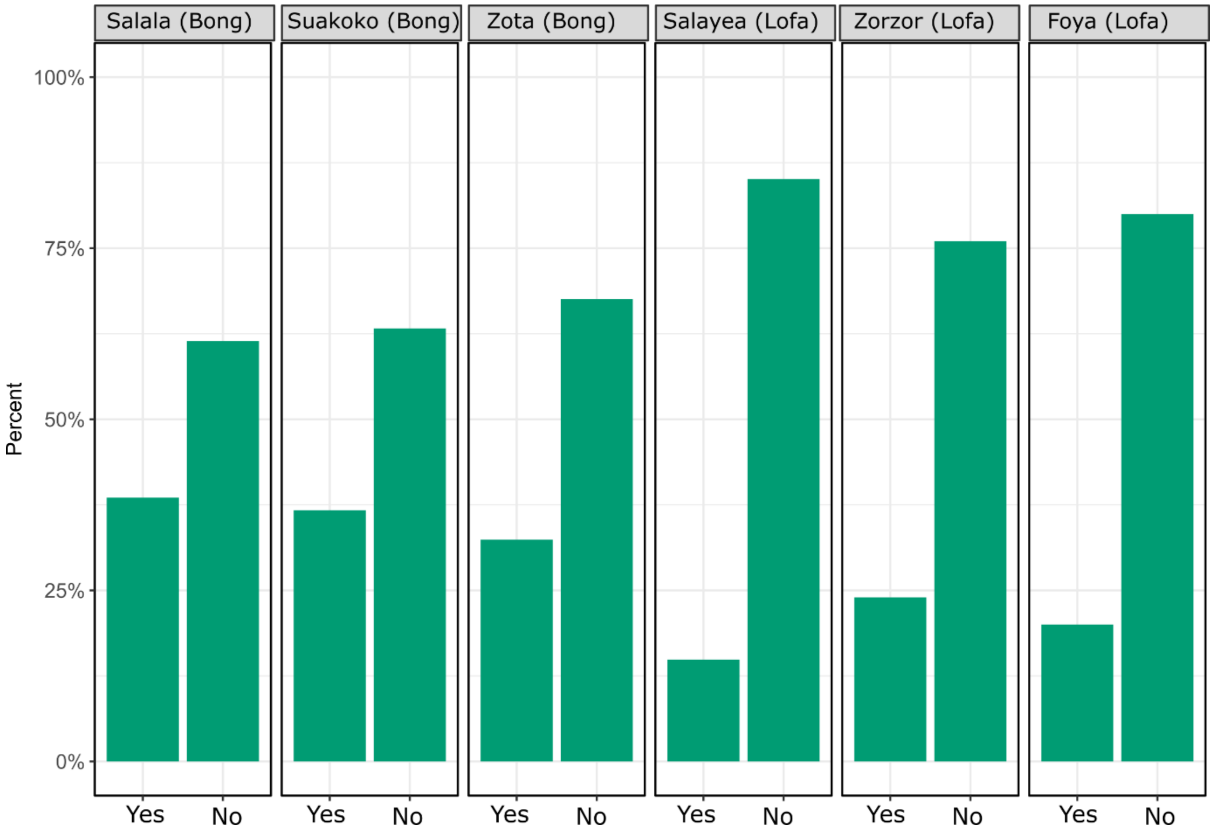

Figure 6.5 Participants access to markets to sell farm products.

Likewise, during the KII, some of leaders across the study districts described the farm to market roads access as "*horrible*". They further explained that:

"*My son, see the roads condition in our areas (see Figure 6.6) is very, very bad. Sometimes when we harvest our crops to carry to the cities to sell in order to get cash, we sometimes spent more than one week on the road. This can make our crops to even spoil on the road*."

(District chiefs in Foya, (Lofa County, February 2022). Similarly, a leader in Zorzor district indicated that "*due to the bad roads condition, their farm products sometime purchased at a lower rate by those merchants to come to the village after spending few days on the road".* Furthermore, a district in Zota also said that *"most farmers in his district usually rent a motorcycle to transport their crops on a weekly basis to the market be sold during the market day."* (January 2022).

Figure 6.6 Road between Bong and Lofa Counties, Liberia (December 2021).

Having access to markets increases the likelihood that farmers will sell their farm products, mainly rice and cassava, more frequently at any given time when cultivated. Furthermore, access to market increases the likelihood of changes in consumption pattern as a coping strategy. Adimassu and Kessler (2016) have reported on the significant effect of access to market on the choice of coping strategies in SSA.

6.5.4.4 Access to Climate Information

Accessibility to climate information is another component of physical capital assets that greatly influence the ability of the farmers to cope with extreme weather and adapt to climate change and variability. Variability in annual and seasonal rainfall totals as well as mean annual temperatures in the area were reported in chapter 3 of this thesis. During the field survey, rice, and cassava farmers in all six districts were asked whether they have access to climate information. The results obtained (see Figure 5.7) indicate that the majority (> 65%) of rice and cassava farmers have no access to climate information, while less than 35% reported to have limited access to only weather information without consideration for trends of rainfall and forecasts, economic analysis on impacts of climate change on food prices, and counselling of farmers on adaptation strategies.

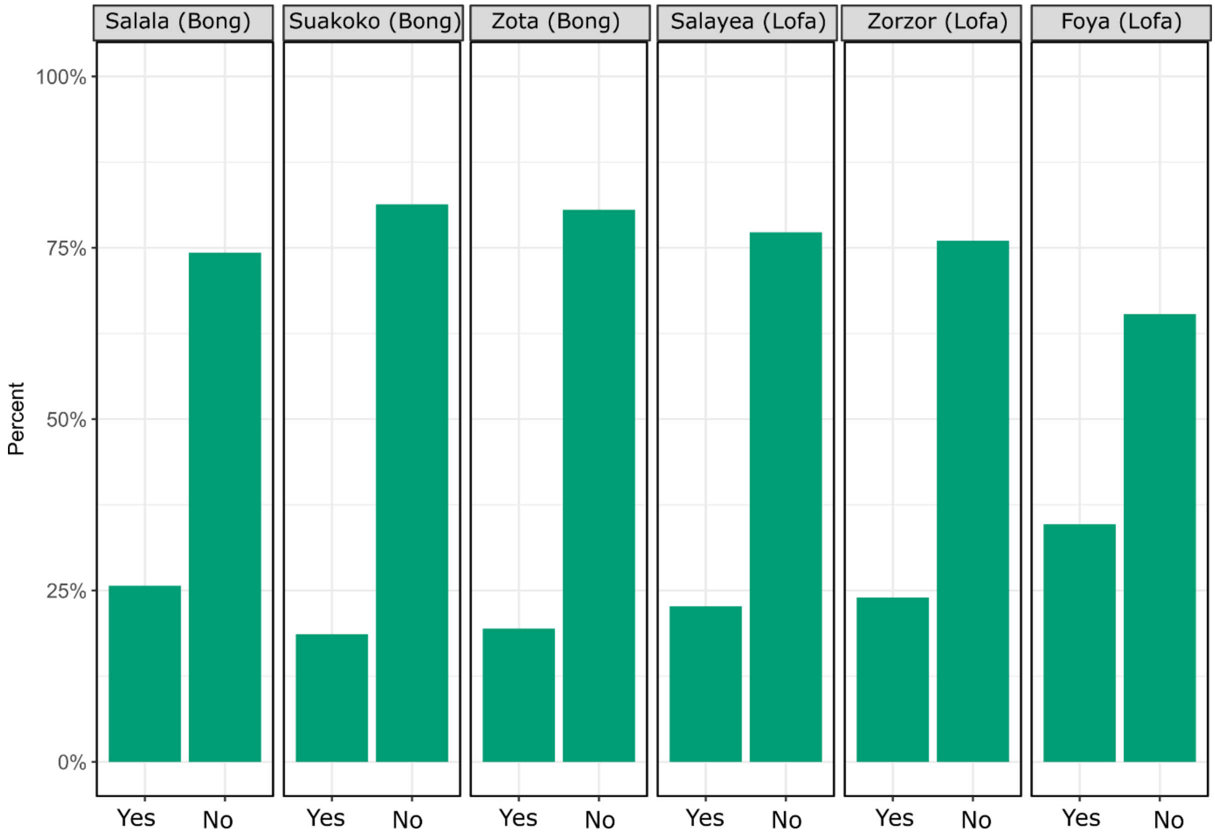

Figure 6.7 Farmer access to climate information.

According to Naab et al. (2019), this situation renders farmers vulnerable as they do not have sector-specific information packages about the length of the rainy season, types of crops to grow, farming practices to adopt, or the number of resources to commit to farming. In conjunction with the Naab et al. (2019) finding policy alignment is also lacking. One solution could be found in a more coordinated policy approach that specifically addresses the types of climate services accessible to farmers. A District chief in Foya explained that:

"Lack of basic climate information has negatively impacted crops production process during the past 5-20 years". (A district chief in Foya, Lofa County, December 2021- January 2022). Likewise, a youth leader in Zorzo district said "*Because we cannot get climate information, such as when the rain will fall, from the government, is making us not to plant our crops on time. And if we sometime plant early and there is no rainfall, our crops can die."* (A youth leader, Zorzor, Lofa County, February 2022). Similarly, another KII also confirmed that *"Since we cannot get any information on rainfall, the community is faced with serious food shortages."* (A district chief, Salayea, Lofa County, February 2022). Overall, farmers' limited access to climate information is also a contributing to farmers being at risk to climate variability.

Additionally, farmers in the study areas also adapted a range of strategies against short-term (coping) strategies of climate variability and change. The strategies can be grouped into two broad categories as livelihoods diversification and adjustment (off-farm income, temporary migration, change in consumption number and size of consumption, change stable food, assistance from NGOs and government, selling of charcoal taking credit, and help from family and friends). Based on the availability of data at have, nine copies of strategies were drawn. The choice of a certain strategy over another depends on access, cost, profitability, acceptance, and suitability to the local context. Most of these strategies are not new and have been in use in different parts of the region for a long period of time. As a result, it can be claimed as to whether the strategies are climate change driven.

Households in the study areas reported several strategies relating to coping with the adverse impact of climate change and variability. These strategies, include, help from friends, temporary migration, riding of commercial motorbike, livelihood diversification, reduced number of diets, reduce size of diets, change stable food, selling of charcoal and relying on governmental and non-governmental organisations. These strategies are also analysed and discussed in this section.

Table 6.2 Coping strategy adopted by the rural framers (N = 160)

Counties/districts	Coping Strategies (%)								
	Help from family and friends.	Temporary migration	Off-farm income	Livelihood diversification	Reduce number of consumptions	Reduce size of consumption	Change staple food.	Selling of charcoal	Assistance from NGOs and government
A. Bong									
i. Salala	45.2	38.0	62.3	58.0	63.4	57.1	35.4	66.4	29.0
ii. Suakoko	52.0	60.1	58.4	67.2	66.3	59.3	40.1	71.0	21.2
iii. Zota	58.3	53.5	53.0	53.4	59.1	60.2	38.2	68.0	35.4
B. Lofa									
i. Salayea	61.3	65.4	68.2	66.1	65.1	59.2	37.1	69.4	38.1
ii. Zorzor	43.2	58.3	70.1	69.3	70.0	65.3	20.3	58.3	29.4
iii. Foya	56.1	48.3	66.1	78.1	59.3	63.4	33.4	70.1	35.3
Tota (%)	53.0	54.0	63.0	65.4	64.0	61.0	34.1	67.2	31.4

6.5.4.5 Help from Family and Friends

In agriculture-dependent rural areas, rural households depend on social networks. Findings from the household survey revealed that 53.0% (n=160) of sampled households claimed to have relied on friends and families' members on at least one occasion in the last 12 months (i.e., January 2021-December 2021) to cope with the impacts imposed by the changing weather patterns on their livelihood activities. Most rural households rely on social networks including farmer-based associations that help in the form of food in times of crisis and also assist members to secure loans. Mostly, rural households in these districts had more opportunities for greater social integration. During the researcher's personal interactions with some members of the district's leaders, it was noticed that the type of settlements in the study areas are greatly influenced by the extent of social networks and interactions. The study districts have sparse settlements that may not enhance social integration. In such communities, individual households settle on a piece of land, practise compound farming (cultivating the land around the closed vicinity of the homestead). There are therefore wider distances among various homesteads and fewer interactions among the households in the vulnerable communities. Hence, there are regular and frequent social contacts among different households in the rural areas. It was discovered during KIIs, a 59-year-old leader said: "*We interact with different people for help. social networks can provide a range of benefits, for instance, sharing of information of forthcoming climatic condition and the opportunity to engage in temporary migration"* (A 59-year chief in Zorzor, December 2021 – January 2022).

6.5.4.6 Temporary Migration

Temporary migration has long been part of the history of rural households' activity in SSA including Liberia (Dick and Schraven, 2021; Teye and Nikoi, 2022). However, changes in rainfall and temperature over the past 40 years (1981-2020) have added a greater dimension to the importance of temporary migration as a climate adaptation strategy more widely in SSA (Findley, 1994; Nielsen and Reenberg, 2010a;). Accordingly, findings from the survey revealed that more than 50% (n = 160) of the rural households sampled in the study areas indicated that at least one to two members of their household mostly migrate to the cities on an annual basis after since the past 5-20 years (2000-2020) as a strategy to cope with climate variability.

After harvesting in late October or early November, many of the farmers, mostly the younger ones, leave for the cities, especially the capital city of Liberia (Monrovia), where job opportunities are better. Rural farmers were asked to provide reasons why they or members of their family migrated out of these communities. The results show that farmers migrated on a seasonal basis in response to lack of opportunity to work and other harsh environmental conditions as well as socioeconomic pressures. This is detailed in a typical comment during the Key Informant Interview (KII):

"Our children go to the cities to find jobs to work so that they can get some monies, save some monies for the family for next farming season and sometimes send monies to their families to buy foods. This is done for such families to cope with climate change impacts" A district chief at Zota (Bong County, December 2021 – January 2022). Another district chief clarified that:

*"From November to February, there is no farm work in our areas, since there is no rainfall in that period, it is not good for our children to be here. So, the best way is for them to move out to find jobs (sell in people shops during the Christmas and New Year's season to get money to help the family back in the communities" (*Zorzor Lofa County, December 2021 – January 2022). Information obtained from these observations is the fact that farmers in these districts migrate partly due to inadequate rainfall which leads to delayed rainfall or prolonged dry spells and eventually famine or crop failure. Nonetheless, these farmers are confronted with other socio-economic challenges that could partly influence their decision to migrate (Kugbega and Aboagye, 2021). These results confirm several studies carried out by Sam et al. (2020), Wilkinson et al. (2022), Kaczan and Orgill-Meyer, (2020) in SSA which indicate that people migrate from their communities in response to harsh climatic conditions as a coping mechanism. Studies by Wolde et al. (2023) also confirmed that environmental and ecological factors including shifts in rainfall seasons and increased intensity and frequency of droughts are among the key drivers for migration of farmers in Sub-Sahara Africa.

6.5.4.7 Off-farm Income

Access to transport is essential for agrarian development in isolated rural areas. Over the last 20 years, most countries in Sub-Saharan Africa have seen a dramatic change in farm-to-market transport following the introduction and spread of motorcycle taxis (as it is commonly called). This motorcycle taxi is used to generate off form income for rural families, especially the youth, purchase food for the family and be able to send their children to school. So far, this has also been a spontaneous and market-driven phenomenon (Jenkins et al., 2020) in most counties in West Africa including Liberia. In Liberia, a quarter of the population (more than 2 million) is living in villages connected to the national road network by no more than a footpath (Winters, 2014). Upgrading these footpaths to a motorcycle accessible track is easy and much cheaper than feeder road rehabilitation, let alone construction. But donors and governments are reluctant to do this without hard data on the socio-economic impact of these upgraded footpaths (Starkey et al., 2017). Findings from the household survey revealed that 63.0% of the sampled households confirmed to be involved in commercial motorcycles (called Pen-pen in Liberia) as a means of getting extract monies to help purchase rice and other food stuff for their families. In addition, the extra money received from this process is also used to supplement their income when farming is poor. When asked, a chief the district, he emphasized that:

"Since farming cannot give us enough food to keep our families for the whole year, the young people ride Pen-pen to get some monies. Those that are unable to go to the cities, rent or credit motorcycle, used it to transport people where vehicles cannot go easily for money. And this has helped many families to sustain them for some years now" (Chief in Suakoko district, Bong County, January 2022).

Observation during the data collection confirmed that motorcycle business generate income for the operators and owners. This was visibly cleared that the families with commercial motorcycle (Pen-pen) were living in better condition compared to the families without commercial motorcycle. In support of this finding, Olvera et al., (2016) mentioned that a reasonable number of motorcycle drivers earn enough income from the activity to meet their day to day needs and to invest to increase human and economic assets. For instance, about 40.3% of motorcycle operators in Jigawa State, Nigeria, earn between ₦ 901 and ₦ 1,200 per ride (USD 2.97-USD 3.96) from the motorcycle operation and save an average ₦ 2000 (USD 6.65) per day (State et al., 2019). Elsewhere in the world, commercial motorcyclists have been enabled to acquire assets such as cars and houses. For instance, with incomes from commercial motorcycle transportation in Thailand, the actors have been able to procure cars for their prestige, convenience, comfort, and safety (Wankie et al., 2021). This is also in the case of other Africa countries such as Kenya where about 50% of commercial motorcycle operators in of the rural areas earn between Ksh 900-Ksh 2000 (USD 8.796-USD 19.549) per day (Zuure and Yiboe, 2017).

6.5.4.8 Livelihood Diversification

Livelihood diversification as defined by Mudzielwana et al. (2022) and Gukurume, (2013) as a process by which rural households embark on diversification of a portfolio of activities and social support capabilities for survival in order to improve their standard of living. In dryland SSA, crop production systems are characterized by inherently high rainfall variability, diversification has been used as a key adaptation strategy to reduce the production risk associated with climate variability (Seifert, 2020; Mulwa and Visser, 2020).

To reduce the risks of failed harvests and their consequences on livelihoods, most participants (65.4%) in all districts (see Table 6.2) reported to have diversified their activities to sustain their livelihoods. According to Aschinger et al. (2023) and Daidone et al. (2013), most studies farmers in SSA have adapted livelihoods diversification strategy in order to reduce that of climate variability by planting varieties of crops. This study revealed that livelihood diversification is one of the common strategies amongst rural rice and cassava farmers against the uncertainty of agricultural activities owing to climate change. From the narrations provided by the participants (KII) and observations made by the researcher, it is evident that most rural households are engaging in a mix of livelihood activities and diversified income portfolios. The following statements confirm this:

"Our area (district) is now doing somethings after the farming season to get some money to feed our families. Farming in this area is like a game, we can win or lose (i.e., gain more crops or crops failure). In this situation, we do lot of things to provide for our children and send them to school" (KII, Youth lader, Foya, Lofa County, January 2021). Similarly, a district chief in Zota has this to say:

"Most of the farmers here plant rice and cassava. Sometimes, after the farming season, where they don't have enough yield to feed their families, they began to move to other non-farm activities (jobs)such as selling in the market that have nothing to do with rainfall" (KII, District Chief, Zota, Bong County, January 2022). The deterioration in agricultural productivity at continuous level has made a substantial proportion of rural households to resort to a diverse livelihood mechanisms and economic activities throughout the years. The common activities were forms of casual labour such as weeding and harvesting in the neighbouring irrigated areas. Artisanal fishing, gold and diamond mining, and sawmills in the study areas were identified as another livelihood diversification activity. The result of this study confirmed to a study carried by Mulwa and Visser, (2020) in Namibia, which indicates that most households in rural areas use adaptation strategies linked to livelihood diversification to adapt to the increased climate variability seen in recent decades. Most households now engage in multiple non-arable farming livelihood activities to avoid destitution because of crop failure linked to climate variability (particularly drought).

6.5.4.9 Reduce Number of Meals, Reduce the Size of Diet, and Change of Stable Food

Adaptation options such as reducing number of meals, size of meals and change of staple food were tested in the study districts. Findings from the survey revealed that 64.0% (n=160) of the sampled household study areas confirmed that they have been reducing their number of meals as coping strategy in response to climate change and variability. Rural household explained that during the civil crisis and climate events (such as crops failure), they often relied on food supplies from NGOs and sometimes some religions institutions. A discussion during KII, a chief and youth leaders explained that:

"When some families are hungry because of food shortage as a result of crops failure due to lack of rainfall and increased temperature, do you think the families don't have any choice? Any food given to us at that time is accepted in order to save our lives." (District chief in Salayea, Lofa County, January 2022)

With respect to the reduction of diets and changing of staple food, 34.1% (n=160) of rural household indicated to have reduced their food diets since the 2000s when rainfall became more erratic (thereby affecting of stable food production as one of the key strategies to cope with climate variability during the dry season. Additionally, less than 35% (n=160) of the rural farmers (see Table 6.2) indicated that they changed their stable food (rice and cassava) to Plantains, corns, and eddoes as another strategy to cope with climate variability during the dry season. The findings of this study comply with that of Asare-Nuamah and Mandaza, (2020) who reported that farmers in northern Ghana have resorted to changing their food consumption behavior such as changed their staple food, reduced the size of meals per day and number of diet in response to climate change and variability. This result however has some health implications on the rural farmers because reducing food consumption can also have serious consequences on the health of such rural households, more importantly children which rather make them more vulnerable to the adverse impacts of climate variability. For example, it will affect them to various ailments that will make them more susceptible to microbial diseases (Ebi and Hess, 2020; Duchenne-Moutien and Neetoo, 2021).

6.5.4.10 Selling of Charcoal

Majority of respondents (67%) in Bong and Lofa Counties confirmed to have adopted the sale of charcoal as an alternative to off-farm coping measures for their households, especially for households whose harvest were poor due to climatic extremes. Charcoal (sometimes known as firewood) trading was reported to be another economic activity common amongst both men and women in the study areas. It was observed that selling of firewood was seen within and without the municipality in large quantities. Vehicles were often seen loaded with charcoal moving to Bong from Lofa, and to Monrovia from Bong for sale. An extract during the KII, across all districts revealed that:

"*We produced and sell charcoal to buy school materials such as uniforms, sandals, and books for our children. We also use the money to make and take care of our families' health. We sometimes use the money we get from the sale of charcoal to buy food items to* *supplement household food supply when we get little from my farm."* (District chief, Zota, Bong County, January 2022)

The researcher argues that cutting and selling of firewood from the nearby forest in the study areas may have backlashes on the sustainability of the environment as it contributes substantially to deforestation and degradation which the people must protect. This is because, selling of firewood involves the felling of trees including trees of economic value such as shea (*Vitellaria paradoxa*), dawadawa (*Parkia biglobosa*), and other species. The International Panel for climate change (IPCC (2014) posits that climate change is a threat to human life and their livelihoods. Musara (2018) highlights that what is imperative on climate change and livelihoods is to adopt sustainable livelihoods which people can cope with, maintain, and use for adaptation to stresses and shocks whilst providing benefits for other livelihoods without suffocating the natural resource base.

6.5.4.11 Relying on Governmental and Non-Governmental Organisations

The 14 years of civil and political crisis of Liberia left a pattern of problems, which made the majority of the population dependent on the supports from non-governmental organizations (NGOs) and the central government. These assistances have also been very useful in helping some rural households to cope with the shortfalls in agricultural production caused by extreme climatic events such as dry spell, and floods in the study areas. Finding from the survey, 31.4% of the rural households interviewed, indicated receiving some form of assistance from NGOs such as World Food Programme, religious organizations, and central government. This shows that certain number of the rural households in the study districts used to rely more on assistance from NGOs compared to central government assistance. As part of the survey, rural households were asked about the kind of assistance they have received from the government. Responses provided by the rural households indicated that they have received food supply such as rice, wheat, beans, oil that could keep them on a monthly basis. Furthermore, Key informants (KII) at Foya district claimed that:

"*During the 1990s through 2000s, during and immediately after the civil crisis. NGOs and the central government provided relief items including food, mattresses, and iron sheets. Households claimed that the government supplied them with food items including rice to cope with climate variabilities."* (Foya district, Lofa County, January 2022).

6.6 Adaptation Strategies

In Africa, households in dryland are frequently confronted by multiple stressors including lack of markets to sell their farm products, poor educational attainment, droughts, and economic development (Sugden et al., 2022; Voss, 2022) and as reflected in the finding of this study. Even though, adaptation may be prompted by climate events such as floods and droughts, it should be acknowledged that these adaptation strategies are taken in response to the complex interplay of both climatic and non-climatic conditions such as political, economic, and socio-environmental changes (Voss, 2022).

In this respect, it is difficult to attribute specific adaptation strategies to climate change and variability. However, it is important to stress that climate change and variability are major threats in dryland farming systems in Africa (Dhliwayo et al., 2022; Mekonnen et al., 2021), henceforth, the ability of small-scale farmers in West Africa to withstand drought and other stressors such as dry spell are seen as critical in coping with other non-climatic stressors. What follows next is a quantitative and qualitative analysis aimed at understanding the adaptation strategies that influence rural farming household's choice of adaptation strategies in the study areas. Therefore, the adaptation strategies employed by the rural households to deal with climate variability in the study districts are identifies and generally grouped into two categories, namely:

Adaptation strategies that refer to a series of agricultural management practices that are undertaken by households on the farm site, aimed at reducing the adverse impacts of climate change and variability. These strategies include the socio-demographic factors (age and gender), crop diversification, farm expansion, delays in farming, drought resistance crops, fertilizer application, irrigation method, multiple cropping, use of chicken droppings, and planting early maturing crops.

6.6.1 Determination of Adaptation Strategies

6.6.1.1 Age of Rice and Cassava Farmers in the Study Areas

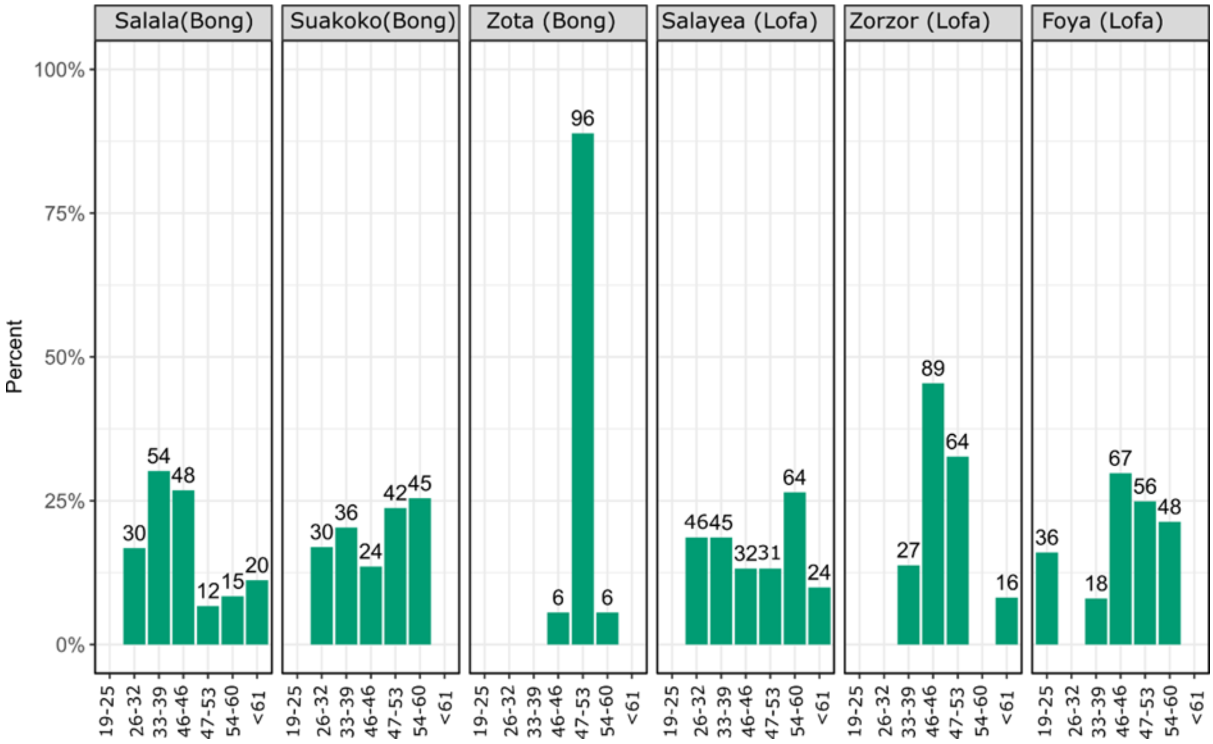

Figure 6.8 Age (years) of the rural rice and cassava's farmers in Bong and Lofa Counties.

The consideration of age in this study is a way to reflect the importance of experience. They have extensive knowledge of the reality of climate change and probably understand the necessity of adaptation to farmers' livelihoods (Amare and Simane, 2017). Similarly, Belay et al. (2022), Pande et al. (2023) also reported that the determination of the farm households' awareness and perception of extreme weather and climate change, the age of the farmer plays a pivotal role in understanding the realities of climate issues. Figure 5.8 illustrates the ages of the rice and cassava farming farmers that influence the choice of adaptation strategies. According to the analysis, the age of the farmers varied between 19 to above 61 years, with age range of the sampled rural farmers being 47-53 years, whilst the youngest aged 19-25 years and the oldest 61 years and above across all districts. As indicated, over 70 % of the sampled farmers in Salayea (Lofa) district are within the age range of 47-53 years of age. While in Zorzor and Foya districts in Lofa county, approximately 50% and 40% are within the age range 40-46 years. The rest of the districts, for example, Salala, Suakoko and Zota, (Bong), less that than 30 % of the farmers are within the age range of 33-39 years and 40-46 years, respectively. On average, more than 60% of the farmers across all districts are within the age range of 47-53 years. Agriculture in Africa has been reported to be unattractive to the youthful population (aged 19-40 years), but in recent times, the application of technologies and innovations, as well as the intensification of education and awareness of agribusiness, are gradually changing its appeal (Harris and Consulting, 2014).

6.6.1.2 Gender of the Farmers in the Study Areas

Participant's gender is presented in Figure 6.9. About 75% of the sampled households were male dominated. It is, however, interesting to note that women play an active role in subsistence agriculture in Africa and therefore contribute substantially to household food security and the eradication of hunger, especially in rural and poor communities (Adebayo and Worth, 2022; Tambe et al., 2023). Furthermore, gender is often a powerful indicator of adaptive capacity that intersects with other markers of vulnerability to constrain or enable adaptive behaviours (Voss, 2022). A growing body of literature illustrates the differentiation of climate change perceptions, impacts, and adaptations among men and women in sub-Saharan Africa (Assan et al.,2020; Carr & Thompson, 2014; Fisher & Carr, 2015; Harmer & Rahman, 2014; Jost et al., 2016; Mehar et al., 2016; Schofield & Gubbels, 2019; Sultana, 2014; Wrigley-Asante et al., 2017). These differences are attributed to the fact that women and men in rural areas, including rural Liberia, frequently occupied distinct roles on the farm and in the household, with women responsible for the majority of domestic tasks, such as childcare, and subsistence agricultural production. However, women often lack decision-making authority related to on-farm and off-farm activities; social norms can also limit their mobility and thus their ability to leverage adaptive strategies beyond the bounds of their community, as has been shown in West African countries like Mali (Djoudi & Brockhaus, 2011). Resource access, including access to climate information, market, financial resources, agricultural inputs and equipment, extension services, and even adaptation interventions themselves are also mediated by gender in many contexts, limiting women's adaptive options to those that require few such resources.

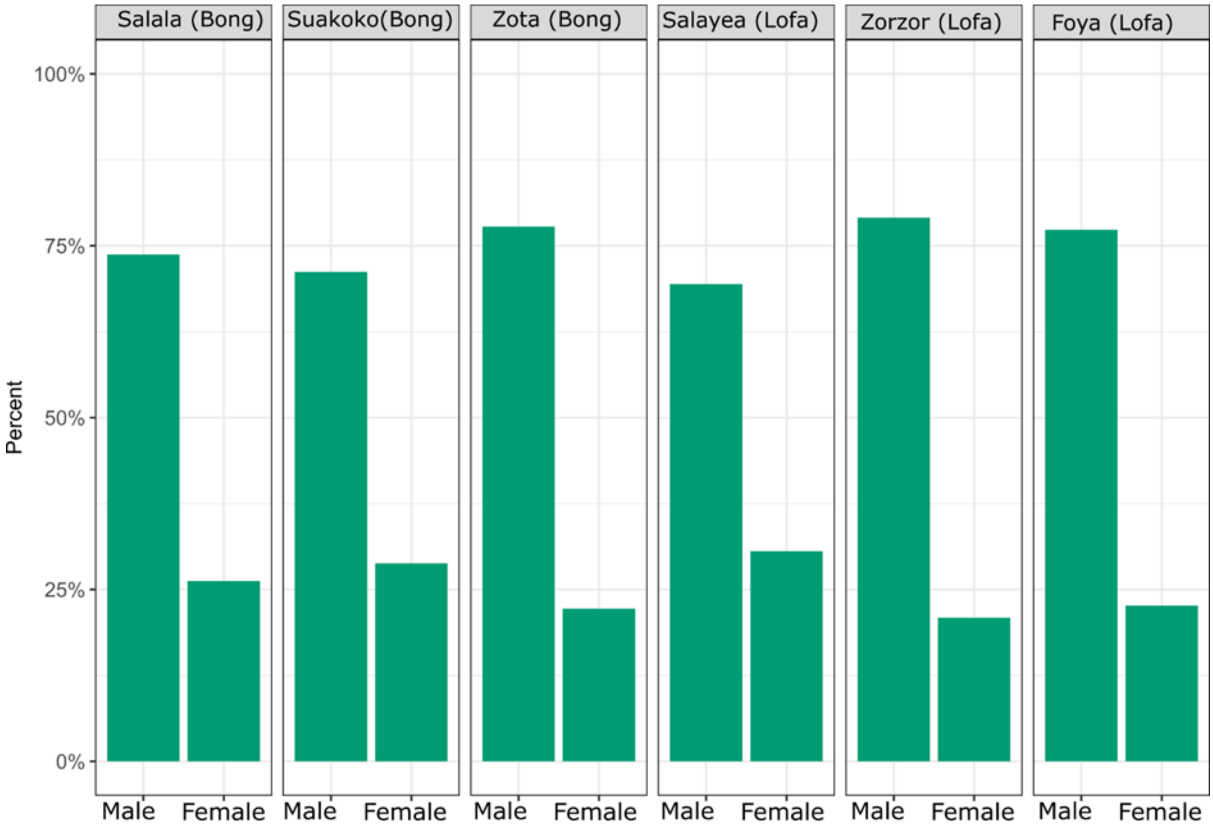

Figure 6.9 Gender of sampled farmers.

6.6.1.3 Access to Extension Services

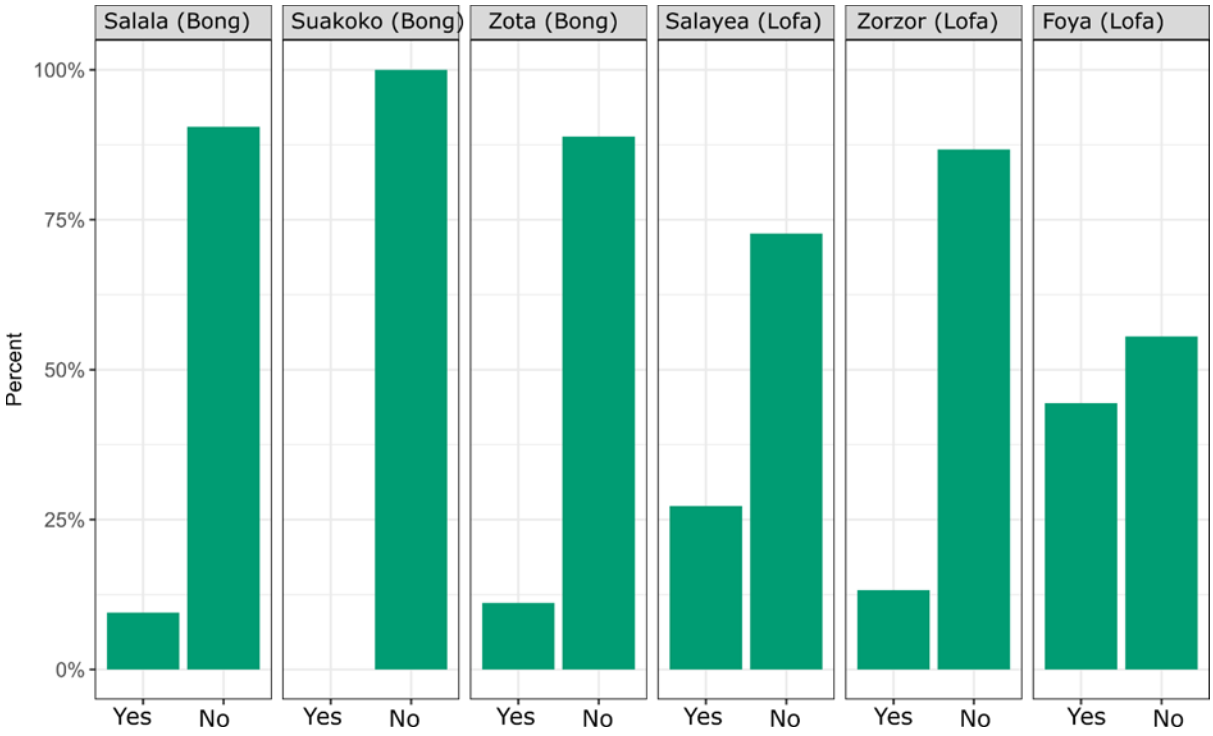

Figure 6.10 Access to extension services.

Extension service is an important source of information on climate change impacts and adaptation strategies and various land management practices. Therefore, it is assumed that accessing extension service is an important determinant of adaptation strategies in the study areas. Majority of farmers in the study areas (see Figure 6.10) indicated they have limited access to extension services which has impacted their adaptation strategies. Lack of institutional support through extension services, and the failure of Government of Liberia through the Ministry of Agriculture's extension officers to reach to the rural districts has limited the farmers access to improved varieties of crops and lack of farm implements to climate risk adaptation.

6.6.1.4 Adaptation Strategies Adopted by the Farmers in the Study Areas

In this section, farmers' adaptation strategies are reported. Before delving into the climate change adaptation strategies adopted by rural farmers in the study areas, the study considered the primary (quantitative and qualitative) and secondary sources of economic livelihoods among rural farmers. It was realized that 90% of the farmers in the study areas depended exclusively on crop cultivation (mainly rice and farming) as the main source of livelihood to provide for themselves and their families. About 10% had other sources of livelihood and remittances to support their families. This implies that strategies to manage the negative impact of climate variability and change on the livelihoods of the rural farmers are crucial, thereby compelling the rural farmers to look for adaptation strategies that enhance productivity from agriculture and improve household incomes and food security. Previous studies have argued that rural farmers value agriculture as a crucial livelihood and food security strategy, particularly among poor and vulnerable farmers (IPCC 2018). Consequently, rural farmers implement strategies that mitigate the adverse impact of climate change on their agricultural practices. Table 5.3 presents the adaptation strategies employed by the farmers in the study areas. These strategies include crop diversification, changing the timing of planting, drought resistance crops, crops rotation, planting early maturing, fertilizer application, use of irrigation facilities, chicken dropping and farm expansion. These strategies are analysed and discussed in the following sections.

6.6.1.5 Crops Diversification

Using the quantitative and qualitative data, the analysis showed that rural rice and cassava farmers are increasingly using crop diversification as an adaptation strategy to reduce yield losses associated with erratic rainfall patterns in the study districts. Different crops have different biological/physical properties and hence may differ in their sensitivities to rainfall and temperature variability (Hernández-Ochoa et al. 2020). Analysis of the quantitative data and discussions with stakeholders during the key informants' interview indicated that farmers have very clear ideas as to why they were planting different crops at the same time, using it as a risk spreading measure against total crop failure.

The results showed that 85% (n=160) reported using crop diversification as an adaptation strategy (Table 6.3). Rural households claimed that delays in rainfall events since the 1990s farming seasons added another factor to the need to diversify crops. Different crops have different biological properties and hence may differ in their sensitivities to rainfall and temperature variability (Magesa et al., 2023). Discussions with KII indicated that farmers have very clear ideas as to why they were planting different crops at the same time, using it as a risk spreading measure against total crop failure.

Youth leaders and district chiefs, also farmers in Zota and Foya emphasized similar views:

"*Planting many crops at the same time is helpful because, when one crop fails, for example due to disease outbreak because of inadequate rainfall and increasing temperature patterns, sometimes we can get rewarded by the yield from other crops and avoid total crop failure…". In areas where rainfall variability is a perennial feature, growing two or more crops on the same piece of land acts as a type of insurance against total crop failure.* (Zota and Foya districts, December 2021-January 2022). These results are similar to other studies that have been conducted elsewhere in SSA (e.g., Bedeke, 2023; van Zonneveld et al.,2023), suggesting that farmers are increasingly diversifying their crops to cope with climate variability.

6.6.1.6 Crop Rotation/Shifting Cultivation

Crop rotation/shifting cultivation is a predominant farming practice, especially in the rural areas in Liberia. During the household surveys it was established by 56% (n=160) that rural rice and cassava farmers used crop rotation/shifting cultivation as a way of increasing diversity and maintaining soil fertility (Table 6.3). The rural rice and cassava farmers in the study areas have one main farming seasons, which runs from May-October. Crop rotation and shifting cultivation is a type of farming system usually practiced in Liberia by rural farmers who do not have money to purchase fertilizer to improve their soil fertility. Rotational effects can be created because of alternating crops land in time, and this ensures that land is left for a while to gain fertility and be ready for the next farming season. Furthermore, the addition of plant residues to the soil through crop rotation has the potential to stimulate the activities of different micro-organisms (Gliessman, 2007). Incorporating temporary diversity through crop rotation also has the potential to break the life cycles of diseases and insect pests that may affect crop growth and overall productivity (Altieri and Nicholls, 2005) and, which are likely to increase due to risks associated with climate change (Gan, 2004). An extract from a KII response illustrates the importance of crop rotation/shifting cultivation:

"We can plant rice and other crops like beans and cassava in a particular area at a time then, the next planting season, we will move other land alone so that all grasses will get rotten and make the land fertile for the next season. In short, rotating land restores soil fertility, which eventually increases the productivity of the crops". (District chief in Zota, Bong County, February 2022). This result is supported by Vongkhamho and Ingalls (2023) who indicated that shifting/rotation cultivation is a dominant adaptation strategy practiced by farmers in in Lao.

6.6.1.7 Changing the Time of Planting

The results from the house household survey showed that 79.2% (n = 160) of the rural rice and cassava farmers interviewed in six districts reported changing their planting time in response to the delayed onset of the rains since the late 1990s. An extract from the Key Informant Interview (KII) illustrate that:

"When our people started farming in the 1980s, most of us used to start planting early or late March and the distribution of the rains was not as irregular as it is today. Since the late 2000s, most of us plant in late May through April to be sure of good rains. Even with that we are not sure whether the rains will continue for the crops. Consequently, the best time to plant in this district now is to wait for the second rain when you will be sure it will be sustained for enough rainfall for the crops to grow" (A district chief explained, Salala, Bong County, January 2022).

An analysis of the available rainfall data from the University of East Anglia Climate Change Unit shows that the onset of the rains, which determines the beginning of the farming season in the study areas has changed (see chapter 3), which shows that whilst the rains for planting by farmers in the districts used to start in March in the 1980s through to early 1990s, this rainfall pattern has changed and farmers had to wait until late May or early June since the late 1990s for the onset of the rains.

6.6.1.8 Planting Drought Resistant Plants

One of the adaptation strategies used by rural rice and cassava farmers, especially those in the study areas was the plating of drought resistant plants as a measure to reduce the adverse impact of crop failure due to climate variability. The result of the study shows that majority of the rural farmer 59.0% (n=160, see Table 5.1B) across all districts was the planting of drought resistance crops of such as banana and plantain (Musa spp.), which also have multiple uses. The use of drought resistant crops and plants has been reported Hawkins et al. (2024) as one of the major recommended adaptation strategies in food systems. For instance, households at Foya, Salayea, and Suakoko reported that the prolonged delayed rainfall or dry spells events of 2010 and 2011 triggered most of them to start growing these drought resistance crops. According to the KII, *households realised that rice is becoming more susceptible to climate variability, particularly dry spells.* Most rural farmers grow plantain and sometimes cassava in addition to rice. KII interviewee highlighted that: *These crops are more resistant to dry spell compared with rice and cassava and are therefore we are increasingly growing them*.

However, rural households recounted difficulties they faced with the production of these crops including the fact that they cannot be stored for very long compared with rice. Households also reported that there is a limited market for plantain compared with rice and cassava.

6.6.1.9 Farm Expansion

Farm expansion is one of the adaptive strategies used by few rural farmers (25%) across all districts, even though it is not practiced extensively by many rural farmers due to the stringent procedures to acquire farmland in most West African countries including Liberia. Farmers acquire land for rice and other crops cultivation in the study area through four mechanisms: inheritance, donation, loan, and rental. Men most frequently mentioned land acquisition through inheritance, while women mainly accessed land through donation. Land inheritance is based on the traditional lineage ownership system, where a matrilineal inheritance is applied to rice lands. For instance, when a woman passes away, her land is passed on to her sisters, nieces, and daughters based on the decision of the lineage head.

The study indicates that crop lands are predominantly owned by lineages and are often acquired through donation, particularly among the indigenous population. The two other types of land acquisition, loan, and rental are less prevalent among the population and are primarily adopted by the non-indigenous population. Furthermore, rice and other crop producers who acquire land through donation, rental, or loan are typically not permitted to plant trees on their farmland, simply because lands are loan and rented on an annual basis.

6.6.1.10 Fertilizer Application

Fertilizer applications are vital for crop growth and development, and ultimately the yields of crops. However, the farming in Liberia, particularly Bong and Lofa Counties, are facing issues due to climate change, and limited use of fertilizers and chemicals (MOA, 2013.) Approximately 37% (n= 160, see Table 6.2) of the respondents confirmed to use fertilizer to cope with climate variability. A study reported that extreme weather events and global food demands are likely to cause a reduction in crop yield, including rice production, thereby threatening food production (Omotoso et al., 2023).

6.6.1.11 Irrigation Facilities

Irrigation infrastructures are not being used much by rural farmers in the study areas. According to the household survey, 27.0% (n=160) of the sampled household confirmed to be using some irrigation methods (see Table 6.3) as a way of adapting to climate variability. A key informant at Suakoko where there are few rivers, indicated that: *households that have their owned land around the rivers, can grow vegetables such as peppers, corns, and tomatoes used traditional method such as using water to water their farms during the dry season. The KII further explained that Those farmers that are far away from the river are unable to engage in irrigation activities because they don't have the facilities and money to pay for the services. As a result of this, most farmers experienced crops failure (January 2022)*. Also, a KII explained that*, using irrigation as a way of coping during dry spell assumed greater importance especially in the districts, when rainfall variability became predominant, leading to a shortened growing season*. For instance, in the rural part of the study districts without irrigation facilities, farming is only possible from June-September whilst during the previous years (1980s-1990s) rural households could farm from March to November. The consequence of not adapting irrigation as a strategy in the study areas is captured in the following remarks by a some KIIs emphasized that:

"Having land near a river is important in this village. But not everyone in this area is able to acquire land near the river or stream. Those who are lucky to have land, grow vegetables such as peppers, corns, and tomatoes during the dry season when there are no rains to grow crops such as rice, cassava, and potatoes. The money our farmers get from the sale of these vegetables is used to buy food to feed their family" (Suakoko, Foya and Zota (Districts chief and a Youth leader in December 2021- January 2022).

This result shows that irrigation has helped few farmers that practiced irrigation to mitigate the impact of climate variability compared to those farmers who could not use irrigation method. This result is supported by Mohapatra et al. (2024); Reddy et al. (2022) who indicated that unavailability of irrigation facilities has substantially increased crop failure due to meteorological dry spell in dryland agricultural systems.

Table 6.3 Adaptation strategy adopted by the rural framers (N = 160)

Counties/districts		**Adaptation Strategies (%)**								
		Crops diversification	Farm expansion	Changed the timing of planting	Drought resistant crops	Fertilizer application	Irrigation method	Crop rotation	Chicken manure	Planting early maturing crops
A. Bong										
i.	Salala	78.4	28.2	88.3	54.0	32.3	27.4	50.1	18.0	38.0
ii.	Suakoko	86.2	17.4	71.0	65.1	42.1	42.3	55.3	19.2	47.1
iii.	Zota	88.0	33.0	82.3	55.3	39.1	17.0	58.0	23.4	49.4
B. Lofa										
i.	Salayea	90.3	21.4	78.4	61.2	38.2	25.3	62.4	20.4	42.1
ii.	Zorzor	79.4	19.1	85.3	59.0	31.4	32.1	53.2	32.2	45.3
iii.	Foya	85.1	28.4	70.4	58.1	37.1	17.4	58.1	17.3	32.4
Total (%)		85.0	25.0	79.2	59.0	37.0	27.0	56.1	22.0	42.3

6.6.1.12 Chicken Manure

Chicken manure application is also gaining prominence among few rural farmers in the study areas, as a substitute for chemical fertilizer, which is believed to be expensive. The application of manure and selling chicken is one of the on-farm coping strategies that is used by some farmers as a livelihood diversification. This finding is consistent with previous studies conducted by Antwi-Agyei et al. (2018), which showed that smallholder farmers in rural areas can adjusted their livelihood and food security strategies as a response to changing climate.

6.6.1.13 Planting Early Maturing Crops

Planting early maturing crops has also been one of the adaptation strategies used by rural farmers in the study areas to reduce their vulnerability to climate variability. The survey results indicates that 42.3% (n=160) of rural households in the study areas reported using this adaptation strategy. Rural farmers in the districts have been planting early maturing crops such as banana, pineapple as drought resistant. Additionally, the rural farmers claimed that these varieties take between less than or 90 days to mature compared with the traditional varieties, which could take four to five months. According to them, by the time seasonal delayed in rainfall sets in, these drought resistant crops would have passed the most critical stages of their development such as flowering and tasselling, which require an appreciable amount of water to produce a good harvest. By maturing earlier, these crops reduce the risk associated with climate variability. An extract from a household questionnaire open ended response illustrates the importance of planting early maturing varieties:

"We, most farmers in this area can harvest our early plantain in late July and this harvest is essential for the survival of most households in this area. This first harvest after long period of stress is used to prevent hunger and destitution" (Youth leader, Salayea district, Lofa County, January 2022).

6.7 Correlation Between Socio-Demographic Characteristics and Coping and Adaptation Strategies

Accordingly, the coping and adaptation strategies used by the farmers in the study areas have been identified and evaluated in previous section in this chapter. However, by using Pearson's correlation model, this section explores some variables (i.e., sociodemographic characteristics and perception of farmers) with some of the main coping and adaption strategies. The results from the Pearson's correlation models Table 5.4 indicates that (1) farmers' educational attainment, (2) age of the farmers (3) gender of the farmers and (4) farmers' perceptions of climate change and variability are some of the main factors influencing in farmers' coping and adaptation strategies. Some of these variables are significant at different significance levels for some coping and adaptation measures. For example, the age of the household head has a negative relationship with the likelihood of crop reduction as a reaction adaptation strategy. Furthermore, the relationship between the age of the farmers and adaptation choices is only statistically significant in the case of selecting crops diversification and crops rotation ($P > 0.05$). The correlation, however, is negatively but significant with changing crop reduction and failure ($P < 0.01$). The result indicates that old farmers are less likely to diversify their livelihood activities and access to information. The reason behind this fact is that most old household heads are illiterate and belong to the traditional custom; they therefore still cultivate as they carried out in the past, as well as not implement other coping and adaptation responses, such as migration, getting money from friends and family or finding off-farm jobs, etc.

The level of educational attainment is positively and significantly ($P > 0.05$) correlated with access to climate information, and positive significantly with farm size, crop rotation and crop reduction (>0.01). It means that educated farmers tend to focus on climate information to cope with climate stress. This result conformed to the finding of Ali et al., (2020), Chakraborty et al., (2020) who indicated that educated farmers used climate information as a coping strategy to improve their agricultural productivity. Furthermore, the results also show that gender household head statistically influenced the choice of access to climate information, changing of crops planting dates as an adaptation strategy ($p > 0.05$). By farmers contrast, farm size and crops diversification were negatively significant influenced by gender household farmers.

Farmers' perceptions of climate change and variability are found to be positive and significant correlated to access to climate information and crops diversification ($p > 0.5$), but negative relationships in the cases of changing of crops planting date. Consequently, farmers who observe increasing trends of temperature and decrease in rainfall are more likely to adapt by means of crop diversification and obtaining climate information before planting, while, unexpectedly, farmers who do not notice increasing trends are more likely to adapt by changing cropping date. The reasoning behind this is that changes in cropping patterns, for example, from rice to cassava, may not come from the perception of increased likelihood resulting in climate change and variability; but derive from the economic benefits of other crops. The next section presents findings barriers to adaptation strategies available to rural households in the study areas.

Table 6.4 Correlation between socio-demographic characteristics and coping and adaptation strategies.

Variables	**Coping strategies**			**Adaptation strategies**			
	Livelihood diversification	Access to climate information	Farm size	Changing of crops planting date	Crops diversification	Crops rotation	Food reduction
Educational attainment	0.284	0.56**	0.229*	0.001	- 0.024	0.084*	0.061*
	0.000	0.003	0.000	0.016	0.018	0.002	0.040
Age	0.161*	-0.068	0.021	0.008*	0.048	0.181*	-0.100**
	0.002	0.017	0.241	0.004	0.005	0.000	0.001
Gender	-0.160	0.138**	-0.83*	0.423**	-0.113**	0.023	0.015
	0.000	0.000	0.003	0.003	0.000	0.217	0.606
Perception	0.128*	0.461**	0.284	− 0.106*	0.183**	0.13*	0.031
	0.000	0.211	0.000	0.112	0.064	0.07	0.199

*Correlation is significant at the 0.05 level (2-tailed),

**Correlation is significant at the 0.01 level (2-tailed)

6.8 Barriers to Adaptation Strategies

To fully comprehend the risk of agriculture-dependent districts to climate variability requires exploration of the barriers that constrain the implementation of adaptation strategies. This section identified and assessed the main barriers to the implementation of adaptation strategies by rural farmers at the local levels, providing a broader understanding of the extent of risk of farming households to climate variability. This will help to provide improved guidance on appropriate interventions to enhance the resilience of agriculture-dependent districts. Documentation of farmers' perceptions of barriers to farming were based on their responses to questions on: (a) factors contributing meaningfully to variability of farm productivity and profitability; and (b) constraints to farmers' adaptation strategies. In addition, farmers' views on reducing risks and minimising constraints to adaptation were also essential.

The result of the study identified some major barriers such as limited access to climate information, lack of access to market, financial constraint, lack of subsidy from national government, and limited farm size that hindering rural farmers' ability to adapt with climate change and variability (see Table 6.5).

Table 6.5 Major barriers to adaptation strategies in the study counties.

Variables	Counties (N=160)		
	Bong (%)	Lofa (%)	Total (%)
Limited access to climate information	86.3	75.8	81.1
Limited access to market	88.8	95.0	92.0
Financial constraint	92.5	96.3	94.4
Lack of subsidy from government	96.3	97.5	97.0
Limited farm size	90.0	87.5	89.0

Although, most rural farmers are of the opinion that identified weather events (increased incidence and intensity of untimely decrease rainfall and erratic rainfall patterns and variability in temperatures), as the most critical constraints to farming by contributing to the seasonal variability of crop yields (rice and cassava) and increased irrigation costs. These factors also contributed to the deterioration of groundwater aquifers, reduce soil moisture stress and pest infestation. Despite, reduced irrigation and pesticide application, farmers are unable to control crop damage caused by dry spells and insect pest damage during the crop cycle. In addition, reduced rainfall during the reproductive stage of crops (mainly rice) development severely affected crop productivity in the study areas. Adding to this, lack of subsidy from government (97.0%) and financial constraints are also contributory barriers to adaptation. Studies have shown that access to both government and non-governmental extension support is imperative for sustainable agricultural production in West Africa (Attipoe et al., 2021). Aside this, weather uncertainties are also a key barrier, and this is often complicated by the limited access to climate services among rice and cassava farmers.

Key informants emphasised that:

"Combination of a lack of access to adaptation strategies (e.g., limited access to climate information, limited access to farm to market roads, financial constraints, lack of subsidy from government, limited size of farmland), extension services and information about appropriate adaptation measures, are some of the key barriers to adaptation." (Youth leader, Salayea district, Lofa County. December 2021).

Although few farmers received some extension support from informal extension providers, like traders, and formal sources such as NGOs, they often lack confidence in these organisations due mainly to their concerns about their motives (particularly traders). It is felt that sometimes the traders are not scrupulous in their dealings with farmer producers, particularly in relation to the provision of inputs.

Key Informant in the study areas also highlighted the lack of irrigation services as one of the barriers to adaption. According to a district chief who explained that:

"The cost of irrigation is increasing because of dry spell/rising temperatures, low soil water holding capacity and high fuel prices. Some 50-60 years old farmers also emphasized that: *"They lack ready access to soft agricultural credit. They mainly borrowed money from NGOs and commercial banks at high interest rates. Very rigid conditionality of weekly instalments for credit union and the highly bureaucratic nature of the banking operations, make the system less enabling for the farmers.* (Districts Chief, Zota district, Bong County, December 2021)

6.9 Discussion

The results illustrated in this chapter provide useful insights into the sociodemographic and environmental characteristics of the rural farmers, and the structure of the major coping and adaptation strategies that are employed by the rural farmers in the study areas to manage the adverse impacts of climate change and variability. These results on livelihood diversification as a coping strategy support other studies (e.g. Helmy, 2020; Ayana et al., 2021; Bwalya, 2023) that suggest households may pursue non-farm livelihood activities as a way of spreading the risk associated with crop failure due to erratic rainfall patterns. Livelihood diversification could increase the asset base of households in dryland farming systems. This will enable such households to separate themselves against adverse impacts of climate changes as well as economic shocks, thereby reducing their overall vulnerability to food insecurity (Chifamba, 2020; Sirba and Chimdessa, 2021). Hence, by supporting their livelihood activity portfolio, the smallholder farmer in dryland farming systems in SSA will be reducing the risks of an overall adverse livelihood outcome or production failure (Delvaux and Riesgo, 2020; Chifamba, 2020). This contributes to livelihood resilience at the household level (Gebremariyam, 2021).

The result also indicates that rural farmers reported engaging in multiple non-arable farming activities such as petty trading, selling and charcoal production to complement agricultural activities. These off-farm livelihood activities could be described as complementary activities as crop production remains the main livelihood activity for such households. Farmers reported that the profits from these activities are invested in foodstuffs to keep the household food secure after they have run out of provisions from their own farms. Key informant interview with stakeholders reported that part of the income from selling charcoal is also invested in agricultural production in terms of buying farm inputs. Such claims by farmers are consistent with other findings that suggest that income from off-farm activities such as artisanal diamond and gold mining in Ghana, Sierra Leone are invested to revive agricultural production (Osumanu, 2020; Amoako et al. 2023). Rural farmers claimed that selling charcoal is one of the most profitable off-farm activities in the areas. Stressing the significance of charcoal to households, KIIs indicated that charcoal can be easily sold during crisis because most household use that it for cooking, especially during the lean season, to raise money for the family compared with crops because there is a ready market for livestock. These views are consistent with that of Rwabukambiza, (2022) and Mashizha and Tirivangasi, 2023) who suggested that in most agriculture dependent rural African households, the availability of other off-farm activities represent wealth and serves as an important insurance mechanism because households can easily engage in off- farm activities to purchase grain.

The results further indicates that women engaged in non-farm livelihood activities such as petty trading, such as biking kala (traditional bread making using oil) processing charcoal and selling some food items such as mini shop to raise some income to make to provide for the family. Traditionally, in most west African counties including Liberia, rural women share the greater household management burden and hence are supposed to get food for the household (Archibong et al. 2020). The role of women in the study communities and Liberia more widely is socially defined. Culturally, females do all the household jobs including cooking, fetching water, washing and cleaning. In some cases, females are also obliged to help their husbands on their farms for activities such as planting, weeding and harvesting. This sometimes leaves such female farmers limited time to work on their own farms. In addition, social organisation means that most women in the study communities and rural Liberia more widely are often responsible for providing educational expenses and clothing for their children (Archibong et al. 2020). To meet these household obligations women, diversify their livelihoods into off-farm activities that require less skills and low capital expense. Despite their critical role in ensuring household food security (Mbow et al. 2020; Clapp et al., 2022), women in the study districts and Liberia more widely do not have the social and political capitals that are often necessary to participate in decisions regarding assets management for profitable investments in off-farm activities" (Nigussie et al. 2024; Adesugba et al. 2020). For example, women in many rural farming districts have limited access to resources including land and credit that will enable them to actively engage in off-farm livelihood opportunities (Ampaire et al. 2020). Mostly in rural Liberia, women find it difficulties to access financial credit from commercial banks because of lack of guarantee/collateral in order to obtain the loan. Even in cases where women may have physical assets as collateral for bank credit, these assets are usually registered in their husband's name or joint registration, making it difficult to use such assets for credit without the expressed consent of their husband. This is due to unequal power relations between women and men in such communities, where there are power imbalances against women, which further exacerbates the risk of women to climate variability (Nigussie et al. 2024; Adesugba et al. 2020). Although women are fundamental to environmental management and sustainable development, they have often been neglected or under-represented in decision-making in most rural communities relating to adaptation to climate change and variability (Ampaire et al. 2020).

It is important to emphasise that most of the coping and adaptation measures highlighted in this chapter are used by rural farmers in Liberia and SSA more widely as risk measures to reduce the negative impacts of climate variability, but that they fail to take advantage of the opportunities presented in relatively good farming seasons (Schipper, 2020; Ngetich et al. 2022). Such measures are more of coping strategies (rather than adaptive) that reduce present climate risk without necessarily accounting for future climate changes. In this regard, for adaptation strategies to be effective and successful, they should reduce present and future risk to climate change as well as increasing resilience (Naqvi et al., 2020; Mozumder et al., 2023). Climate adaptation strategies should seek to maximise the potential benefits that can be derived from a more resilient society (Keenan and Maxwell, 2022) and be consistent with national developmental agenda (see Chapter 7 for more on this).

6.10 Conclusion

This chapter builds a national and county-level risk assessment (see Chapter 4) to evaluate the main coping, and adaptive strategies used by the rural farmers in the study districts to manage the impact of climate variability on their livelihoods' activities, mainly crop food production. This was carried out considering the perceived changes observed by the households in relation to increase temperature, rainfall variability and delayed onset of rains for the farming season compared with the 1980s and 2000s. The results shows that rural farmers in the study districts employ a series of different on-farm and off-farm adaptation strategies to mitigate the adverse effects of climate variability.

On-farm adaptation strategies include changing the timing of planting, diversification of crops, planting early maturing varieties, planting drought-tolerant crops and using irrigation systems, where possible. Typically, off-farm adaptation strategies identified in the study include, livelihood diversification, reducing number of diets, temporary migration, changing food diets, and selling of charcoal. The chapter has shown that rural farmers employ coping strategies that are mostly linked to livelihood diversification. Regarding livelihood diversification, this chapter also presented empirical evidence that suggests that rural farmers in the study districts and Liberia more widely engaged in off-farm activities such as petty trading, production and selling charcoal, working as forest assistants, food vendors, and shea nuts gathering to cope with climate variability. Further, the results indicated that a household's choice of a particular climate adaptation strategy may be partly influenced by different socioeconomic factors including gender, age, educational level and land tenure system as well as agro-ecological location.

Climate change and variability continues to adversely impact on the livelihoods of many households, especially agriculture-dependent communities in dryland SSA (IPCC, 2014), presenting serious challenges to the attainment of the Sustainable Development Goal of eradicating poverty and hunger. Therefore, there is an urgent need to develop practical adaptation strategies to deal with the threat posed by climate change and variability. In their attempt to implement appropriate strategies to cope and adapt to climate variability and change, rural farmers in the study districts and SSA more generally have been found to be challenged with a number of barriers that revolve around a range of climatic and non-climatic factors. Some of the main barriers include a lack of access to markets, lack of financial resources, lack of access to climate to information on climate adaptation, complex land tenure systems due to social-cultural barriers and gender issues. Regarding land tenure, findings in this chapter demonstrate that land tenure is importantly involved in disposing female farmers by limiting the access of their access due to socio- cultural factors to land. It is significant to stress that until these barriers are focused on and addressed with appropriate solutions, Liberian government's efforts and policies aimed at reducing the climate risk of agriculture-dependent areas to climate change and variability may not achieve the desired results. By highlighting the barriers to climate adaptation, this section has contributed to this thesis by providing a detailed understanding of the main barriers that need to be addressed for climate adaptation by households in the study districts to be effective.

Policy makers should carefully consider these socioeconomic factors in the design and implementation of climate change adaptation policy in the study regions. Building on previous studies on climate adaptation in SSA (Mensah et al. 2022; Carr et al. 2022 MacCarthy et al. 2022), this chapter contributes to scientific debates on livelihood resilience at the household by enhancing our understanding of how small-scale farmers in the study communities and more widely are coping with the challenges posed by climate variability.

The implication of the findings is that policy makers should formulate appropriate and targeted climate adaptation policies and programmes that are linked to improving livelihood diversification, promotion asset building, as well as encouraging rural farmers in different farming districts to share knowledge on climate adaptation, building from the positive actions that are already been taken to manage climate change.

As highlighted in climate adaptation strategies in this study, rural farmers in the study districts, like many other SSA communities, are confronted with multiple climatic and non-climatic stresses including drought and lack of infrastructural development, and it is therefore difficult to isolate climate adaptation from other non-climate adaptations. Even though adaptation may be prompted by climate events such as droughts, prolonged delayed in rainfall or dry spells and floods, it should be acknowledged that these adaptation strategies are taken in response to the multifaceted interplay of both climatic and non-climatic conditions including political, economic and socio-environmental changes (Scheffran et al. 2023). Hence, it is recommended that feedback and drivers from these non-climate factors should be considered in adaptation policy and implementation in order to increase the effectiveness of the policy.

This chapter also provides innovative methodological steps in relation to livelihood assessment that can be used to explore coping and adaptive strategies and hence, the climate risk of a particular farming community or district. Although it is acknowledged that local-level risk assessment is very resource intensive, the innovative methodological approach drawn in this chapter is reproducible and will improve risk assessments in Liberia and more widely in the south region. This chapter has provided a more nuanced understanding of how different households could be impacted by climate variability. The next phase of this thesis is focussed on policy analysis aimed at reducing risks of agricultural production system to climate change and possible recommendations to mitigate the impact on agricultural production.

Chapter 7 Policy Documents Available to Mitigate the Adverse Impact of Climate Change and Variability in Liberia

7.1 Introduction

Based on the findings of the previous Chapters (4,5,6), this chapter recognizes policy recommendations that aim to reduce climate risk of crop production systems and livelihoods to climate variability.

To achieve this, the chapter focussed on the following specific objectives:

a. Identify policy recommendations based on the policy analysis and the findings from this research that can be implemented to reduce the vulnerability of agricultural production systems and rural livelihoods to climate variability in Liberia and other West African regions.

b. Underscore the key stakeholders in the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Convention to Combat Desertification (UNCCD) at the national level in Liberia. The UNFCCC and UNCCD are explored because these two international conventions seek to address the challenges posed by climate change and desertification, which could have negative impacts on agricultural production leading to food insecurity in Liberia.

c. Analyse the various policies aiming to tackle climate change and desertification as well as food security and examine the links and complementarity between these policies.

   The results of the content analysis of the key policy documents, together with the findings of this study (Chapters 4, 5, and 6) were presented to experts and stakeholders in a series of expert interviews from December 2021 - March 2022 to deliberate possible policy recommendations from the evidence generated in this thesis. At present, the government of Liberian has developed a National Climate Change Policy Framework and finalized document on National Climate Change Adaptation Strategy. The finding from this Chapter in the form of policy briefing will input into these national documents aimed at buffering the Liberia economic against the negative impacts of climate change and variability.

7.2 Stakeholders Responsible for the Implementation of the UNFCCC and UNCCD in Libera

The primary international tool for addressing the issues of climate change globally is the United Nations Framework Convention on Climate Change (UNFCCC) (Klein et al., 2007). Liberia signed the UNFCCC in 1992 and ratified it in November 2002 (MOFA, 2002). Regarding drought and desertification, the major international convention for addressing desertification is the United Nations Convention to Combat Desertification (UNCCD) (Stringer et al., 2007; Kong et al., 2021; Yahaya, 2022), which Liberia ratified in March 1998 (EPA, 2019). The ratification of these international conventions provided a mandate for the government of Liberia to initiate programmes and policies to address issues relating to climate change and desertification.

The Environmental Protection Agency (EPA) of Liberia, is the main institution of government established by the Environment Protection Agency Act of Liberia, 2002, mandated to formulate appropriate policies aimed at addressing issues such as environmental, climate change and desertification. It is Liberia's designated National Authority for the UNFCCC and has the mandate as the national regulatory agency for sustainable environmental management, including climate change. Section 5 of the Act creating the Environment Protection Agency of the Republic of Liberia, mandates the Agency to among other mandates (EPA Act, 2002). The EPA collaborates with other ministries and agency to ensure that policies and programmes are implemented. Prominent among these are the Ministry of Finance and Development Planning which serves as chair of the EPA's Board, Forestry Development Authority, Ministry of Agriculture, National Disaster Management Agency, Ministry of Mines and Energy, Ministry of Internal Affairs, among others. This collaboration extends to the fulfilment of Liberia's commitment to the Paris Agreement including the development of the NDC. Thus, in recognizing the need for adaptation towards impacts of climate change and variability, the Liberian Government established the National Climate Change Steering Committee (NCCSC) aimed at strengthening nationwide actions towards climate change adaptation and mitigation of GHG emissions and is located within the EPA (Figure 7.1) (GoL 2010, 2021).

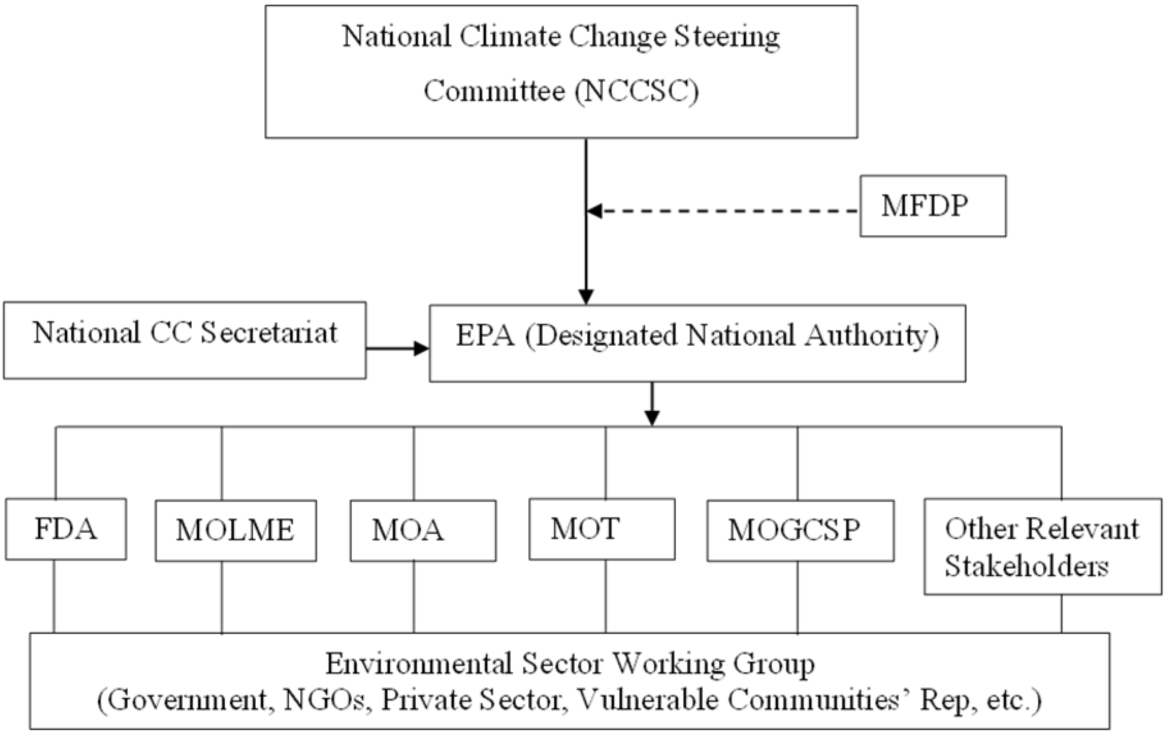

Figure 7.1 National Climate Change Steering Committee (NCCSC) (Source: EPA, 2021).

NCCSC: National Climate Change Steering Committee.
MFDP: Ministry of Finance and Development Planning.
FDA: Forestry Development Authority.
MOLME: Ministry of Lands Mines and Energy.
MOA: Ministry of Agriculture; MOT: Ministry of Transport.
MOGCSP: Ministry of Gender and Social Protection.

The NCCSC established by the President of Liberia in October 2010, also chaired by the Minister of Finance and Development Planning (MFDP) collaborates with 16 members ministries and agencies to provide high-level policy coordination and oversight. The committee is guided by expert advice from its technical working groups (EPA, 2020, 2021). The NCCSC further has the mandate to coordinate and supervise the implementation of the climate change and adaptation policies in Liberia. Established by the President in October 2010, also chaired by the Minister of Finance and Development Planning (MFDP) and its 16 members provide high-level policy coordination and oversight. The committee is guided by expert advice from its technical working groups (EPA, 2020, 2021).

The National Climate Change Secretariat (NCCS) serves as the operational arm of the NCCSC and provides coordination, monitoring, and evaluation. The secretariat coordinates climate change-related activities, accesses information, monitors key programs and activities, and promotes inter-institutional cooperation. The EPA as indicated in previous paragraph, is the Liberia's regulatory agency responsible for ensuring the sustainable usage, management and protection of the environment and its natural resources. Based on the agency's mandate, it coordinates with other ministries and agencies to implement major activities under the policy. The EPA is also the Focal Point for the UNFCCC, the Operational Focal Point for the Global Environment Facility (GEF) and the National Designated Authority (NDA) for the Green Climate Fund (GCF) (EPA, 2021).

7.3 Analysis of Relevant Policy Documents Relating to Agriculture and Climate Change in Liberia

Adaptation in agriculture requires the involvement of key local stakeholders with different, yet often interrelated points of view on climate change (Mertz et al., 2009). The latter includes individuals, groups or organisations that operate at local level and have in-depth experience in dealing with climate change (Antwi et al. 2015). Their knowledge on and experience with climate change risks is critical in taking adaptation decisions and actions.

This section presents an analysis of the main policies relating to climate change, agricultural production and desertification in Liberia. The following policy documents relating to climate change, agricultural production and desertification in Liberia considered in this thesis are:

1. Initial National Communication (INC) and Second National Communication (SNC)
2. Nationally Determined Contribution (NDC 1&2)
3. National Climate Change Adaptation Strategy (NCCAS),
4. Liberia National Drought Plan (LNDP, 2019)
5. Policies leading to agriculture sector development and national land policy (LASIP II, 2018 – 2023, FAPS, APFS, 2005)
6. National Land Policy, 2013.

These policies documents are selected based on experts' guidance and thematic analysis of different sector policy documents that highlighted agricultural production, climate change adaptation, drought, and desertification in Liberia. Giving that this study seeks to determine the extent of climate risk of crops production to climate change and variability in order to identify policy recommendations, these policy documents are important as together provide a complete picture of programmes and practices that have been formulated. In this regards, Table 7.1 highlights key themes covered in these policy documents as identified through the content analysis of the policy documents.

Table 7.1 Key Points relating to climate change and sustainable agricultural production cover in Liberia's NDC, INC, NAP, and other agricultural policy documents.

SN	Key Points relating to climate change and sustainable agricultural development	NDC 1&2	INC	NAP LNDP	Agricultural policy documents (FAPS, LASIP II, APFS)
1	Diversification of livelihood (Off-farm enterprises)	✓	✓	✓	
2	Diversification of agricultural production	✓		✓	
3	Vegetation cover management	✓		✓	
4	Developed early warning system	✓	✓	✓	✓
5	Education and public awareness	✓	✓		✓
6	Sustainable land use management and practices	✓	✓	✓	✓
7	Develop and implement alternative livelihoods programs with forest dependent people in 5 forested counties, including development of markets for non-timber forest products and ecotourism, by 2030 (Linked to Adaptation target)	✓	✓	✓	✓
8	Increase access to market	✓		✓	
9	Planting varieties of rice that are resistant to droughts,	✓	✓	✓	✓
10	Increase access to farm tools			✓	
11	Sustainable forest management	✓	✓	✓	✓
12	Strengthen agricultural climate services and early warning systems	✓	✓	✓	✓
13	Mainstream national development to climate	✓	✓	✓	✓
14	Improve institutional coordination	✓	✓	✓	✓
15	Deploy at least 1 solar water pump and/or spring irrigation system for crop irrigation for communal farms with land constraints in each county by 2030.	✓			

NDC 1&2 = Liberia's Nationally Determined Contribution (2015-2020; 2021)
INC = Initial National Communication
NAP = Liberia National Drought Plan (2020-2030)
LASIP II = Liberia Agriculture Sector Investment Plan, (2018-2023)
FAPS = Food and Agricultural Policy and Strategy, 2014-2019
NAP = National Adaptation Plan, 2019

7.4 Initial National Communication and the Adaption Climate Change Adaptation Strategy

In compliance with decision 17 CP/8; Liberia presented its Initial National Communication (INC) and the "First Adaptation Communication to the UNFCCC" in 2013 and submitted the "Second National Communication in 2021 respectively. Under the UNFCCC, Liberia is required to implement appropriate programmes to ensure the integration of climate change challenges into national development planning (EPA, 2013, 2021). The economy of Liberia being heavily dependent on rain-fed agriculture, with more than 70% of the population depending on rain-fed agriculture for their livelihoods (LISGIS, HIES, 2016) needed national programmes to ensure crops productivities. Therefore, there is the need to develop appropriate strategies to mitigate the adverse impacts of climate change and variability (such as drought and dry spells) on livelihoods.

The First INC is Liberia's national climate change document seeking to address key issues such as national greenhouse gas (GHG) inventory, vulnerability and adaptation measures, and mitigation of GHG emissions. This document focuses mainly on four key sectors such as Agriculture, Energy, Forestry, and Waste, that has not only contributed to a better understanding of the sources emissions of greenhouse gases within Liberia, but also identified some important sectors of the national economy that could be adversely affected by climate impacts such as coastal zones and agriculture (EPA, 2013). Additionally, the SNC gives an account of many climates change adaptation and mitigation initiatives and efforts undertaken in the country. The SNC also highlights on climate change vulnerability and adaptation assessment, national greenhouse gas inventory, greenhouse gas mitigation assessment, climate change technology transfer, and development assessment and capacity building to address climate change-related impacts which are linked to UNFCCC (EPA, 2021).

Similarly, Liberia also developed the Nationally Determined Contributions (NDCs 1&2) to the United Nations Framework Conventions on Climate Change (UNFCCC) Secretariat. The NDCs are at the core of the Paris Agreement (PA)(EPA, 2018, and 2021), under which 191 countries, including Liberia, members countries are committed to limit global warming to "well below 2 degrees above preindustrial levels," and to pursue efforts to limit the temperature increase to 1.5°C. NDCs are the delivery mechanism to reach the PA goals and achieving the overall global greenhouse gas (GHG) mitigation target, embodying efforts by each country to reduce national emissions and adapt to the impacts of climate change. These NDCs are expected to reflect increased ambition, whether in terms of strengthened targets, accelerated timelines, or a broader scope covering additional sectors or greenhouse gases. Liberia submitted her first NDC in 2015 and submitted the revised version in 2021 as required by the Paris Agreement (EPA, 2015, 2021). The first NDC recognizes current and future threats of climate change and describes some efforts and initiatives that have been undertaken by Liberia to address climate change threats (EPA, 2015). The second NDC, focuses to reducing its economy-wide greenhouse gas emissions by 64% below the projected business-as-usual level by 2030. This could be done through a combination of unconditional greenhouse gas reductions of 10% below business-as-usual, resulting in an absolute emissions level of 11,187Gg CO2e in 2030. The NDC 2 also aimed at adding 54% reduction conditional upon international support, which would result in an absolute emissions level of 4,537Gg CO2 e in 2030. The NDC 2 also highlights a national system for monitoring and evaluation (M&E) for adaptation actions, and measurement, reporting, and verification (MRV) for mitigation actions. It states the policy and institutional arrangements for NDC 2 implementation, which includes an analysis of the co-benefits of adaptation and mitigation and highlights the direct and indirect investment needed to implement the NDC (EPA, 2021). Furthermore, the National Policy and Response Strategy on Climate Change (NPRSCC) was developed, primarily to identify ways to increase the country's resilience to reduce the adverse impacts of climate variability. The NPRSCC adopts a cross-sectoral and participatory approach in highlighting the major sectors of the Liberian economy (Forestry and Wildlife Policy, agriculture, health, tourism, mining, energy, fishery, water resources, industry, transport, Infrastructure, Urbanization and Settlement) that are particularly at risk to climate change (EPA, 2018). The NPRSCC is the product of various vulnerability and adaptation assessments that have been conducted since 2002 by multiple stakeholders including experts from the country's national universities and other research institutes, governmental ministries, and agencies as well as NGOs under the United Nations Economic Commission for Africa (UNECA) for the development of the National Policy and Response Strategy on Climate Change of the Republic of Liberia (EPA, 2018). Hence, the NPRSCC identifies adaptation strategies for various sectors. For agriculture, the NPRSCC identifies programmes including the promotion of alternative livelihoods, enhancing early warning systems as well as encouraging agricultural diversification and improved land use management practices. The next policy developed by Liberia to address drought and desertification is the Liberia National drought Plan.

With respect to the implementation, the EPA is mandated to have a supervisory role. At the national and county level, the EPA is assisted in its supervisory role by the National Climate Change Steering Committee (NCCSC) that is represented by an Act, experts from governmental ministries, and agencies (EPA, 2020, 2021). The EPA exercises its role as supervisor over the various ministries and agencies who are supposed to implement the programmes and practices identified in the NCCSC (Figure 7.1)

7.5 Liberia National Drought Plan

Drought related crop failure has been well covered in some policy documents (EPA, 2018 2019). As a signatory to the UNCCD and a country that considers itself affected by desertification, Liberia was obliged to prepare a National Adaptation Plan (NAP) to combat drought and mitigate the adverse effects of desertification. The EPA, which is mandated with the responsibility of preparing this action plan, developed a national action plan in 2019 that was submitted to the UNCCD secretariat. The objective of the NAP is to "emphasize environmentally sound and sustainable integrated local development programmes for drought-prone semi-arid and arid areas, based on participatory mechanisms, an integration of strategies for poverty alleviation and other sector programmes including agriculture, forestry, health, industry and water supply into efforts to combat the effects of drought" (EPA, 2021).

In Liberia, agricultural production and farming practices have been negatively affected by reduced soil moisture, greater difficulty in identifying the optimal time to plant crops and more frequent occurrence of pets, weeds, and animal diseases (EPA, 2018) These changes are occurring within a country already at risk to climate change and variability by unsustainable logging and high level of charcoal and firewood consumption and decreasing river flow due to evaporation (EPA, 2018). Hence, desertification affects the livelihoods of many land users (EPA, 2018). An estimated proportion of Liberia's landmass affected by desertification and land degradation is still minimum, the upsurge in extreme climate events documented in both the Liberia National Adaptation Program and the National Policy and Response Strategy on Climate Change (NPRSCC), especially changing rainfall patterns, are giving reasons for serious concerns (EPA, 2018).The policy and strategy document ensures that climate change adaptation and mitigation issues are mainstreamed at the policy level and in key sectorial and cross-sectorial development efforts. The NPRSCC includes concrete policies and measures in specific areas such as agricultural production, forestry, fishery, energy etc on climate change adaptation and mitigation, actions, resource mobilization plans, and monitoring and evaluation framework.

The UNCCD seeks to promote and encourage the use of participatory approaches to combat drought and desertification (UN, 1994) despite the challenges this brings (Stringer et al., 2007; Kong et al., 2021; Yahaya, 2022). Particularly, the UNCCD advocates the involvement of women, youth, and NGOs (UN, 1994). Hence, the Liberia's NAP was prepared because of extensive regional and district level consultative workshops on desertification and promoted active participation of local communities in addressing the challenges posed by desertification and land degradation (EPA, 2019). The NAP focuses on six sectors that are priorities of the Government of Liberia in its efforts to adapt to the impacts of climate change (EPA, 2020):

i. Adaptation programmes for the agriculture sector
ii. Management of coastal zones
iii. Sustainable use of forestry resources,
iv. Energy resource management,
v. Waste management and
vi. Fisheries development.

Most of these sectors cover adaptations which are considered central to achieving food security by sustaining rural farmers that are threatened by land degradation (EPA, 2020). Specific actions that seek to promote adaptation within these sectors include, but are not limited to, promotion of off-farm enterprises, provision of credit to farmers, agro-forestry, promotion of organic farming, creation of green belts around water bodies and improving marketing of agricultural products as well as provision of better road networks linking rural farming communities. Further, efforts to improve the socioeconomic environment for poverty reduction, there is a food security action plan that highlights different programmes such as the development and promotion of drought-resistant crops. The agro-forestry practices as highlighted in the NAP, could promote rural development whilst mitigating climate change through carbon sequestration or capturing and storing atmospheric carbon dioxide (EPA, 2020).

7.6 Policies Leading to Agriculture Sector Development and National Land Policy of Liberia

Since the end of the civil and political crisis in 2003, Liberia has developed several policies and strategies gearing towards agricultural production in the country. Some of these policies and strategies include:

1. Food and Agricultural Policy and Strategy (FAPS), 2014-2019
2. Liberia Agricultural Sector Investment Programme, (LASIP II), 2018-2022
3. Agricultural Policy and Food Security in Liberia (APFS), 2005
4. Land Rights Policy, 2013

These documents provide broad policy and strategy measures for agricultural sector in Liberia that guide the development and interventions linked to food and agriculture production (Tefft, 2005; Hendriks, 2018; MOA, 2012,2018, 2023; LC,2013). For instance, the FAPS highlighted few policy objectives such as to revitalize and modernize food and agriculture sector that is contributing to shared, inclusive and sustainable economic growth and development of Liberia by; Making safe and nutritious foods available in sufficient quantity and quality at all times to satisfy the nutritional needs of all Liberians; ensuring inclusive and pro-poor growth in agricultural production, mainstreaming environmental considerations in agricultural programmes, monitor sector activities to prevent contribution to climate change, reduced impact of climate change in sector, value addition and diversification of agricultural production, and linkages to markets; and building effective and efficient human and institutional capacities of stakeholders to plan, deliver services, while concurrently sustaining natural resources, mitigating risks to producers and mainstreaming gender and youth considerations. The document further proposes the improvement of other support services to food and agriculture, including extension and advisory services, agricultural education and training, agro-business and market development, agricultural research, and development, improving production services like seeds, fertilizer, pest, and disease control, etc. The Policy also emphasizes on social development with a focus on gender issues, youths, and vulnerable groups. Similarly, the LASIP II has four policy objectives: (1) ensure food and nutrition security of the population and strengthen the resilience of vulnerable populations and their livelihoods; (2) diversify the economy through robust agricultural value chains and a modern industrial policy to increase production, productivity and incomes; (3) improve research and extension services to support the transformation of agriculture; and (4) manage responsibly and sustainably the unique natural resources while adopting agricultural practices that maintain the ecological and biological integrity of natural resources (Hendriks, 2018). Furthermore, The Agricultural Policy and Food Security in Liberia is aimed at improving access to food through broad-based participation in income-generating activities in key agricultural supply chains, together with the development of safety nets that protect the welfare of Liberia's diverse types of vulnerable individuals and households represent two of the major food security challenges facing the Liberian government after fourteen years of civil conflict (Tefft, 2005). The major emphasis of these policies is to increase food production in Liberia.

The 2013 Land Rights Policy provides policy recommendations for all individuals and are distinguished into categories (Public Land, Government Land, Customary Land and Private Land) and a cross-cutting sub-category (Protected Areas). The policy aims at ensuring that Liberian’s law sector is orderly, just and contributes to economic growth and development for all Liberians. Overriding principles of the policy are among others: secure land rights, economic growth, equitable benefits, equal access, equal protection, environmental protection, and participation. In some cases, land title may be invested in a particular clan or families. The main policy provisions of the national land policy include facilitating equitable access to land, ensuring sustainable use of land, guaranteeing security of tenure and protection of land rights, and enhancing land capability and land conservation (LC, 2013). In terms of equitable access to land, the Constitution gives all Liberians "the right to own property alone as well as in association with others," which means land ownership is permitted for all Liberians regardless of their identity, whether based on custom, ethnicity, tribe, language, gender, or otherwise. This is a fundamental constitutional principle that has informed every part of the Land Commission's Policy recommendations.

7.7 Complementarity Analysis Between the Various Policies Document in Liberia

Analysis of relevant policy documents, through content analysis suggests mostly that there seems to be complementarity between the NDC 1&2, INC and NAP and other policy documents (Tefft, 2005; Hendriks, 2018; MOA, 2012, 2018, 2023; LC, 2013) relating to agricultural production (e.g., crops) in Liberia. Most of the measures aimed at reducing land degradation and desertification identified in the NAP under UNCCD seek to strengthen the coping capacity of farmers to climate variability (particularly drought and dry spells). For instance, the development and promotion of drought resistance crops identified in the NAP as an adaptive strategy is also linked to increasing resilience to climate change (NDC 1&2 and INC). Further, the NDC 1&2, INC and NAP recognised the need to diversify agricultural production to become less dependent on rain-fed agriculture. The various agricultural policies of Liberia are appropriately aligned to Liberia National Development Agenda such as the Pro-Poor Agenda for Prosperity and Development (PAPD), and long-term sustainable development vision for 2030 (AfT, 2023). The alignment of these documents is crucial in facilitating NDC 1&2, INC and NAP implementation through the public investment framework.

Agriculture being the backbone of sub-Saharan Africa (SSA) economies, including Liberia, contribute substantially to its Gross Domestic Product (GDP) and plays a significant role as a source of livelihood for majority of Africans (Antwi-Agyei et al., 2021; Jerome and Ajakaiye, 2019; Usman, 2022). The attainment of the Sustainable Development Goals (SDGs), particularly Goals 1 (alleviate poverty), 2 (achieving food security and improved nutrition), and 13 (climate action) and the Nationally Determined Contributions (NDCs) under the Paris Agreement is contingent on enhancing the resilience of the agricultural sector, and yet the agricultural sector is arguably the most vulnerable sector (Serdeczny et al., 2017).

Mainstreaming climate change adaptation strategies into national developmental agenda as widely discussed in the literature (Sorgho et al., 2020), will play a leading role in climate change adaptation in Liberia, and also works in close collaboration with the Ministry of Finance and Development Planning (MFDP), which oversees the development and implementation of appropriate developmental activities. The NDCs 1&2 and INC specifically highlights strategies to integrate national climate change concerns into Liberia's national development. These include reducing the emission of greenhouse gases by promoting the use of highly energy efficient appliances as well as the application of clean energy technology (EPA, 2013, 2021). Additionally, the need to reduce agricultural sector dependence on rain-fed farming systems is emphasized in the Liberia National Development Agenda such as the Pro-Poor Agenda for Prosperity and Development (PAPD), and long-term sustainable development vision for 2030 (AfT, 2023), which seek to promote rural development and livelihood diversification (PAPD, 2018; MPEA, 2012). The PAPD is a five-year national development plan aimed at addressing the basic needs of Liberians better access to basic services and greater opportunities for self-improvement in an enabling environment that is inclusive and stable. The alignment of PAPD with the African Union Agenda 2063 and Sustainable Development Goals (SDGs) across all three sustainability dimensions such as economic, social, and environmental issues. While at the same time, the Aft recognizes climate change adaptation and mitigation under Pillar V as a cross-cutting issue. This could, indirectly, improve rural households' abilities to withstand climate variability as it enhances the financial assets base of such households.

Whilst there are shared goals across the policies that have been examined, there are also some skirmish policies among some documents. For instance, whilst the threat of climate change is clearly recognised in the NDC 1&2, INC 1&2 and NAP, the agricultural policy documents did not articulate specific measures to help farmers to cope with the adverse impacts of climate variability on their livelihoods. Further, the NDC 1&2, INC, NAP, and the various agricultural policies did not to recognise fully the need to integrate local knowledge in finding solutions to the problems posed by climate change. Certainly, one of the key adaptation strategies identified in Chapter 6 is the use of local knowledge including diversification of crops and livelihood activities to cope with dry spells. However, none of these policy documents highlighted this as a means of enhancing the coping capacity of rural households in farming communities in Liberia. Local people have coped with dry spells-related food insecurity with different practices, and these should be promoted in policy documents. This could facilitate the implementation of adaptation strategies as rural areas will appreciate and own such policy options.

7.8 Policy Recommendations to Reduce Climate Risk

As indicated in previous section (i.e., 7.1), the findings of this study, together with the major issues that emerged from the analysis of various policy documents (Table 7.1), were presented to experts in a series of expert interviews and discussions, in order to obtain possible policy implications of this study. Table 7.2 shows the key policy recommendations that were highlighted by 9 sampled experts during the field survey from December 2021-March 2022. According to the findings, across three institutions (EAP, MOA and LISGIS), mentioned land tenure reform 77.7%, improve access to market 100.0%, increase education and public awareness and livelihood diversification 66.6%, provision of credit facilities and subsides 44.4%, use of drought resistance crops 88.8%, and crop diversification 77.7%.

Table 7.2 Linking experts' quotes to the coping and adaptation strategies from the survey conducted in 2022.

SN	Policy option	No. of experts	Quotes by experts	Study result from Chapter 6
1	Land tenure reform	7	"The tenure system in Liberia need to be reformed so that it will be accessible for agricultural production." (Experts: MOA, EPA, LISGIS)	From the results in Figure 6.5, the average farm size across all districts is about 1-5 acres, which is the dominant farmland for subsistence farming in the study areas. From Table 6.1B, expansion of farmland is one of the major adaptation strategies. The survey results revealed 25% of farmer across all districts could expand their farmland as an adaptation measure to mitigate the adverse impact of climate in the study areas. Experts' recommendation from the field survey indicates land reform. The application of this recommendation by policy makers will enhance more farmers to expand their farmland.
2	Improve access to market	9	"Farms to market roads are very deplorable. It prevents many rural farmers from carrying their farms product to the market to be sold. Therefore, there is need to improve farm to market roads so that farmers will be able to get to the market to sell their farm products." (Experts: EPA, MOA, LISGIS).	Based on the results of Figure 6.6, more than 70% across all districts do not have access to markets due to poor road conditions. The result of the study is linked to the recommendation from experts during the survey. If this recommendation is implemented by decision makers will improve market to farm roads which will enable farmers to cope with the adverse impact of climate change and variability.
3	Increase education and	6	"Education and public awareness are very importance for farmers. Even though, majority of the rural farmer in	From the study, the educational levels of farmers were low across all districts, as more than 25% of the survey household heads did not acquire any formal education in Salala, Suakoko, Zota (Bong County), Salayea and

	public awareness		Liberia are illiterate, but GOL need to embark on education so that they can be aware of climatic situation. Moreso, farmers need to be educated on the threat of climate change to the populace to increase the awareness of climate change." (Experts: EPA, MOA).	Foya (Lofa County), while less than 20% in Zorzor (Lofa County), respectively (Figure 6.2). While at the same time, majority (> 70%) of farmers have no access to climate information, and less than 30% reported to have limited access to only weather information without consideration for trends of rainfall and forecasts, economic analysis on impacts of climate change on food prices, and counselling of farmers on adaptation strategies (Figure 6.8). Based on experts recommended, GOL should embark on encouraging farmers to be educated so that they can be aware of the threat's climate change and variability.
4	Livelihood diversification	6	"The Government of Liberia (GOL) need to encourage farmers to diversify their livelihood activities into off-farm income activities that are less vulnerable to the changing weather condition." (Experts: EPA, MOA)	The study results revealed that 65.4% of farmers across all districts (see Table 6.2) reported to have diversified their activities to sustain their livelihoods. This result is link to the recommendation of experts during the field survey.
5	Provision of credit facilities and subsides	4	"Government of Liberia through the commercial banks should provide credit opportunity to farmers to expand their farmland and purchase farms tools. The GOL, should also provide subsidies to farmers." (Experts: MOA, LISGIS).	From the field survey, almost all the sampled household (96%) indicated that they have no credit facility to carry out their agricultural productions. Most of the money generated are obtained from friends and relative at the start of the farming season. Based on experts' recommendation, provision of credit as to farmers will enhance farmers to expand their farmland and purchase tools as a means of adapting to the adverse impact of climate change and variability.

6	Use of drought resistant crops	8	“The GOL, through its relevant ministries and agencies should encourage rural farmers to adopt new crop varieties that are drought resistance and early maturing. More research is needed in this direction.” (Experts: EPA, MOA, LISGIS)	The study results also revealed that 59.0% of the sampled farmers (Table 6.3) across all districts was planting drought resistance crops of such as banana and plantain (Musa spp.), which also have multiple uses. Experts’ recommendation revealed that GOL encourage farmers to planting drought resistant crops as a means of adaptation strategies.
7	Crops diversification	7	“Planting variety of crops important. Rural farmers should be encouraged to plant various crops to avoid the adverse impact of climate change.” (Experts: MOA, EPA, LISGIS).	From the survey 85% of the sampled household reported using crop diversification as an adaptation strategy (Table 6.3). The farmers claimed that delays in rainfall events since the 1990s farming seasons added another factor to the need to diversify their crops. This results also link to experts’ recommendation from the survey which indicated that farmer should be encouraged to planting varieties of crops to mitigate the impact of climate change and variability.

MOA = Ministry of Agriculture
EPA = Environmental Protection Agency of Liberia
LISGIS = Liberia Institute of Statistics and Geo-Information services

Experts in these institutions were asked to rank and discussed the policies most likely to improve current climate situation of farmers in Liberia. Most of their policy recommendations agreed with the main points identified in prevailing policy documents including the NDC 1&2 INC, NAP, and other agricultural policy documents in relation to climate change adaptation and agricultural production in Liberia (Table 6.1). For example, the use of drought resistance crops, provision of credit facilities, agricultural diversification and strengthening extension services (see Table 6.1) are all highlighted in the various policy recommendations (identified through expert interviews indicated in Table 6.2). The were specified policy options that arose from the expert interviews and discussion that are not included in the existing policy documents. These include the development of county-specific adaptation policy and encouraging weather-based insurance schemes. Others include integrating local knowledge with scientific adaptation assessments to cope with delayed rainfall (dry spells). Therefore, it is recommended that future reviews of the existing policies as highlighted should take appropriate cognisance of these policy options that arose from expert policy interviews and discussion whilst at the same time promotion efforts to implement those options already covered in the existing policies. Moving forward, this study considers each of the policy recommendations identified from the expert interviews and discussion and expanded on in the next sections.

7.9 Land Tenure Reforms to Increase Accessibility to Lands by Farmers

Access to land is one of the major challenges facing farmers in Liberia. Land tenure challenges in Liberia is due to the confusion that exists on a range of legal, administrative, boundary, claim, and ownership status. The link between such confusion and wide-ranging land tenure insecurity is specific (Unruh, 2009). With little clarity regarding different types of ownership, which rights are held by whom and how, how disputes are resolved, where boundaries exist, and who the authorities are in land matters, the resulting insecurity of claim, residence, food supply, and investments (small and large) is high (GRC, 2007). Specific challenge that requires attention is the issue of gender and land tenure in relation to sustainable development which has attracted wide attention from gender activists, civil society, and development partners (Uwayezu, 2023). Access to and ownership of farmland remains one of the greatest challenges confronting farmers, especially female farmers in the rural areas, in implementing appropriate climate adaptation strategies (see Chapter 5). Though, women's land rights and tenure security are increasingly seen as important, for reasons of gender equity, to promote economic growth and development, and to reduce poverty. They are gaining prominence on the international agenda since two of the Sustainable Development Goals (SDG) indicators (5.A.1 and 1.4.2), which focus on women's land rights (Statistics, 2019; Leboeuf, 2018). Women access to land; security of ownership is generally not always guaranteed. There remain cultural biases and discrimination against women in terms of access to and ownership of land in the study areas. This is very common in most SSA countries (Supraptiningsih et al., 2023; Guo and Akudugu, 2023; Uwayezu, 2023). As cited in Chapter 5, inheritance of farmland by female is through male heir and female right of usufruct is not recognised by the traditional land inheritance system (Unruh, 2009). Hence, women access farmlands through marriage or male children. Experts and policy makers in a series of interviews and discussions stressed the need to reform the land tenure policies in Liberia. Based on these findings, the thesis makes the following policy suggestions:

- Women's rights regarding land ownership are not comprehensively covered in the current national land policy. Hence, there is the need to institute appropriate measures to reduce or eliminate these cultural discriminations against women. This could be achieved by restructuring the land tenure system to ensure that the rights of women on land ownership are fully recognised and granted. This will require intensive education programmes to sensitise chiefs and other opinion leaders who are custodians of farmlands in these communities, on the need to recognise women in decision-making relating to land tenure arrangements.
- The government of Liberia should also encourage block farming, whereby the government rents a vast area of farmland and distributes this to various households to produce various agricultural crops. Households may be provided with farm inputs such as seeds and fertilizers. This affords vulnerable households, which otherwise would not be able to access such farmlands and inputs, the opportunity to improve their livelihoods. This will be particularly a policy intervention for marginalised female-headed households that are culturally discriminated by land ownership and acquisition practices in the study areas. Careful criteria would need to be drawn up to determine eligibility.

7.10 Improved Access to Markets by Farmers

Access to market is one of the fundamental challenges faced by farmers in Liberia, especially the study areas. Whilst better access to markets allows rural farmers to reliably sell more produce, at higher prices and with better quality, but this is not case for rural farmers in Liberia. The lack of readily available markets (chapter 5) in the study areas is perceived by rural households sampled as a barrier to effective climate adaptation as it limits options.

Therefore, during the experts' consultations and interview, the following policy recommends were made:

- The Government of Liberia, through its principal agents such as the Liberian Produce and Marketing Corporation (LPMC), could make special arrangements to purchase food stuffs from farmers especially during the peak period where farmers find it extremely difficult to access markets for their produce. In this case, farmers could be guaranteed a pre-determined price for agricultural produce to encourage farmers to produce more.
- Concerted efforts should be made to improve road infrastructure and transport to facilitate the transportation of farm produce to the market centres to enable farmers to sell their crops to pay off their feed their families and settle some basic family's commitments. Certainly, lack of transport in the areas does not enable rural farmers to get their produce to market thus limiting them to the immediate area to sell produce (Rivero et al., 2022). Therefore, there is also a need to improve roads into the fields to get the produce from the fields to the 'markets. Access to transport would indeed improve the road networks in the rural areas to get their produce to the market.

7.11 Better Education and Awareness on Climate Change

Educational level of household heads was assumed to be a significant determinant of coping and adaptation capacities to climate change. This is because attaining a higher level of education is more likely to provide a better understanding of climate change impacts and the strategies to mitigate them. Unfortunately, educational levels of the study areas are low (see Chapter 5). Farmers' willingness and ability to adapt agricultural systems depend on their knowledge about changes in climate and perceived risks of extreme events (Mairura et al., 2022). Though, households perceived increasing temperature and a decreasing rainfall amount in the study counties. These observations can be put into perspective in terms of climate adaptation. Rural farmers are more likely to invest in adaptation strategies if they can perceive changes in the climate (Thinda et al., 2020). In this regard, the following policy actions are proposed for the Government of Liberia (GOL) to consider:

- Environmental education aimed at creating awareness of the changing climate patterns and the associated adverse effects on the livelihoods of many agriculture-dependent communities should be promoted. As indicated, the Marrakesh Accord encourages parties to the UNFCCC to build capacity in climate change by improving education and public awareness of the menace of climate change. In this case, environmental education should be vigorously pursued under the national educational curriculum. This will ensure that children grow to adopt environmentally friendly lifestyles. Although such environmental education is highlighted in the NAP, further efforts are needed. Perhaps the slow progress to date is due to a lack of funds and may the political will to implement appropriate programmes that will endear environmental education into the citizenry.

- National educational institutions should be encouraged and promote the teaching and learning of issues relating to sustainable development and climate change through the establishment of sustainability school curriculum across Liberian schools (high school), to inculcate the ideas of green behaviour and green consumerism into the Liberian society.
- To encourage and motivate researchers, it is suggested that GOL, through the EPA, establishes a special fund dedicated to funding research activities relating to climate change issues.

7.12 Livelihood Diversification

Rural households have several ways to diversify their incomes. For instance, beyond farming crops, they can rear livestock, run small businesses to sell and buy goods from village-to-village markets or from rural to urban markets, or household members can migrate to other cities or countries to look for additional financial resources for the family.

Livelihood diversification 66.6% (n = 9) of the experts that were interviewed highlighted the need for farming households to diversify their livelihood strategies to be able to cope with the impacts of climate variability and change. Results from Chapter 6 suggest that households that undertake a wider range of livelihood activities were less vulnerable to the adverse impacts of climate change and variability, while households that depend solely on crop farming were more vulnerable. Based on these findings, the thesis suggests the following policy actions:

- As highlighted in Chapter 6, selling of charcoal is one of the principals off farming alternative livelihood opportunities, especially for households in the study areas. Hence, efforts should be made to develop local expertise aimed at enhancing the production of livelihood activities in these districts through regular meetings on off-farm production.
- Appropriate programmes that seek to foster asset building such as skills training and craftsmanship should be integrated into the national climate change adaptation

strategy to enable farming communities such as those in the study counties to venture into off-farm livelihood strategies.

7.13 Credit Facilities and Subsidies on Agricultural Inputs

Results from Chapter 5 suggest that lack of financial resources constitutes a major barrier to climate adaptation by households in the study districts. Most of the experts (86%; n = 9) shared the opinion that farmers should be given adequate credit facilities to enable them to implement appropriate climate adaptation strategies. Also, lack of financial resources was mentioned as a major barrier to climate adaptation. Hence, there is the need to make credit facilities accessible to small-scale farmers to enable them to purchase the necessary agricultural inputs at the appropriate times of the year. In this regard, the following policy actions are proposed:

- The Government of Liberia should liaise with commercial banks to extend credit facilities to farmers because most farmers cannot provide the necessary collateral that banks demand for the provision of credit. The government of Liberia through its agencies such as the Ministry of Finance and development Planning (MFDP) can act as guarantor to facilitate this.
- In Chapter 5, the thesis demonstrated that timing of financial assistance to farmers is critical. It is significant to stress that it is most desirable to give financial assistance to farmers at the beginning of the farming season when they need to e.g., hire tractors to prepare their farmlands and purchase farm inputs to take advantage of the early rains. This means that the processes involved in granting credit facilities and loans to farmers should be initiated well in advance of the farming season.
- The GOL should give to famers in the form of agricultural inputs such as fertilizers, seeds, and other agrochemicals (Konadu-Agyemang, 2000). This has had serious repercussions for agricultural productivity. The next review of the agricultural policies documents should give considerable attention to this policy recommendation.

7.14 Development of Drought Resistance Crops

One of the major findings from Chapter 5 is that households are using drought resistant crops to cope with climate change but most of them lack the financial resources to access such varieties. It is therefore recommended that policy makers should enact appropriate policies that will improve the accessibility of drought resistant crops to farmers. This thesis suggests the following policy actions:

- The Government of Liberia should make credit facilities more accessible to rural farmers and at the right time, possibly at the beginning of the farming season when such funds are mostly wanted to invest in agricultural inputs including drought resistance crops. For example, study conducted by Abdul-Razak and Kruse, (2017) revealed that farmers in northern Ghana with access to credit are more economically able to adapt to climate change than those with less access to credit facilities. This finding is consistent with several studies in sub-Saharan Africa which have indicated the importance of credit accessibility in determining smallholders' adaptation strategies to climate change and variability (Belay et al., 2017).
- Specifically, efforts should be made to increase research into drought-resistance of crop varieties such as, rice, cassava, corn eddo, beans that hold great prospect for food security. GOL can access and invest part of the climate adaptation fund into research activities related to drought resistance crops. Again, findings from such research should be extended to farmers through extension services and radio communication in local dialects.

7.15 Institutional Support to Farmers

Institutions are defined as "formal rules and arrangements that govern behaviour among and within organization" Ruttan, (2006:250) and normalize the practices of society (Giddens, 1979). Institutions vary in formality, ambiguity, power, and contestation, making them dynamic and subject to reshaping (McCormick et al., 2020). In the case of climate adaptation, institutions may help society to interpret scientific knowledge and devise adaptation strategies (Roshani et al., 2022) and adaptation may not occur in institutional vacuum (Muringai et al., 2022; Agrawal, 2010; Ghimire et al., 2022). Technological innovations in agriculture may come from multiple sources: public institutions, private firms, and farmers. Yeny et al., (2022); Apriyana, et al., (2021) reveal that countries that have been successful in developing location-specific technologies were able to "socialize" the process of technological innovation, i.e., increase interactions between farmers and their supporting institutions. For institutions to operate effectively, there is a need for dialog among entities that are public (administrative units, government organizations), private (business organizations), and civic (NGOs, service, and community-based organizations) (Tofu et al., 2022; Cobbinah et al., 2022) while ensuring a meaningful collective action among them (Abbass et al., 2022; Aryal et al., 2022). During the expert interview and discussion, lack of climate adaptation information including institutional support in terms of adequate all-year-round extension services was highlighted as one of the major barriers to implementing appropriate climate adaptation strategies by households in the study community (see Chapter 5). Experts believed the government of Liberia should improve institutional structure to enhance climate change adaptation at the county and national levels. Therefore, the following policies are recommended:

- The Government of Liberia (GOL) should invest heavily in early warning systems on drought and floods to aid farmers in planning their farming operations. It is recommended that appropriate communication mechanisms including the use of local radio stations broadcasting in local dialect could be used to ensure that such climate information and warnings reach the intended farmers.
- There is the need to enhance coordination among the various institutions and agencies involved in climate change adaptation. It was discovered during expert interviews that data on climate change are scarce and quite fragmented at various institutions and agencies, making proper assessment of adaptation options quite difficult. Therefore, the GOL should through the National Statistics office (LISGIS) and the EPA, Liberia set up a harmonised data hub for climate data.
- Efforts should be made by policy makers to improve farming practices by strengthening the capacity of extension officers through increased staff numbers and training of staff with different specialisms linked to different crops, especially staple crops such as rice, cassava, and other crops.

7.16 Improve Crop Diversification

Crop diversification refers to planting crops on the same plot through mixed cropping or intercropping. This type of farming system can greatly protect food security and production in regions where farmers have little access to chemical, structural, or technological resources (Vernooy, 2022). The crop diversification might stabilize the productivity of cropping systems and reduce negative environmental impacts and loss of biodiversity (Hufnagel et al., 2020). The households with more than one crop grown tend to be more secure in food supplies and income (Mango et al., 2018). During the experts' interview and discussion, 77.7% (n = 9) of the experts highlighted the need for farming households to diversify their crops varieties as a strategy to cope with the impacts of climate variability and change (Table 6.2). Results from Chapter 5 suggest that households that undertake a wider range of crop diversification activities were less vulnerable to the adverse impacts of climate change and variability, while households that depend solely on crop farming were more vulnerable. Crop diversification hence improves food security through improving food stocks in terms of quantity and variety and in improving income through sale of crop produced from a variety of grown crop species which then is used to further improve consumption patterns. Based on these findings, the thesis suggests the following policy actions:

- The Government of Liberia (GOL) need to intensify promotion of crop diversification in smallholder farming, especially to those currently less diversified to improve the food security status of the rural people.
- Crop diversification should be developed as a tool for improving cropping systems, developing novel value-chains, and providing other socio-economic benefits, it is necessary to develop a shared conceptual understanding. Without such concept, the numerous results of the different scientific communities on the crop diversification will use different terms for the same thing or same terms for different things (e.g., diversification, diversity, crop rotation, mixed cropping). This will prevent synergetic effects and generalisation of results.

7.17 Conclusions

This chapter studied probable policy implications of this study. The chapter has shown that, mostly, there are collaborations between the national action plans related to the UNFCCC for climate change and variability and UNCCD for desertification. The key themes that surfaced from the policy analysis, together with the findings of this study, were discussed with experts and stakeholders in a series of experts' interviews. Based on this exercise, several policy recommendations were recognized. Prominent amongst these recommendations include land reforms to make land more accessible to all individuals including female farmers, improve education and awareness on climate issues, diversification of livelihood activities, provision of credit facilities and subsidies to farmers, and the use of drought resistant crops to implement adaptation strategies. Others include, increase provision of institutional support such as building extension capacity. Additionally, crops diversification should be pursued to enable rural farmers to practice the cultivation of more than one variety of crop belonging to the same or different species in each area in the form of rotation and or intercropping. Finally, policy makers need to encourage and strengthen social-exchange relations in farming communities and seek ways of integrating local knowledge into scientific adaptation assessments, as indicated in the literature. When these policy recommendations outlined in this chapter are successfully implemented could reduce the overall vulnerability of Liberia's food production systems and livelihoods to climate variability (particularly dry spells and erosion). Eventually, this will reduce the level of food insecurity in rain-fed agriculture-dependent communities in rural Liberia and in West Africa in general. Notwithstanding, it is acknowledged that these policy recommendations will be implemented within constrained resourcing environments. For instance, the implementation of most of these policy recommendations requires significant financial investments and given the current developmental challenges confronting Liberia. Finally, policies and investment strategies of the government should be geared towards supporting improved extension service, providing on-farm demonstration training, and disseminating information about climate change adaptation strategies, particularly for smallholder farmers in Liberia. Investment in institutions such as extension services is essential for development and might encourage farmers to adopt appropriate climate change adaptation strategies. Thus, the government, stakeholders, and donor agencies must provide capacity-building innovations around the agricultural extension system on climate change using information and communication technologies.

When implemented successfully the policy recommendations outlined in this chapter could reduce the overall vulnerability of Liberia’s food production systems and livelihoods to climate variability (most especially, delayed rainfall or dry spells). Ultimately, this will reduce the level of food insecurity in rain-fed agriculture-dependent districts in rural Liberia and more widely, the sub region. Although, it is also acknowledged that these policy recommendations will be implemented within constrained resourcing environments. For instance, the implementation of most of these policy recommendations requires significant financial investments and given the current developmental challenges confronting Liberia who have emerged from civil war, it is envisaged that serious efforts will be needed on the part of policy makers to address barriers to successful implementation of climate adaptation.

Chapter 8 Summary and Conclusions and Implications

8.1 Summary

This study has used innovative multi-scale quantitative and qualitative approaches to explore the risk caused by climate variability and change in Bong and Lofa Counties in the Central and Northern Liberia, and the way the rural farmers implemented livelihood strategies as adaptive response to address these. By using a multi-scale quantitative and qualitative approaches, this thesis analyses the livelihood changes that have taken place across all districts in the face of delay rainfall or dry spells especially during the planting season, and the ways households deployed their livelihood capitals (e.g. land, natural resources, human and social capital) to mitigate the adverse impact of climate variability and change. This study has combined insights from climate risk analysis with livelihoods approaches and the concept of adaptation strategies to advance the understanding of climate risk shaped by delay rainfall or dry spells, by drawing attention to the social dynamics of capacity as expressed in farmers' everyday livelihood practices, and the factors that support or impede local people efforts. It advances an understanding of the complex gender dynamics that result in socially differentiated pathways towards greater risk in the face of anthropogenic environmental hazards, in this case relating to climate variability.

Four key findings emerge and are categorized as follows:

First, climate risk due to delayed rainfall or dry spells has visible geographical and socioeconomic patterns, with the Central and Northern counties of Liberia being mostly at risk to climate variability. These counties have the lowest coping and adaptive capacities due to low socioeconomic development, and have economies based mainly on rain-fed agriculture. This thesis has established where within Liberia crop food production systems and livelihoods are mostly at risk to climate variability, most especially delay rainfall or dry spells. Observed and modelled data depicted in Chapter 4 demonstrated that the risk of crop production due to delay rainfall or dry spells has visible geographical and socioeconomic patterns, with the Central and Northern counties of Liberia being mostly at risk to climate variability. The results illustrate that these counties have the lowest coping and adaptive capacities due to low socioeconomic development, and have economies based mainly on rain-fed agriculture. The study also confirmed that the decline in rainfall and increase in temperature in the study regions coupled with future projection of mean annual temperature increases (Figure 4.9) presents serious challenges to farmers in the country most especially the study counties since they depend entirely on rainfall for crop production and other rural livelihoods. Increase in temperature increases evaporation and evapotranspiration that leads to a reduction in soil moisture content.

The methodological approach outlined in Chapter 4 demonstrated how a quantitative national and county multi-scale risk assessment is crucial (and mostly overlooked) first step in assessing differences in climate sensitivity of crop food production systems across large areas. Besides, the approach guided the formulation of more targeted district research that explored the drivers of climate risk and change on a local scale. The methodological approach has wider significance as it can improve climate sensitivity and risk assessments in functioning dryland farming systems where there are several drivers of change and thresholds of risk that vary in both space and time (Conway et al. 2019; Warren et al. 2018). The results also establish the need for county-specific policies to reduce climate risk and enhance delay rainfall preparedness within dryland farming districts. By developing and applying such combined suite of quantitative approaches for climate change risk assessment, this thesis contributes to environmental and scientific debates on the development of cohesive risk assessments that can be applied in geographical areas for which detailed data may be lacking.

Second, using a vulnerability and risk approaches, the data presented in chapter 5 identified spatial variation of climate induce risks of rice and cassava cultivation at the district levels, which relates strongly to localized geographical differences in the impact of the climate variability, and the consequences this has on farmers' livelihoods. The study found that within the same agroecological setting, different districts experience a degree of vulnerability and risks that may be attributed to differences in socioeconomic characteristics such as poverty line of the counties. The thesis also confirmed there are variations of vulnerability and risk of farming districts. This finding has wider significance as it builds on previous research on vulnerability and climate risk on crops food production (Schneider and Asch, 2020; Vesco et al, 2021; Omerkhil et al., 2020; Kogo et al., 2021) and emphasized the need to support rural farmers to develop off-farm livelihood activities that can reduce the impacts of climate variability. In addition, this thesis has provided a nuanced understanding of how different households could be affected by climate variability.

The implications of these results are that policy makers need to identify and provide appropriate interventions that foster climate adaption strategies building and improve institutional capacity so as to enhance the living standard of rural farming households and districts.

Third, livelihood diversification and adaptive livelihood strategies are critical dimensions of the general response to climate variability. However, there is unevenness in how successfully these are applied, which relates strongly to localized geographical differences in the impact of the climate variability, and the consequences this has for livelihoods. By exploring the nature of risk to climate variability with a focus on crops food production and livelihoods, this thesis has enhanced our understanding of the drivers of risk to climate variability in rain-fed agricultural systems in Liberia and beyond. It was noticed that within the same agroecological setting, different districts and households experience different risks that may be attributed to differences in socioeconomic characteristics. The thesis also confirmed that the risk of farming districts can be linked to access to livelihood capital assets (Isaac et al., 2019; Manlosa et al., 2022a, Manlosa et al., 2022b), and that districts at risk tend to have households that are characterized by low levels of human, natural, financial, physical and social capitals.

In addition, this thesis has provided a nuanced understanding of how different households could be affected by climate variability. Empirical evidence in this Chapter (i.e., Chapter 6) reaffirms previous studies that suggest that female-headed households without any reliable off-farm income jobs could be more vulnerable than male-headed households (Rajkhowa and Qaim, 2022; Li et al., 2022; Obi-Egbedi et al., 2021). Given the future projected climate change in Liberia (see chapter 4) and SSA more widely (Bedeke, 2023; Wens et al., 2022), it is expected that such households will become more at risk unless they are supported through appropriate policies aimed at reducing drought vulnerability. Furthermore, empirical data used in Chapter 6 show that farmers in the study district were employing a range of on-farm and off-farm adaptation strategies to mitigate the negative impacts of climate variability on their livelihoods. Farmers employed on-farm adaptation strategies such as changing the timing of planting, planting drought-tolerant crops and early maturing varieties, diversifying their crops, using crop rotation and using irrigation. Off-farm adaptation strategies included livelihood diversification, temporary migration, relying on social networks, using traditional agroecological knowledge, changing of staple food, assistance from NGOs and governmental as well as reducing the size of food consumption to manage climate variability.

One of the more significant results that emerged is that most farming households and districts were using coping strategies that are linked to livelihood diversification and that most of these households were using a range of off-farm livelihood diversification strategies in an attempt to avoid hardship because of crop failure linked to delayed rainfall or dry spells.

Such strategies include petty trading, engage in small cash businesses, selling livestock, working as commercial motorcycle riders, and charcoal production. These activities are being pursued by households as complementary livelihood options. Building on previous studies (e.g., Jha and Gupta, 2021; Paudel et al., 2022; Megersa et al., 2022; Guodaar and Appiah, 2022; Ngetich et al., 2022; Assefa and Gebrehiwot, 2023; Acheampong et al., 2023), the findings showed that socioeconomic factors such as gender, age (based on local perception), education level, land tenure system as well as agroecological setting could influence the choice of adaptation strategies used by farmers in the study districts (Chapter 6). Though, empirical evidence in Chapter 6 also provided valuable insights into the nature of barriers to climate adaptation by rural farmers in rain-fed agricultural systems. Farming households and districts are confronted with a range of barriers in their attempts to adapt to climate variability. Prominent amongst these barriers were a lack of subsidy from government and financial constraint, which were reported by 97% and 94 % (n = 160) of study households respectively. A lack of subsidy from government and financial resources are also linked to other barriers to adaptation such as limited access to markets, limited farm size and lack of access to climate information. The study also established that poor access to information on climatic issues, complex access to farmland, and social-cultural barriers and gender issues are other challenges that confronted households in their attempts to implement climate adaptation strategies. In addition, lack of access to markets as well as a lack of institutional support in terms of adequate all-year-round extension services constituted serious barriers to climate adaptation. It should be acknowledged that most of these barriers also relate to agricultural production more broadly and hinder adaptation to factors in addition to climate change. By identifying these barriers to climate adaptation, this thesis has provided policy recommendations as to how farmers could be supported to reduce livelihood and food production system's risk to climate change in Liberia and beyond.

Fourth, gender disparities in access to land for farming practices, acquisition restrictions, and household-decision making procedures contribute to the socioeconomic risk of female across all districts. Patriarchal relationships and care giving roles hindered the women's capacity to develop viable livelihood responses and this in turn accentuated the impact of the climate variability on household well-being. This implication of this chapter is that policy makers need to consider these socioeconomic factors when designing climate adaptation policies, such as enabling farmers to engage in alternative livelihood diversification strategies, aimed at reducing the adverse impacts of climate variability on rural livelihoods. Further, appropriate programmes that seek to foster asset building, improve institutional capacity such as skill training and craftsmanship should be integrated into the national climate change adaptation strategy to enable farming households to undertake into off-farm livelihood strategies. These recommendations are also possible to be more widely applicable beyond Liberia.

8.2 Conclusions

Based on the findings of this study (Chapters 4-7), one can confirm that rural farmers in Liberia have experienced changes in climate with a great potential to alter their socioeconomic development. The study highlights the past and future situations and the challenges rural farmers in Liberia have faced and would potentially face as a result of rising temperatures, erratic rainfall, and delayed rainfall or dry spells, which affect their agriculture productivity and food security through the reduction in the quantity and quality of crop yields. The study also highlights that rural farmers in Central and Northern Liberia located in savanna and agroecological zone are coping and adapting to climate variability and ecological challenges. Due to the impacts of recurrent shocks (delayed rainfall or dry spells, soil infertility, soil erosion, etc.), the uncertainty of the limited access to financial and technical resources and the lack of support to indigenous knowledge systems, rural farmers have often adopted to short term coping strategies and long-term sustainable adaptation strategies. Key coping strategies such as continuous selling of productive assets, for example selling of charcoal, selling livestock and land are sources of disappearing tangible assets. The migration (out migration) of some households identified as a key coping strategy can be damaging and therefore needs to be conceptually reconsidered in the savanna context. Reducing food consumption and adjusting staple food as a coping strategy also poses consequences on the health and well-being of households. To enable rural farmers, shift from coping to planned adaptation strategies, there is the need for exchange of knowledge (innovation adoption) on adaptation between rural farmers and the formal institutions notably the NGOs and government agencies such as Ministry of Agriculture.

8.3 Implications

The findings presented in this thesis (Chapters 4-7) have significant implications that policymakers need to carefully consider enhancing agricultural production systems and mitigate farmers' risks associated with climate change and variability in Liberia and Sub-Saharan Africa (SSA). Policymakers need to develop explicit and targeted climate adaptation programmes and policies that are sustainable, long-term, and directly linked to livelihood diversification. For instance, integrating appropriate livelihood development programmes that foster asset building (training) into larger climate change adaptation initiatives is crucial. Additionally, providing credit facilities and subsidies on agricultural inputs, implementing land tenure reforms to increase land accessibility and ownership (especially for women), and improving market access for agricultural produce are essential steps. These approaches will address the challenges rural farmers face due to the adverse impacts of climate change on their livelihoods.

Moreover, supporting rural farmers in establishing communication channels for knowledge and information sharing is vital. Farmers' groups and social networks can be initiated through forums and workshops led by the Ministry of Agriculture's extension officers. Forming these associations and networks will enable rural farmers to access social capital, facilitating effective sharing and adoption of innovations. This study contributes to scientific debates on climate risk assessment and adaptation strategies by clarifying our understanding of how rural farmers adapt to the risks posed by ecological change and climate variability.

8.3.1 Methodological Reflections on Mixed Method, Multi-Scale Risks Assessment

Climate risk assessment in Liberia faces a significant methodological gap that hinders the country's ability to effectively understand and respond to climate-related challenges. The previous methodologies for assessing climate risks in Liberia lacks robustness, accuracy, or specificity to the local context, making it difficult to capture the full extent of climate vulnerabilities and impacts on crop food production system. This study uses series of methods such as mixed method, multi-scale approach to assess the risks of crop production and livelihood to climate change and variability at the district and household levels in Liberia. Climate variability and change is a complex problem interacting with different processes at different geographical scales (Fraschini et al., 2022; Tieminie et al., 2022; Almheiri, 2022). The use of mixed-method approaches allowed the validation and deepening of understanding of the main issues involved in risk and vulnerability assessment of the agricultural or farming systems to climate variability through triangulation, thus providing a significantly comfortable understanding of the different dimensions of the problem through its exploration across scales. Combining different methods enable input from local farmers through participatory approaches provided local insights to enhance understanding into how past climate events shape livelihoods activities of agriculture-dependent districts. This is especially important in the face of new and unfamiliar climatic conditions, where local knowledge could be a useful source of information for districts adaptation to climate change and variability, so such dialogue between district members is valuable.

The multi-scale integrated approach for risk assessment in Liberia developed in this thesis has wider significance for dryland farming systems across Africa. Most risk assessments (e.g., Chang et al., 2019; Hagenlocher et al., 2019; Menk et al., 2022; Simpson et al., 2021) have been conducted at only one scale, using either quantitative or qualitative methods (see Chapter 3), although attempt by Swadling et al. (2023); Simpson et al., (2021) and Hagenlocher et., (2019) to undertake multi-scale risk analysis was acknowledged. Single scale assessments fail to fully capture the range of interacting socioeconomic and biophysical factors and processes operating at different levels to affect risks.

Applying an interdisciplinary approach, this study has addressed a significant research gap by integrating different participatory methods and household surveys to assess the extent of food production systems and livelihoods' risk to climate variability across multiple scales: mapping exposure, risk and vulnerability at the district levels. Indeed, several authors have argued that climate change studies should move away from one-scale approach to a multi-scale approach (Rather et al., 2020; Juerges et al., 2020; Fu et al., 2021; Naulleau et al., 2021). Whilst the mixed method, multi-scale approach adopted for this study has provided useful insights into the extent and drivers of food production system's risk to hazards, the socio-cultural context within which this study took place should not be ignored. Hence, caution should be exercised in generalising from the findings of this study because of the different contextual factors that influence hazards at the local level. Therefore, assessing its wider applicability will require a larger sample size involving the different agro-ecological zones in Liberia to provide additional insights in relation to livelihoods and food systems' risk to climate variability.

8.3.2 Practical Reflection in the Study

After a thorough literature search on vulnerability and risk assessments in Liberia, this research identified key practical limitations. For example, most assessments (e.g., Masike et al., 2024; Togbah, 2024; Hahn et al., 2014) focus on current conditions or past trends, lacking future scenarios of drought hazards, exposure, and vulnerability, which are crucial for preventive planning. This study utilizes past climate information (1981-2020) and four GCM scenarios to project future (2020-2100) hazards, providing essential data for planning processes and formulating coping and adaptive strategies to mitigate the adverse impacts of climate variability and change. In addition, limited accessibility and tools, insufficient capacity, user friendly data and tool etc., this study successfully addressed these practical gaps by developing and integrating local knowledge, scientific data, and decision-support tools that enhances the research's ability to effectively identify and analyze the results of this study. These models are valuable planning tools for farmers and policymakers to anticipate and mitigate adverse effects on agriculture (Müller and Döll, 2024). This analysis identified immediate challenges, underscoring the need for coping and adaptive farming practices (Tatemoto et al. 2020).

The study's findings underscore the critical importance of bridging practical gaps to inform evidence-based decision-making and policy development in Liberia. By offering a user-friendly and context-specific approach to assessing climate risks, particularly in crop food production systems, the researcher engages farmers, stakeholders, and experts at various levels, providing the necessary tools and insights to prioritize coping, adaptation, and mitigation strategies. This practical framework not only addresses Liberia's specific needs but also serves as a replicable model for other developing countries facing similar challenges in climate risk assessment.

Moreover, the study emphasizes stakeholder engagement and capacity-building initiatives for agricultural extension officers, ensuring the sustainability and uptake of the practical framework within the local context. This fosters a culture of informed decision-making and proactive climate risk management in Liberia. The research contributes to building a more resilient and climate-ready society capable of navigating the complexities of a changing climate landscape. These recommendations, based on thorough analysis, aim to improve the overall resilience of Liberia's agricultural sector (Asad et al., 2024).

In conclusion, this study represents a significant advancement in addressing practical gaps in climate risk assessment in Liberia. It offers a tailored framework that supports informed decision-making, enhances coping and adaptive capacities, and fosters sustainable development in the face of climate change and variability. The study's practical implications and real-world applications underscore its value in shaping policy and practice towards a more climate-resilient future for Liberia and beyond.

8.3.3 Conceptual Reflection in the Study

This study found that most accessed articles defined drought risk using the IPCC concepts from 2001 and 2007 (IPCC, 2001, 2007). However, since the publication of the IPCC SREX Report (IPCC, 2012) and the subsequent Fifth Assessment Report (IPCC, 2014), there has been a shift in the conceptualization of risk towards a stronger focus on assessing the risk of specific consequences or impacts that would harm a system, wherein risk is a function of (drought) hazard, exposure, and vulnerability (IPCC, 2014). This shift has been reflected to some degree in studies assessing drought risk (e.g., Kim et al., 2015; Zhang et al., 2015; Carrão et al., 2016; Asare-Kyei et al., 2017; Sena et al., 2017), even though the share of assessments applying this newest concept since its release has remained stable.

This study utilizes the IPCC 2014 definition and conceptualizes and operationalizes drought risk by adopting a framework that defines the risk of negative impacts as a function of hazard, exposure, and vulnerability. It incorporates country and county-specific climate data together with county and district socioeconomic data, improving the accuracy and relevance of risk assessments in Liberia. By including socio-economic variables, the research provides a more holistic understanding of how climate risks impact crop food production at different district levels in Liberia. The study also employs participatory methods, ensuring that rural farmers and traditional knowledge are integral to the research process. This approach offers a comprehensive view of the risks of climate change and variability on crop food production and aids in formulating robust coping and adaptation strategies.

These innovative approaches significantly advance the field of climate risk assessment in Liberia and beyond. The study addresses the conceptual gap by developing models that simulate future climate change under various scenarios. These models incorporate both current climate and future projections and their impact on crop growth, providing a framework for anticipating and planning for future agricultural challenges (Rosenzweig et al., 2014). Conclusively, this study not only fills critical conceptual gaps but also offers practical recommendations for policymakers and stakeholders, thereby contributing to more effective and inclusive climate strategies in Liberia and the sub-region.

8.4 Priorities for Future Research

Despite the valuable insights provided in this research, there remain a number of unanswered questions that require further research. First, further research is needed to refine the dry spells exposure, vulnerability and risk assessment to enhance its wider applicability. For instance, research could not explore the possibility of using daily rainfall data instead of monthly rainfall data for the construction of the exposure index in the risks analysis. Similarly, the estimation of coping and adaptive capacities could be improved if more proxy indicators such as irrigation potential of the various counties, access to credit, soil degradation index, farm assets and farm income were included in detail. The consideration of such data would provide a significantly better understanding of the extent of agricultural production systems' exposure and vulnerability (physical and socioeconomic susceptibilities) to dry spell or delayed rainfall and drought in Liberia and SSA more widely. Second, about 36% of farming households that participated in the study cited the importance of finance in mitigating the adverse impacts of dry spells and drought. However, this thesis did not explore the extent of social capital/finance and how this could be enhanced by formal and informal institutions. Therefore, there is the need for future research to explore how institutions could promote social capital for districts coping and adaptation to climate change and variability.

8.5 Concluding Statements

Agricultural crop productions in Liberia are generally at risk to climate change and variability. Meteorological and Field-based participatory studies were used in this study to develop and apply an innovative multi-scale approach for assessing climate risks in order to identify where agricultural crop production systems are mostly at risk (particularly in the form of delayed rainfall or dry spells) to climate variability and change. The methodological approach outlined in this thesis has wider significance for climate risks assessments in dryland farming systems where delayed rainfall or dry spells and drought are serious threat to livelihoods. Combined with social-environmental assessments are illustrate by spatial and temporal changes that pose significant geographical challenges in developing appropriate risk assessment frameworks (De Vos et al., 2019). Therefore, the use of a quantitative multi-scale approach supported by qualitative data through the use of key informants' interview (KIIs) and experts' interviews and discussion to climate risk provides useful contribution towards reliable and more comprehensive results that may be lacking in a single-scale approach. Findings in this thesis will contribute to a general discussion of the sorts of livelihoods and agricultural production systems that augment coping and adaptive capacities to future climate variability and changes and will inform future national policy developments.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, *29*(28), 42539-42559.

Abdu, U. A. A. W. A. (2021). Effect of Participatory Forest Management (PFM) on Local Community Livelihood in Case of Bale Highlands, Southeast Ethiopia.

Acharya, K. K., Dixit, A. K., Sharma, A. K., & Pouchepparadjou, A. (2021). Assessment of vulnerability to climate change–A systematic bibliometric visualization analysis with a focus on Indian agriculture.

Acheampong, P. P., Yeboah, S., Adabah, R., Asibuo, J. Y., Nchanji, E. B., Opoku, M., ... & Kweyu Lutomia, C. (2023). Gendered perceptions and adaptations to climate change in Ghana: What factors influence the choice of an adaptation strategy? *Frontiers in Sustainable Food Systems*, *7*, 1091812.

Acosta-Motos, J. R., Franco-Navarro, J. D., Gómez-Bellot, M. J., & Alvarez, S. (2024). Crop resistance mechanisms to alleviate climate change-related stress. *Frontiers in Plant Science*, *15*, 1368573.

Acosta, L. A., Maharjan, P., Peyriere, H. M., & Mamiit, R. J. (2020). Natural capital protection indicators: Measuring performance in achieving the Sustainable Development Goals for green growth transition. *Environmental and Sustainability Indicators*, *8*, 100069.

Acosta, L. A., Virk, A., Kumar, R., Sharma, S., Ikeda, T., Joshi, G. R., ... & Takahashi, Y. (2018). Options for governance and decision-making across scales and sectors. *IPBES: The regional assessment report on biodiversity and ecosystem services for Asia and the Pacific*, 429-535.

Adaawen, S. (2021). Understanding climate change and drought perceptions, impact and responses in the rural Savannah, West Africa. *Atmosphere*, *12*(5), 594.

Adamou, R., Ibrahim, B., Bonkaney, A. L., Seyni, A. A., & Idrissa, M. (2021). Niger-Land, climate, energy, agriculture and development: A study in the Sudano-Sahel Initiative for Regional Development, Jobs, and Food Security.

Addaney, M., Akugudu, J. A., Asibey, M. O., Akaateba, M. A., & Kuusaana, E. D. (2022). Changing land tenure regimes and women's access to secure land for cocoa cultivation in rural Ghana. *Land Use Policy*, *120*, 106292.

Adebisi-Adelani, O., & Oyesola, O. B. (2014). Farmers' perceptions of the effect of climate change on tomato production in Nigeria. *International journal of vegetable science*, *20*(4), 366-373.

Adesete, A. A., Olanubi, O. E., & Dauda, R. O. (2022). Climate change and food security in selected Sub-Saharan African Countries. *Environment, Development and Sustainability*, 1-19.

Adesete, A. A., Olanubi, O. E., & Dauda, R. O. (2023). Climate change and food security in selected Sub-Saharan African Countries. *Environment, Development and Sustainability*, *25*(12), 14623-14641.

Adesugba, M., Oughton, E., & Shortall, S. (2020). Farm household livelihood strategies. In *Routledge Handbook of Gender and Agriculture* (pp. 315-325). Routledge.

Adger, W. N., Brown, I., & Surminski, S. (2018). Advances in risk assessment for climate change adaptation policy. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2121), 20180106.

Adhikari, S. (2020). Assessment of people's participation in soil conservation activities and its contribution in livelihood of involved people (A case study from Rupakot, Kaski). A Project paper submitted for the partial fulfillment of Bachelor degree of Science in Forestry, Tribhuvan University, Kathmandu Forestry College, Kathmandu, Nepal.

Adimassu, Z., & Kessler, A. (2016). Factors affecting farmers' coping and adaptation strategies to perceived trends of declining rainfall and crop productivity in the central Rift valley of Ethiopia. *Environmental Systems Research*, *5*, 1-16.

Ado, A. M., Leshan, J., Savadogo, P., Bo, L., & Shah, A. A. (2019). Farmers' awareness and perception of climate change impacts: case study of Aguie district in Niger. *Environment, Development and sustainability*, *21*, 2963-2977.

Ado, A. M., Savadogo, P., Pervez, A. K., & Mudimu, G. T. (2020). Farmers' perceptions and adaptation strategies to climate risks and their determinants: insights from a farming community of Aguie district in Niger. *GeoJournal*, *85*, 1075-1095.

Adjei, V. (2021). Climate change: Threat to agricultural system and food security in Africa. *Glob Scient Res Env Sci*, *1*(4), 1-05.

Adu, K., Puthenkalam, J. J., & Kwabena, A. E. (2022). Agricultural and extension education for sustainability approach. *British Journal of Environmental Studies*, *2*(1), 20-37.

Adzawla, W., Azumah, S. B., Anani, P. Y., & Donkoh, S. A. (2020). Analysis of farm households' perceived climate change impacts, vulnerability and resilience in Ghana. *Scientific African*, *8*, e00397.

Affoh, R., Zheng, H., Dangui, K., & Dissani, B. M. (2022). The impact of climate variability and change on food security in sub-saharan africa: Perspective from panel data analysis. *Sustainability*, *14*(2), 759.

Aghdasi, M., Omidi Najafabadi, M., Mirdamadi, S. M., & Farajollah Hoseini, S. J. (2022). Expanding Protection Motivation Theory: Investigating Farmers' Pro-Environmental Behavior and Their Impact on a Sustainable Alternative Livelihood under Drought. *Journal of Agricultural Science and Technology*, *24*(2), 305-320.

Agrawal, A. (2010). Local institutions and adaptation to climate change. *Social dimensions of climate change: Equity and vulnerability in a warming world*, *2*, 173-178.

Ahmadalipour, A., Moradkhani, H., Castelletti, A., & Magliocca, N. (2019). Future drought risk in Africa: Integrating vulnerability, climate change, and population growth. *Science of the Total Environment*, *662*, 672-686.

Ahmadalipour, A., & Moradkhani, H. (2018). Multi-dimensional assessment of drought vulnerability in Africa: 1960–2100. *Science of the total environment*, *644*, 520-535.

Ahmed, A. (2020). Adaptation to climate change in the Sahel: the success stories of Eritrea. *Savanna J Basic Appl Sci*, *2*, 187-199.

Ahmed, K., Shahid, S., & Nawaz, N. (2018). Impacts of climate variability and change on seasonal drought characteristics of Pakistan. *Atmospheric research*, *214*, 364-374.

Ahmed, S. M. (2020). Impacts of drought, food security policy and climate change on performance of irrigation schemes in Sub-saharan Africa: The case of Sudan. *Agricultural Water Management*, *232*, 106064.

Ahmad, Q. U. A., Moors, E., Biemans, H., Shaheen, N., & Masih, I. (2023). Climate-Induced Shifts in Irrigation Water Demand and Supply during Sensitive Crop Growth Phases in South Asia.

Ahmad, D., Afzal, M., & Rauf, A. (2021). Farmers' adaptation decisions to landslides and flash floods in the mountainous region of Khyber Pakhtunkhwa of Pakistan. *Environment, Development and Sustainability*, *23*, 8573-8600.

Ahmad, M. I., & Ma, H. (2020). Climate change and livelihood vulnerability in mixed crop–livestock areas: the case of province Punjab, Pakistan. *Sustainability*, *12*(2), 586.

Ajayi, V. O., & Ilori, O. W. (2020). Projected drought events over West Africa using RCA4 regional climate model. *Earth Systems and Environment*, *4*, 329-348.

Ajibade, I., & McBean, G. (2014). Climate extremes and housing rights: A political ecology of impacts, early warning and adaptation constraints in Lagos slum communities. *Geoforum*, *55*, 76-86.

Akanwa, A. O., Mba, H. C., Jiburum, U., & Ogboi, K. C. (2019). Strategies for combating climate change. *Sustainable Agriculture, Forest and Environmental Management*, 393-435.

Akanwa, A. O., Okeke, F. I., Nnodu, V. C., & Iortyom, E. T. (2017). Quarrying and its effect on vegetation cover for a sustainable development using high-resolution satellite image and GIS. *Environmental Earth Sciences*, *76*, 1-12.

Akanwa, A. O., Banerjee, A., Jhariya, M. K., Muoghalu, L. N., Okonkwo, A. U., Ikegbunam, F. I., ... & Madukasi, E. I. (2023). Climate-Induced Conflicts Between Rural Farmers and Cattle Herders: Implications on Sustainable Agriculture and Food Security in Nigeria. *Ecorestoration for Sustainability*, 373-416.

Albert, M., Bergez, J. E., Couture, S., Faivre, R., & Willaume, M. (2021). Decision-making process factors explain some of the heterogeneity of irrigation practices among maize farmers in Southwestern France. *Water*, *13*(24), 3504.

Alemu, T., & Mengistu, A. (2019). Impacts of climate change on food security in Ethiopia: adaptation and mitigation options: a review. *Climate Change-Resilient Agriculture and Agroforestry: Ecosystem Services and Sustainability*, 397-412.

Alden Wily, L. (2007). So who owns the forest: an investigation into forest ownership and customary land rights in Liberia. *Monrovia: Sustainable Development Institute/FERN*.

Alewoye Getie, M., Legesse, S. A., Mekonnen, M., & Aschalew, A. (2020). Soil properties and crop productivity strategies as a potential climate variability adaptation option in Adefwuha Watershed, Ethiopia. *Earth Systems and Environment*, *4*(2), 359-368.

Alexandridis, T. K., Ovakoglou, G., Cherif, I., Gómez Giménez, M., Laneve, G., Kasampalis, D., ... & Suarez Beltran, J. (2021). Designing AfriCultuReS services to support food security in Africa. *Transactions in GIS*, *25*(2), 692-720.

Akinyoola, J. A., Imoukhuede, B. O., & Oloruntade, J. A. (2021). Recent Trends and Future Projection in Precipitation and Temperature Changes in Nigeria.

Alexander, S., Atsbeha, E., Negatu, S., Kirksey, K., Brossard, D., Holzer, E., & Block, P. (2020). Development of an interdisciplinary, multi-method approach to seasonal climate forecast communication at the local scale. *Climatic Change*, *162*, 2021-2042.

Ali, U., Wang, J., Ullah, A., Tan, Y., Nurgazina, Z., & Khan, Z. A. (2020). Determinants of farmers' choice adaptation strategies to climate change: Evidence from Khyber Pakhtunkhwa Pakistan. *Pakistan Journal of Agricultural Sciences*, *57*(3), 941-951.

Ali, K. A. (2024). Exploring Multidisciplinary Solutions to Global Food Security Challenges. *Zealous & Energetic Scholarly Texts*, *2*(01), 26-36.Ali, U., Wang, J., Ullah, A., Tan, Y., Nurgazina, Z., & Khan, Z. A. (2020). Determinants of farmers' choice adaptation strategies to climate change: Evidence from Khyber Pakhtunkhwa Pakistan. *Pakistan Journal of Agricultural Sciences*, *57*(3), 941-951.

Alam, K. (2015). Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. *Agricultural water management*, *148*, 196-206.

Almazroui, M., Saeed, F., Saeed, S., Nazrul Islam, M., Ismail, M., Klutse, N. A. B., & Siddiqui, M. H. (2020). Projected change in temperature and precipitation over Africa from CMIP6. *Earth Systems and Environment*, *4*, 455-475.

Al Mamun, A., Islam, A. R. M. T., Alam, G. M., Sarker, M. N. I., Erdiaw-Kwasie, M. O., Bhandari, H., & Mallick, J. (2023). Livelihood vulnerability of char land communities to climate change and natural hazards in Bangladesh: an application of livelihood vulnerability index. *Natural Hazards*, *115*(2), 1411-1437.Almheiri, M. M. A. M. (2022). Climate Change Awareness in the United Arab Emirates.

Alves, P. B., Djordjević, S., & Javadi, A. A. (2022). Addressing social and institutional vulnerabilities in the context of flood risk mitigation. *Journal of Flood Risk Management*, *15*(4), e12839.

Amin, A., Wane, A., Kone, I., Krah, M., & N'Goran, A. (2023). Impacts of climate change on regional cattle trade in the central corridor of Africa. *Regional Environmental Change*, *23*(1), 35.

Amoako, C., Adarkwa, K. K., & Koranteng, K. A. (2023). Survival now, sustainability later: the emerging artisanal mining and the dying agricultural livelihoods in the Akyem Abuakwa traditional area of Ghana. *Environment, Development and Sustainability*, *25*(2), 1645-1666.

Ampaire, E. L., Acosta, M., Huyer, S., Kigonya, R., Muchunguzi, P., Muna, R., & Jassogne, L. (2020). Gender in climate change, agriculture, and natural resource policies: insights from East Africa. *Climatic change*, *158*(1), 43-60.

Amrutha, T. G., Shubhashree, K. S., Shilpa, H. D., Nayaka, G. V., Yamaji, K. G., & Nalina, C. N. (2023). Agro-Forestry–A Crop Diversification Strategy for Adaption and Mitigation of Climate Change. *International Journal of Environment and Climate Change*, *13*(10), 865-873.

Amosi, N., & Anyah, R. O. (2024). Trends of precipitation and temperature extremes over Malawi and Mozambique during the recent decades from models and observations. *Theoretical and Applied Climatology*, *155*(2), 783-804.

Anaafo, D., Ayamga, A., & Bata Domanban, P. (2023). Custom, modernity, and stability of land rights in Ghana: An empirico-legal review. *Cogent Social Sciences*, *9*(1), 2209366.

Ananda, G. A., Moseti, B., & Mugehera, L. (2020). Women's Land Rights Scorecard: The failure of land policy and legal reforms in securing women's land rights in Africa.

Andersson-Sköld, Y., Thorsson, S., Rayner, D., Lindberg, F., Janhäll, S., Jonsson, A., ... & Granberg, M. (2015). An integrated method for assessing climate-related risks and adaptation alternatives in urban areas. *Climate Risk Management*, *7*, 31-50.

Ani, K. J., Anyika, V. O., & Mutambara, E. (2022). The impact of climate change on food and human security in Nigeria. *International Journal of Climate Change Strategies and Management*, *14*(2), 148-167.

Aniah, P., Kaunza-Nu-Dem, M. K., & Ayembilla, J. A. (2019). Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon*, *5*(4).

Ankrah, D. A., Freeman, C. Y., & Afful, A. (2020). Gendered access to productive resources–evidence from small holder farmers in Awutu Senya West District of Ghana. *Scientific African*, *10*, e00604.

Antwi-Agyei, P., Dougill, A. J., Stringer, L. C., & Codjoe, S. N. A. (2018). Adaptation opportunities and maladaptive outcomes in climate vulnerability hotspots of northern Ghana. *Climate Risk Management*, *19*, 83-93.

Antwi-Agyei, P., Quinn, C. H., Adiku, S. G. K., Codjoe, S. N. A., Dougill, A. J., Lamboll, R., & Dovie, D. B. K. (2018). Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: a participatory approach. *Regional Environmental Change*, *17*, 213-227.

Antwi-Agyei, P., Dougill, A. J., Doku-Marfo, J., & Abaidoo, R. C. (2021). Understanding climate services for enhancing resilient agricultural systems in Anglophone West Africa: The case of Ghana. *Climate Services*, *22*, 100218.

Antwi, E. K., Boakye-Danquah, J., Owusu, A. B., Loh, S. K., Mensah, R., Boafo, Y. A., & Apronti, P. T. (2015). Community vulnerability assessment index for flood prone savannah agro-ecological zone: A case study of Wa West District, Ghana. *Weather and Climate Extremes*, *10*, 56-69.

Appiah, S., Antwi-Asare, T. O., Agyire-Tettey, F. K., Abbey, E., Kuwornu, J. K., Cole, S., & Chimatiro, S. K. (2021). Livelihood vulnerabilities among women in small-scale fisheries in Ghana. *The European Journal of Development Research*, *33*, 1596-1624.

Apriyana, Y., Surmaini, E., Estiningtyas, W., Pramudia, A., Ramadhani, F., Suciantini, S., ... & Syahbuddin, H. (2021). The Integrated Cropping Calendar Information System: A coping mechanism to climate variability for sustainable agriculture in Indonesia. *Sustainability*, *13*(11), 6495.

Archibong, B., Annan, F., & Ekhator-Mobayode, U. (2020). The Epidemic Effect: On the Politics and Economic Burden of Infectious Disease.

Arias, P., Bellouin, N., Coppola, E., Jones, R., Krinner, G., Marotzke, J., ... & Zickfeld, K. (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; technical summary.

Arjwech, R., Everett, M. E., & Wanakao, P. (2019). The relationship between geological factors and the distribution of saline soil: A case study in the Khon Kaen Basin of Thailand. *Songklanakarin Journal of Science & Technology*, *41*(5).

Aronson, R. B., Precht, W. F., Macintyre, I. G., & Murdoch, T. J. (2000). Coral bleach-out in Belize. *Nature*, *405*(6782), 36-36.

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045-5075.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Gartaula, H. N., & Stirling, C. (2022, August). Gender and climate change adaptation: A case of Ethiopian farmers. In *Natural Resources Forum* (Vol. 46, No. 3, pp. 263-288). Oxford, UK: Blackwell Publishing Ltd.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Krupnik, T. J., Shahrin, S., Jat, M. L., & Stirling, C. M. (2020). Major climate risks and adaptation strategies of smallholder farmers in coastal Bangladesh. *Environmental Management*, *66*(1), 105-120.

Asad, T., Ahmed, M., Malik, S., & Al Zarouni, F. A. (2024). Assessing the Effectiveness of UNDP's Climate Action Initiatives at the Local Level: A Thematic Analysis of Implementation Strategies and Outcomes. American Journal of Environment and Climate, 3(2), 18-24.

Asafu-Adjaye, J. (2014). The economic impacts of climate change on agriculture in Africa. *Journal of African Economies*, *23*(suppl_2), ii17-ii49.

Asare-Kyei, D., Renaud, F. G., Kloos, J., Walz, Y., & Rhyner, J. (2017). Development and validation of risk profiles of West African rural communities facing multiple natural hazards. *PloS one*, *12*(3), e0171921.

Asare-Nuamah, P., & Mandaza, M. S. (2020). Climate change adaptation strategies and food security of smallholder farmers in the rural Adansi North District of Ghana. *Handbook of climate change management: Research, leadership, transformation*, 1-20.

Asare-Nuamah, P., & Amungwa, A. F. (2021). Climate change adaptation among smallholder farmers in rural Ghana. In *African Handbook of Climate Change Adaptation* (pp. 1497-1513). Cham: Springer International Publishing.

Asmall, T., Abrams, A., Röösli, M., Cissé, G., Carden, K., & Dalvie, M. A. (2021). The adverse health effects associated with drought in Africa. *Science of The Total Environment*, *793*, 148500.

Asmare, M., & Alemu, M. (2021). Climate compatible development in Ethiopia: A policy review on water resources and disaster risk management of Ethiopia. *International Journal of Water Resources and Environmental Engineering*, *13*(3), 206-215.

Assefa, E., & Gebrehiwot, G. (2023). Gender dimensions of climate change adaptation in Tigray, Ethiopia. *Global Environmental Change*, *82*, 102737.

Assefa, D., & Haile, F. (2021). Climate Change Induced Shocks, Consequent Impacts, Vulnerability and Farmers Endeavor to Adapt in Northern Highland: Implication for Designing Household and Community Level Strategies.

Ashley, P., & Boyd, B. W. (2006). Quantitative and qualitative approaches to research in environmental management. *Australasian Journal of environmental management*, *13*(2), 70-78.

Asrat, P., & Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecological processes*, *7*(1), 1-13.

Atampugre, G., Mensah, E., Boateng, E., Mabhaudhi, T., & Cofie, O. O. (2022). Situational analysis of a social-ecological landscape in the Ahafo Ano Southwest District of Ghana. *Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Initiative on West and Central African Food Systems Transformation. 57p.*

Atanga, R. A., & Tankpa, V. (2021). Climate change, flood disaster risk and food security nexus in Northern Ghana. *Frontiers in Sustainable Food Systems*, *5*, 706721.

Atiah, W. A., Amekudzi, L. K., Aryee, J. N. A., Preko, K., & Danuor, S. K. (2020). Validation of satellite and merged rainfall data over Ghana, West Africa. *Atmosphere*, *11*(8), 859.

Attoh, E. M., Afriyie, R., Kranjac-Berisavljevic, G., Bessah, E., & Ludwig, F. (2023). Evidence of climate change impacts and adaptive responses of Dagbani Indigenous communities, northern Ghana. *Routledge Handbook of Climate Change Impacts on Indigenous Peoples and Local Communities*, 244.

Atukunda, P., Eide, W. B., Kardel, K. R., Iversen, P. O., & Westerberg, A. C. (2021). Unlocking the potential for achievement of the UN Sustainable Development Goal 2–'Zero Hunger'–in Africa: targets, strategies, synergies and challenges. *Food & Nutrition Research*, *65*., P., Eide,

Auffhammer, M., Ramanathan, V., & Vincent, J. R. (2012). Climate change, the monsoon, and rice yield in India. *Climatic change*, *111*, 411-424.

Avnery, S., Mauzerall, D. L., Liu, J., & Horowitz, L. W. (2011). Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. *Atmospheric Environment*, *45*(13), 2284-2296.

Awazi, N. P., & Quandt, A. (2021). Livelihood resilience to environmental changes in areas of Kenya and Cameroon: a comparative analysis. *Climatic Change*, *165*(1), 33.

Awazi, N. P., Tchamba, M. N., Temgoua, L. F., & Tientcheu-Avana, M. L. (2022). Agroforestry as an adaptation option to climate change in Cameroon: assessing farmers' preferences. *Agricultural Research*, 1-12.

Awazi, N. P., Temgoua, L. F., Tientcheu-Avana, M. L., Chimi, D. C., & Tchamba, M. N. (2022). Climate change and peasant farmers' adoption of multifunctional agroforestry systems in Cameroon: Determinants and policy ramifications. *Forestist*, *20*(10), 1-14.

Ayal, D. Y. (2021). Climate change and human heat stress exposure in sub-Saharan Africa. *CABI Reviews*, (2021).

Ayana, G. F., Megento, T. L., & Kussa, F. G. (2021). The extent of livelihood diversification on the determinants of livelihood diversification in Assosa Wereda, Western Ethiopia. *GeoJournal*, 1-25.

Ayanlade, A., Oluwaranti, A., Ayanlade, O. S., Borderon, M., Sterly, H., Sakdapolrak, P., ... & Ayinde, A. F. (2022). Extreme climate events in sub-Saharan Africa: A call for improving agricultural technology transfer to enhance adaptive capacity. *Climate Services*, *27*, 100311.

Ayanlade, A., Oladimeji, A. A., Okegbola, O. M., Eludoyin, A. O., Eslamian, S., Ayinde, A. F., & Perkins, P. E. (2022). Effect of climate change on water availability and quality: an assessment of socio-resilience in Nigeria. In *Disaster Risk Reduction for Resilience: Disaster and Social Aspects* (pp. 245-262). Cham: Springer International Publishing.

Ayodotun, B., Bamba, S., & Adio, A. (2019). Vulnerability assessment of West African countries to climate change and variability. *Journal of Geoscience and Environment Protection*, *7*(6), 13-15.

Ayugi, B. O., & Tan, G. (2019). Recent trends of surface air temperatures over Kenya from 1971 to 2010. *Meteorology and Atmospheric Physics*, *131*, 1401-1413.

Ayugi, B., Eresanya, E. O., Onyango, A. O., Ogou, F. K., Okoro, E. C., Okoye, C. O., ... & Ongoma, V. (2022). Review of meteorological drought in Africa: historical trends, impacts, mitigation measures, and prospects. *Pure and Applied Geophysics*, *179*(4), 1365-1386.

Ayugi, B., Tan, G., Niu, R., Dong, Z., Ojara, M., Mumo, L., ... & Ongoma, V. (2020). Evaluation of meteorological drought and flood scenarios over Kenya, East Africa. *Atmosphere*, *11*(3), 307.

Azad, M. S., & Ancev, T. (2020). Assessing the dynamics of natural capital on farms: A soil natural capital indicator. *Ecological Economics*, *168*, 106500.

Azadi, Y., Yazdanpanah, M., Forouzani, M., & Mahmoudi, H. (2019). Farmers' adaptation choices to climate change: a case study of wheat growers in Western Iran. *Journal of Water and Climate Change*, *10*(1), 102-116.

Azócar, G., Billi, M., Calvo, R., Huneeus, N., Lagos, M., Sapiains, R., & Urquiza, A. (2021). Climate change perception, vulnerability, and readiness: inter-country variability and emerging patterns in Latin America. *Journal of Environmental Studies and Sciences*, *11*(1), 23-36.

Azzarri, C., & Signorelli, S. (2020). Climate and poverty in Africa South of the Sahara. *World development*, *125*, 104691.

Babu, S., Gajanan, S., & Sanyal, P. (2014). *Food security, poverty and nutrition policy analysis: statistical methods and applications*. Academic Press.

Baig, M. H. A., Abid, M., Khan, M. R., Jiao, W., Amin, M., & Adnan, S. (2020). Assessing meteorological and agricultural drought in Chitral Kabul river basin using multiple drought indices. *Remote Sensing*, *12*(9), 1417.

Bandh, S. A., Shafi, S., Peerzada, M., Rehman, T., Bashir, S., Wani, S. A., & Dar, R. (2021). Multidimensional analysis of global climate change: a review. *Environmental Science and Pollution Research*, *28*(20), 24872-24888.

Bannor, F. (2022). *Agriculture, climate change and technical efficiency: The case of sub-Saharan Africa* (Doctoral dissertation, University of Johannesburg).

Balehey, S., Tesfay, G., & Balehegn, M. (2018). Traditional gender inequalities limit pastoral women's opportunities for adaptation to climate change: Evidence from the Afar pastoralists of Ethiopia. *Pastoralism*, *8*(1), 1-14.

Barros, V., & Stocker, T. F. (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the Intergovernmental Panel on Climate Change*.

Barua, P., Rahman, S. H., Barua, S., & Rahman, I. M. (2020). Climate change vulnerability and responses of fisherfolk communities in the South-Eastern coast of Bangladesh. *Water Conservation and Management*, *4*(1), 20-31.

Baruah, B., & Najjar, D. (2022). Gender Equality, Climate Change and Agriculture in the MENA region: Priorities and Possibilities.

Bateman, I. J., & Mace, G. M. (2020). The natural capital framework for sustainably efficient and equitable decision making. *Nature Sustainability*, *3*(10), 776-783.

Batung, E. S. (2021). *Climate Change Vulnerability and Perceived Resilience Among Smallholder Farmers in the Upper West Region of Ghana* (Master's thesis, The University of Western Ontario (Canada).

Bauer, T., de Jong, W., Ingram, V., Arts, B., & Pacheco, P. (2022). Thriving in turbulent times: Livelihood resilience and vulnerability assessment of Bolivian Indigenous Forest households. *Land Use Policy*, *119*, 106146.

Beall, J. (2014). Living in the present, investing in the future–Household security among the urban poor. In *Urban Livelihoods* (pp. 71-87). Routledge.

Baeza, A., Bojorquez-Tapia, L. A., Janssen, M. A., & Eakin, H. (2019). Operationalizing the feedback between institutional decision-making, socio-political infrastructure, and environmental risk in urban vulnerability analysis. *Journal of environmental management*, *241*, 407-417.

Beccari, B. (2016). A comparative analysis of disaster risk, vulnerability and resilience composite indicators. *PLoS currents*, *8*.

Bechoff, A. (2017). *Use and nutritional value of cassava roots and leaves as a traditional food*. Burleigh Dodds Science Publishing Limited.

Bedair, H., Alghariani, M. S., Omar, E., Anibaba, Q. A., Remon, M., Bornman, C., ... & Alzain, H. M. (2023). Global warming status in the African continent: sources, challenges, policies, and future direction. *International Journal of Environmental Research*, *17*(3), 45.

Bedeke, S. B. (2023). Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: A review on concepts, approaches and methods. *Environment, Development and Sustainability*, *25*(2), 1017-1051.

Bedeke, S. B., Vanhove, W., Wordofa, M. G., Natarajan, K., & Van Damme, P. (2020). Vulnerability to climate change among maize-dependent smallholders in three districts of Ethiopia. *Environment, Development and Sustainability*, *22*, 693-718.

Beguería, S., Vicente-Serrano, S. M., Reig, F., & Latorre, B. (2014). Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets, and drought monitoring. *International journal of climatology*, *34*(10), 3001-3023

Benjaminsen, T. A. (2021). Climate change and human conflict in the Sahel. *The Oxford Handbook of the African Sahel*, *269*, 270-275.

Berhane, A. (2018). Climate change and variability impacts on agricultural productivity and food security. *Clim. Weather Forecast*, *6*, 240.Blaikie, N., & Priest, J. (2017). *Social research: Paradigms in action*. John Wiley & Sons.

Berhanu, G., Woldemikael, S. M., & Beyene, E. G. (2022). The interrelationships of sustainable livelihood capital assets deprivations and asset based social policy interventions: The case of Addis Ababa informal settlement areas, Ethiopia. *Research in Globalization*, *4*, 100081.

Berrang-Ford, L., Sietsma, A. J., Callaghan, M., Minx, J. C., Scheelbeek, P. F., Haddaway, N. R., ... & Dangour, A. D. (2021). Systematic mapping of global research on climate and health: a machine learning review. *The Lancet Planetary Health*, *5*(8), e514-e525.

Bessah, E., Boakye, E. A., Agodzo, S. K., Nyadzi, E., Larbi, I., & Awotwi, A. (2021). Increased seasonal rainfall in the twenty-first century over Ghana and its potential implications for agriculture productivity. *Environment, Development and Sustainability*, *23*, 12342-12365.

Bhaga, T. D., Dube, T., Shekede, M. D., & Shoko, C. (2020). Impacts of climate variability and drought on surface water resources in Sub-Saharan Africa using remote sensing: A review. *Remote Sensing*, *12*(24), 4184.

Bin Rahman, A. R., & Zhang, J. (2023). Trends in rice research: 2030 and beyond. *Food and Energy Security*, *12*(2), e390.

Birkmann, J., Jamshed, A., McMillan, J. M., Feldmeyer, D., Totin, E., Solecki, W., ... & Alegría, A. (2022). Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. *Science of The Total Environment*, *803*, 150065.

Blaikie, N., & Priest, J. (2017). *Social research: Paradigms in action*. John Wiley & Sons.

Blanco-Ward, D., Ribeiro, A., Paoletti, E., & Miranda, A. I. (2021). Assessment of tropospheric ozone phytotoxic effects on the grapevine (Vitis vinifera L.): A review. *Atmospheric Environment*, *244*, 117924.

Bogale, G. A., & Bekele, S. E. (2023). Sustainability of Agroforestry Practices and their Resilience to Climate Change Adaptation and Mitigation in Sub-Saharan Africa: A Review. *Ekológia (Bratislava)*, *42*(2), 179-192.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko A, Medany, M., Osman-Elasha, B., Tabo, R., & Yanda, P. (2007). Africa Climate Change 2007: impacts, adaptation and vulnerability. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Contribution of Working Group II to the Fourth Assessment Report of the*

Intergovernmental Panel on Climate Change (pp. 433–467). Cambridge, UK: Cambridge University Press.

Bonaccorsi, A. (2022). *An epistemic approach to research assessment in the social sciences* (pp. 14-47). Edward Elgar Publishing.

Bongaarts, J. (2020). United Nations Department of Economic and Social Affairs, Population Division World Family Planning 2020: Highlights, United Nations Publications, 2020. 46 p.

Borhara, K., Pokharel, B., Bean, B., Deng, L., & Wang, S. Y. S. (2020). On Tanzania's precipitation climatology, variability, and future projection. *Climate*, *8*(2), 34.

Borras Jr, S. M., Scoones, I., Baviskar, A., Edelman, M., Peluso, N. L., & Wolford, W. (2022). Climate change and agrarian struggles: an invitation to contribute to a JPS Forum. *The Journal of Peasant Studies*, *49*(1), 1-28.

Botterill, L. C., & Hayes, M. J. (2012). Drought triggers and declarations: science and policy considerations for drought risk management. *Natural Hazards*, *64*, 139-151.

Brookes, G., & Barfoot, P. (2020). GM crop technology use 1996-2018: farm income and production impacts. *GM Crops & Food*, *11*(4), 242-261.

Bruce, J. W., & Migot-Adholia, S. E. (1994). *Searching for land tenure security in Africa*. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Brügger, A., Demski, C., & Capstick, S. (2021). How personal experience affects perception of and decisions related to climate change: A psychological view. *Weather, climate, and society*, *13*(3), 397-408.

Bruinsma, J. (2017). *World agriculture: towards 2015/2030: an FAO study*. Routledge.

Brychkova, G., Kekae, K., McKeown, P. C., Hanson, J., Jones, C. S., Thornton, P., & Spillane, C. (2022). Climate change and land-use change impacts on future availability of forage grass species for Ethiopian dairy systems. *Scientific Reports*, *12*(1), 20512.

Bryman, A. (2016). *Social research methods*. Oxford university press.

Buchner, J., Brightman, M., Nandra, K., Nikutta, R., & Bauer, F. E. (2019). X-ray spectral and eclipsing model of the clumpy obscurer in active galactic nuclei. *Astronomy & Astrophysics*, *629*, A16.

Bullock, R. C., Diduck, A., Luedee, J., & Zurba, M. (2022). Integrating Social Learning, Adaptive Capacity and Climate Adaptation for Regional Scale Analysis: A Conceptual Framework. *Environmental Management*, *69*(6), 1217-1230.

Bukar, Y., Monguno, A. K., & AbdulRahman, A. T. (2021). Environmental Change and Livelihood Activities in Hadejia-Nguru Wetlands of Yobe State, Northeast Nigeria. *Journal of Geography and Geology*, *12*(3), 1-12.

Burdon, J. J., & Zhan, J. (2020). Climate change and disease in plant communities. *PLoS biology*, *18*(11), e3000949.

Burkley, A. L., Brown, K., Holben, D. H., Shubrook, J. H., & Schwartz, F. L. (2011). Adult Food Security and Social Capital among Patients Using Free and Fee-for-Service Diabetes Clinics in Rural, Appalachian Ohio. *Journal of the American Dietetic Association*, *9*(111), A100.

Busby, J. W., Smith, T. G., White, K. L., & Strange, S. M. (2013). Climate change and insecurity: mapping vulnerability in Africa. *International Security*, *37*(4), 132-172.

Buxton, D. N. B. (2020). Climate Change Responses of Cocoa Farmers in Ghana. *International Journal of Environment and Climate Change*, *10*(8), 26-35.

Buyruk, H. (2020). An exploration of human capital theory and its effects on the world of education. In *Understanding Education and Economics* (pp. 64-76). Routledge.

Bwalya, D. (2023). *Livelihood diversification to combat climate change effects in Sachitema chiefdom, Kalomo district* (Doctoral dissertation, The University of Zambia)

Caggiano, H., Landau, L. F., Campbell, L. K., Johnson, M. L., & Svendsen, E. S. (2022). Civic stewardship and urban climate governance: opportunities for transboundary planning. *Journal of Planning Education and Research*, 0739456X221104010.

Cai, J., Ma, E., Lin, J., Liao, L., & Han, Y. (2020). Exploring global food security patterns from the perspective of spatio-temporal evolution. *Journal of Geographical Sciences*, *30*, 179-196.Cai, W., Lengaigne, M., Borlace, S., Collins, M., Cowan, T., McPhaden, M. J., ... & Widlansky, M. J. (2012). More extreme swings of the South Pacific convergence zone due to greenhouse warming. *Nature*, *488*(7411), 365-369.

Cairns, G., Angus, K., Hastings, G., & Caraher, M. (2013). Systematic reviews of the evidence on the nature, extent, and effects of food marketing to children. A retrospective summary. *Appetite*, *62*, 209-215.

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, *5*, 345-360.

Calicioglu, O., Flammini, A., Bracco, S., Bellù, L., & Sims, R. (2019). The future challenges of food and agriculture: An integrated analysis of trends and solutions. *Sustainability*, *11*(1), 222.

Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A., & Tol, R. S. (2013). Climate change impacts on global agriculture. *Climatic change*, *120*, 357-374.

Camarasa-Belmonte, A. M., Rubio, M., & Salas, J. (2020). Rainfall events and climate change in Mediterranean environments: an alarming shift from resource to risk in Eastern Spain. *Natural Hazards*, *103*, 423-445.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., ... & Wollenberg, E. (2016). Reducing risks to food security from climate change. *Global food security*, *11*, 34-43.

Cannon, T., & Müller-Mahn, D. (2010). Vulnerability, resilience and development discourses in context of climate change. *Natural hazards*, *55*, 621-635.

CAPI Application: https://www.csprousers.org/help/CSPro/what_is_cspro.html, Date Accessed: 02/02/2022.

Capone, R., Bottalico, F., Palmisano, G. O., El Bilali, H., & Dernini, S. (2019). Food systems sustainability, food security, and nutrition in the Mediterranean Region: The contribution of the Mediterranean diet.

Carr, T. W., Mkuhlani, S., Segnon, A. C., Ali, Z., Zougmoré, R., Dangour, A. D., ... & Scheelbeek, P. (2022). Climate change impacts and adaptation strategies for crops in West Africa: a systematic review. *Environmental Research Letters*, *17*(5), 053001.

Carr, T. W., Mkuhlani, S., Segnon, A. C., Ali, Z., Zougmoré, R., Dangour, A. D., ... & Scheelbeek, P. (2022). Climate change impacts and adaptation strategies for crops in West Africa: a systematic review. *Environmental research letters*, *17*(5), 053001.

Carter, T. R., Benzie, M., Campiglio, E., Carlsen, H., Fronzek, S., Hildén, M., ... & West, C. (2021). A conceptual framework for cross-border impacts of climate change. *Global Environmental Change*, *69*, 102307.

Carrão, H., Naumann, G., & Barbosa, P. (2016). Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure, and vulnerability. *Global Environmental Change*, *39*, 108-124.

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in planning*, *95*, 1-66.

Carter, J., & Connelly, A. (2016). RESIN conceptual framework: Supporting decision making for resilient cities. *European Union*.

Chary, G. R., Gopinath, K. A., Kumar, P. R., Bhaskar, S., Singh, V. K., Deepika, S., ... & Rasul11, B. R. K. A. (2021). Management of major abiotic stresses in field crops. *Indian J. Agron.*, *66*, S258-S278.

Ceci, P., Monforte, L., Perelli, C., Cicatiello, C., Branca, G., Franco, S., ... & Scarascia Mugnozza, G. (2021). Smallholder farmers' perception of climate change and drivers of adaptation in agriculture: A case study in Guinea. *Review of Development Economics*, *25*(4), 1991-2012.

Central Bank of Liberia (CBL), 2018: Central Bank of Liberia Annual Report for 2018. 2018.

Central Bank of Liberia (CBL), 2017: Central Bank of Liberia Annual Report for 2018. 2018.

Cervantes-Godoy, D., Kimura, S., & Antón, J. (2013). Smallholder risk management in developing countries.

Chakraborty, T., Mukherjee, D., & Saha, S. (2020). *Contemporary Issues in Sustainable Development*. CRC Press.

Chakravarty, S., Puri, A., Abha, M. K., Rai, P., Lepcha, U., Pala, N. A., & Shukla, G. (2020). Linking social dimensions of climate change: transforming vulnerable smallholder producers for empowering and resiliency. In *Climate Change and Agroforestry Systems* (pp. 169-208). Apple Academic Press.Challinor, A. J., Adger, W. N., Benton, T. G., Conway, D., Joshi, M., & Frame, D. (2018). Transmission of climate risks across sectors and borders. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2121), 20170301.

Chambers, R., Conway, G., & Brighton Institute of Development Studies. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century* (Vol. 296). Brighton: Institute of development studies.

Chang, K. T., Merghadi, A., Yunus, A. P., Pham, B. T., & Dou, J. (2019). Evaluating scale effects of topographic variables in landslide susceptibility models using GIS-based machine learning techniques. *Scientific reports*, *9*(1), 12296.

Change, I. C. (2014). Impacts, adaptation and vulnerability. *Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental Panel on Climate Change*, *1132*.

Changnon, S. A. (Ed.). (2000). *El Niño 1997-1998: the climate event of the century*. Oxford University Press.

Chandio, A. A., Gokmenoglu, K. K., Ahmad, M., & Jiang, Y. (2021). Towards sustainable rice production in Asia: The role of climatic factors. *Earth Systems and Environment*, 1-14.

Chapman, S., E Birch, C., Pope, E., Sallu, S., Bradshaw, C., Davie, J., & H Marsham, J. (2020). Impact of climate change on crop suitability in sub-Saharan Africa in parameterized and convection-permitting regional climate models. *Environmental Research Letters*, *15*(9), 094086.

Chauhan, B. S., Jabran, K., & Mahajan, G. (Eds.). (2017). *Rice production worldwide* (Vol. 247). Cham, Switzerland: Springer International Publishing.

Chen, Y., Yang, J., Wang, Y., Qi, J., & Luan, Q. (2023). The impact on climate change perception and adaptation of smallholder concepts: evidence from a sugarcane community, China. *Environmental Impact Assessment Review*, *102*, 107213.

Chepkoech, W., Mungai, N. W., Stöber, S., & Lotze-Campen, H. (2020). Understanding adaptive capacity of smallholder African indigenous vegetable farmers to climate change in Kenya. *Climate Risk Management*, *27*, 100204.

Chifamba, E. (2020). *Strategies for coping with household food insecurity in Chipinga District of Zimbabwe* (Doctoral dissertation).

Choden, K., Keenan, R. J., & Nitschke, C. R. (2020). An approach for assessing adaptive capacity to climate change in resource dependent communities in the Nikachu watershed, Bhutan. *Ecological Indicators*, *114*, 106293.

Choi, Y. W., Campbell, D. J., & Eltahir, E. A. (2023). Near-term regional climate change in East Africa. *Climate Dynamics*, *61*(1), 961-978.

Choi, Y. W., & Eltahir, E. A. (2023). Near-term climate change impacts on food crops productivity in East Africa. *Theoretical and Applied Climatology*, *152*(1), 843-860.Choudhary, B. B., & Sirohi, S. (2022). Understanding vulnerability of agricultural production system to climatic stressors in North Indian Plains: a meso-analysis. *Environment, development and sustainability*, 1-20.

Chirwa, P. W., & Adeyemi, O. (2020). Deforestation in Africa: implications on food and nutritional security. *Zero hunger*, 197-211.

Chriest, A., & Niles, M. (2018). The role of community social capital for food security following an extreme weather event. *Journal of Rural Studies*, *64*, 80-90.

Christensen, O. B., Kjellström, E., Dieterich, C., Gröger, M., & Meier, H. E. M. (2022). Atmospheric regional climate projections for the Baltic Sea region until 2100. *Earth System Dynamics*, *13*(1), 133-157.

Cianconi, P., Betrò, S., & Janiri, L. (2020). The impact of climate change on mental health: a systematic descriptive review. *Frontiers in psychiatry*, *11*, 74.

Cinner, J. E., Caldwell, I. R., Thiault, L., Ben, J., Blanchard, J. L., Coll, M., ... & Pollnac, R. (2022). Potential impacts of climate change on agriculture and fisheries production in 72 tropical coastal communities. *Nature communications*, *13*(1), 3530.

Cismaș, L. M., Miculescu, A., & Oțil, M. (2020). Human capital and impact on sustained economic growth in Romania. *Essential Issues in Corporate Social Responsibility: New Insights and Recent Issues*, 121-138.

Clapp, J., Moseley, W. G., Burlingame, B., & Termine, P. (2022). The case for a six-dimensional food security framework. *Food Policy*, *106*, 102164.

Clay, N., & King, B. (2019). Smallholders' uneven capacities to adapt to climate change amid Africa's 'green revolution': Case study of Rwanda's crop intensification program. *World Development*, *116*, 1-14.

Clarke, B., Otto, F., Stuart-Smith, R., & Harrington, L. (2022). Extreme weather impacts of climate change: an attribution perspective. *Environmental Research: Climate*, *1*(1), 012001.

Climate Knowledge Portal of World Bank (https://climateknowledgeportal.worlbank.org/download-data). Date Accessed: Mach 2021

Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge (2022), p. 34

Cock, J.A. (1982). Cassava: A basic energy source in the tropics. Science 218, 755-762.

Cobbinah, P. B., & Finn, B. M. (2022). Planning and climate change in African cities: Informal urbanization and 'Just'Urban transformations. *Journal of Planning Literature*, 08854122221128762.

Coleman, P. (2022). Validity and reliability within qualitative research for the caring sciences. *International Journal of Caring Sciences*, *14*(3), 2041-2045.

Collier, P., & Dercon, S. (2014). African agriculture in 50 years: smallholders in a rapidly changing world?. *World development*, *63*, 92-101.

Contreras, D., Chamorro, A., & Wilkinson, S. (2020). The spatial dimension in the assessment of urban socio-economic vulnerability related to geohazards. *Natural Hazards and Earth System Sciences*, *20*(6), 1663-1687.

Conway, D., Nicholls, R. J., Brown, S., Tebboth, M. G., Adger, W. N., Ahmad, B., ... & Wester, P. (2019). The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nature Climate Change*, *9*(7), 503-511.

Corlet Walker, C., Druckman, A., & Cattaneo, C. (2020). Understanding the (non-) use of societal wellbeing indicators in national policy development: What can we learn from civil servants? A UK case study. *Social Indicators Research*, *150*(3), 911-953.

Coulibaly ON, Abdoulaye T, Arinloye D-DAA, Vodouhe F. Regional Cassava Value Chains Analysis in West Africa (2014): Regional Summary. JANUARY):49.

Creswell, John W., and J. Creswell. *Research design*. Thousand Oaks, CA: Sage publications, 2003.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Cui, P., Peng, J., Shi, P., Tang, H., Ouyang, C., Zou, Q., ... & Lei, Y. (2021). Scientific challenges of research on natural hazards and disaster risk. *Geography and Sustainability*, *2*(3), 216-223.

Cyrilo, E., & Mung'ong'o, C. G. (2020). Assessment of socio-ecological resilience of agropastoralists to climate change and variability impacts in Bariadi district, Tanzania. In *Climate change impacts and sustainability: ecosystems of Tanzania* (pp. 122-152). Wallingford UK: CABI.

Czúcz, B., Keith, H., Maes, J., Driver, A., Jackson, B., Nicholson, E., ... & Obst, C. (2021). Selection criteria for ecosystem condition indicators. *Ecological Indicators*, *133*, 108376.

Dadzie, S. K. N. (2021). Farmers' Perception of Climate Change Compared with Objective Data: Evidence from the Central Region of Ghana. *Climate Change Economics*, *12*(01), 2050015.

Dagar, J. C., Gupta, S. R., & Teketay, D. (Eds.). (2020). *Agroforestry for Degraded Landscapes*. Springer.

Dakurah, G. (2021). How do farmers' perceptions of climate variability and change match or and mismatch climatic data? Evidence from North-west Ghana. *GeoJournal*, *86*(5), 2387-2406.

Dai, A. (2013). Increasing drought under global warming in observations and models. *Nature climate change*, *3*(1), 52-58.

Dagadu, N. A., Barker, K. M., Okello, S. B., Kerner, B., Simon, C., Nabembezi, D., & Lundgren, R. I. (2022). Fostering gender equality and reproductive and sexual health among adolescents: results from a quasi-experimental study in Northern Uganda. *BMJ open*, *12*(3), e053203.

Dakurah, G. (2021). How do farmers' perceptions of climate variability and change match or and mismatch climatic data? Evidence from North-west Ghana. *GeoJournal*, *86*(5), 2387-2406.

Dang, H. L., Li, E., Nuberg, I., & Bruwer, J. (2019). Factors influencing the adaptation of farmers in response to climate change: A review. *Climate and Development*, *11*(9), 765-774.

Das, T. K. (2023). Climate Change Vulnerability in Agriculture on Rural Farmers. *Journal of Krishi Vigyan*, *11*(2), 28-35.

Dassou, E. F., Ombolo, A., Chouto, S., Mboudou, G. E., Essi, J. M. A., & Bineli, E. (2016). Trends and geostatistical interpolation of spatio-temporal variability of precipitation in Northern Cameroon. *American Journal of Climate Change*, *5*(2), 229-244.

Davis, K. F., Rulli, M. C., Seveso, A., & D'Odorico, P. (2017). Increased food production and reduced water use through optimized crop distribution. *Nature Geoscience*, *10*(12), 919-924.

De Longueville, F., Ozer, P., Gemenne, F., Henry, S., Mertz, O., & Nielsen, J. Ø. (2020). Comparing climate change perceptions and meteorological data in rural West Africa to improve the understanding of household decisions to migrate. *Climatic Change*, *160*, 123-141.

Delaquis, E., de Haan, S., & Wyckhuys, K. A. (2018). On-farm diversity offsets environmental pressures in tropical agro-ecosystems: a synthetic review for cassava-based systems. *Agriculture, Ecosystems & Environment*, *251*, 226-235.

Delvaux, G., & Riesgo, L. (2020). Sustainable agricultural practices and their adoption in sub-Saharan Africa.

D'emilio, A., Aiello, R., Consoli, S., Vanella, D., & Iovino, M. (2018). Artificial neural networks for predicting the water retention curve of sicilian agricultural soils. *Water*, *10*(10), 1431.

Dendir, Z., & Simane, B. (2021). Farmers' perceptions about changes in climate variables: Perceived risks and household responses in different agro-ecological communities, Southern Ethiopia. *Climate Services*, *22*, 100236.

Derbile, E. K., Bonye, S. Z., & Yiridomoh, G. Y. (2022). Mapping vulnerability of smallholder agriculture in Africa: Vulnerability assessment of food crop farming and climate change adaptation in Ghana. *Environmental Challenges*, *8*, 100537.

Derbile, E. K., Chirawurah, D., & Naab, F. X. (2022). Vulnerability of smallholder agriculture to environmental change in North-Western Ghana and implications for development planning. *Climate and Development*, *14*(1), 39-51.

Deressa, T., Hassan, R. M., & Ringler, C. (2008). *Measuring Ethiopian farmers' vulnerability to climate change across regional states*. Intl Food Policy Res Inst.

De Vos, A., Biggs, R., & Preiser, R. (2019). Methods for understanding social-ecological systems: a review of place-based studies. *Ecology and society*, *24*(4).

Dhanya, P., & Ramachandran, A. (2016). Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi-arid region of south India. *Journal of Integrative Environmental Sciences*, *13*(1), 1-18.

Dharmawan, A. H., & Nissa, Z. N. A. (2020). Rural livelihood vulnerability and resilience: A typology drawn from case studies of small-scale farmers and fishermen in Indonesia. *Sodality: Jurnal Sosiologi Pedesaan*, *8*(1), 1-13.

Diallo, A., Donkor, E., & Owusu, V. (2020). Climate change adaptation strategies, productivity and sustainable food security in southern Mali. *Climatic Change*, *159*(3), 309-327.

Dick, E., & Schraven, B. (2021). Rural-urban migration in West Africa: Contexts, trends and recommendations. *KNOMAD Policy Brief*, *13*, 2021-03.

Dick-Sagoe, C., Hope, K. N., & Asare-Nuamah, P. (2022). Perceived impact of climate variability and change on livelihoods of smallholder farmers in Lesotho. *African Journal of Science, Technology, Innovation and Development*, 1-10.

Dick-Sagoe, C., & Nyamadi, W. K. (2022). Assessing Community Participation in District Development Facility Funded Projects in the Adentan Municipality of Ghana. *Loyola Journal of Social Sciences*, *36*(1).

Dickinson, K. L., Monaghan, A. J., Rivera, I. J., Hu, L., Kanyomse, E., Alirigia, R., ... & Wiedinmyer, C. (2017). Changing weather and climate in Northern Ghana: comparison of local perceptions with meteorological and land cover data. *Regional environmental change*, *17*, 915-928.

Diop, M., Chirinda, N., Beniaich, A., El Gharous, M., & El Mejahed, K. (2022). Soil and water conservation in Africa: State of play and potential role in tackling soil degradation and building soil health in agricultural lands. *Sustainability*, *14*(20), 13425.

Downing, T. E., Patwardhan, A., Klein, R. J., Mukhala, E., Stephen, L., Winograd, M., & Ziervogel, G. (2005). Assessing vulnerability for climate adaptation.

Doss, C., & Meinzen-Dick, R. (2020). Land tenure security for women: A conceptual framework. *Land Use Policy*, *99*, 105080.

Duchenne-Moutien, R. A., & Neetoo, H. (2021). Climate change and emerging food safety issues: a review. *Journal of food protection*, *84*(11), 1884-1897.

Duku, C., & Hein, L. (2021). The impact of deforestation on rainfall in Africa: a data-driven assessment. *Environmental Research Letters*, *16*(6), 064044.

Dumenu, W. K., & Takam Tiamgne, X. (2020). Social vulnerability of smallholder farmers to climate change in Zambia: the applicability of social vulnerability index. *SN Applied Sciences*, *2*, 1-16.

Dutta, R., & Maity, R. (2022). Value addition in coupled model intercomparison project phase 6 over phase 5: global perspectives of precipitation, temperature and soil moisture fields. *Acta Geophysica*, *70*(3), 1401-1415.

Eastin, J. (2018). Climate change and gender equality in developing states. *World Development*, *107*, 289-305.

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., ... & Tubiello, F. N. (2007). Food, fibre and forest products. *Climate change*, *2007*, 273-313.

Ebi, K. L., & Hess, J. J. (2017). The past and future in understanding the health risks of and responses to climate variability and change. *International journal of biometeorology*, *61*, 71-80.

Ebi, K. L., & Hess, J. J. (2020). Health Risks Due to Climate Change: Inequity in Causes And Consequences: Study examines health risks due to climate change. *Health Affairs*, *39*(12), 2056-2062.

Edmonds, H. K., Lovell, J. E., & Lovell, C. A. K. (2020). A new composite climate change vulnerability index. *Ecological Indicators*, *117*, 106529.

Egbebiyi, T. S., Crespo, O., Lennard, C., Zaroug, M., Nikulin, G., Harris, I., ... & Warren, R. (2020). Investigating the potential impact of 1.5, 2 and 3° C global warming levels on crop suitability and planting season over West Africa. *PeerJ*, *8*, e8851.

Eiser, J. R., Bostrom, A., Burton, I., Johnston, D. M., McClure, J., Paton, D., ... & White, M. P. (2012). Risk interpretation and action: A conceptual framework for responses to natural hazards. *International journal of disaster risk reduction*, *1*, 5-16.

El Bilali, H., Bassole, I. H. N., Dambo, L., & Berjan, S. (2020). Climate change and food security. *Agriculture & Forestry/Poljoprivreda i Sumarstvo*, *66*(3).

Emediegwu, L. E., Wossink, A., & Hall, A. (2022). The impacts of climate change on agriculture in sub-Saharan Africa: a spatial panel data approach. *World Development*, *158*, 105967.

Emran, S. A., Krupnik, T. J., Aravindakshan, S., Kumar, V., & Pittelkow, C. M. (2021). Factors contributing to farm-level productivity and household income generation in coastal Bangladesh's rice-based farming systems. *PloS one*, *16*(9), e0256694.

Environmental Protection Agency of Liberia. (2013) Liberia's Initial National Communication to the UNFCCC. Monrovia, Liberia

Environmental Protection Agency of Liberia. (2021) Liberia's Second National Communication to the UNFCCC. Headquarters 3rd Street, Sinkor, P.O. Box 4024 Monrovia Liberia

Environmental Protection Agency of Liberia (2018). National Policy and Response Strategy on Climate Change (NPRSC), Headquarters 3rd Street, Sinkor, P.O. Box 4024 Monrovia Liberia.

Environmental Protection Agency of Liberia. (2020). Liberia National Adaptation Plan, Headquarters 3rd Street, Sinkor, P.O. Box 4024 Monrovia Liberia

Environmental Protection Agency of Liberia (2015). Liberia's Nationally Determined Contribution (NDC), Headquarters 3rd Street, Sinkor, P.O. Box 4024 Monrovia Liberia

Ekwezuo, C. S. (2016). Climate model simulation and projections of precipitation changes over West Africa. *Unpublished M. Sc. thesis, University of Nigeria, Nsukka*.

Eslamian, S., Ostad-Ali-Askari, K., Singh, V. P., Dalezios, N. R., Ghane, M., Yihdego, Y., & Matouq, M. (2017). A review of drought indices. *Int. J. Constr. Res. Civ. Eng*, *3*, 48-66.

Ensor, J. E., Wennström, P., Bhatterai, A., Nightingale, A. J., Eriksen, S., & Sillmann, J. (2019). Asking the right questions in adaptation research and practice: Seeing beyond climate impacts in rural Nepal. *Environmental Science & Policy*, *94*, 227-236.

Etana, D., Snelder, D. J., van Wesenbeeck, C. F., & de Cock Buning, T. (2021). The impact of adaptation to climate change and variability on the livelihood of smallholder farmers in central Ethiopia. *Sustainability*, *13*(12), 6790.

Etana, D., Snelder, D. J., van Wesenbeeck, C. F., & de Cock Buning, T. (2020). Dynamics of smallholder farmers' livelihood adaptation decision-making in Central Ethiopia. *Sustainability*, *12*(11), 4526.

Etim, N. V., Ebong, E., & Ene, H. V. (2020). Climate Change Financing in Africa-Possible Principles and Mechanisms for Public Policy.

Etwire, P. M., Koomson, I., & Martey, E. (2022). Impact of climate change adaptation on farm productivity and household welfare. *Climatic Change*, *170*(1-2), 11.

Ezekannagha, E. (2020). Assessing the climatic suitability of Bambara groundnut as an underutilised crop to future climate projections in Sikasso and Ségou, Mali.

Fadairo, O., Olajuyigbe, S., Osayomi, T., Adelakun, O., Olaniyan, O., Olutegbe, S., & Adeleke, O. (2020). Climate change, rural livelihoods and ecosystem nexus: Forest communities in Agro-ecological zones of Nigeria. *African Handbook of Climate Change Adaptation*, 1-24.

Fadairo, O., Williams, P. A., & Nalwanga, F. S. (2020). Perceived livelihood impacts and adaptation of vegetable farmers to climate variability and change in selected sites from Ghana, Uganda and Nigeria. *Environment, Development and Sustainability*, *22*, 6831-6849.

Fagan, M., & Huang, C. (2019). A look at how people around the world view climate change.

Fahad, S., & Wang, J. (2018). Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. *Land use policy*, *79*, 301-309.

Fahad, S., & Wang, J. (2020). Climate change, vulnerability, and its impacts in rural Pakistan: a review. *Environmental Science and Pollution Research*, *27*, 1334-1338.

Fairbairn, M., Fox, J., Isakson, S. R., Levien, M., Peluso, N. L., Razavi, S., ... & Sivaramakrishnan, K. (Eds.). (2021). *New directions in agrarian political economy*. Routledge.

Fakhruddin, B. S., Boylan, K., Wild, A., & Robertson, R. (2020). Assessing vulnerability and risk of climate change. *Climate Extremes and Their Implications for Impact and Risk Assessment*, 217-241.

Falkenberg, M., Galeazzi, A., Torricelli, M., Di Marco, N., Larosa, F., Sas, M., ... & Baronchelli, A. (2022). Growing polarization around climate change on social media. *Nature Climate Change*, *12*(12), 1114-1121.

FAO, O. (2021). OECD-FAO Agricultural Outlook 2021–2030. *OECD-FAO Agricultural Outlook*.

FAO, F. AO (2017) The future of food and agriculture–trends and challenges. *The future of food and agriculture: trends and challenges*

FAO, E. (2018). Africa regional overview of food security and nutrition. *Addressin g the Threat from Climate Variability and Extremes for Food Security and Nutrition. Food and Agriculture Organization of the United Nations, Rome, Italy and the Unite d Nations Economic Commission for Africa, Addis Ababa, Ethiopia*.

FAO, IFAD, UNICEF, WFP, WHO (2021) The state of food security and nutrition in the world 2021. In Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, Italy:FAO.

FAO, F. (2018). The impact of disasters and crises on agriculture and food security. *Report*.

Farooq, M. S., Uzair, M., Raza, A., Habib, M., Xu, Y., Yousuf, M., ... & Ramzan Khan, M. (2022). Uncovering the research gaps to alleviate the negative impacts of climate change on food security: a review. *Frontiers in plant science*, *13*, 927535.

Feliciano, D., Recha, J., Ambaw, G., MacSween, K., Solomon, D., & Wollenberg, E. (2022). Assessment of agricultural emissions, climate change mitigation and adaptation practices in Ethiopia. *Climate policy*, *22*(4), 427-444.

Fellmann, T. (2012). The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. *Building resilience for adaptation to climate change in the agriculture sector*, *23*, 37.

Field, C. B., & Barros, V. R. (Eds.). (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Fischer, A. P., & Denny, R. C. (2024). Evaluating behavioral responses to climate change in terms of coping and adaptation: An index approach. *Global Environmental Change*, *86*, 102837.

Food Security Information Network. (2020). Global report on food crises. *Technical report*.

Fosu-Mensah, B. Y. (2012). *Modelling maize (Zea mays L.) productivity and impact of climate change on yield and nutrient utilization in sub-humid Ghana*. Zentrum für Entwicklungsforschung.

Fraval, S., Hammond, J., Bogard, J. R., Ng'endo, M., van Etten, J., Herrero, M., ... & van Wijk, M. T. (2019). Food access deficiencies in sub-Saharan Africa: prevalence and implications for agricultural interventions. *Frontiers in Sustainable Food Systems*, *3*, 104.

Fraschini, F., Hunt, A., & Zoboli, R. (2022). Decision tools for adaptation to climate change: Portfolio analysis of tea plantation investments in Rwanda. *Ecological Economics*, *200*, 107528.

Frischen, J., Meza, I., Rupp, D., Wietler, K., & Hagenlocher, M. (2020). Drought risk to agricultural systems in Zimbabwe: A spatial analysis of hazard, exposure, and vulnerability. *Sustainability*, *12*(3), 752.Fu, G., Wang, W., Li, J., Xiao, N., & Qi, Y. (2021). Prediction and Selection of Appropriate Landscape Metrics and Optimal Scale Ranges Based on Multi-Scale Interaction Analysis. *Land*, *10*(11), 1192.

Fünfgeld, H., & Schmid, B. (2020). Justice in climate change adaptation planning: conceptual perspectives on emergent praxis. *Geographica Helvetica*, *75*(4), 437-449.

Funna, A. (2020). *Population Density and Spatial Distribution of Neglected Tropical Diseases in Sierra Leone* (Doctoral dissertation, Walden University).

Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic change*, *75*(3), 301-329.

Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M., & Kahlenborn, W. (2014). The vulnerability sourcebook: concept and guidelines for standardised vulnerability assessments.

Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic change*, *75*(3), 301-329.

Gai, A. M., Poerwati, T., Maghfirah, F., & Sir, M. M. (2020). Analysis of sustainable livelihood level and its influence on community vulnerability of Surumana village, central Sulawesi. *Journal of Regional and Rural Development Planning (Jurnal Perencanaan Pembangunan Wilayah dan Perdesaan)*, *4*(3), 209-220.

Gaikwad, D. J., Ubale, N. B., Pal, A., Singh, S., Ali, M. A., & Maitra, S. (2022). Abiotic stresses impact on major cereals and adaptation options-A review. *Research on Crops*, *23*(4), 896-915.

Galappaththi, E. K., Susarla, V. B., Loutet, S. J., Ichien, S. T., Hyman, A. A., & Ford, J. D. (2022). Climate change adaptation in fisheries. *Fish and Fisheries*, *23*(1), 4-21.

Gallo, A. M., Ayoade, O. J., & Adelekan, O. I. (2020). Vulnerability of peasant farmers to climate variability and change in semi-arid Ethiopia.

Garba, A., Gana, B. A., Mohammed, I., & Adamu, H. (2022). Climate Change Vulnerability Assessment: An Evaluation of Social Dimension. *Journal of Sustainability and Environmental Management*, *1*(2), 52-61.

García Acosta, V. (2005). El riesgo como construcción social y la construcción social de riesgos. *Desacatos*, (19), 11-24.

Garschagen, M., Doshi, D., Reith, J., & Hagenlocher, M. (2021). Global patterns of disaster and climate risk—an analysis of the consistency of leading index-based assessments and their results. *Climatic Change*, *169*(1-2), 11.Gaworek-Michalczenia, M. F., Sallu, S. M., Di Gregorio, M., Doggart, N., & Mbogo, J. (2022). Evaluating the impact of adaptation interventions on vulnerability and livelihood resilience. *Climate and Development*, *14*(10), 867-883.

Gashu, D., Demment, M. W., & Stoecker, B. J. (2019). Challenges and opportunities to the African agriculture and food systems. *African Journal of Food, Agriculture, Nutrition and Development*, *19*(1), 14190-14217.

Gaworek-Michalczenia, M. F., Sallu, S. M., Di Gregorio, M., Doggart, N., & Mbogo, J. (2022). Evaluating the impact of adaptation interventions on vulnerability and livelihood resilience. *Climate and Development*, *14*(10), 867-883.

Gbadebo, A., & Owolade, E. O. (2020). Adaptation Strategies to Mitigate Impact of Climate Change on Food Crops Farming in Oyo State, Nigeria. *NASS Journal of Agricultural Sciences*, *2*(2), 8-8.

Gbayisemore, O. O., Edwin-Wosu, N. L., & Osuji, L. C. (2022). Ecological Evaluation of Natural Resources: A Baseline Study of Sustainable Livelihood Capital in Parts of Ilaje Riparian Community, Ondo State, Nigeria. *Asian Journal of Environment & Ecology*, *19*(4), 72-88.

Gebremariyam, D. E. (2021). Livelihood Adaptation to Climate Change and Variability among Smallholder Farmers in Central Ethiopia: Dynamics and Effectiveness.

Gezie, M. (2019). Farmer's response to climate change and variability in Ethiopia: A review. *Cogent Food & Agriculture*, *5*(1), 1613770.

Ghimire, R., Khatri-Chhetri, A., & Chhetri, N. (2022). Institutional Innovations for Climate Smart Agriculture: Assessment of Climate-Smart Village Approach in Nepal. *Frontiers in Sustainable Food Systems*, *6*, 734319.

Giannini, T. C., Costa, W. F., Cordeiro, G. D., Imperatriz-Fonseca, V. L., Saraiva, A. M., Biesmeijer, J., & Garibaldi, L. A. (2017). Projected climate change threatens pollinators and crop production in Brazil. *PLoS One*, *12*(8), e0182274.

Giannini, A., Krishnamurthy, P. K., Cousin, R., Labidi, N., & Choularton, R. J. (2017). Climate risk and food security in Mali: A historical perspective on adaptation. *Earth's Future*, *5*(2), 144-157.

Gibson, L., Moffatt, C. J., Narahari, S. R., Kabiri, L., Ikhile, D., Nchafack, A., ... & Gorry, J. (2021). Global knowledge gaps in equitable delivery of chronic edema care: A political economy case study analysis. *Lymphatic Research and Biology*, *19*(5), 447-459.

Giddens, A. (1979). *Central problems in social theory: Action, structure, and contradiction in social analysis* (Vol. 241). Univ of California Press.

Gikonyo, N. W. (2022). *Smallholder Farmers' Household Savings and Their Influence on Adoption of Climate Smart Agriculture Technologies in Nyando Basin, Kenya* (Doctoral dissertation, University of Nairobi).

Giller, K. E., Delaune, T., Silva, J. V., Descheemaeker, K., van de Ven, G., Schut, A. G., ... & van Ittersum, M. K. (2021). The future of farming: Who will produce our food?. *Food Security*, *13*(5), 1073-1099.

Glynn, P. W., & De Weerdt, W. H. (1991). Elimination of two reef-building hydrocorals following the 1982-83 El Niño warming event. *Science*, *253*(5015), 69-71.

Gnanasubramaniam, S., & Hemachandra, D. (2020). Perception of Climate Change and Farmers' Adaptation: An Analysis for Effective Policy Implementation. *Asia-Pacific Journal of Rural Development*, *30*(1-2), 27-54.

Gibson, G. R., Hutkins, R., Sanders, M. E., Prescott, S. L., Reimer, R. A., Salminen, S. J., ... & Reid, G. (2017). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of prebiotics. *Nature reviews Gastroenterology & hepatology*, *14*(8), 491-502.

Gomez-Zavaglia, A., Mejuto, J. C., & Simal-Gandara, J. (2020). Mitigation of emerging implications of climate change on food production systems. *Food Research International*, *134*, 109256.

Gomez-Zavaglia, A., Mejuto, J. C., & Simal-Gandara, J. (2020). Mitigation of emerging implications of climate change on food production systems. *Food Research International*, *134*, 109256.ecurity. *Handbook on Public Policy and Food Security*, 322-332.

Gond, S., Gupta, N., & Gupta, S. K. (2019). Evaluation of Drought Severity Indices and their Trend for Mirzapur (Uttar Pradesh).

Gora, J. S., Verma, A. K., Singh, J., & Choudhary, D. R. (2019). Climate change and production of horticultural crops. In *Agricultural Impacts of Climate Change [Volume 1]* (pp. 45-61). CRC Press.

Governance Reform Commission (GRC) 2007. The way forward: land & property right issues in the republic of Liberia. Governance Reform Commission, Government of Liberia, Monrovia

Government of Liberia Pro Poor Agenda for Prosperity and Development 2018. Government of Liberia, Monrovia

Government of Liberia Agenda for Transformation (Aft) 2013. Steps Towards Liberia Rising. Ministry of planning and Economic Affairs, Monrovia, Liberia.

Green, K. M., Selgrath, J. C., Frawley, T. H., Oestreich, W. K., Mansfield, E. J., Urteaga, J., ... & Crowder, L. B. (2021). How adaptive capacity shapes the Adapt, React, Cope response to climate impacts: insights from small-scale fisheries. *Climatic Change*, *164*, 1-22.

Grey, M. S., & Manyani, A. (2020). Integrating local indigenous knowledge to enhance risk reduction and adaptation strategies to drought and climate variability: The plight of smallholder farmers in Chirumhanzu district, Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, *12*(1).

Grigorieva, E., Livenets, A., & Stelmakh, E. (2023). Adaptation of agriculture to climate change: A scoping review. *Climate*, *11*(10), 202.

Guenang, G. M., & Kamga, F. M. (2014). Computation of the standardized precipitation index (SPI) and its use to assess drought occurrences in Cameroon over recent decades. *Journal of Applied Meteorology and Climatology*, *53*(10), 2310-2324.

Guja, M. M., & Bedeke, S. B. (2024). Smallholders' climate change adaptation strategies: exploring effectiveness and opportunities to be capitalized. *Environment, Development and Sustainability*, 1-30.

Gumel, D. Y. (2022). Assessing climate change vulnerability: A conceptual and theoretical review. *Journal of Sustainability and Environmental Management*, *1*(1), 22-31.

Gunarathne, P. K. K. S., Tennakoon, T. M. S. P. K., & Edirisinghe, J. C. (2020). Capital assets impact on rubber farming in Moneragala in Sri Lanka: Rubber smallholders' perception.

Gundersen, C., Lohman, B. J., Garasky, S., Stewart, S., & Eisenmann, J. (2008). Food security, maternal stressors, and overweight among low-income US children: results from the National Health and Nutrition Examination Survey (1999–2002). *Pediatrics*, *122*(3), e529-e540.

Guo, E., & Akudugu, M. A. (2023). Factors Affecting the Adoption of Agricultural Mechanization Technologies by Women Farmers in the Karaga District of Ghana. *Agricultural Sciences*, *14*(9), 1238-1248.

Guo, H., Xia, Y., Jin, J., & Pan, C. (2022). The impact of climate change on the efficiency of agricultural production in the world's main agricultural regions. *Environmental Impact Assessment Review*, *97*, 106891.

Guo, H., Xie, S., & Pan, C. (2021). The impact of planting industry structural changes on carbon emissions in the three northeast provinces of China. *International Journal of Environmental Research and Public Health*, *18*(2), 705.

Guodaar, L., Bardsley, D. K., & Suh, J. (2021). Integrating local perceptions with scientific evidence to understand climate change variability in northern Ghana: A mixed-methods approach. *Applied Geography*, *130*, 102440.

Guodaar, L., & Appiah, D. O. (2022). Evolving farm-level adaptation to climate variability and change risks in the forest-savanna transitional zone of Ghana. *Environmental Challenges*, *9*, 100654.

Gwambene, B., Liwenga, E., & Mung'ong'o, C. (2023). Climate change and variability impacts on agricultural production and food security for the smallholder farmers in Rungwe, Tanzania. *Environmental Management*, *71*(1), 3-14.

Hagenlocher, M., Renaud, F. G., Haas, S., & Sebesvari, Z. (2018). Vulnerability and risk of deltaic social-ecological systems exposed to multiple hazards. *Science of the total environment*, *631*, 71-80.

Hagenlocher, M., Meza, I., Anderson, C. C., Min, A., Renaud, F. G., Walz, Y., ... & Sebesvari, Z. (2019). Drought vulnerability and risk assessments: state of the art, persistent gaps, and research agenda. *Environmental Research Letters*, *14*(8), 083002.

Hahn, B., Barber, J., Johnson, D., & Garbo, H. W. (2014). Liberia-environmental threat and opportunities.

Haile, G. G., Tang, Q., Hosseini-Moghari, S. M., Liu, X., Gebremicael, T. G., Leng, G., ... & Yun, X. (2020). Projected impacts of climate change on drought patterns over East Africa. *Earth's Future*, *8*(7), e2020EF001502.

Haile, B. T., Bekitie, K. T., Feyissa, G. L., & Zeleke, T. T. (2020). El Niño Southern Oscillation and Its Impact on Rainfall Distribution and Productivity of Major Agricultural Crops: The Case of Kemabata Tembaro Zone, Southern Ethiopia.

Haile, B., Signorelli, S., Azzarri, C., & Johnson, T. (2018). Welfare effects of weather variability: Multi-country evidence from Africa south of the Sahara. *PloS one*, *13*(11), e0206415.

Hamed, K. H. (2008). Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis. *Journal of hydrology*, *349*(3-4), 350-363.

Hamed, M. M., Nashwan, M. S., & Shahid, S. (2022). Inter-comparison of historical simulation and future projections of rainfall and temperature by CMIP5 and CMIP6 GCMs over Egypt. *Int. J. Climatol*, *42*(8), 4316-4332.

Hammer, G. L., McLean, G., Chapman, S., Zheng, B., Doherty, A., Harrison, M. T., ... & Jordan, D. (2014). Crop design for specific adaptation in variable dryland production environments. *Crop and Pasture Science*, *65*(7), 614-626.

Harris, I. P. D. J., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations–the CRU TS3. 10 Dataset. *International journal of climatology*, *34*(3), 623-642

Hassan, I., Kalin, R. M., White, C. J., & Aladejana, J. A. (2020). Selection of CMIP5 GCM ensemble for the projection of Spatio-temporal changes in precipitation and temperature over the Niger Delta, Nigeria. *Water*, *12*(2), 385.

Hassan, C. K., Jonathan, S., & Idris, A. (2022). Determinant of Allocative Efficiency Among Rainfed Rice Farmers in Ardo-Kola and Jalingo Local Government Areas of Taraba State. Nigeria. *Journal of Agripreneurship and Sustainable Development*, *5*(1), 94-102.

Hawkins, P., Geza, W., Mabhaudhi, T., Sutherland, C., Queenan, K., Dangour, A., & Scheelbeek, P. (2022). Dietary and agricultural adaptations to drought among smallholder farmers in South Africa: a qualitative study. *Weather and climate extremes*, *35*, 100413.

Hayes, M. J. (2000). Revisiting the SPI: clarifying the process.

Hayes, M. J., Alvord, C., & Lowrey, J. (2007). Drought indices. *Intermountain west climate summary*, *3*(6), 2-6.

Heitzmann, K., Canagarajah, R. S., & Siegel, P. B. (2002). Guidelines for assessing the sources of risk and vulnerability. *WB Social Protection Discussion Paper*, *218*.

Helmy, I. (2020). *Livelihood diversification strategies: Resisting vulnerability in Egypt* (No. 441). GLO Discussion Paper.

Hendren, K., Newcomer, K., Pandey, S. K., Smith, M., & Sumner, N. (2023). How qualitative research methods can be leveraged to strengthen mixed methods research in public policy and public administration? *Public Administration Review*, *83*(3), 468-485.

Hendriks, S. L. (2018). Review of the Draft Liberia Agricultural Sector Investment Plan (LASIP II) For 2018–2022 with a Focus on Component 4 of the Malabo CAADP Results Framework.

Hernández-Morcillo, M., Burgess, P., Mirck, J., Pantera, A., & Plieninger, T. (2018). Scanning agroforestry-based solutions for climate change mitigation and adaptation in Europe. *Environmental Science & Policy*, *80*, 44-52.

Hernández-Ochoa, I. M., Gaiser, T., Kersebaum, K. C., Webber, H., Seidel, S. J., Grahmann, K., & Ewert, F. (2022). Model-based design of crop diversification through new field arrangements in spatially heterogeneous landscapes. A review. *Agronomy for Sustainable Development*, *42*(4), 74.

Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., ... & Rosegrant, M. (2010). Smart investments in sustainable food production: revisiting mixed crop-livestock systems. *Science*, *327*(5967), 822-825.

Hessebo, M. T., Woldeamanuel, T., & Tadesse, M. (2021). Spatial and temporal climate variability and change in the bilate catchment, central Rift Valley lakes region, Ethiopia. *Physical Geography*, *42*(3), 199-225.

Hilson, G., & Van Bockstael, S. (2012). Poverty and livelihood diversification in rural Liberia: exploring the linkages between artisanal diamond mining and smallholder rice production. *Journal of Development Studies*, *48*(3), 413-428.

Hirose, M., & Creswell, J. W. (2023). Applying core quality criteria of mixed methods research to an empirical study. *Journal of Mixed Methods Research*, *17*(1), 12-28.

Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., ... & Zhang, Y. (2019). High mountain areas. In *IPCC special report on the ocean and cryosphere in a changing climate* (pp. 131-202). H.-O. Pörtner, DC Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, NM Weyer (eds.).

Hoffmann, R. (2022). Contextualizing climate change impacts on human mobility in African drylands. *Earth's Future*, *10*(6), e2021EF002591.

Hoffmann, R., & Blecha, D. (2020). Education and disaster vulnerability in Southeast Asia: Evidence and policy implications. *Sustainability*, *12*(4), 1401.

Huggi, L., Thimmegowda, M. N., Sridhara, S., Manjunatha, M. H., & Das, B. (2024). Climate change-induced spatiotemporal monsoon variability: assessment of its implications on global and regional production systems. In *Climate Change Impacts on Soil-Plant-Atmosphere Continuum* (pp. 713-758). Singapore: Springer Nature Singapore.

Household Income and Expenditure Survey (2016): Liberia Institute of Statistics and Geo-Information Services (LISGIS), Monrovia, Liberia

Hosseini, S. S., Charvadeh, M. P., Salami, H., & Flora, C. (2017). The impact of the targeted subsidies policy on household food security in urban areas in Iran. *Cities*, *63*, 110-117.

Howe, P. D., Marlon, J. R., Mildenberger, M., & Shield, B. S. (2019). How will climate change shape climate opinion? *Environmental Research Letters*, *14*(11), 113001.

Hufnagel, J., Reckling, M., & Ewert, F. (2020). Diverse approaches to crop diversification in agricultural research. A review. *Agronomy for Sustainable Development*, *40*, 1-17.

Huyer, S., Simelton, E., Chanana, N., Mulema, A. A., & Marty, E. (2021). Expanding opportunities: a framework for gender and socially-inclusive climate resilient agriculture. *Frontiers in Climate*, *3*, 718240.

Ibrahim, F. M., Shaib-Rahim, H. O., Olatunji, B. T., Eniola, O., Oyedeji, M. B., & Babatunde, R. O. (2020). Socio-demographic associates of perceived social support among crop farmers in Ido local government area, Ibadan, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, *12*(2).

Ignatyeva, M., Yurak, V., & Logvinenko, O. (2020). A new look at the natural capital concept: Approaches, structure, and evaluation procedure. *Sustainability*, *12*(21), 9236.

Ilori, O. W., & Ajayi, V. O. (2020). Change detection and trend analysis of future temperature and rainfall over West Africa. *Earth systems and Environment*, *4*, 493-512.

Impa, S. M., Raju, B., Hein, N. T., Sandhu, J., Prasad, P. V., Walia, H., & Jagadish, S. K. (2021). High night temperature effects on wheat and rice: Current status and way forward. *Plant, Cell & Environment*, *44*(7), 2049-2065.

IPCC (2018a) Summary for policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V et al (eds)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, p 3-24, Doi: https://doi.org/10.1017/9781009157940.001, date accessed: 03/05/2023

IPCC. (2019b). Glossary. In H. O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a changing climate*. In press. (pp. 677–699).

IPCC, 2023: Climate Change 2023: Synthesis Report, Summary for Policymakers. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.

IPCC. (2018). Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H.

O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (eds.)]. In Press.

IPCC (2014). Climate Change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, RK Pachauri, LA Meyer (eds.). IPCC, Geneva, Switzerland, p 151

IPCC. (2019a). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, & J. Malley, (eds.)]. In press.

IPCC, F. C. (2014). Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA*.

IPCC 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report: Africa Regional Context. Geneva, Switzerland: IPCC Secretariat.

IPCC. (2007). Climate change 2007: Impacts, adaptation and vulnerability. *Report of the working group II to the fourth assessment report of the IPCC.* https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf; Accessed: 15/06/2024

IPCC, C. C. (2007). Impacts, adaptation and vulnerability. contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. *Intergovernmental Panel on Climate Change (IPCC)*.

IPCC, C. C. (2022). Impacts, adaptation and vulnerability. contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. *Intergovernmental Panel on Climate Change (IPCC)*.

IPCC 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report: Africa Regional Context. Geneva, Switzerland: IPCC Secretariat.

IPCC, I. (2014). Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change.

IPCC (Intergovernmental Panel on Climate Change). (2018). *Global Warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Geneva: ipcc.

Ipcc, I. P. C. C., & Meyer, L. A. (2014). Climate change 2014: synthesis report. Contribution of Working Groups I. *II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*, *27*, 408-420.

International Electrotechnical Commission. (2019). *Risk Management: Risk Assessment Techniques*. International electrotechnical commission.

Ishtiaque, A. (2021). Multilevel governance in climate change adaptation: conceptual clarification and future outlook. In *Climate change and extreme events* (pp. 171-185). Elsevier.

Islam, M. A., Warwick, N., Koech, R., Amin, M. N., & de Bruyn, L. L. (2020). The importance of farmers' perceptions of salinity and adaptation strategies for ensuring food security: Evidence from the coastal rice growing areas of Bangladesh. *Science of the Total Environment*, *727*, 138674.

Iyakaremye, V., Zeng, G., Yang, X., Zhang, G., Ullah, I., Gahigi, A., ... & Ayugi, B. (2021). Increased high-temperature extremes and associated population exposure in Africa by the mid-21st century. *Science of The Total Environment*, *790*, 148162.

Jadhav, A. (2024). Unsustainable, Imperial Dreams: What India’s Blue Economy Portends for “Life Below Water”. In *Sustainability: Science, Policy, and Practice in India: Challenges and Opportunities* (pp. 187-213). Cham: Springer International Publishing.

Javadi, A., Ghahremanzadeh, M., Sassi, M., Javanbakht, O., & Hayati, B. (2023). Economic evaluation of the climate changes on food security in Iran: application of CGE model. *Theoretical and applied climatology*, *151*(1), 567-585.

Java-Indonesia, W. (2020). Rural Youth Capacity Building Model of the Chili Farming Community in Garut Regency West Java, Indonesia. *Journal of the Social Sciences*, *48*(4).

Javadinejad, S., Dara, R., & Jafary, F. (2019). Taking urgent actions to combat climate change impacts. *Annals of Geographical Studies*, *2*(4), 1-13.

Jayne, T. S., & Sanchez, P. A. (2021). Agricultural productivity must improve in sub-Saharan Africa. *Science*, *372*(6546), 1045-1047.

Jensen, N. D., Fava, F. P., Mude, A. G., Barrett, C. B., Wandera-Gache, B., Vrieling, A., ... & Banerjee, R. (2024). *Escaping Poverty Traps and Unlocking Prosperity in the Face of Climate Risk: Lessons from Index-Based Livestock Insurance*. Cambridge University Press.

Jellason, N. P., Conway, J. S., Baines, R. N., & Ogbaga, C. C. (2021). A review of farming challenges and resilience management in the Sudano-Sahelian drylands of Nigeria in an era of climate change. *Journal of Arid Environments*, *186*, 104398.

Jerneck, A. (2018). What about gender in climate change? Twelve feminist lessons from development. *Sustainability*, *10*(3), 627.

Jerome, A., & Ajakaiye, O. (2019). Reviving industrialization in Africa. In *African economic development* (pp. 425-448). Emerald Publishing Limited.

Jevnaker, B. H., & Olaisen, J. (2019). The dynamics of societal and corporate ideas: The knowledge work design of the future. In *European Conference on Knowledge Management* (pp. 565-XXIV). Academic Conferences International Limited.

Jia, H., Chen, F., & Du, E. (2021). Adaptation to disaster risk—an overview. *International journal of environmental research and public health*, *18*(21), 11187.

Jiang, D., Wang, Q., Ding, F., Fu, J., & Hao, M. (2019). Potential marginal land resources of cassava worldwide: A data-driven analysis. *Renewable and Sustainable Energy Reviews*, *104*, 167-173.

Johansson, K. E. (2015). *Barriers and bridges for introducing agroforestry and community-based forestry among food insecure households in eastern Africa*. School for Forest Management, Swedish University of Agricultural Sciences.

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global environmental change*, *13*(1), 51-59.

Jones, L., Dougill, A., Jones, R. G., Steynor, A., Watkiss, P., Kane, C., ... & Vincent, K. (2015). Ensuring climate information guides long-term development. *Nature Climate Change*, *5*(9), 812-814.

Juerges, N., Leahy, J., & Newig, J. (2020). A typology of actors and their strategies in multi-scale governance of wind turbine conflict within forests. *Land Use Policy*, *96*, 104691.

Kaczan, D. J., & Orgill-Meyer, J. (2020). The impact of climate change on migration: a synthesis of recent empirical insights. *Climatic Change*, *158*(3), 281-300.

Kajwang, B. (2022). Weather based index insurance and its role in agricultural production. *International Journal of Agriculture*, *7*(1), 13-25.

Kalekin-Fishman, D. and David silverman (2001). Interpreting qualitative data: methods for analysing talk, text and interaction. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research* (Vol. 2, No. 3).

Kamali, B., Jahanbakhshi, F., Dogaru, D., Dietrich, J., Nendel, C., & AghaKouchak, A. (2022). Probabilistic modeling of crop-yield loss risk under drought: a spatial showcase for sub-Saharan Africa. *Environmental Research Letters*, *17*(2), 024028.

Kandasamy, S. U. L., Singh, P. K., & Swain, D. K. (2022). Climate change vulnerability assessment of dryland farmers and factors Identification using machine learning techniques. *Local Environment*, *27*(7), 824-846.

Kanerva, J., & Krizsán, A. (2021). Discouraging climate action through implicit argumentation: An analysis of linguistic polyphony in the Summary for Policymakers by the Intergovernmental Panel on Climate Change. *Discourse & Communication*, *15*(6), 609-628.

Kangalawe, R. Y., Mung'ong'o, C. G., Mwakaje, A. G., Kalumanga, E., & Yanda, P. Z. (2017). Climate change and variability impacts on agricultural production and livelihood systems in Western Tanzania. *Climate and Development*, *9*(3), 202-216.

Karki, G., Bhatta, B., Devkota, N. R., Acharya, R. P., & Kunwar, R. M. (2021). Climate change adaptation (CCA) interventions and indicators in Nepal: implications for sustainable adaptation. *Sustainability*, *13*(23), 13195.

Karki, G., Bhatta, B., Devkota, N. R., Acharya, R. P., & Kunwar, R. M. (2022). Climate change adaptation (CCA) research in Nepal: implications for the advancement of adaptation planning. *Mitigation and Adaptation Strategies for Global Change*, *27*(3), 18.

Karman, A. (2020). Flexibility, coping capacity and resilience of organizations: between synergy and support. *Journal of Organizational Change Management*, *33*(5), 883-907.

Keenan, J. M., & Maxwell, K. (2022). Rethinking the design of resilience and adaptation indicators supporting coastal communities. *Journal of environmental planning and management*, *65*(12), 2297-2317.

Kehler, S., & Birchall, S. J. (2021). Social vulnerability and climate change adaptation: The critical importance of moving beyond technocratic policy approaches. *Environmental Science & Policy*, *124*, 471-477.

Kelly, C. I., Hancock, C. M., Grebby, S., Marsh, S., Ferreira, V. G., & Hamm, N. A. S. (2022). Impact of meteorological conditions on water resources in the Upper East Region of Ghana using remotely-sensed and modelled hydrological data. *Journal of Hydrology: Regional Studies*, *42*, 101124.

Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change andFacilitating adaptation. *Climatic change*, *47*(4), 325-352.

Kendon, E. J., Stratton, R. A., Tucker, S., Marsham, J. H., Berthou, S., Rowell, D. P., & Senior, C. A. (2019). Enhanced future changes in wet and dry extremes over Africa at convection-permitting scale. *Nature communications*, *10*(1), 1794.

Kendall, M. G. (1948). Rank correlation methods.

Kennard, N. J. J. (2023). *Evaluating the sustainability and resiliency of local food systems* (Doctoral dissertation, University of Sheffield).

Khadka, A. (2022). *Women's Empowerment and Adaptive Capacity to Climate Change: A Case of Changes in the Chitwan District of Nepal* (Doctoral dissertation, Texas A&M University).

Khan, I., Lei, H., Shah, I. A., Ali, I., Khan, I., Muhammad, I., ... & Javed, T. (2020). Farm households' risk perception, attitude and adaptation strategies in dealing with climate change: Promise and perils from rural Pakistan. *Land use policy*, *91*, 104395.

Khan, M. R., & Munira, S. (2021). Climate change adaptation as a global public good: implications for financing. *Climatic Change*, *167*(3), 50.

Khan, N. A., Gao, Q., Abid, M., & Shah, A. A. (2021). Mapping farmers' vulnerability to climate change and its induced hazards: evidence from the rice-growing zones of Punjab, Pakistan. *Environmental Science and pollution research*, *28*, 4229-4244.

Khanal, U., Wilson, C., Rahman, S., Lee, B. L., & Hoang, V. N. (2021). Smallholder farmers' adaptation to climate change and its potential contribution to UN's sustainable development goals of zero hunger and no poverty. *Journal of Cleaner Production*, *281*, 124999.

Khanal, U., Wilson, C., Hoang, V. N., & Lee, B. (2018). Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. *Ecological economics*, *144*, 139-147.

Khanal, U., Wilson, C., Hoang, V. N., & Lee, B. L. (2019). Autonomous adaptations to climate change and rice productivity: a case study of the Tanahun district, Nepal. *Climate and development*, *11*(7), 555-563.

Khoshmaram, M., Shiri, N., Shinnar, R. S., & Savari, M. (2020). Environmental support and entrepreneurial behavior among Iranian farmers: The mediating roles of social and human capital. *Journal of Small Business Management*, *58*(5), 1064-1088.

Kiehbadroudinezhad, M., Merabet, A., & Hosseinzadeh-Bandbafha, H. (2024). Health impacts of greenhouse gases emissions on humans and the environment. In *Advances and Technology Development in Greenhouse Gases: Emission, Capture and Conversion* (pp. 265-291). Elsevier.

Kihupi, M. L. (2020). Barriers in Implementation of Climate Change Adaptation Strategies among Smallholder Farmers in Semi-Arid Areas of Iringa District Tanzania. *Journal of Co-operative and Business Studies (JCBS)*, *5*(2).

Kim, T. W., & Jehanzaib, M. (2020). Drought risk analysis, forecasting and assessment under climate change. *Water*, *12*(7), 1862.

Kinnunen, P., Heino, M., Sandström, V., Taka, M., Ray, D. K., & Kummu, M. (2022). Crop yield loss risk is modulated by anthropogenic factors. *Earth's future*, *10*(9), e2021EF002420.

Kitoh, A., Endo, H., Krishna Kumar, K., Cavalcanti, I. F., Goswami, P., & Zhou, T. (2013). Monsoons in a changing world: A regional perspective in a global context. *Journal of Geophysical Research: Atmospheres*, *118*(8), 3053-3065.

Kızıldeniz, T., Ceribas, R., & Naeem, M. Y. (2023). Nutrition-Sensitive Climate-Smart Agriculture. In *Climate Change Impacts on Agriculture: Concepts, Issues and Policies for Developing Countries* (pp. 79-87). Cham: Springer International Publishing.

Klasic, M., Fencl, A., Ekstrom, J. A., & Ford, A. (2022). Adapting to extreme events: small drinking water system manager perspectives on the 2012–2016 California Drought. *Climatic Change*, *170*(3), 26.

Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts crop productivity in Africa and South Asia. *Environmental research letters*, *7*(3), 034032.

Konan, K. M., Coulibaly, S. S., Kouassi, K. I., Zoro, B. I. A., & Dogbo, D. O. (2020). Coupling Compost from Chicken Manure and Inorganic Fertilizer to Improve Cassava (Manihot esculenta Crantz) Growth and Yield on a Ferralitic Soil in Côte d 'Ivoire. *Turkish Journal of Agriculture-Food Science and Technology*, *8*(7), 1472-1478.

Kogo, B. K., Kumar, L., & Koech, R. (2021). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, *23*, 23-43.

Kong, Z. H., Stringer, L., Paavola, J., & Lu, Q. (2021). Situating China in the global effort to combat desertification. *Land*, *10*(7), 702.

Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, *13*, 587-605.

Kling, G., Volz, U., Murinde, V., & Ayas, S. (2021). The impact of climate vulnerability on firms' cost of capital and access to finance. *World Development*, *137*, 105131.

Knorr, W., & Scholze, M. (2008). A global climate change risk assessment of droughts and floods. *Economics and Management of Climate Change: Risks, Mitigation and Adaptation*, 37-52.

Kpoor, A. (2019). Assets and livelihoods of male-and female-headed households in Ghana. *Journal of Family Issues*, *40*(18), 2974-2996.

Kreft, S., Eckstein, D., & Melchior, I. (2016). Global climate risk index 2017. Who suffers most from extreme weather events? Weather-related loss events in 2015 and 1996 to 2015.

Krishna, K. R. (2023). *The Agricultural Sky: A Concept to Revolutionize Farming*. Apple Academic Press.

Kumar, N., Poonia, V., Gupta, B. B., & Goyal, M. K. (2021). A novel framework for risk assessment and resilience of critical infrastructure towards climate change. *Technological Forecasting and Social Change*, *165*, 120532.

Kumar, M., Kalra, N., Singh, H., Sharma, S., Rawat, P. S., Singh, R. K., ... & Ravindranath, N. H. (2021). Indicator-based vulnerability assessment of forest ecosystem in the Indian Western Himalayas: An analytical hierarchy process integrated approach. *Ecological Indicators*, *125*, 107568.

Kumar, S., Merwade, V., Kinter III, J. L., & Niyogi, D. (2013). Evaluation of temperature and precipitation trends and long-term persistence in CMIP5 twentieth-century climate simulations. *Journal of Climate*, *26*(12), 4168-4185.

Kumar, S., Kumar, R. S., & Prabhu, M. G. N. (2020). Sampling framework for personal interviews in qualitative research. *PalArch's Journal of Archaeology of Egypt/Egyptology*, *17*(7), 7102-7114.

Kumi, N., Adeliyi, T. E., Asante, V. A., Abiodun, B. J., & Lamptey, B. L. (2023). Impact of rainfall onset date on crops yield in Ghana. *Frontiers in Sustainable Food Systems*, *7*, 1176385.

Kugbega, S. K., & Aboagye, P. Y. (2021). Farmer-herder conflicts, tenure insecurity and farmer's investment decisions in Agogo, Ghana. *Agricultural and Food Economics*, *9*(1), 19.

Kundzewicz, Z. W., Su, B., Wang, Y., Wang, G., Wang, G., Huang, J., & Jiang, T. (2019). Flood risk in a range of spatial perspectives–from global to local scales. *Natural Hazards and Earth System Sciences*, *19*(7), 1319-1328.

Kuyper, J., Schroeder, H., & Linnér, B. O. (2018). The Evolution of the UNFCCC. *Annual Review of Environment and Resources*, *43*, 343-368.

Labiru, M. A., Fada, S. J., Yahaya, S., Maton, S. M., Binbol, N. L., Hadiza, N., ... & Bena, M. A. (2023). Public perception of climate change impact on health and environment in Taraba State, Nigeria. *Journal of Meteorology and Climate Science*, *22*(1), 88-100.

Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, *369*(6503), 500-502.

Lamb, W. F., Mattioli, G., Levi, S., Roberts, J. T., Capstick, S., Creutzig, F., ... & Steinberger, J. K. (2020). Discourses of climate delay. *Global Sustainability*, *3*, e17.

Land Commission (LC) 2013. Land Rights and Policy, Government of the republic of Liberia, Monrovia.

Lanlan, J., Sarker, M. N. I., Ali, I., Firdaus, R. R., & Hossin, M. A. (2023). Vulnerability and resilience in the context of natural hazards: a critical conceptual analysis. *Environment, Development and Sustainability*, 1-24.

Le, T. D. N. (2020). Climate change adaptation in coastal cities of developing countries: characterizing types of vulnerability and adaptation options. *Mitigation and Adaptation Strategies for Global Change*, *25*(5), 739-761.

Leal Filho, W., Tuladhar, L., Li, C., Balogun, A. L. B., Kovaleva, M., Abubakar, I. R., ... & Donkor, F. K. K. (2022). Climate change and extremes: implications on city livability and associated health risks across the globe. *International Journal of Climate Change Strategies and Management*, *15*(1), 1-19.

Leal Filho, W., Azeiteiro, U. M., Balogun, A. L., Setti, A. F. F., Mucova, S. A., Ayal, D., ... & Oguge, N. O. (2021). The influence of ecosystems services depletion to climate change adaptation efforts in Africa. *Science of The Total Environment*, *779*, 146414.

Leal Filho, W., Barbir, J., Gwenzi, J., Ayal, D., Simpson, N. P., Adeleke, L., ... & Yaffa, S. (2022). The role of indigenous knowledge in climate change adaptation in Africa. *Environmental Science & Policy*, *136*, 250-260.

Leal Filho, W., Balogun, A. L., Olayide, O. E., Azeiteiro, U. M., Ayal, D. Y., Muñoz, P. D. C., ... & Li, C. (2019). Assessing the impacts of climate change in cities and their adaptive capacity: Towards transformative approaches to climate change adaptation and poverty reduction in urban areas in a set of developing countries. *Science of the Total Environment*, *692*, 1175-1190.

Leboeuf, C. (2018). Global indicator framework for the Sustainable Development Goals.

Lefe, Y. D. H., Asare-Nuamah, P., Njong, A. M., Kondowe, J., & Musakaruka, R. R. (2024). Does climate variability matter in achieving food security in Sub-Saharan Africa?. *Environmental Challenges*, *15*, 100870.

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... & Park, Y. (2023).

Lemi, T., & Hailu, F. (2019). Effects of climate change variability on agricultural productivity. *Int. J. Environ. Sci. Nat. Resour*, *17*, 14-20.

Li, L., Cao, R., Wei, K., Wang, W., & Chen, L. (2019). Adapting climate change challenge: A new vulnerability assessment framework from the global perspective. *Journal of cleaner production*, *217*, 216-224.

Liberia Institute of Statistics and Geo-Information Services (LISGIS, 2016). Household Income and Expenditure Survey (HIES). Monrovia, Republic of Liberia

Liberia Demographic and Health survey (2019). Liberia Institute of Statistics and geo-Information services (LISGIS), Monrovia, Liberia

Liberia Demographic and Health survey (2013). Liberia Institute of Statistics and geo-Information services (LISGIS), Monrovia, Liberia

Linke, A., & Raleigh, C. (2023). Conflict and cooperation: the adverse effects of climate change. In *Making Geographies of Peace and Conflict* (pp. 237-255). Routledge.

Liru, P. N. (2020). *The influence of climate change on the livelihoods of women involved in rural agriculture in Kakamega county, Kenya* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Lloyd-Hughes, B. (2014). The impracticality of a universal drought definition. *Theoretical and applied climatology*, *117*, 607-611.

Lloyd-Hughes, B., & Saunders, M. A. (2002). A drought climatology for Europe. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, *22*(13), 1571-1592.

Lombamo, T. (2021). Reviewing Climate Change Related Shifts in the Agricultural System and Livelihood of the Farming Community.

López, M. F. V. (2024). *State, Science, and Religion: Adaptation to Climate Change in the Hispanic Monarchy, 1516–1759* (Doctoral dissertation, State University of New York at Binghamton).

Little, P. D. (2021). Does livelihood and asset diversification contribute to pastoralist resilience?: the case of Il Chamus, Baringo county, Kenya, 1980-2018. *Nomadic Peoples*, *25*(2), 181-205.

Lottering, S., Mafongoya, P., & Lottering, R. (2021). Drought and its impacts on small-scale farmers in sub-Saharan Africa: a review. *South African Geographical Journal*, *103*(3), 319-341.

Lottering, S. J., Mafongoya, P., & Lottering, R. T. (2021). Assessing the social vulnerability of small-scale farmers to drought in uMsinga, KwaZulu-Natal. *International Journal of Disaster Risk Reduction*, *65*, 102568.

Loucks, D. P. (2021). Impacts of climate change on economies, ecosystems, energy, environments, and human equity: A systems perspective. In *The impacts of climate change* (pp. 19-50). Elsevier.

Lovelace, R., Dumont, M., Ellison, R., & Založnik, M. (2017). *Spatial microsimulation with R*. Chapman and Hall/CRC.

Liu, Y., & Chen, J. (2021). Future global socioeconomic risk to droughts based on estimates of hazard, exposure, and vulnerability in a changing climate. *Science of the total environment*, *751*, 142159.

Ludena, C., Yoon, S. W., Sánchez-Aragón, L., Miller, S., & Yu, B. K. (2015). Vulnerability indicators of adaptation to climate change and policy implications for investment projects. *Inter-American Development Bank*.Madubula, N. P. (2021). *A comparative analysis of the vulnerability of informal and formal households to disaster risks: the case of Bekkersdal* (Doctoral dissertation).

Macharia, D., Kaijage, E., Kindberg, L., Koech, G., Ndungu, L., Wahome, A., & Mugo, R. (2020). Mapping climate vulnerability of river basin communities in Tanzania to inform resilience interventions. *Sustainability*, *12*(10), 4102.

MacCarthy, D. S., Adam, M., Freduah, B. S., Fosu-Mensah, B. Y., Ampim, P. A., Ly, M., ... & Adiku, S. G. (2021). Climate change impact and variability on cereal productivity among smallholder farmers under future production systems in West Africa. *Sustainability*, *13*(9), 5191.

Mac Gregor-Gaona, M. F., Angles-Hernandez, M., Guibrunet, L., & Zambrano-Gonzalez, L. (2021). Assessing climate change risk: An index proposal for Mexico City. *International Journal of Disaster Risk Reduction*, *65*, 102549.

MacCarthy, D. S., Akinseye, F. M., Ly, M., Timpong-Jones, E. C., Hathie, I., & Adiku, S. G. K. (2023). Modelling the impact of climate change on agriculture in West Africa.

Mackay, A. (2008). Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. *Journal of Environmental Quality*, *37*(6), 2407.

Madamombe, S. M., Ng'ang'a, S. K., Öborn, I., Nyamadzawo, G., Chirinda, N., Kihara, J., & Nkurunziza, L. (2024). Climate change awareness and adaptation strategies by smallholder farmers in semi-arid areas of Zimbabwe. *International Journal of Agricultural Sustainability*, *22*(1), 2293588.

Madhi, Y. (2023). A systematic review of climate adaptation planning in African cities.

Mahmah, A. E., & Amar, A. (2021). Food Security in the MENA Region: Does Agriculture Performance Matter?. *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa: Climate Risks and Resource Scarcity*, 101-125.

Maharana, P., Abdel-Lathif, A. Y., & Pattnayak, K. C. (2018). Observed climate variability over Chad using multiple observational and reanalysis datasets. *Global and Planetary Change*, *162*, 252-265.

Mainuddin, M., Peña-Arancibia, J. L., Karim, F., Hasan, M. M., Mojid, M. A., & Kirby, J. M. (2022). Long-term spatio-temporal variability and trends in rainfall and temperature extremes and their potential risk to rice production in Bangladesh. *PLOS Climate*, *1*(3), e0000009.

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., ... & Ngetich, F. K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. *Weather and Climate Extremes*, *34*, 100374.

Mares, C., Dobrica, V., Mares, I., & Demetrescu, C. (2022). Solar Signature in Climate Indices. *Atmosphere*, *13*(11), 1898.

Marie, M., Yirga, F., Haile, M., & Tquabo, F. (2020). Farmers' choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon*, *6*(4).

Manevska-Tasevska, G., Duangbootsee, U., Bimbilovski, I., Thathong, P., & Ha, T. M. (2023). A systematic scoping review and content analysis of policy recommendations for climate-resilient agriculture. *Climate Policy*, *23*(10), 1271-1287.

Mango, N., Makate, C., Mapemba, L., & Sopo, M. (2018). The role of crop diversification in improving household food security in central Malawi. *Agriculture & Food Security*, *7*(1), 1-10.

Mansaray, B., & Jin, S. (2020). Do the determinants of food security differ in improved rice variety adoption? Evidence from Sierra Leone. *Open Agriculture*, *5*(1), 466-484.

Mantzourani, I. (2022). Climate Change and Food Production. In *The Academic Language of Climate Change: An Introduction for Students and Non-native Speakers* (pp. 79-84). Emerald Publishing Limited.

Martínez-Valderrama, J., & Ibáñez Puerta, J. (2023). System Dynamics Tools to Study Mediterranean Rangeland’s Sustainability. *Land*, *12*(1), 206.

Ματηθγαμα, Σ. Ψ., & Πειρισ, Τ. Σ. Γ. (2011). Critical evaluation of dry spell research. *Int. J. Basic Appl. Sci*, *11*(6), 153-160

Ματηθγαμα, Σ. Ψ., & Πειρισ, Τ. Σ. Γ. (2011). Critical evaluation of dry spell research. *Int. J. Basic Appl. Sci*, *11*(6), 153-160.

Masih, I., Maskey, S., Mussá, F. E. F., & Trambauer, P. (2014). A review of droughts on the African continent: a geospatial and long-term perspective. *Hydrology and earth system sciences*, *18*(9), 3635-3649.

Mashizha, T. M., & Tirivangasi, H. M. (2023). Climate Change, Food Security and Poverty: A Tale of African Social Problems Hindering Rural Development in Zimbabwe. In *The Palgrave Handbook of Global Social Problems* (pp. 1-26). Cham: Springer International Publishing.

Maslin, M. (2014). *Climate change: a very short introduction*. OUP Oxford.

Masike, S., Urich, P., Li, Y., & Mmereki, D. (2024). An investigation of the agriculture vulnerability and risk from climate change in Liberia: an institutional-socio-economic-technological-system framework approach.

Masson-Delmotte, V. P., Zhai, P., Pirani, S. L., Connors, C., Péan, S., Berger, N., ... & Scheel Monteiro, P. M. (2021). Ipcc, 2021: Summary for policymakers. in: Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change.

McCormick, D., Manga, E., Upadhyaya, R., Kamau, P., Wamalwa, H., & Ngigi, S. (2020). 4. Informality and development in Africa. *Research Handbook on Development and the Informal Economy*, 79.

McCarthy, N., Kilic, T., Brubaker, J., Murray, S., & de la Fuente, A. (2021). Droughts and floods in Malawi: impacts on crop production and the performance of sustainable land management practices under weather extremes. *Environment and Development Economics*, *26*(5-6), 432-449.

McCarthy, J. J. (Ed.). (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).

Mekonen, A. A., & Berlie, A. B. (2021). Rural households' livelihood vulnerability to climate variability and extremes: A livelihood zone-based approach in the Northeastern Highlands of Ethiopia. *Ecological Processes*, *10*, 1-23.

Mechiche-Alami, A., & Abdi, A. M. (2020). Agricultural productivity in relation to climate and cropland management in West Africa. *Scientific reports*, *10*(1), 1-10.

Medina, N., Abebe, Y. A., Sanchez, A., & Vojinovic, Z. (2020). Assessing socioeconomic vulnerability after a hurricane: A combined use of an index-based approach and principal components analysis. *Sustainability*, *12*(4), 1452.

Menk, L., Terzi, S., Zebisch, M., Rome, E., Lückerath, D., Milde, K., & Kienberger, S. (2022). Climate change impact chains: a review of applications, challenges, and opportunities for climate risk and vulnerability assessments. *Weather, Climate, and Society*, *14*(2), 619-636.

Mensah, H., Nalumu, D. J., Simpeh, E. K., & Mensah, A. A. (2022). An overview of climate-sensitive sectors and its implications for future climate change risk and adaptation in sub-Saharan Africa, Ghana. *SN Social Sciences*, *2*(7), 90.

Mekonnen, A., Tessema, A., Ganewo, Z., & Haile, A. (2021). Climate change impacts on household food security and farmers adaptation strategies. *Journal of Agriculture and Food Research*, *6*, 100197.

Mekonen, A. A., & Berlie, A. B. (2021). Rural households' livelihood vulnerability to climate variability and extremes: A livelihood zone-based approach in the Northeastern Highlands of Ethiopia. *Ecological Processes*, *10*, 1-23.

Melketo, T. A., Geta, E., & Sieber, S. (2020). Understanding livelihood diversification patterns among smallholder farm households in Southern Ethiopia. *Sustainable Agriculture Research*, *9*(1), 26-41.

Mertz, O., Mbow, C., Reenberg, A., & Diouf, A. (2009). Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental management*, *43*, 804-816.

Mertz, O., D'haen, S., Maiga, A., Moussa, I. B., Barbier, B., Diouf, A., ... & Dabi, D. (2012). Climate variability and environmental stress in the Sudan-Sahel zone of West Africa. *Ambio*, *41*, 380-392.

Metcalf, S. J., van Putten, E. I., Frusher, S., Marshall, N. A., Tull, M., Caputi, N., ... & Shaw, J. (2015). Measuring the vulnerability of marine social-ecological systems: a prerequisite for the identification of climate change adaptations. *Ecology and Society*, *20*(2).

Meza, I., Siebert, S., Döll, P., Kusche, J., Herbert, C., Eyshi Rezaei, E., ... & Hagenlocher, M. (2020). Global-scale drought risk assessment for agricultural systems. *Natural Hazards and Earth System Sciences*, *20*(2), 695-712.

Meza, I., Rezaei, E. E., Siebert, S., Ghazaryan, G., Nouri, H., Dubovyk, O., ... & Hagenlocher, M. (2021). Drought risk for agricultural systems in South Africa: Drivers, spatial patterns, and implications for drought risk management. *Science of the Total Environment*, *799*, 149505.

Mihiretu, A., Eric, N. O., & Tesfaye, L. (2020). Small holder farmers' perception and response mechanisms to climate change: lesson from Tekeze lowland goat and sorghum livelihood zone, Ethiopia. Cogent Food Agric., 6 (1), 1763647.

Ministry of Agriculture and the Liberia Institute of Statistics and Geo-Information Services Annual Agricultural Survey (2012). Republic of Liberia.

Ministry of Agriculture Annual Agricultural Survey (2008), Republic of Liberia.

Ministry of Commerce and Industry (2017): R of L. Liberia: Ministry of Commerce and Industry Transition Report_2017 [Internet]. 2017. Available from: http://moci.gov.lr/doc/MoCI.Min.Addy.Transition.Rebranding Commerce.Final_small_1.pdf/ Accessed: 07/28/2023

MOA. (2014). Annual agriculture reports. Monrovia: Ministry of Agriculture Republic of Liberia.

MOA (2015). Annual agriculture reports. Monrovia: Ministry of Agriculture Republic of Liberia.

MOA (2006). Annual agriculture reports. Monrovia: Ministry of Agriculture Republic of Liberia.

Mitter, H., Schönhart, M., Larcher, M., & Schmid, E. (2018). The Stimuli-Actions-Effects-Responses (SAER)-framework for exploring perceived relationships between private and public climate change adaptation in agriculture. *Journal of Environmental Management*, *209*, 286-300.

Ministry of Foreign Affairs (2003). An Act Creating the Environmental Protection Agency of Republic of Liberia.

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of hydrology*, *391*(1-2), 202-216.

Mkonda, M. Y., He, X., & Festin, E. S. (2018). Comparing smallholder farmers' perception of climate change with meteorological data: experience from seven agroecological zones of Tanzania. *Weather, Climate, and Society*, *10*(3), 435-452.

Mohammadi, S., Rydgren, K., Bakkestuen, V., & Gillespie, M. A. (2023). Impacts of recent climate change on crop yield can depend on local conditions in climatically diverse regions of Norway. *Scientific Reports*, *13*(1), 3633.

Mohmmed, A., Li, J., Elaru, J., Elbashier, M. M., Keesstra, S., Artemi, C., ... & Teffera, Z. (2018). Assessing drought vulnerability and adaptation among farmers in Gadaref region, Eastern Sudan. *Land use policy*, *70*, 402-413.

Mohammed, R. I., Audu, I., & Ndomi, B. M. (2024). A Theoretical Framework on Farmer's Perception and Awareness of Climate Change and Adaptation Strategies for Crop

Production in Northeast Nigeria. *ATBU Journal of Science, Technology and Education*, *11*(4), 441-452.

Mohammed, K., Batung, E., Kansanga, M., Nyantakyi-Frimpong, H., & Luginaah, I. (2021). Livelihood diversification strategies and resilience to climate change in semi-arid northern Ghana. *Climatic Change*, *164*, 1-23.

Mohapatra, S., Sahoo, D., Sahoo, A. K., Sharp, B., & Wen, L. (2024). Heterogeneous climate effect on crop yield and associated risks to water security in India. *International Journal of Water Resources Development*, *40*(3), 345-378.

Mohite, S. (2023). Likelihood of livelihood: A framework to study the sustainability of household tailors in Kolhapur district.

Momolu, E. (2023). Assessment of Upland Rice Production Constraints and Farmers' Preferred Varieties in Liberia.

Moran-Ellis, J., Alexander, V. D., Cronin, A., Dickinson, M., Fielding, J., Sleney, J., & Thomas, H. (2006). Triangulation and integration: Process, claims and implications. *Qualitative research*, *6*(1), 45-59.

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, *104*(50), 19680-19685.

Moore, A. (2017). Agricultural extension in post-conflict Liberia: progress made, and lessons learned. In *Building agricultural extension capacity in post-conflict settings* (pp. 1-22). Wallingford UK: CABI.

Mousavi, A., Ardalan, A., Takian, A., Ostadtaghizadeh, A., Naddafi, K., & Bavani, A. M. (2020). Climate change and health in Iran: a narrative review. *Journal of Environmental Health Science and Engineering*, *18*, 367-378.

Mozumder, M. M. H., Schneider, P., Islam, M. M., Deb, D., Hasan, M., Monzer, M. A., & Nur, A. A. U. (2023). Climate change adaptation strategies for small-scale Hilsa fishers in the coastal area of Bangladesh: social, economic, and ecological perspectives. *Frontiers in Marine Science*, *10*, 1151875.

Mubangizi, J. C., & Tlale, M. T. (2023, January). How gender-based cultural practices violate women's property rights and inhibit property ownership: A South African perspective. In *Women's Studies International Forum* (Vol. 96, p. 102678). Pergamon.

Muiruri, S. K., Ntui, V. O., Tripathi, L., & Tripathi, J. N. (2021). Mechanisms and approaches towards enhanced drought tolerance in cassava (Manihot esculenta). *Current Plant Biology*, *28*, 100227.

Mukherjee, S. (2021). *Quantification of Compound and Cascading Hydroclimatic Extreme Events* (Doctoral dissertation, Clemson University).

Mukherjee, S., Mishra, A., & Trenberth, K. E. (2018). Climate change and drought: a perspective on drought indices. *Current climate change reports*, *4*, 145-163.

Mulungu, K., & Ng'ombe, J. N. (2019). Climate change impacts on sustainable maize production in Sub-Saharan Africa: A review. *Maize Prod. Use*, 47-58.

Mulwa, C., Marenya, P., & Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate risk management*, *16*, 208-221.

Mulwa, C. K., & Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development*, *129*, 104906.

Mumo, L., Yu, J., & Fang, K. (2018). Assessing impacts of seasonal climate variability on maize yield in Kenya. *International Journal of Plant Production*, *12*(4), 297-307.

Mundial, B. (2023). Social dimensions of climate change. *Washington, DC. Retrieved May*, *14*.

Munkombwe, J., Phiri, J., & Siankwilimba, E. (2022). Financial innovation among smallholder farmers: Enhancing the uptake of Weather Index Insurance through a pragmatic approach. *Journal of Social Sciences Advancement*, *3*(1), 01-19.

Murken, L., & Gornott, C. (2022). The importance of different land tenure systems for farmers' response to climate change: A systematic review. *Climate Risk Management*, *35*, 100419.

Murray, C., Rose, S. B., Kvalsvig, A., & Baker, M. G. (2023). Key informant perspectives on a centralised contact tracing system for sexually transmitted infections. *The New Zealand Medical Journal (Online)*, *136*(1587), 65-74.

Muringai, R. T., Mafongoya, P., & Lottering, R. T. (2022). Sub-Saharan Africa freshwater fisheries under climate change: a review of impacts, adaptation, and mitigation measures. *Fishes*, *7*(3), 131.

Mushashu, D. M. (2023). Nature Towards Global Climate Change: The Pertinence of Nature-based Solutions (NbS) to Combating Effects of Climate Change on Human Livelihoods on a Global and Country-Specific Context–Zambia as an Example.

Musumba, M., Palm, C. A., Komarek, A. M., Mutuo, P. K., & Kaya, B. (2022). Household livelihood diversification in rural Africa. *Agricultural economics*, *53*(2), 246-256.

Musyoka, P. K., & Onjala, J. (2023). Livelihood Diversification and Household Vulnerability to Climate Shocks in Rural Kenya. *International Journal of Economics Development Research (IJEDR)*, *4*(1), 27-47.

Muthoni, F. (2020). Spatial-temporal trends of rainfall, maximum and minimum temperatures over West Africa. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *13*, 2960-2973.

Mwendwa, S. M., Mbuvi, J. P., Kironchi, G., & Gachene, C. K. (2022). Assessing spatial variability of selected soil properties in Upper Kabete Campus coffee farm, University of Nairobi, Kenya. *Heliyon*, *8*(8), e10190.

Mwinkom, F. X., Damnyag, L., Abugre, S., & Alhassan, S. I. (2021). Factors influencing climate change adaptation strategies in North-Western Ghana: evidence of farmers in the Black Volta Basin in Upper West region. *SN Applied Sciences*, *3*, 1-20.

Naazie, G. K., Dakyaga, F., & Derbile, E. K. (2023). Agro-ecological intensification for climate change adaptation: Tales on soil and water management practices of smallholder farmers in rural Ghana. *Discover Sustainability*, *4*(1), 27.

Nasrnia, F., & Ashktorab, N. (2021). Sustainable livelihood framework-based assessment of drought resilience patterns of rural households of Bakhtegan basin, Iran. *Ecological Indicators*, *128*, 107817.

Nadeem, F., Jacobs, B., & Cordell, D. (2022). Mapping agricultural vulnerability to impacts of climate events of Punjab, Pakistan. *Regional Environmental Change*, *22*(2), 66.

Namubiru-Mwaura, E. L., Knox, A., & Kaiser Hughes, A. (2012). *Land Policy and Institutional Support (Lpis) Project. Customary land tenure in Liberia: findings and implications drawn from 11 case studies*. Technical report, USAID.

Ndlovu, E., Prinsloo, B., & Le Roux, T. (2020). Impact of climate change and variability on traditional farming systems: Farmers' perceptions from south-west, semi-arid Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, *12*(1), 1-19.

Nkoana, M. A., Belete, A., & Hlongwane, J. J. (2021). Determinants of choice of climate change adaptation strategies amongst small-scale crop-livestock farmers: Case study of Limpopo province, South Africa. In *Handbook of Climate Change Management: Research, Leadership, Transformation* (pp. 539-569). Cham: Springer International Publishing.

Natarajan, N., Newsham, A., Rigg, J., & Suhardiman, D. (2022). A sustainable livelihoods framework for the 21st century. *World Development*, *155*, 105898.

National Account Annual Survey (2014): Liberia Institute of Statistics and Geo-Information Services, (LISGIS), Monrovia, Liberia

Nations, U. (2015). Transforming our world: The 2030 agenda for sustainable development. *New York: United Nations, Department of Economic and Social Affairs*, *1*, 41.

Naulleau, A., Gary, C., Prévot, L., & Hossard, L. (2021). Evaluating strategies for adaptation to climate change in grapevine production–A systematic review. *Frontiers in plant science*, *11*, 607859.

Nawaz, A., Rehman, A. U., Rehman, A., Ahmad, S., Siddique, K. H., & Farooq, M. (2022). Increasing sustainability for rice production systems. *Journal of Cereal Science*, *103*, 103400.

Naqvi, S. A. A., Hasis ul Hassan, R., Wu, W., Shah, A. A., Makhdum, M. S. A., & Shah, S. A. R. (2020). Synergy between adaptations and resilience of livelihood from climate change vulnerability: a group-wise comparison of adapters and non-adapters. *PloS one*, *15*(8), e0236794.

Neupane, D., Adhikari, P., Bhattarai, D., Rana, B., Ahmed, Z., Sharma, U., & Adhikari, D. (2022). Does climate change affect the yield of the top three cereals and food security in the world?. *Earth*, *3*(1), 45-71.

Neupane, D., Adhikari, P., Bhattarai, D., Rana, B., Ahmed, Z., Sharma, U., & Adhikari, D. (2022). Does climate change affect the yield of the top three cereals and food security in the world?. *Earth*, *3*(1), 45-71.

New, M., Reckien, D., Viner, D., Adler, C., Cheong, S. M., Conde, C., ... & Solecki, W. (2022). Decision-making options for managing risk.

Newman, R. J. S., Capitani, C., Courtney-Mustaphi, C., Thorn, J. P. R., Kariuki, R., Enns, C., & Marchant, R. (2020). Integrating insights from social-ecological interactions into sustainable land use change scenarios for small Islands in the western Indian ocean. *Sustainability*, *12*(4), 1340.

Ngetich, F. K., Mairura, F. S., Musafiri, C. M., Kiboi, M. N., & Shisanya, C. A. (2022). Smallholders' coping strategies in response to climate variability in semi-arid agro-ecozones of Upper Eastern Kenya. *Social sciences & humanities open*, *6*(1), 100319.

Ngcamu, B. (2022). Climate change and disaster preparedness issues in Eastern Cape and Kwazulu-Natal, South Africa. *Town and regional planning*, *81*, 53-66.

Ngegba, M. P., Moriba, P., Kandeh, J. B., Moiwo, J. P., & Massaquoi, S. B. (2022). Evaluating the Efficiency of Action Aid Sierra Leone (AASL) Extension Services in Sierra Leone. *New Innovations in Economics, Business and Management Vol. 10*, 14-25.

Ngetich, F. K., Mairura, F. S., Musafiri, C. M., Kiboi, M. N., & Shisanya, C. A. (2022). Smallholders' coping strategies in response to climate variability in semi-arid agro-ecozones of Upper Eastern Kenya. *Social sciences & humanities open*, *6*(1), 100319.

Ngoran, S. D., Dogah, K. E., & Xue, X. (2015). Assessing the impacts of climate change on water resources: The Sub-Saharan Africa perspective. *Journal of Economics and Sustainable Development*, *6*(1), 185-193.

Ngozi, S., Mshenga, P., Kariuki, I. M., & Hepelwa, A. S. (2020). Boosting Potato Enterprise Performance among Smallholder Farmers in Tanzania through Risks Management.

Nguyen, C. V. (2015). *Development and application of a social vulnerability index at the local scale* (Doctoral dissertation, RMIT University).

Ngwenya, S. (2021). *The influence of livelihood projects on food security resilience levels in Zimbabwe* (Doctoral dissertation, North-West University (South Africa).

Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C. R., Muchara, B., Karuaihe, S. T., & Mpandeli, S. (2020). Climate change impacts on water and agriculture sectors in Southern Africa: Threats and opportunities for sustainable development. *Water*, *12*(10), 2673.

Nicholson, S. E., Nash, D. J., Chase, B. M., Grab, S. W., Shanahan, T. M., Verschuren, D., ... & Umer, M. (2013). Temperature variability over Africa during the last 2000 years. *The Holocene*, *23*(8), 1085-1094.

Nicmanis, M. (2024). Reflexive Content Analysis: An Approach to Qualitative Data Analysis, Reduction, and Description. *International Journal of Qualitative Methods*, *23*, 16094069241236603.

Nidumolu, U., Lim-Camacho, L., Gaillard, E., Hayman, P., & Howden, M. (2020). Linking climate forecasts to rural livelihoods: Mapping decisions, information networks and value chains. *Weather and Climate Extremes*, *27*, 100174.

Nigussie, L., Diallo, A., & Minh, T. T. (2024). *Investment and cultivation strategies for women and youth inclusion: cases from on-farm, off-farm and non-farm activities in Ethiopia and Mali*. International Water Management Institute.

Nikiema, P. M., Sylla, M. B., Ogunjobi, K., Kebe, I., Gibba, P., & Giorgi, F. (2017). Multi-model CMIP5 and CORDEX simulations of historical summer temperature and precipitation variabilities over West Africa. *International Journal of Climatology*, *37*(5), 2438-2450.

Njieassam, E. E. (2019). Gender inequality and land rights: The situation of indigenous women in Cameroon. *Potchefstroom Electronic Law Journal/Potchefstroomse Elektroniese Regsblad*, *22*(1).

Niu, Y., Li, Z., Gao, Y., Liu, X., Xu, L., Vardoulakis, S., ... & Liu, Q. (2021). A systematic review of the development and validation of the heat vulnerability index: major factors, methods, and spatial units. *Current Climate Change Reports*, *7*(3), 87-97.

Nkwi, G. E., Fani, D. C. R., Ahungwa, G. T., & Ukpe, U. H. (2023). Climate Change and Agricultural Output: The Need for Policy. In *Agricultural Transformation in Africa: Contemporary Issues, Empirics, and Policies* (pp. 137-151). Cham: Springer International Publishing.

Nnadi, O. I., Lyimo, J. G., Liwenga, E. T., & Madukwe, M. C. (2021). Equity and implications of response strategies on gender relations: Identifying ways of mainstreaming gender into response strategies in Southeast Nigeria. *Environmental Development*, *39*, 100618.

Nyadzi, E., Ajayi, O. C., & Ludwig, F. (2021). Indigenous knowledge and climate change adaptation in Africa: a systematic review. *CABI Reviews*, (2021).

Obodoh, C. M., Aniagolu, C. O., & Obodoh, D. A. (2022). Issues and Challenges in Land Ownership in Enugu State, Nigeria: Gender Perspective. *ONLY One Earth*, 183.

Odwori, E. O. (2021). Temperature Variability and Trends in Nzoia River Basin, Kenya. *Asian Journal of Geographical Research*, 17-37.

Ofori, S. A., Cobbina, S. J., & Obiri, S. (2021). Climate change, land, water, and food security: Perspectives From Sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, *5*, 680924.

Oduniyi, O. S., & Olawuyi, S. O. (2020). Exploring the Link between Livelihood Capital Assets as Index of Climate Change Adaptive Capacity and Socio-economic Issues: A Case of Small-Scale Maize Farmers in South Africa. *J. Hum. Ecol*, *71*, 198-211.

Oguntunde, P. G., Abiodun, B. J., Lischeid, G., & Abatan, A. A. (2020). Droughts projection over the Niger and Volta River basins of West Africa at specific global warming levels. *International Journal of Climatology*, *40*(13), 5688-5699.

Ojemade, A. C., Osuafor, O. O., & Offiah, E. O. (2020). The Role of the Agricultural Economist in Agricultural Adaptation to Climate Change in the Oil Palm Industry in the Southern Nigeria. *Journal of Agriculture and Sustainability*, *13*.

Ojo, T. O., Adetoro, A. A., Ogundeji, A. A., & Belle, J. A. (2021). Quantifying the determinants of climate change adaptation strategies and farmers' access to credit in South Africa. *Science of the Total Environment*, *792*, 148499.

Okigbo, B. N. (2020). Sustainable agricultural systems in tropical Africa. In *Sustainable agricultural systems* (pp. 323-352). CRC Press.

Okitasari, M., & Katramiz, T. (2022). The national development plans after the SDGs: Steering implications of the global goals towards national development planning. *Earth System Governance*, *12*, 100136.

Okonya, J. S., Syndikus, K., & Kroschel, J. (2013). Farmers' perception of and coping strategies to climate change: Evidence from six agro-ecological zones of Uganda. *Journal of agricultural science*, *5*(8), 252.

Oluwatimilehin, I. A., & Ayanlade, A. (2023). Climate change impacts on staple crops: Assessment of smallholder farmers’ adaptation methods and barriers. *Climate Risk Management*, *41*, 100542.

Olorunfemi, T. O., Olorunfemi, O. D., & Oladele, O. I. (2020). Determinants of the involvement of extension agents in disseminating climate smart agricultural initiatives: Implication for scaling up. *Journal of the Saudi Society of Agricultural Sciences*, *19*(4), 285-292.

Omotoso, A. B., Letsoalo, S., Olagunju, K. O., Tshwene, C. S., & Omotayo, A. O. (2023). Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on agriculture. *Journal of Cleaner Production*, *414*, 137487.

O’Neil, G. M. M., Tovihoudji, G. P., Ollabodé, N., Akponikpè, P. I., & Yabi, J. A. (2022). Perception des producteurs des changements climatiques et stratégies d’adaptation dans les systèmes de culture à base de maïs (Zea mays) au Nord-Bénin. *Annales de l'Université de Parakou-Série Sciences Naturelles et Agronomie*, *12*(1), 1-14.

O'Neill, B. C., van Aalst, M., Zaiton Ibrahim, Z., Berrang-Ford, L., Bhadwal, S., Buhaug, H., ... & Oppenheimer, M. (2022). Key risks across sectors and regions.

O'Neill, B. C., Carter, T. R., Ebi, K., Harrison, P. A., Kemp-Benedict, E., Kok, K., ... & Pichs-Madruga, R. (2020). Achievements and needs for the climate change scenario framework. *Nature climate change*, *10*(12), 1074-1084.

Onoja, A. O., Onudorogu, C., Chagwiza, C., & Tagwi, A. (2022). Status and determinants of farm household poverty in South East, Nigeria. *The Journal of Developing Areas*, *56*(2), 169-184.

Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O'Neill, B., ... & Hsiang, S. (2015). Emergent risks and key vulnerabilities. In *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (pp. 1039-1100). Cambridge University Press

Onwunali, M. R. O., Chima, C. I., & Ochigbo, B. G. (2024). Linkages between economic growth, health expenditures, education, and environment: dynamic analysis of Nigeria. *Science World Journal*, *19*(1), 17-28.

Onyenekwe, C. S., Opata, P. I., Ume, C. O., Sarpong, D. B., & Egyir, I. S. (2023). Heterogeneity of adaptation strategies to climate shocks: Evidence from the Niger Delta region of Nigeria. *Bio-based and Applied Economics*, *12*(1), 17-35.

Onyutha, C. (2021). Trends and variability of temperature and evaporation over the African continent: Relationships with precipitation. *Atmósfera*, *34*(3), 267-287.

Orlove, B., Roncoli, C., Kabugo, M., & Majugu, A. (2010). Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. *Climatic change*, *100*(2), 243-265.

Osumanu, I. K. (2022). Climate Change Adaptation and Agricultural Livelihoods of Smallholder Farmers. In *The Routledge Handbook on Livelihoods in the Global South* (pp. 481-489). Routledge.

Osman, M. A., Onono, J. O., Olaka, L. A., Elhag, M. M., & Abdel-Rahman, E. M. (2021). Climate variability and change affect crops yield under rainfed conditions: A case study in Gedaref State, Sudan. *Agronomy*, *11*(9), 1680.

Osumanu, I. K. (2020). Small-scale mining and livelihood dynamics in North-Eastern Ghana: Sustaining rural livelihoods in a changing environment. *Progress in Development Studies*, *20*(3), 208-222.

Osman, B. (2021). Coping and Adapting to Climate Risks and Impacts: The Role of Assets and Institutions in Agricultural Livelihoods in Semiarid Ghana. In *Handbook of Climate Change Management: Research, Leadership, Transformation* (pp. 491-512). Cham: Springer International Publishing.

Osinski, A. (2021). Towards a critical sustainability science? Participation of disadvantaged actors and power relations in transdisciplinary research. *Sustainability*, *13*(3), 1266.

Otekunrin, O. A., Otekunrin, O. A., Sawicka, B., & Pszczółkowski, P. (2021). Assessing food insecurity and its drivers among smallholder farming households in rural Oyo State, Nigeria: the HFIAS approach. *Agriculture*, *11*(12), 1189.

Owusu-Sekyere, E. (2024). Approaches to evaluating the impact of climate change on food s

Owusu, V., & Yiridomoh, G. Y. (2021). Assessing the determinants of women farmers' targeted adaptation measures in response to climate extremes in rural Ghana. *Weather and Climate Extremes*, *33*, 100353.

Oyelere, G. O., Sadiq, M. M., Olagoke, O. O., Adisa, J. O., & Abass, A. O. (2020). Adaptation practices among arable crop farmers against perceived effects of climate change in rural Southwestern Nigeria. *International Journal of Sciences: Basic and Applied Research*, *52*, 191-202.

Paaske, D. M. (2021). Impact of climate change, intergenerational justice, and human rights on SDGs. In *Reduced Inequalities* (pp. 473-481). Cham: Springer International Publishing.

Pagnani, T., Gotor, E., & Caracciolo, F. (2021). Adaptive strategies enhance smallholders’ livelihood resilience in Bihar, India. *Food Security*, *13*(2), 419-437.

Pakravan-Charvadeh, M. R., Khan, H. A., & Flora, C. (2020). Spatial analysis of food security in Iran: associated factors and governmental support policies. *Journal of Public Health Policy*, *41*, 351-374.

Palmer, W. C. (1965). *Meteorological drought* (Vol. 30). US Department of Commerce, Weather Bureau.

Pandey, R., Jha, S. K., Alatalo, J. M., Archie, K. M., & Gupta, A. K. (2017). Sustainable livelihood framework-based indicators for assessing climate change vulnerability and adaptation for Himalayan communities. *Ecological indicators*, *79*, 338-346.

Papagiannaki, K., Kotroni, V., Lagouvardos, K., & Papagiannakis, G. (2019). How awareness and confidence affect flood-risk precautionary behavior of Greek citizens: the role of perceptual<? xmltex\break?> and emotional mechanisms. *Natural Hazards and Earth System Sciences*, *19*(7), 1329-1346.

Pardoe, J., Vincent, K., Conway, D., Archer, E., Dougill, A. J., Mkwambisi, D., & Tembo-Nhlema, D. (2020). Evolution of national climate adaptation agendas in Malawi, Tanzania and Zambia: the role of national leadership and international donors. *Regional Environmental Change*, *20*(4), 118.

Parks, R. O. B. B. I. E., McLaren, M., Toumi, R., & Rivett, U. L. R. I. K. E. (2019). Experiences and lessons in managing water from Cape Town. *Grantham Institute Briefing Paper*, *29*, 1-20.

Parmesan, C., Morecroft, M. D., Trisurat, Y., Adrian, R., Anshari, G. Z., Arneth, A., ... & Young, K. (2022). Terrestrial and freshwater ecosystems and their services. Cambridge University Press.

Parry, M. (2014). Effects of climate change on potential food production and risk of hunger. In *Plant genetic resources and climate change* (pp. 61-77). Wallingford UK: CABI.

Pasquini, L., van Aardenne, L., Godsmark, C. N., Lee, J., & Jack, C. (2020). Emerging climate change-related public health challenges in Africa: A case study of the heat-health vulnerability of informal settlement residents in Dar es Salaam, Tanzania. *Science of the total environment*, *747*, 141355.

Pattnayak, K. C., Abdel-Lathif, A. Y., Rathakrishnan, K. V., Singh, M., Dash, R., & Maharana, P. (2019). Changing climate over Chad: is the rainfall over the major cities recovering?. *Earth and Space Science*, *6*(7), 1149-1160.

Paudel, S., Filipski, M. J., & Minten, B. (2022). *Income diversification and the rural non-farm economy* (Vol. 27). Intl Food Policy Res Inst.

Pei, J., Liu, P., Fang, H., Gao, X., Pan, B., Li, H., ... & Zhang, F. (2023). Estimating Yield and Economic Losses Induced by Ozone Exposure in South China Based on Full-Coverage Surface Ozone Reanalysis Data and High-Resolution Rice Maps. *Agriculture*, *13*(2), 506.

Pellowe, K. E., & Leslie, H. M. (2020). The interplay between formal and informal institutions and the potential for co-management in a Mexican small-scale fishery. *Marine Policy*, *121*, 104179.

Pendley, S. C., Mock, N. B., & Theall, K. P. (2020). How you measure matters; defining social capital in drought-prone areas. *International Journal of Disaster Risk Reduction*, *50*, 101715.

Pereira, S. I. A., Abreu, D., Moreira, H., Vega, A., & Castro, P. M. L. (2020). Plant growth-promoting rhizobacteria (PGPR) improves the growth and nutrient use efficiency in maize (Zea mays L.) under water deficit conditions. *Heliyon*, *6*(10), e05106.

Philander, S. G. H. (1983). Meteorology: Anomalous El Niño of 1982–83. *Nature*, *305*(5929), 16-16.

Pickson, R. B., He, G., & Boateng, E. (2021). Impacts of climate change on rice production: evidence from 30 Chinese provinces. *Environment, Development and Sustainability*, 1-19.

Pickson, R. B., & Boateng, E. (2022). Climate change: a friend or foe to food security in Africa?. *Environment, Development and Sustainability*, 1-26.

Pickson, R. B., & Boateng, E. (2022). Climate change: a friend or foe to food security in Africa?. *Environment, Development and Sustainability*, 1-26.

Piggott-McKellar, A. E., McNamara, K. E., Nunn, P. D., & Watson, J. E. (2019). What are the barriers to successful community-based climate change adaptation? A review of grey literature. *Local Environment*, *24*(4), 374-390.

Pironon, S., Etherington, T. R., Borrell, J. S., Kühn, N., Macias-Fauria, M., Ondo, I., ... & Willis, K. J. (2019). Potential adaptive strategies for 29 sub-Saharan crops under future climate change. *Nature Climate Change*, *9*(10), 758-763.

Piya, L., Maharjan, K. L., Joshi, N. P., Piya, L., Maharjan, K. L., & Joshi, N. P. (2019). Climate change and rural livelihoods in developing countries. *Socio-economic issues of climate change: A livelihood analysis from Nepal*, 11-33.

Pour, S. H., Abd Wahab, A. K., Shahid, S., Asaduzzaman, M., & Dewan, A. (2020). Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: Current trends, issues and challenges. *Sustainable Cities and Society*, *62*, 102373.

Pörtner, H. O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., ... & Ibrahim, Z. Z. (2022). *Climate change 2022: impacts, adaptation and vulnerability*. IPCC.

Policy. Paper presented at the Inaugural Conference on Land Policy in Africa, 11-14

Poudel, S., Funakawa, S., Shinjo, H., & Mishra, B. (2020). Understanding households' livelihood vulnerability to climate change in the Lamjung district of Nepal. *Environment, Development and Sustainability*, *22*(8), 8159-8182.

Potapov, P., Turubanova, S., Hansen, M. C., Tyukavina, A., Zalles, V., Khan, A., ... & Cortez, J. (2022). Global maps of cropland extent and change show accelerated cropland expansion in the twenty-first century. *Nature Food*, *3*(1), 19-28.

Proutsos, N. D., Solomou, A. D., Koulelis, P. P., Bourletsikas, A., Chatzipavlis, N. E., & Tigkas, D. (2022). Detecting changes in annual precipitation trends during the last two climatic periods (1955–1984 and 1985–2018) in Nestos River basin, N Greece. In *Proceedings of the 10th International Conference on Information and Communication Technologies in Agriculture, Food and Environment, HAICTA*.

Qiu, L., Kim, J. B., Kim, S. H., Choi, Y. W., Im, E. S., & Bae, D. H. (2022). Reduction of the uncertainties in the hydrological projections in Korean river basins using dynamically downscaled climate projections. *Climate Dynamics*, *59*(7), 2151-2167.

Quinn, C., Carrie, R., Chapman, S., Jennings, S., Jensen, P., Smith, H., & Whitfield, S. (2020). Rapid Climate Risk Assessment for the Southern Africa Development Community (SADC) Region.

Rabarijohn, H., Rajaofara, H., & MacKinnon, J. L. (2014). Extreme vulnerability of smallholder farmers to agricultural.

Rahman, M. A., Kang, S., Nagabhatla, N., & Macnee, R. (2017). Impacts of temperature and rainfall variation on rice productivity in major ecosystems of Bangladesh. *Agriculture & Food Security*, *6*, 1-11.

Rahman, H. T., Albizua, A., Soubry, B., & Tourangeau, W. (2021). A framework for using autonomous adaptation as a leverage point in sustainable climate adaptation. *Climate Risk Management*, *34*, 100376.

Raj, A., Jhariya, M. K., Yadav, D. K., Banerjee, A., & Toppo, P. (2020). Agroforestry for climate change mitigation, natural resource management, and livelihood security. In *Climate Change and Agroforestry Systems* (pp. 27-46). Apple Academic Press.

Ramli, M. W. A., Alias, N. E., Yusop, Z., & Taib, S. M. (2020, June). Disaster Risk Index: A Review of Local Scale Concept and Methodologies. In *IOP Conference Series: Earth and Environmental Science* (Vol. 479, No. 1, p. 012023). IOP Publishing.

Ranasinghe, R. D. A. K., Korale-Gedara, P. M., & Weerasooriya, S. A. (2023). Climate change adaptation and adaptive capacities of dairy farmers: Evidence from village tank cascade systems in Sri Lanka. *Agricultural Systems*, *206*, 103609.

Raneri, J. E., Boedecker, J., Fallas Conejo, D. A., Muir, G., Hanley-Cook, G., & Lachat, C. (2023). Can common dietary assessment methods be better designed to capture the nutritional contribution of neglected, forest, and wild foods to diets?. *Frontiers in Nutrition*, *10*, 1186707.

Rangel-Buitrago, N., Neal, W. J., & de Jonge, V. N. (2020). Risk assessment as tool for coastal erosion management. *Ocean & Coastal Management*, *186*, 105099.

Rasche, A. (2020). The United Nations Global Compact and the sustainable development goals. In *Research handbook of responsible management* (pp. 228-241). Edward Elgar Publishing.

Rather, T. A., Kumar, S., & Khan, J. A. (2020). Multi-scale habitat selection and impacts of climate change on the distribution of four sympatric meso-carnivores using random forest algorithm. *Ecological Processes*, *9*(1), 1-17.

Ray, D. K., West, P. C., Clark, M., Gerber, J. S., Prishchepov, A. V., & Chatterjee, S. (2019). Climate change has likely already affected global food production. *PloS one*, *14*(5), e0217148.

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, *8*(2), 34.

Raziei, T., Saghafian, B., Paulo, A. A., Pereira, L. S., & Bordi, I. (2009). Spatial patterns and temporal variability of drought in western Iran. *Water resources management*, *23*, 439-455.

Reboita, M. S., Kuki, C. A. C., Marrafon, V. H., de Souza, C. A., Ferreira, G. W. S., Teodoro, T., & Lima, J. W. M. (2022). South America climate change revealed through climate indices projected by GCMs and Eta-RCM ensembles. *Climate Dynamics*, *58*(1), 459-485.

Reddy, K. V., Paramesh, V., Arunachalam, V., Das, B., Ramasundaram, P., Pramanik, M., ... & Mattar, M. A. (2022). Farmers' perception and efficacy of adaptation decisions to climate change. *Agronomy*, *12*(5), 1023.

Reed, M. S., Podesta, G., Fazey, I., Geeson, N., Hessel, R., Hubacek, K., ... & Thomas, A. D. (2013). Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options. *Ecological Economics*, *94*, 66-77.

Ricart, S., Gandolfi, C., & Castelletti, A. (2023). Climate change awareness, perceived impacts, and adaptation from farmers' experience and behavior: a triple-loop review. *Regional Environmental Change*, *23*(3), 82.

Ríos-Reyes, C. A., Chacon, C., Villarreal, C., Meza, J., Arenas, J., Trespalacios, J., ... & Salazar, L. A Generalized Workflow for the Integral Evaluation of Unconventional Reservoirs Using Multi-Scale Imaging and Analyses. *Available at SSRN 4531699*.

Rivas, S., Bertoldi, P., Yagnik, K., Vetters, N., Pittalis, M., Palermo, V., ... & Ortega, A. (2022). Guidebook: How to develop a Climate Action Plan for cities in India. *European commission: Italy: Joint Research Centre. Ispra VA*.

Rivero, R. M., Mittler, R., Blumwald, E., & Zandalinas, S. I. (2022). Developing climate-resilient crops: improving plant tolerance to stress combination. *The Plant Journal*, *109*(2), 373-389.

Robles, M. (2021). Agricultural insurance for development: Past, present, and future. *Agricultural development: New perspectives in a changing world*, 563-594.

Rodriguez, N., Eakin, H., & de Freitas Dewes, C. (2017). Perceptions of climate trends among Mexican maize farmers. *Climate Research*, *72*(3), 183-195.

Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K., ... & Bengio, Y. (2022). Tackling climate change with machine learning. *ACM Computing Surveys (CSUR)*, *55*(2), 1-96.

Rosati, A., Borek, R., & Canali, S. (2021). Agroforestry and organic agriculture. *Agroforestry Systems*, *95*, 805-821.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., ... & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the national academy of sciences*, *111*(9), 3268-3273.

Rötter, R. P., Hoffmann, M. P., Koch, M., & Müller, C. (2018). Progress in modelling agricultural impacts of and adaptations to climate change. *Current Opinion in Plant Biology*, *45*, 255-261.

Roshani, Sajjad, H., Kumar, P., Masroor, M., Rahaman, M. H., Rehman, S., ... & Sahana, M. (2022). Forest vulnerability to climate change: A review for future research framework. *Forests*, *13*(6), 917.

Rowell, D. P., & Chadwick, R. (2018). Causes of the uncertainty in projections of tropical terrestrial rainfall change: East Africa. *Journal of Climate*, *31*(15), 5977-5995.

Rowhani, P., Lobell, D. B., Linderman, M., & Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and forest meteorology*, *151*(4), 449-460.

Rusere, F., Crespo, O., Mkuhlani, S., & Dicks, L. V. (2019). Developing pathways to improve smallholder agricultural productivity through ecological intensification technologies in semi-arid Limpopo, South Africa. *African Journal of Science, Technology, Innovation and Development*, *11*(5), 543-553.

Ruttan, L. (2006). Sociocultural heterogeneity and the commons. *Current anthropology*, *47*(5), 843-853.

Ruwanza, S., Thondhlana, G., & Falayi, M. (2022). Research progress and conceptual insights on drought impacts and responses among smallholder farmers in South Africa: a review. *Land*, *11*(2), 159.

Rwabukambiza, V. (2022). Household livelihoods and food security in jeopardy.

Sabagh, A. E., Hossain, A., Islam, M. S., Ahmed, S., Raza, A., Iqbal, M. A., ... & Fahad, S. (2021). Elevated CO2 in combination with heat stress influences the growth and productivity of cereals: adverse effect and adaptive mechanisms. In *Engineering Tolerance in Crop Plants Against Abiotic Stress* (pp. 125-161). CRC Press.

Saha, S., Hasan, T., Maukeeb, A. R., Sarker, M., & Haque, A. R. (2022). Agroforestry Practices for Sustainable Production in Bangladesh: A Rewiew. *Asian Journal of Advances in Research*, *5*(1), 186-203.

Sam, A. S., Padmaja, S. S., Kächele, H., Kumar, R., & Müller, K. (2020). Climate change, drought and rural communities: Understanding people's perceptions and adaptations in rural eastern India. *International Journal of Disaster Risk Reduction*, *44*, 101436.

Saikia, M., & Mahanta, R. (2023). Vulnerability to climate change and its measurement: A survey. *Boreal Environment Research*, *28*.

Saint Ville, A., Po, J. Y. T., Sen, A., Bui, A., & Melgar-Quiñonez, H. (2019). Food security and the Food Insecurity Experience Scale (FIES): ensuring progress by 2030. *Food Security*, *11*, 483-491.

Sanga, U., Sidibé, A., & Olabisi, L. S. (2021). Dynamic pathways of barriers and opportunities for food security and climate adaptation in Southern Mali. *World Development*, *148*, 105663.

Sanogo, M., Kabore, D., Taonda, S. J. B., & Kestemont, M. P. (2020). Analysis of labor opportunity cost on the economic profitability of fertilizer microdosing (FM) in Burkina Faso. *Journal of Development and Agricultural Economics*, *12*(3), 198-205.

Sarkodie, S. A., Ahmed, M. Y., & Owusu, P. A. (2022). Global adaptation readiness and income mitigate sectoral climate change vulnerabilities. *Humanities and Social Sciences Communications*, *9*(1).

Savari, M., & Zhoolideh, M. (2021). The role of climate change adaptation of small-scale farmers on the households food security level in the west of Iran. *Development in Practice*, *31*(5), 650-664.

Savari, M., Sheykhi, H., & Amghani, M. S. (2020). The role of educational channels in the motivating of rural women to improve household food security. *One Health*, *10*, 100150.

Savari, M., & Shokati Amghani, M. (2021). Factors influencing farmers' adaptation strategies in confronting the drought in Iran. *Environment, Development and Sustainability*, *23*, 4949-4972.

Saysay, J. L., Gabagambi, D. M., Mlay, G. I., Minde, I. J., & Kikuu, C. (2018). Technical Efficiency in Rice Production Among Smallholder Farmers in Central Liberia: A Stochastic Production Frontier Analysis. *J Econ Sustain Dev*, *9*(20), 47-53.

Scheffran, J., Guo, W., Krampe, F., & Okpara, U. (2023). Tipping cascades between conflict and cooperation in climate change. *EGUsphere*, *2023*, 1-27.

Schilling, J., Hertig, E., Tramblay, Y., & Scheffran, J. (2020). Climate change vulnerability, water resources and social implications in North Africa. *Regional Environmental Change*, *20*, 1-12.

Schipper, E. L. F. (2020). Maladaptation: when adaptation to climate change goes very wrong. *One Earth*, *3*(4), 409-414.

Schulz, P. (2022). Progress in and Challenges to the Rights of Women to Non-discrimination and Gender Equality. In *Gender Equality in the Mirror* (pp. 25-52). Brill Nijhoff.

Scoones, I. (2013). Livelihoods perspectives and rural development. In *Critical perspectives in rural development studies* (pp. 159-184). Routledge.

Sen, A. (1981). An essay on entitlement and deprivation. *Poverty and Famines*.

Sen, A. (1984). Resources, values and development. Oxford: Basil Blackwell.

Seifert, M. (2020). *The potential of on-farm trees for sustainable charcoal production challenges, opportunities and human and social capital implications of charcoal production from on-farm trees in Kilosa District, Tanzania* (Master's thesis, University of Zurich).

Shackleton, S., Methner, N., Sibanda, D., Few, R., & Tebboth, M. (2022). Framing the potential of climate change intervention to support poverty reduction and promote ewquity whilst reducing climate risk.

Sebesvari, Z., Renaud, F. G., Haas, S., Tessler, Z., Hagenlocher, M., Kloos, J., ... & Kuenzer, C. (2016). A review of vulnerability indicators for deltaic social–ecological systems. *Sustainability Science*, *11*, 575-590.

Seidl, C., Wheeler, S. A., & Zuo, A. (2021). The drivers associated with Murray-Darling Basin irrigators' future farm adaptation strategies. *Journal of Rural Studies*, *83*, 187-200.

Sekyi-Annan, E., Acheampong, E. N., & Ozor, N. (2017). Modeling the Impact of Climate Variability on Crops in Sub-Saharan Africa. *Quantification of Climate Variability, Adaptation and Mitigation for Agricultural Sustainability*, 39-70.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., ... & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, *17*, 1585-1600.

Sewando, P. T. (2022). Efficacy of risk reducing diversification portfolio strategies among agro-pastoralists in semi-arid area: A modern portfolio theory approach. *Journal of Agriculture and Food Research*, *7*, 100262. Mohammed, K., Batung, E., Kansanga, M., Nyantakyi-Frimpong, H., & Luginaah, I. (2021). Livelihood diversification strategies and resilience to climate change in semi-arid northern Ghana. *Climatic Change*, *164*, 1-23.

Shah, M. A. R., Renaud, F. G., Anderson, C. C., Wild, A., Domeneghetti, A., Polderman, A., ... & Zixuan, W. (2020). A review of hydro-meteorological hazard, vulnerability, and risk assessment frameworks and indicators in the context of nature-based solutions. *International journal of disaster risk reduction*, *50*, 101728.

Shan, Z., Luo, X., Wei, M., Huang, T., Khan, A., & Zhu, Y. (2018). Physiological and proteomic analysis on long-term drought resistance of cassava (Manihot esculenta Crantz). *Scientific Reports*, *8*(1), 17982.

Shahzad, L., Shah, M., Saleem, M., Mansoor, A., Sharif, F., Tahir, A., ... & Ghafoor, G. (2021). Livelihood vulnerability index: a pragmatic assessment of climatic changes in flood affected community of Jhok Reserve Forest, Punjab, Pakistan. *Environmental Earth Sciences*, *80*, 1-16.

Sharaunga, S., & Mudhara, M. (2021). Analysis of livelihood strategies for reducing poverty among rural women's households: A case study of KwaZulu-Natal, South Africa. *Journal of International Development*, *33*(1), 127-150.

Sharma, A., Patel, P. L., & Sharma, P. J. (2023). Climate change impact on crop stress and food security in a semi-arid river basin. *AQUA—Water Infrastructure, Ecosystems and Society*, *72*(12), 2313-2330.

Sharma, A., Patel, P. L., & Sharma, P. J. (2023). Climate change impact on crop stress and food security in a semi-arid river basin. *AQUA—Water Infrastructure, Ecosystems and Society*, *72*(12), 2313-2330.

Shaw, R. M., Howe, J., Beazer, J., & Carr, T. (2020). Ethics and positionality in qualitative research with vulnerable and marginal groups. *Qualitative Research*, *20*(3), 277-293.

Shawul, A. A., & Chakma, S. (2020). Trend of extreme precipitation indices and analysis of long-term climate variability in the Upper Awash basin, Ethiopia. *Theoretical and Applied Climatology*, *140*(1), 635-652.

Shackleton, S., Bezerra, J. C., Cockburn, J., Reed, M. G., & Abu, R. (2021). Interviews and surveys. In *The Routledge handbook of research methods for social-ecological systems* (pp. 107-118). Routledge.

Shah, S. A., & Kiran, M. (2021). Mann-Kendall test: trend analysis of temperature, rainfall and discharge of Ghotki feeder canal in district Ghotki, Sindh, Pakistan. *Environment & Ecosystem Science (EES)*, *5*(2), 137-142.

Sharafi, Z., Nooripour, M., & Karamidehkordi, E. (2018). Assessing livelihood capitals and their sustainability in rural households (the case of the Central District of Dena County). *Iranian Agricultural Extension and Education Journal*, *13*(2).

Sheffield, J., Wood, E. F., & Roderick, M. L. (2012). Little change in global drought over the past 60 years. *Nature*, *491*(7424), 435-438.

Sheets, S. L. G. (2001). SL Approaches in Practice. *DFID: London, UK*, 1-24.

Accessed: 05/18/2024; Sustainable Livelihoods Guidance Sheets Section 7 (ennonline.net)

Sheydayi, A., & Dadashpoor, H. (2023). Conducting qualitative content analysis in urban planning research and urban studies. *Habitat International*, *139*, 102878.

Shiru, M. S., Shahid, S., Chung, E. S., & Alias, N. (2019). Changing characteristics of meteorological droughts in Nigeria during 1901–2010. *Atmospheric Research*, *223*, 60-73.

Shiru, M. S., Shahid, S., Dewan, A., Chung, E. S., Alias, N., Ahmed, K., & Hassan, Q. K. (2020). Projection of meteorological droughts in Nigeria during growing seasons under climate change scenarios. *Scientific reports*, *10*(1), 10107.

Serdeczny, O., Andrijevic, M., Fyson, C., Lissner, T., Menke, I., Schleussner, C. F., ... & Thomas, A. (2024). Climatic risks to adaptive capacity. *Mitigation and Adaptation Strategies for Global Change*, *29*(1), 10.

Silva, F., Coward, F., Davies, K., Elliott, S., Jenkins, E., Newton, A. C., ... & Williams, A. (2022). Developing transdisciplinary approaches to sustainability challenges: The need to model socio-environmental systems in the longue durée. *Sustainability*, *14*(16), 10234.

Sime, C. H., & Demissie, T. A. (2022). Assessment and prediction of the climate change impact on crop yield, in Jimma Zone Upper Gilgel Gibe Districts, Ethiopia. *Arabian Journal of Geosciences*, *15*(3), 313.

Sirba, H. Y., & Chimdessa, T. B. (2021). Review of impact of climate change on food security in Africa. *International Journal of Research and Innovations in Earth Science*, *8*(3), 40-66.

Smith, G. S., Anjum, E., Francis, C., Deanes, L., & Acey, C. (2022). Climate change, environmental disasters, and health inequities: the underlying role of structural inequalities. *Current environmental health reports*, *9*(1), 80-89.

Smith, S. C., & Malik, A. S. (2021). Autonomous and Planned Climate Change Adaptation in Low-Income Countries: Lessons from Research and Questions for Future Research. In *World Scientific Encyclopedia of Climate Change: Case Studies of Climate Risk, Action, and Opportunity Volume 2* (pp. 287-318).

Simpson, N. P., Mach, K. J., Constable, A., Hess, J., Hogarth, R., Howden, M., ... & Trisos, C. H. (2021). A framework for complex climate change risk assessment. *One Earth*, *4*(4), 489-501.

Singh, A. K., & Bhargawa, A. (2020). Ascendancy of Solar Variability on Terrestrial Climate: A Review. *Journal of Basic & Applied Sciences*, *16*, 105-130.

Singh, R. K., Singh, A., Kumar, S., Sheoran, P., Sharma, D. K., Stringer, L. C., ... & Singh, D. (2020). Perceived climate variability and compounding stressors: Implications for risks to livelihoods of smallholder Indian farmers. *Environmental Management*, *66*, 826-844.

Singh, R., Dell'Angelo, J., Oguge, N., & Odote, C. (2024). The role of livelihoods in agrifood sustainability transitions. *Environmental Innovation and Societal Transitions*, *50*, 100799.

Sirba, H. Y., & Chimdessa, T. B. (2021). Review of impact of climate change on food security in Africa. *International Journal of Research and Innovations in Earth Science*, *8*(3), 40-66.

Sivakumar, M. (2021). Climate change, agriculture adaptation, and sustainability. *Climate Resilience and Environmental Sustainability Approaches: Global Lessons and Local Challenges*, 87-109.

Sivakumar, M. V. (2020). Climate extremes and impacts on agriculture. *Agroclimatology: Linking Agriculture to Climate*, *60*, 621-647.

Sniukas, M., & Sniukas, M. (2020). Research design and methodology. *Business Model Innovation as a Dynamic Capability: Micro-Foundations and Case Studies*, 45-65.

Skaf, L., Buonocore, E., Dumontet, S., Capone, R., & Franzese, P. P. (2020). Applying network analysis to explore the global scientific literature on food security. *Ecological Informatics*, *56*, 101062.

Sohoulande Djebou, D. C., Price, E., Kibriya, S., & Ahn, J. (2017). Comparative analysis of agricultural assets, incomes and food security of rural households in Ghana, Senegal and Liberia. *Agriculture*, *7*(5), 38.

Soni, M. L., Subbulakshmi, V., Sheetal, K. R., Yadava, N. D., & Dagar, J. C. (2017). Agroforestry for increasing farm productivity in water-stressed ecologies. *Agroforestry: anecdotal to modern science*, 369-411.

Sorgho, R., Quiñonez, C. A. M., Louis, V. R., Winkler, V., Dambach, P., Sauerborn, R., & Horstick, O. (2020). Climate change policies in 16 West African countries: A systematic review of adaptation with a focus on agriculture, food security, and nutrition. *International journal of environmental research and public health*, *17*(23), 8897.

Speranza, C. I., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics. *Global Environmental Change*, *28*, 109-119.

Sperber, K. R., Annamalai, H., Kang, I. S., Kitoh, A., Moise, A., Turner, A., ... & Zhou, T. (2013). The Asian summer monsoon: an intercomparison of CMIP5 vs. CMIP3 simulations of the late 20th century. *Climate dynamics*, *41*, 2711-2744.

Sohoulande Djebou, D. C., Price, E., Kibriya, S., & Ahn, J. (2017). Comparative analysis of agricultural assets, incomes and food security of rural households in Ghana, Senegal and Liberia. *Agriculture*, *7*(5), 38.

Sousa, P. M., Blamey, R. C., Reason, C. J., Ramos, A. M., & Trigo, R. M. (2018). The 'Day Zero'Cape Town drought and the poleward migration of moisture corridors. *Environmental Research Letters*, *13*(12), 124025.

Spence, C. (2022). The tongue map and the spatial modulation of taste perception. *Current research in food science*, *5*, 598-610.

Sperstad, I. B., Kjølle, G. H., & Gjerde, O. (2020). A comprehensive framework for vulnerability analysis of extraordinary events in power systems. *Reliability Engineering & System Safety*, *196*, 106788.

Staupe-Delgado, R. (2019). Analysing changes in disaster terminology over the last decade. *International Journal of Disaster Risk Reduction*, *40*, 101161.

Statistics, U. N. (2019). Global indicator framework for the sustainable development goals and targets of the 2030 agenda for sustainable development. *Developmental Science and Sustainable Development Goals for Children and Youth*, 439.

Stevanović, M., Popp, A., Lotze-Campen, H., Dietrich, J. P., Müller, C., Bonsch, M., ... & Weindl, I. (2016). The impact of high-end climate change on agricultural welfare. *Science advances*, *2*(8), e1501452.

Stickler, M. M., & Huntington, H. (2015, March). Perceptions of tenure security: an exploratory analysis of pre-treatment data in rural communities across Ethiopia, Guinea, Liberia, and Zambia. In *World Bank Conference on Land and Poverty* (pp. 1-50).

Stojanov, R., Rosengaertner, S., de Sherbinin, A., & Nawrotzki, R. (2021). Climate mobility and development cooperation. *Population and Environment*, *43*(2), 209-231.

Stringer, L. C., Thomas, D. S., & Twyman, C. (2007). From global politics to local land users: applying the United Nations Convention to combat desertification in Swaziland. *Geographical Journal*, *173*(2), 129-142.

Sultan, B., & Gaetani, M. (2016). Agriculture in West Africa in the twenty-first century: climate change and impacts scenarios, and potential for adaptation. *Frontiers in plant science*, *7*, 1262.

Sultan, B., Defrance, D., & Iizumi, T. (2019). Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Scientific reports*, *9*(1), 12834.

Sultana, N., & Luetz, J. M. (2022). Adopting the local knowledge of coastal communities for climate change adaptation: A case study from Bangladesh. *Frontiers in Climate*, *4*, 823296.

Sung, J. H., Kwon, M., Jeon, J. J., & Seo, S. B. (2019). A projection of extreme precipitation based on a selection of CMIP5 GCMs over North Korea. *Sustainability*, *11*(7), 1976.

Supraptiningsih, U., Jubba, H., Hariyanto, E., & Rahmawati, T. (2023). Inequality as a cultural construction: Women's access to land rights in Madurese society. *Cogent Social Sciences*, *9*(1), 2194733.

Susilo, E., Purwanti, P., Fattah, M., Qurrata, V. A., & Narmaditya, B. S. (2021). Adaptive coping strategies towards seasonal change impacts: Indonesian small-scale fisherman household. *Heliyon*, *7*(4).

Swart, J., Kinnie, N., Van Rossenberg, Y., & Yalabik, Z. Y. (2014). Why should I share my knowledge? A multiple foci of commitment perspective. *Human Resource Management Journal*, *24*(3), 269-289.

Swadling, D. S., West, G. J., Gibson, P. T., Laird, R. J., & Glasby, T. M. (2023). Multi-scale assessments reveal changes in the distribution of the endangered seagrass Posidonia australis and the role of disturbances. *Marine Biology*, *170*(11), 147.

Swemmer, A. M., Bond, W. J., Donaldson, J., Hempson, G. P., Malherbe, J., & Smit, I. P. (2018). The ecology of drought-a workshop report. *South African Journal of Science*, *114*(9-10), 1-3.

Sylla, M. B., Giorgi, F., Pal, J. S., Gibba, P., Kebe, I., & Nikiema, M. (2016). Projected changes in the annual cycle of high-intensity precipitation events over West Africa for the late twenty-first century. *Journal of Climate*, *28*(16), 6475-6488.

Sylla, M. B., Diallo, I., & Pal, J. S. (2013). West African monsoon in state-of-the-science regional climate models. *Climate Variability—Regional and Thematic Patterns*, *10*(55140), 1805-1817.

Tafara Gadzirayi, C., Manatsa, D., & Mutandwa, E. (2020). Tailoring conservation farming to climate change in the smallholder farming sector: Case of lowveld areas in Zimbabwe. *African Journal of Science, Technology, Innovation and Development*, *12*(5), 581-590.

Takale, A. B., & Lazarus, T. P. (2022). Impact of Climate Extremes on the Livelihood. *Food and Nutrition Science-An International Journal*, *6*.

Tariq, A., & Rashid, M. A. (2020). Impact of climate change on crop production: effects and management. *Crop Protection Under Changing Climate*, 171-187.

Tessema, I., & Simane, B. (2021). Smallholder Farmers' perception and adaptation to climate variability and change in Fincha sub-basin of the Upper Blue Nile River Basin of Ethiopia. *GeoJournal*, *86*(4), 1767-1783.

Teixeira, E. I., Fischer, G., Van Velthuizen, H., Walter, C., & Ewert, F. (2013). Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology*, *170*, 206-215.

Teixeira, E. I., Fischer, G., Van Velthuizen, H., Walter, C., & Ewert, F. (2013). Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology*, *170*, 206-215.

Temam, D., Uddameri, V., Mohammadi, G., Hernandez, E. A., & Ekwaro-Osire, S. (2019). Long-term drought trends in Ethiopia with implications for dryland agriculture. *Water*, *11*(12), 2571.

Tesfaye, K., Zaidi, P. H., Gbegbelegbe, S., Boeber, C., Rahut, D. B., Getaneh, F., ... & Stirling, C. (2017). Climate change impacts and potential benefits of heat-tolerant maize in South Asia. *Theoretical and Applied Climatology*, *130*, 959-970.

Teye, J. K., & Nikoi, E. G. (2022). Climate-induced migration in West Africa. In *Migration in West Africa: IMISCOE regional reader* (pp. 79-105). Cham: Springer International Publishing.

Thanh, P. T., The Duy, D., & Bao Duong, P. (2022). Disruptions to agricultural activities, income loss and food insecurity during the COVID-19 pandemic: evidence from farm households in a developing country. *Journal of Agribusiness in Developing and Emerging Economies*, *12*(3), 531-547.

Thapa, S., Li, B., Fu, D., Shi, X., Tang, B., Qi, H., & Wang, K. (2020). Trend analysis of climatic variables and their relation to snow cover and water availability in the Central Himalayas: a case study of Langtang Basin, Nepal. *Theoretical and Applied Climatology*, *140*, 891-903.

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2017). How climate-smart is conservation agriculture (CA)?–its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security*, *9*, 537-560.

Thinda, K. T., Ogundeji, A. A., Belle, J. A., & Ojo, T. O. (2020). Understanding the adoption of climate change adaptation strategies among smallholder farmers: Evidence from land reform beneficiaries in South Africa. *Land Use Policy*, *99*, 104858.

Thompson, H. E., Berrang-Ford, L., & Ford, J. D. (2010). Climate change and food security in sub-Saharan Africa: a systematic literature review. *Sustainability*, *2*(8), 2719-2733.

Thornton, P. K., Loboguerrero Rodriguez, A. M., Campbell, B. M., Mercado, L., Shackleton, S., & Kavikumar, K. S. (2019). Rural livelihoods, food security and rural transformation under climate change.

Thornton, P. K., Rosenstock, T., Förch, W., Lamanna, C., Bell, P., Henderson, B., & Herrero, M. (2018). A qualitative evaluation of CSA options in mixed crop-livestock systems in developing countries. *Climate smart agriculture: Building resilience to climate change*, 385-423.

Thouret, J. C., Wavelet, E., Taillandier, M., Tjahjono, B., Jenkins, S. F., Azzaoui, N., & Santoni, O. (2022). Defining population socio-economic characteristics, hazard knowledge and risk perception: The adaptive capacity to persistent volcanic threats from Semeru, Indonesia. *International Journal of Disaster Risk Reduction*, *77*, 103064.

Tieminie, R. N., Chia, E. L., Tieguhong, J. C., & Awamba, F. L. (2023). Perceptions of climate change and local responses on livelihoods: the case of people around the Mambioko community forest. *GeoJournal*, 1-16.

Tiet, T., To-The, N., & Nguyen-Anh, T. (2022). Farmers' behaviors and attitudes toward climate change adaptation: evidence from Vietnamese smallholder farmers. *Environment, Development and Sustainability*, 1-26.

Tilumanywa, V. T. (2021). Improving Agricultural Support Services for Smallholder Farmers' Adaptation to Climate Variability in Rungwe District in Tanzania. *Tanzania Journal of Development Studies*, *19*(1).

Toe, S., and C. Stevens (2014). Land Reform in Liberia: Developing the First National Land

Tofu, D. A., Woldeamanuel, T., & Haile, F. (2022). Smallholder farmers' vulnerability and adaptation to climate change induced shocks: The case of Northern Ethiopia highlands. *Journal of Agriculture and Food Research*, *8*, 100312.

Tofu, D. A., Haile, F., & Tolossa, T. (2023). Livelihood vulnerability and socio-economic determinants of households to climate change-induced recurrent drought in Ethiopia. *GeoJournal*, *88*(5), 5043-5067.

Tofu, D. A., & Mengistu, M. (2023). Observed time series trend analysis of climate variability and smallholder adoption of new agricultural technologies in west Shewa, Ethiopia. *Scientific African*, *19*, e01448.

Togbah, C. F. (2024). An Analysis of Liberia's Vulnerability to Climate Change in the Context of Least Developed Countries (LDCs): A Review. *American Journal of Climate Change*, *13*(2), 230-250.

Tore, D. B., Alamou, A. E., Obada, E., Biao, E. I., & Zandagba, E. B. J. (2021). Assessment of Intra-Seasonal Variability and Trends of Precipitations in a Climate Change Framework in West Africa. *Atmospheric and Climate Sciences*, *12*(1), 150-171.

Toumi, I., Ghrab, M., & Nagaz, K. (2022). Vegetative growth, yield, and water productivity of an early maturing peach cultivar under deficit irrigation strategies in a warm and arid area. *Irrigation and Drainage*, *71*(4), 938-947.

Tseng, T. W. J., Robinson, B. E., Bellemare, M. F., BenYishay, A., Blackman, A., Boucher, T., ... & Masuda, Y. J. (2021). Influence of land tenure interventions on human well-being and environmental outcomes. *Nature Sustainability*, *4*(3), 242-251.

Tshikolomo, K. A., Nesamvuni, A. E., Petja, M., van Niekerk, J., & Mpandeli, N. S. (2022). Livestock farmer demography and adaptive capacity to climate change and variability in Limpopo and Mpumalanga Province of South Africa. *Technium Soc. Sci. J.*, *27*, 870.

Tripathy, K. P., Mukherjee, S., Mishra, A. K., Mann, M. E., & Williams, A. P. (2023). Climate change will accelerate the high-end risk of compound drought and heatwave events. *Proceedings of the National Academy of Sciences*, *120*(28), e2219825120.

Tshitavhe, T. (2022). *Effects of climate variability on citrus production and rural livelihoods in Mopani District Municipality, South Africa* (Doctoral dissertation).

Uarrota, V. G., Stefen, D. L., de Souza, C. A., & Sánchez-Mora, F. D. (2017). Advances in understanding cassava growth and development Cileide Maria Medeiros Coelho, University of the State of Santa Catarina (UDESC), Brazil; Rodolfo Moresco and Marcelo Maraschin, Federal University of Santa of Manabí (UTM), Ecuador; and Eduardo da Costa Nunes, Enilto de Oliveira Neubert Rural Extension Agency (EPAGRI), Brazil. *Achieving sustainable cultivation of cassava Volume 2*, 23-27.

Ubisi, N. R., Mafongoya, P. L., Kolanisi, U., & Jiri, O. (2017). Smallholder farmer's perceived effects of climate change on crop production and household livelihoods in rural

Limpopo province, South Africa. *Change and Adaptation in Socio-Ecological Systems*, *3*(1), 27-38.

Udoka, C., Bassey, J. G., John, J. I., & Orok, A. B. (2022). Contributory pension fund assets and economic performance of Nigeria. *Frontiers in Management Science ISSN*, 2788-8592.

Ullah, F., Shah, S. A. A., Saqib, S. E., Yaseen, M., & Haider, M. S. (2021). Households' flood vulnerability and adaptation: Empirical evidence from mountainous regions of Pakistan. *International Journal of Disaster Risk Reduction*, *52*, 101967.

United Nations Children Fund (NICEF., 2020). The state of food security and nutrition in the world 2020.

United Nations Climate Change Conference, UK. (2021)

[ARCHIVED CONTENT] COP26 Outcomes - UN Climate Change Conference (COP26) at the SEC – Glasgow 2021 (nationalarchives.gov.uk)/ Date Accessed: 07/12/2027

United Nations Children Fund (UNICEF., 2021). The state of food security and nutrition in the world 2021.

Unruh, J. D. (2009). Land rights in postwar Liberia: the volatile part of the peace process. *Land Use Policy*, *26*(2), 425-433.

USAID/Liberia Strategic Analysis (2020). Biodiversity Sector Assessment, UN Drive Adjacent Gate 3 US Embassy Monrovia, Liberia POC: Carla Trippe, ctrippe@socialimpact.com

Usman, Z. (2022). *Economic diversification in Nigeria: The politics of building a post-oil economy* (p. 312). Bloomsbury Academic.

Uwayezu, e. (2023). *Assessing women's access to credits using land lease certificates: a case study of cyabagarura cell, musanze sector, musanze district* (Doctoral dissertation, University of Rwanda).

Uwimbabazi, J., Jing, Y., Iyakaremye, V., Ullah, I., & Ayugi, B. (2022). Observed changes in meteorological drought events during 1981–2020 over Rwanda, East Africa. *Sustainability*, *14*(3), 1519.

van Meijl, H., Shutes, L., Valin, H., Stehfest, E., van Dijk, M., Kuiper, M., ... & Havlik, P. (2020). Modelling alternative futures of global food security: Insights from FOODSECURE. *Global Food Security*, *25*, 100358.

Van Loon, A. F., & Van Lanen, H. A. (2013). Making the distinction between water scarcity and drought using an observation-modeling framework. *Water Resources Research*, *49*(3), 1483-1502.

van Mil, H. G., Foegeding, E. A., Windhab, E. J., Perrot, N., & Van Der Linden, E. (2014). A complex system approach to address world challenges in food and agriculture. *Trends in food science &*

Van Baalen, S., & Mobjörk, M. (2018). Climate change and violent conflict in East Africa: Integrating qualitative and quantitative research to probe the mechanisms. *International Studies Review*, *20*(4), 547-575.

van Mil, H. G., Foegeding, E. A., Windhab, E. J., Perrot, N., & Van Der Linden, E. (2014). A complex system approach to address world challenges in food and agriculture. *Trends in food science & technology*, *40*(1), 20-32.

Van Oort, P. A., & Zwart, S. J. (2018). Impacts of climate change on rice production in Africa and causes of simulated yield changes. *Global change biology*, *24*(3), 1029-1045.

van Zonneveld, M., Turmel, M. S., & Hellin, J. (2020). Decision-making to diversify farm systems for climate change adaptation. *Frontiers in Sustainable Food Systems*, *4*, 32.

Vanli, Ö., Ustundag, B. B., Ahmad, I., Hernandez-Ochoa, I. M., & Hoogenboom, G. (2019). Using crop modeling to evaluate the impacts of climate change on wheat in southeastern turkey. *Environmental Science and Pollution Research*, *26*, 29397-29408.

Veltman, K., Rotz, C. A., Chase, L., Cooper, J., Forest, C. E., Ingraham, P. A., ... & Jolliet, O. (2021). Assessing and reducing the environmental impact of dairy production systems in the northern US in a changing climate. *Agricultural Systems*, *192*, 103170.

Verheyen, R. (2002). Adaptation to the impacts of anthropogenic climate change-the international legal framework. *Rev. Eur. Comp. & Int'l Envtl. L.*, *11*, 129.

Vernooy, R. (2022). Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. *Agroecology and Sustainable Food Systems*, *46*(6), 877-901.

Verschuur, J., Li, S., Wolski, P., & Otto, F. E. (2021). Climate change as a driver of food insecurity in the 2007 Lesotho-South Africa drought. *Scientific reports*, *11*(1), 3852.

Vicente-Serrano, S. M., & Beguería, S. (2016). Comment on 'Candidate distributions for climatological drought indices (SPI and SPEI)'by James H. Stagge et al. *International Journal of Climatology*, *36*(4), 2120-2131.

Vicente-Serrano, S. M., Camarero, J. J., & Azorin-Molina, C. (2014). Diverse responses of forest growth to drought timescales in the N orthern H emisphere. *Global Ecology and Biogeography*, *23*(9), 1019-1030.

Vicente-Serrano, S. M., Beguería, S., Gimeno, L., Eklundh, L., Giuliani, G., Weston, D., ... & Pegram, G. G. (2012). Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. *Applied Geography*, *34*, 471-486.

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of climate*, *23*(7), 1696-1718.

Viswanathan, P. K., Kavya, K., & Bahinipati, C. S. (2020). Global patterns of climate-resilient agriculture: A review of studies and imperatives for empirical research in India. *Review of Development and Change*, *25*(2), 169-192.

Vinke, K., Bergmann, J., Blocher, J., Upadhyay, H., & Hoffmann, R. (2020). Migration as adaptation?. *Migration Studies*, *8*(4), 626-634.

Villamor, G. B., Griffith, D. L., Kliskey, A., & Alessa, L. (2019). Contrasting stakeholder and scientist conceptual models of food-energy-water systems: A case study in Magic Valley, Southern Idaho. *Socio-Environmental Systems Modelling*, *2*.

Viner, D., Ekstrom, M., Hulbert, M., Warner, N. K., Wreford, A., & Zommers, Z. (2020). Understanding the dynamic nature of risk in climate change assessments—A new starting point for discussion. *Atmospheric Science Letters*, *21*(4), e958.

Vittal, H., & Karmakar, S. (2019). A comprehensive social vulnerability analysis at a national scale. *Climate Change Signals and Response: A Strategic Knowledge Compendium for India*, 163-176.

Vizinho, A., Avelar, D., Branquinho, C., Capela Lourenco, T., Carvalho, S., Nunes, A., ... & Penha-Lopes, G. (2021). Framework for climate change adaptation of agriculture and forestry in Mediterranean climate regions. *Land*, *10*(2), 161.

Vongkhamho, S., & Ingalls*, M. L. (2023). Negotiating the Forest-Fallow Interface: Benzoin trees in the multifunctional shifting cultivation landscapes of Lao PDR. In *Farmer Innovations and Best Practices by Shifting Cultivators in Asia-Pacific* (pp. 735-755). GB: CABI.

Vos, R., Velasco, M., & Edgar de Labastida, R. (1999). *Economic and social effects of El Niño in Ecuador, 1997-1998*. Washington, DC: Inter-American Development Bank.

Wanyama, D., Kar, B., & Moore, N. J. (2021). Quantitative multi-factor characterization of eco-environmental vulnerability in the Mount Elgon ecosystem. *GIScience & Remote Sensing*, *58*(8), 1571-1592.

Walker, S. E., Bruyere, B. L., Zarestky, J., Yasin, A., Lenaiyasa, E., Lolemu, A., & Pickering, T. (2022). Education and adaptive capacity: the influence of formal education on climate change adaptation of pastoral women. *Climate and Development*, *14*(5), 409-418.

Ward, P. S., Makhija, S., & Spielman, D. J. (2020). Drought-tolerant rice, weather index insurance, and comprehensive risk management for smallholders: evidence from a multi-year field experiment in India. *Australian Journal of Agricultural and Resource Economics*, *64*(2), 421-454.

Warren, R. F., Wilby, R. L., Brown, K., Watkiss, P., Betts, R. A., Murphy, J. M., & Lowe, J. A. (2018). Advancing national climate change risk assessment to deliver national adaptation plans. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2121), 20170295.

Warrick, O. (2009). Ethics and methods in research for community-based adaptation: reflections from rural Vanuatu. *Participatory learning and action*, *60*(1), 76-87.

Wayessa, G. O., & Nygren, A. (2023). Mixed Methods Research in Global Development Studies: State-Sponsored Resettlement Schemes in Ethiopia. *The European Journal of Development Research*, 1-25.

Weldearegay, S. K., & Tedla, D. G. (2018). Impact of climate variability on household food availability in Tigray, Ethiopia. *Agriculture & Food Security*, *7*, 1-9.

Whitmarsh, B., & Speed, R. (2021). Greenhouse gas emissions in Winchester District: Part XI.

Winchester, C. (2023). *Adaptation and Evaluation of the Family Behavior Support Application (FBSApp) Paired With Collaborative Coaching for Spanish-Speaking Families* (Doctoral dissertation, Vanderbilt University).

Williams, A. P., Seager, R., Abatzoglou, J. T., Cook, B. I., Smerdon, J. E., & Cook, E. R. (2018). Contribution of anthropogenic warming to California drought during 2012–2014. *Geophysical Research Letters*, *42*(16), 6819-6828.

Wilson, E. T., & Liberia, T. N. A. E. P. A. (2019). Coastal Zone's Technology Needs assessment for Climate Change Adaptation.

Wilhite, D. A., & Glantz, M. H. (1985). Understanding: the drought phenomenon: the role of definitions. *Water international*, *10*(3), 111-120.

Wilhite, D. A. (2000). Drought as a natural hazard: concepts and definitions.

Williams, P. A., Crespo, O., Abu, M., & Simpson, N. P. (2018). A systematic review of how vulnerability of smallholder agricultural systems to changing climate is assessed in Africa. *Environmental Research Letters*, *13*(10), 103004.

Wilkinson, E., Schipper, L., Simonet, C., & Kubik, Z. (2022). *Climate change, migration and the 2030 Agenda for Sustainable Development*. ODI.

Wiréhn, L. (2017). *Climate vulnerability assessment methodology: Agriculture under climate change in the Nordic region* (Vol. 732). Linköping University Electronic Press.

Wily, L. (2007). *So who owns the forest: An investigation into forest ownership and customary land rights in Liberia*. FERN.

Wolf, J. (2011). Climate change adaptation as a social process. *Climate change adaptation in developed nations: From theory to practice*, 21-32.

Wong, S. K. (2021). Sustainable Livelihood Strategies of The Riverine Communities at Sadong Jaya, Sarawak, Malaysia: Role of Capital Assets. *Studies of Applied Economics*, *39*(1).

Woo, M. K. (2012). *Permafrost hydrology*. Springer Science & Business Media.

Wolde, S. G., D'Odorico, P., & Rulli, M. C. (2023). Environmental drivers of human migration in Sub-Saharan Africa. *Global Sustainability*, *6*, e9.

World Health Organization. (2018). *The state of food security and nutrition in the world 2018: building climate resilience for food security and nutrition*. Food & Agriculture Org..

Wu, J., Han, Z. Y., Yan, Y. P., Sun, C. Y., Xu, Y., & Shi, Y. (2021). Future changes in wind energy potential over China using RegCM4 under RCP emission scenarios. *Advances in Climate Change Research*, *12*(4), 596-610.

Wu, T. (2021). Quantifying coastal flood vulnerability for climate adaptation policy using principal component analysis. *Ecological Indicators*, *129*, 108006.

Wudil, A. H., Usman, M., Rosak-Szyrocka, J., Pilař, L., & Boye, M. (2022). Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of environmental research and Public Health*, *19*(22), 14836.

Xenarios, S., Sarker, G. W., Nemes, A., Nagothu, S., Biswas, J. C., & Maniruzzaman, M. (2014). Socio-ecological vulnerability assessment of flood and saline-prone region in rural Bangladesh. *Bioforsk Rapport*.

Xu, X., Wang, L., Sun, M., Fu, C., Bai, Y., Li, C., & Zhang, L. (2020). Climate change vulnerability assessment for smallholder farmers in China: An extended framework. *Journal of Environmental Management*, *276*, 111315.

Yabe, T., Rao, P. S. C., Ukkusuri, S. V., & Cutter, S. L. (2022). Toward data-driven, dynamical complex systems approaches to disaster resilience. *Proceedings of the National Academy of Sciences*, *119*(8), e2111997119.

Yahaya, O. Y. (2022). Adaptation to Desertification Among Rural Households: Local Insight to Enhance Coexistence in the Region of Maradi, Niger republic. *Osun Geographical Review*, *1*(1).

Yakubu, D. H., Akpoko, J. G., Akinola, M. O., & Abdulsalam, Z. (2021). Assessment of perceived effects of climate change on rice production among farmers in North-west zone, Nigeria. *Ghana Journal of Agricultural Science*, *56*(1), 48-64.

Yaro, J. A. (2010). Customary tenure systems under siege: contemporary access to land in Northern Ghana. *GeoJournal*, *75*(2), 199-214.

Yaro, J. A. (2006). Is deagrarianisation real? A study of livelihood activities in rural northern Ghana. *The Journal of Modern African Studies*, *44*(1), 125-156.

Yaro, J. A. (2004). Theorizing food insecurity: building a livelihood vulnerability framework for researching food insecurity. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, *58*(1), 23-37.

Ye, B., Jiang, J., Liu, J., Zheng, Y., & Zhou, N. (2021). Research on quantitative assessment of climate change risk at an urban scale: Review of recent progress and outlook of future direction. *Renewable and Sustainable Energy Reviews*, *135*, 110415.

Yenglier Yiridomoh, G., & Owusu, V. (2022). Do women farmers cope or adapt to strategies in response to climate extreme events? Evidence from rural Ghana. *Climate and Development*, *14*(7), 678-687.

Yengoh, G. T., & Ardö, J. (2020). Climate change and the future heat stress challenges among smallholder farmers in East Africa. *Atmosphere*, *11*(7), 753.

Yeny, I., Garsetiasih, R., Suharti, S., Gunawan, H., Sawitri, R., Karlina, E., ... & Takandjandji, M. (2022). Examining the socio-economic and natural resource risks of food estate development on peatlands: A strategy for economic recovery and natural resource sustainability. *Sustainability*, *14*(7), 3961.

Yihui, D., Guoyu, R., & Guangyu, S. (2007). China's National Assessment Report on Climate Change (I): Climate change in China and the future trend. *气候变化研究进展*, *3*(00), 1.

Yirga, F., Asfaw, Z., Alemu, A., Ewnetu, Z., & Teketay, D. (2024). Exploring the Contribution of Agroforestry Practices to Income and Livelihoods of Rural Households in the Central Highlands of Ethiopia. *Agroforestry Systems*, 1-21.

Yiridomoh, G. Y., Sullo, C., & Bonye, S. Z. (2021). Climate variability and rural livelihood sustainability: evidence from communities along the Black Volta River in Ghana. *GeoJournal*, *86*, 1527-1543.

Zellner, M. L., Milz, D., Lyons, L., Hoch, C. J., & Radinsky, J. (2022). Finding the balance between simplicity and realism in participatory modeling for environmental planning. *Environmental Modelling & Software*, *157*, 105481.

Zewdie, W., & Kindu, M. (2011, November). Land use land cover change analysis in selected drylands of Ethiopia: Implication for sustainable development. In *Annual proceeding of Research and Development in Dryland forests of Ethiopia. Forum for Environment* (pp. 123-135).

Zhao, H., Gao, G., An, W., Zou, X., Li, H., & Hou, M. (2017). Timescale differences between SC-PDSI and SPEI for drought monitoring in China. *Physics and Chemistry of the Earth, Parts a/b/c*, *102*, 48-58.

Zhang, W., Chen, Y., Zhou, T., Chen, X., & Ren, Z. (2023). Evaluating historical climate extremes in the FGOALS-g3 large ensemble in the presence of internal climate variability. *Climate Dynamics*, *61*(11), 5091-5110.

Zhang, J., Xu, W., Liao, X., Zong, S., & Liu, B. (2021). Global mortality risk assessment from river flooding under climate change. *Environmental Research Letters*, *16*(6), 064036.

Zhang, Y., Wang, Y., & Niu, H. (2019). Effects of temperature, precipitation and carbon dioxide concentrations on the requirements for crop irrigation water in China under future climate scenarios. *Science of the Total Environment*, *656*, 373-387.

Ziervogel, G., & Calder, R. (2003). Climate variability and rural livelihoods: assessing the impact of seasonal climate forecasts in Lesotho. *Area*, *35*(4), 403-417.

Zikos, D., & Hagedorn, K. (2017). Competition for water resources from the European perspective. In *Competition for water resources* (pp. 19-35). Elsevier.

Ziro, J. S., Kichamu-Wachira, E., Ross, H., & Palaniappan, G. (2023). Adoption of climate resilient agricultural practices among the Giriama community in South East Kenya: implications for conceptual frameworks. *Frontiers in Climate*, *5*, 1032780.

Zubieta, R., Molina-Carpio, J., Laqui, W., Sulca, J., & Ilbay, M. (2021). Comparative analysis of climate change impacts on meteorological, hydrological, and agricultural droughts in the Lake Titicaca basin. *Water*, *13*(2), 175.

Žurovec, O., Čadro, S., & Sitaula, B. K. (2017). Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina. *Sustainability*, *9*(7), 1208.

Zougmoré, R. B., Partey, S. T., Ouédraogo, M., Torquebiau, E., & Campbell, B. M. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cahiers Agricultures (TSI)*, *27*(3), 1-9.

Appendix

RESEARCH TITLE: Climate Risk Assessment in Central and Northern Liberia

PURPOSE: The overall aim of this research is to assess climate risks in Central and Northern Liberia. This will improve the understanding of the link between Liberia's agricultural production system, climate change and variability.

Researcher: Yusuff M. Sarnoh, I am a PhD research student from the University of Glasgow, Scotland, UK.

Ethical consideration

This study is purely for academic purposes. Names and identities of participants will be duly protected, and informed consents will be obtained from each participant.

SECTION A: General information

Line No	Usual Residents	Relationship to Head of Household	Sex	Age	Marital Status	Education	Literacy	**FOR MEMBERS AGED 5 TO 17 YEARS**					
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
HH ID	List the names of the Household members. **(START FROM THE HEAD)**	Relationship of (Name) to Head of Household 1= Head 2= Spouse 3= Son/Daughter 4= Son/Daughter in Law 5= Parent 6= Grand child 7= Relative	What is (Name) Sex 1= Male 2= Female	What is (Name) Age (in completed years i.e., age at last birthday) 00= less than 1 year	What is (Name) Marital Status **(12 YEARS OR OLDER)** 1= Never married 2= Married	What is (Name) Educational attainment **(FOR PERSONS 5 YEARS AND OLDER)**	LITERACY **(6 YEARS OR OLDER)** Can (Name) Read or Write in any	Is [name] currently going to school? 1= Yes **(Go To q10)** 2 = No	If No, why is [name] not going to school	Is [name's] biological Mother alive? 1 = Yes 2=No, **GO**	If alive does [name's] biological Mother live in this	Is [name's] biological Father alive? 1 = Yes 2=No, **GO**	If alive does (name's) biological Father live in this household? 1 = Yes 2=No

		8= non-relative 9= Domestic Worker		98= If 98 or more 99= Don't know	3= Living together 4= Divorced 5= Widowed 6=Separated 99=Don't know	0=None 1=Pre-primary 2=Primary 3=Junior high 4=Senior High 5=Vocational 6=Degree 99=DK	Language ? 1= Yes 2= No			**TO q12** 8 =DK, **GO TO q12**	house hold? 1 = Yes 2=No 8 =DK	**TO q2q14** 8 =DK, **GO TO q14**	8 =DK

SECTION B: Farming Activities

HH ID	Residency status	Farming activities	Type of crop	Duration of farm					GPS location
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
	How long has [name] been living in this community? Less than 10 years …1 11 -20 years ...2 21-30 years …3 31-40 years...4 31 years and above ...5	Has [Name] been farming in this community? Yes …1. No….2. If yes, continue to the next question	What type of crop has [Name] been farming in this community? Rice...1 Cassava…2 Both rice and cassava …3 Wheat and Wheat Products ...4	What type of rice farm [Name] has been planted? Upland pure =1 Upland Mixed =2 Rainfed swamp =3	What type of cassava farm [has] been planting? Upland pure =1 Irrigated land =2 Rainfed land =3	How long has [name] been farming in this community? Less than 10 years …1 11 – 20 years ...2 21 -30 years …3 31 -40 years...4	Total Farm area farmer's estimate 1-5 acres….1 6-10 Acres….2 11-15Acres...3 16-20 Acres...4	Area cleared and planted. Farmer's estimate 1-5 acres….1 6-10 Acres….2 11-15Acres...3 16-20 Acres...4 Above 21 Acres ...5	(Record GPS location from the corner where you began the measurement of the farms parameter – this should be the most northwest corner of the farmland)

			If rice, continue to q5 If cassava, go to q 6 If all the above, go to q7	Irrigated swamp =4		More than 41 years…. 6 If 31-40 years, Go to the next question…	Above 21 Acres ...5 Other, please specify ……	Other, please specify……							
															(E UTM)
															(N UTM)

SECTION C: Perception of climate change exposure and impacts

<table>
<tr><td>HH ID</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q5</td><td>Q6</td><td>Q7</td><td>Q8</td><td>Q9</td><td>Q10</td></tr>
<tr><td></td>
<td>Has [Name] observed any seasonal change in the farming activities during the previous 5-10 years?
Yes …1
No … 2</td>
<td><table>
<tr><td>Observed change</td><td colspan="5">Rank in term of severity.</td></tr>
<tr><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Delayed rain</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Earl rain</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Intermated rain</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>dryness</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Extended dry month</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>
1 = mild
2 = Moderate</td>
<td>Have these seasonal changes affected [Name] farming systems in the past years?
Yes …1
No …...2</td>
<td>What have been the impacts of these climatic changes and /or variation on your local rice and cassava production?
Crops failure...1</td>
<td>In a normal year, when do you start to experience rainfall?
At the beginning of April each year … 1
At the end of April each year … 2</td>
<td>In a normal year, when do the rainfall end?
At the beginning of October each year … 1
At the end of October each year … 2</td>
<td>Has [Name] observed any change in rainfall pattern?
Yes …1
No ….2</td>
<td>How long has [Name] observed these changes?
Less than 10 years
For the past 10 -19 year …1
For the past 20-29 years …2</td>
<td>When do you think have a ‘good rainfall’ year of farming?
(State year(s) and number of years).
Year (s)</td>
</tr>
</table>

		3 = serious 4 = very serious 5 = very, very serious	If yes to q2, Go to q	Reduction in crops yield ...2 All the above ..3	At the beginning of May …3 At the end of May …4	At the beginning of November…3 At the end of November …4		For the past 30-39 years …3	Number of years

Q11	Q12						
Has [Name] observed any change in temperature during the last 5-10 years? Yes…1 No …2	Which month did [Name] observe highest temperature?						

SECTION D: Irrigation and Access to communication facilities

HH ID											
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8		Q9	Q10	Q11
	Did you use any type of irrigation during the last years? 1= Yes 2= No	Which irrigation method has [Name] was used on the irrigated area? 1= Surface irrigation	What was the source of irrigation water? 1= Surface water (River /Lake/Pond/Mountain (by gravity)) (go to q7) 2= Surface water (River /Lake/Pond (by pumping)) (go to q7) 3= Ground water (Deep Well/Tube well)	Did the holder pay for irrigation ?	Payment terms for irrigation water 1= water fee per area	What was the frequency of water payment for irrigation? 1= Monthly	Does [Name] has access to the following communication facilities? Cellphone …1	Do you receive any climate and weather information ? Yes … 1 No …2	How would the communication equipment listed in q8 helped [Name] to access information on the weather?	Do you have access to ready markets for your agricultural product? Yes ...1 No …2	if yes, where, and how long has [Name] has to travel? Less than 1 hour …1

	IF NO GO TO q7	2 = Sprinklers 3 =Localized irrigation (Drip irrigation)	4= Ground water (Shallow well) 5=Mixed surface water and groundwater 6= Municipal/Town Council Water supply 7= Harvested 8 = Borehole 9 = Treated Wastewater/semi purified 10 = Rural Water Supply 15= Other Canal	1 = Yes 2 = No Skip to q7	irrigated (acres) 2 = water fee per volume of water 3 = other	2 = Quarterly 3= Annually 4= Others	Television …2 Radio …3 All the above…4		Call authorities advise... 1 Listen to radio broadcast ever morning …2 Watch the television mostly in the evening …3		1-2 hours .. 2 3-4 hours …3 5-6 hours …4 7-8 hours …5 More than 9 hours ..6

SECTION E: Identification of adaptation strategies in farming communities

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
HH ID	What are some of the ways you have used to cope with the changes in the climate in the past 40 years? Planting late or early drought/dry spell ...1 Planting drought/dry spell tolerant or resistant varieties ...2 Planting of various crops at different times …3	Please rank the top three adaptation strategies you have used in the past 40 years. (1 being the most important and 3 being the least important). Planting late or early to avoid the drought/dry spell … () Planting drought/dry spell tolerant or resistant varieties... () Planting of various crops at different times … ()	Have you received training to deal with the changes in rainfall and temperature patterns for your farming activity in the past 40 years? Yes … 1	If yes, please specify the person that conducted this training. MOA Extension workers …1	How would describe your way of farming? Shifting cultivation …1	What are some other measures you wish to see implemented to ensure the continued production of rice and cassava in your community?	What measures (related to agricultural production, for example, relocation to higher ground, use of different crop varieties, change in timing of production activities) have to put in place to adapt to the changes in climate?	What are some other measures you wish to see implemented to ensure the continued production of cassava in your community?

	Rely on friends/family/neighbors for supports …4 Receive assistance from the government in the form of relief items …5 Sell non-farm assets to cope with the changes in the climate … 6 Temporary migration to work elsewhere … 7 Others, please specify …8	Rely on friends/family/neighbors for supports … () Receive assistance from the government in the form of relief items… () Sell non-farm assets to cope with the changes in the climate… () Temporary migration to work elsewhere. .( ) Other, please specify ……	No … 2	EPA staff …2 NGOs/CBO … 3 All the above …4	Crop rotation …2			

Please list (and describe) the five most important things that you think could help your household to reduce its vulnerability to climate change variability (please list these in order of importance).

Key informal questionnaire guide

1. **Ministry of Agriculture and Statistics office**
    a. In your opinion, has there been there anything like droughts or dry spell that have occurred in this county over the past 10-40 years?
    b. If yes, what are the common or reoccurring drought /dry spell in this county?
    c. When last did they occur drought or dry spell in this county?
    d. If the impacts of drought/dry spell continue at a consistent pace, as now, how do you see the future of the environment in the county?
    e. What other factors do you think will affect the implementation of drought policy in the county?
    f. What are the most effective measures would you recommend assisting in mitigating the impacts of drought or dry spell in the county?
2. **Environmental Protection Agency of Liberia (EPA)**
    a. Is there a warning system in place to alert communities and/or the government of impending events?
    b. If yes, briefly explain.
    c. Are there any measures put in place by the government to alleviate/mitigate these hazards?
    d. If yes, how effective are these measures?
    e. Is there any involvement of the locals in the erosion and flood risk mitigation plans?
    f. If yes, how effective is it?
    g. Are there any challenges in getting the local community involved in the preventive/mitigation plans?
    h. If yes, what are there?
    i. Apart from the National Drought Policy, what other measures do you think can be taken in order to mitigate the impacts of drought or dry spell at the community level?

Is the Government open to improved policies that will involve local knowledge?

University of Glasgow | College of Science & Engineering

Institute of Neuroscience and Psychology

School of Psychology

Prof Lawrence W. Barsalou

62 Hillhead Street
Glasgow G12 8QB
United Kingdom

Phone: +44 (0) 141 330 3035
Email: lawrence.barsalou@glasgow.ac.uk

25 Oct 2021

Ethical approval for:

Application Number: 300210042

Project Title: Vulnerability Assessment of Central and Northwestern Liberia to Climate Change

Lead Researcher: Professor Jaime Toney

This is to confirm that the College of Science and Engineering Ethics Committee has reviewed the above application and **approved** it. Please download the approval letter from the Research Ethics System for your records.

Please note that if your proposal involves face-to-face research, approval to carry out this research is only granted when one of the following two conditions has been met:

(a) You have a performed a risk assessment of your research protocol in your research facility, had it approved by your Head of School / Director of Institute, and received permission to proceed with this specific research project, or

(b) The University has generally lifted its social distancing restrictions on face-to-face interaction, including research.

In either case, your approval for this project lasts for 6 months from the date you are allowed to proceed with data collection.

If your research collects data in a format that **does not require social contact** (e.g., online research), you may begin data collection now.

Also please download and read the Collated Comments associated your application. This document contains all the reviews of your application and can be found below your approval letter on the Research Ethics System. These reviews may contain useful suggestions and observations about your research protocol for strengthening it. Good luck with your research.

Sincerely,

Lawrence W. Barsalou
Ethics Officer
College of Science and Engineering
University of Glasgow

University of Glasgow | College of Science & Engineering

INVITATION TO PARTICIPATE IN QUESTIONNAIRE SURVEY

Dear Sir/Madam,

I am a PhD research student at the University of Glasgow, the UK, undertaking a research project entitled: “Vulnerability Assessment of Central and North-West Liberia to Climate”. The doctoral research is partially sponsored by the Liberia Institute of Statistic and Geo-Information Service (LISGIS) through the HISWA Project.

As part of this work, therefore, I would like to invite you to kindly participate in answering a questionnaire survey.

The research aims of this research is to assess the vulnerability to agricultural drought in Central and North-Western Liberia in the context of climate change variability. To achieve this objective, the following specific objectives are highlighted:

1. **the assessment of historic patterns and dynamics of drought between 1981 and 2020 using available multispectral satellite datasets and project 40 years into the future,**

2. **identify keys factors that define agricultural drought vulnerability in Liberia, and**
3. **to determine the difference adaptation and or mitigation strategies to manage the impacts of climate change and variability in vulnerable households, communities, and counties.**

A copy of the survey questions is attached. It is estimated that about 20 minutes of your time will be required to answer the questions. Data obtained from the survey will be treated with strict confidence and used for academic purposes only. No records will bear your identity. The questionnaire comprises of three sections. These are: Section A General Information, Section B: Farming Activities, Section C: Perception of climate change exposure and impacts, Section D: Irrigation and Access to communication facilities and Section E: Identification of adaptation strategies in farming communities.

All necessary details and instructions on how to answer the questionnaire are attached including the consent form, which you will sign and keep copy for your record.

If you have any questions or queries, please do not hesitate to contact the interviewer.

Thank you very much in advance for your time and valuable assistance in this research.

Yours sincerely,

Yusuff M. Sarnoh
Doctoral Research Student, University of Glasgow,
Scotland, UK
y.sanoh.1@research.gla.ac.uk

University of Glasgow | College of Science & Engineering

Consent Form

Title of Project: Climate Risks Assessment of Central and Northern Liberia

Name of Researcher: Yusuff M. Sarnoh

No	Description	Option
1	I have read and understood the study information dated [………../……../2021]. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	Yes/No
2	I consent voluntarily to be a participant in this research and understand that I can refuse to answer questions and that I can withdraw from the research at any time without having to give a reason.	Yes/No
3	I agree to be photographed or filmed	Yes/No
4	I agree that my (anonymised) information can be quoted in research outputs.	Yes/No
5	I understand that any personal information that can identify me – such as my name, address, will be kept confidential and not shared with anyone.	Yes/No
6	I give permission for the (anonymised) information I provide to be deposited in a data archive so that it may be used for future research.	Yes/No

__________________________ ____________ ____________________

Name of Participant Date Signature

Yusuff M. Sarnoh

__________________________ ____________ ____________________

Researcher Date Signature