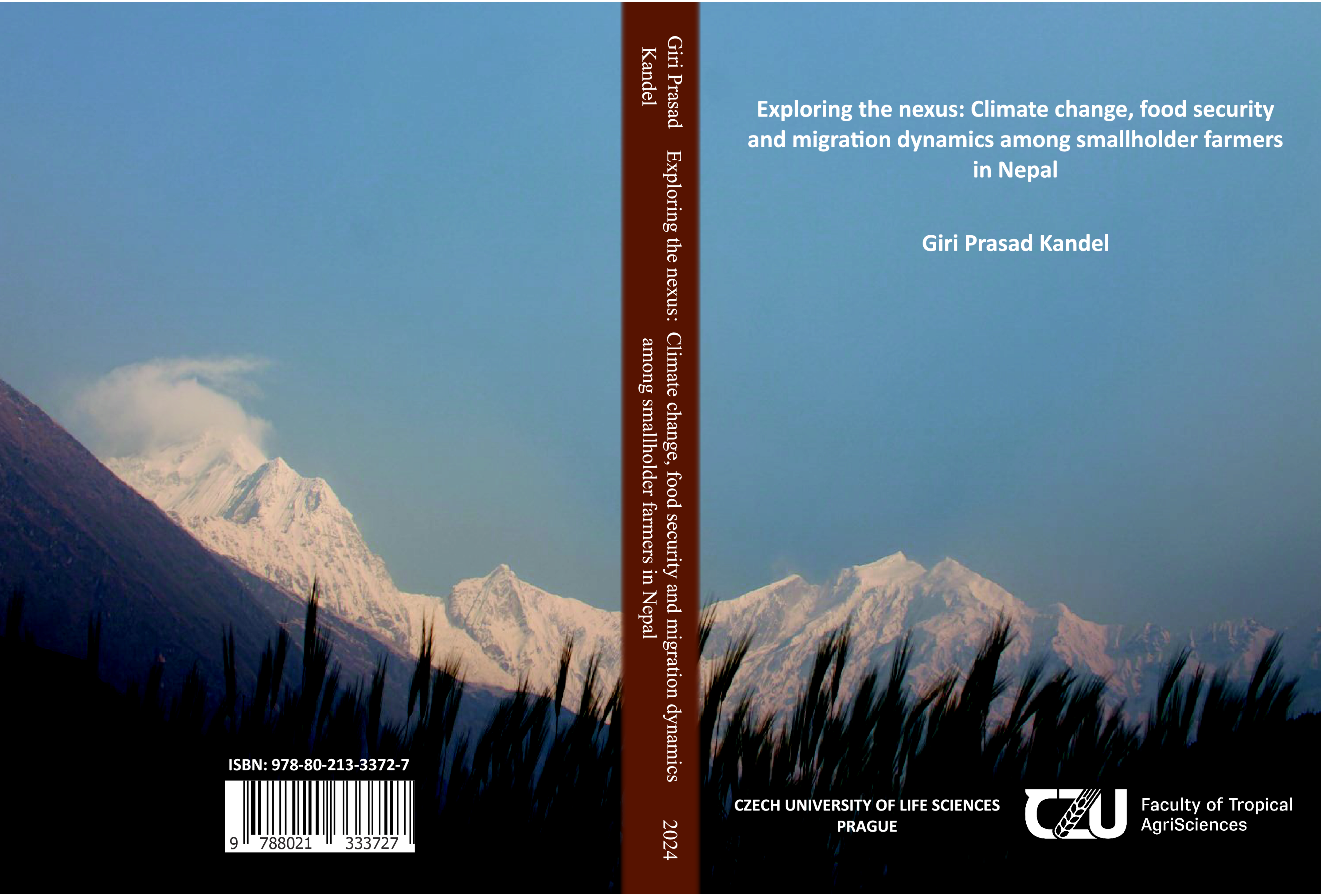

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Giri Prasad Kandel Exploring the nexus: Climate change, food security and migration dynamics among smallholder farmers in Nepal 2024

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

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Department of Economics and Development

Exploring the nexus: Climate change, food security and migration dynamics among smallholder farmers in Nepal

DISSERTATION THESIS

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Declaration

I hereby declare that I have completed this thesis entitled "**Exploring the nexus: Climate change, food security and migration dynamics among smallholder farmers in Nepal**" independently, all texts in this thesis are original, and that all the sources have been quoted and acknowledged by means of complete references. I also ensure that this work has not been and is not being submitted for any other degree to this or any other university.

In Prague, April 2024 ....

Giri Prasad Kandel

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Abstract

Climate change significantly threatens agriculture and food security, especially for smallholder farmers in developing countries like Nepal. Adverse effects, including changing weather patterns and extreme events such as droughts, landslides, and floods, lead to increased vulnerability, food insecurity, and migration. Despite efforts to implement various climate change adaptation strategies, their effectiveness among smallholder farmers remains limited. This dissertation explores the complex linkages between climate change, adaptation strategies, food security and migration in Nepal. It uses a quantitative survey to collect data from 400 smallholder farmers in three agro-ecological zones of Nepal, conducted from March 2021 to June 2021, focusing on smallholder farmers. First, it examines the influence of agro-ecological zones, social groups, and socio-economic factors on the adoption of climate change adaptation strategies, combining the “Action Theory of Adaptation” and the “Intersectionality Framework” and utilizing advanced analytical models such as the Multivariate Probit Model. Second, the study assesses food security status in response to climate extremes, particularly drought, and evaluates the impact of adaptation strategies. It employs two theoretical frameworks, the FAO Food Security Indicators, and the IPCC Vulnerability Dimensions. An ordered logit model is used to explore the complex dynamics of climate change and food security. Finally, the study examines rural migration in the context of climate change and its impact on food security status, incorporating the “Push-Pull theory” and the “Neo-Economics of Labour Migration”. It employs binary probit, propensity score matching, and endogenous switching regression to understand food security dynamics and migration dynamics better. The findings demonstrate the positive impact of adopting climate change adaptation strategies for smallholder farmers facing climate challenges. However, marginalized groups, like those in the Mountain region and Sudra groups, face barriers to adoption due to limited adaptive capacity, leading them to engage in off-farm activities and temporary migration to cope with climate impacts and improve their livelihoods. Climate extremes, particularly droughts, negatively impact food security, but adopting climate change adaptation strategies effectively improves the food security status of smallholder farmers. Rural out-migration has a dual impact on food security, with remittances crucial for increasing household income and food security, but the reduction in the agricultural labour force poses a long-term challenge. We propose empowering disadvantaged farmers by disseminating information on climate change adaptation. To sustain agricultural production, the government should provide subsidies and easy access to credit, especially for disadvantaged Mountain, Hill, and Sudra farmers, possibly through microfinance. Promoting small-scale irrigation, early maturing crop varieties, new crop varieties, and crop-specific weather information will improve climate adaptation and agricultural resilience for sustainable food security. Tailored adaptation strategies for each agro-ecological zone are essential, prioritizing smallholder farmers through technology, credit, and subsidies to prevent long-term land abandonment and excessive migration. Collaboration between governments, NGOs, and stakeholders is essential to address interlinked challenges and ensure smallholder farmers resilience to climate impacts.

Keywords: Climate change adaptation strategies, Sustainable Development, Agroecological zones, Social groups, Food consumption score, Reduced coping strategies index, Multivariate probit model, Endogenous switching regression

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LIST OF THE ABBREVIATIONS

CCA	Climate Change Adaptation
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product Intergovernmental
IPCC	Panel on Climate Change World Food
WFP	Program
FCS	Food Consumption Score
IFAD	International Fund for Agriculture Development
IOM	International Organization for Migration
FANTA	Food and Nutrition Technical Assistance Project
SAFS	Self-assessed measure of food security
HFIAS	Household Food Insecurity Access Scale
HHS	Household Hunger Scale
USAID	United States Agency for International Development
RM	Rural Municipality
GLOF	Glacial Lake Outburst Floods
NELM	New Economics of Labour Migration
MVP	Multivariate Probit Model
PSM	Propensity Score Matching
ESR	Endogenous Switching Regression
ATT	Average Treatment Effect on the Treated
FIML	Full Information Maximum Likelihood
LDC	Least Developed Countries
SDGs	Sustainable Development Goals
SDG1/2	Sustainable Development Goal 1/2

1 Introduction

Climate change causes rising global temperatures, changes in precipitation patterns, and increasingly frequent severe weather that significantly threaten the agricultural sector (FAO, 2008; FAO, 2016; IPCC, 2020; Pradhan et al., 2022). Rural and vulnerable communities that rely on rain-fed agriculture for income and food are most exposed to these adverse effects (Kandel et al., 2023; Javadi et al., 2023; Roy et al., 2022). These communities often lack the resources and adaptive capacity to cope with extreme weather events (Roy et al., 2022) and are already facing significant challenges in attaining food security and sustainable livelihoods (Barrios et al., 2020; Roy et al., 2023).

Climatic conditions are a crucial part of food system resilience (World Bank, 2022). Evolving weather patterns and extreme events reduce crop yields while increasing vulnerability to disease and economic instability. These factors exacerbate overall challenges to food security and long-term sustainability (Yuan et al., 2022; Roy et al., 2022). Food insecurity is high among agricultural households, especially rural smallholders, and members of vulnerable groups (Kogan et al., 2019).

In June 2022, approximately 345 million people worldwide were acutely food insecure (World Bank, 2022). This describes individuals or communities facing severe and immediate deprivation of sufficient, safe, and nutritious food due to natural disasters, conflicts, or emergencies (Brück & d'Errico, 2019; Tirado et al., 2022). Despite Sustainable Development Goal 2's (SDG2) target of eradicating hunger by

2030, projections suggest that approximately 670 million people globally will continue to experience hunger and food insecurity (FAO, 2022). In low-income, agriculture-dependent countries, the number of food-insecure people is expected to exceed 30 million by 2030 (FAO, 2022). This is a major challenge, especially for smallholder farmers who are the backbone of the global agricultural sector (FAO, 2022).

Smallholder farmers are particularly vulnerable to the impacts of climate change due to their reliance on rain-fed agriculture (Ado et al., 2019). Extreme events—droughts, landslides, and floods—devastate agricultural fields and bring new diseases that threaten agricultural products and human health (Ogunniyi et al., 2021). Smallholder farmers' vulnerability is also exacerbated by their limited access to resources like technology, credit, and information (Atube et al., 2021; Ansah et al., 2023). This hinders the adaptation strategies needed to respond to climate change and food security challenges (Atube et al., 2021; Ansah et al., 2023) and is a major constraint to achieving sustainable development in agriculture (FAO, 2022). These factors help explain why smallholder crop productivity has declined significantly (Harkness et al., 2020).

Sustainable agricultural development proactively adopts climate change adaptation (CCA) strategies to strengthen resilience and increase adaptive capacity (Pawlak & Kołodziejczak, 2020). Effective strategies are especially important in least-developed countries (LDCs), where climate change vulnerability is exacerbated by the escalating impacts of climate change (Aryal et al., 2020; Rijal et al., 2022).

Nepal, an LDC, is highly susceptible to climate-related hazards due to its fragile topography, climate-sensitive subsistence livelihoods, and farmers' low adaptive capacity (Rijal et al., 2022; Thapa & Hussain, 2021). The situation in Nepal is 'severe,' as it is the fourth most vulnerable country in the world, according to Maplecroft's 2011 Climate Change Vulnerability Index (Eckstein et al., 2019). The country's climate challenges include higher temperatures, rainfall variability, and extreme events such as droughts, landslides, and floods (Olesen, 2002; Paudel et al., 2020; World Bank, 2021). The Asian Development Bank (2021) estimates that climate change will reduce Nepal's Gross Domestic Product (GDP) by 2.2% annually by 2050, mostly due to agriculture's large (25.8%) contribution to the national economy (Government of Nepal, 2021). Climate-related shocks have already affected agricultural productivity (Aryal et al., 2020), particularly among the 80 percent of farmers who are smallholders (FAO, 2022). Smallholder farmers have low efficiency, so (Rijal et al., 2022) their future food security and livelihoods are at even greater risk.

Addressing these issues requires comprehensive strategies to promote sustainable farming practices, improve access to financial services, and invest in rural infrastructure (Gartaula et al., 2017; Thapa & Hussain, 2021). The country has created some proactive programmes to improve smallholder agriculture that train farmers in sustainable technologies and productive crop varieties (Government of Nepal, 2021). There are also efforts to improve smallholders' access to credit and financial services and boost farming efficiency through investments in irrigation systems and transport (Government of

Nepal, 2021). These initiatives will build resilience against climate change and ultimately enhance the livelihoods of smallholder farmers in the country; however, uptake remains limited (Thapa & Hussain, 2021). Therefore, the country continues to face difficulties in climate change adaptation and food security (FAO, 2022).

In LDCs and developing countries, household members often migrate within or outside their country to improve their household's livelihood (Abebaw et al., 2020). Farmers increasingly abandon farming, opt for off-farm activities, and migrate to urban areas or abroad for better livelihoods (Kandel et al., 2023). This out-migration from rural areas affects agricultural productivity. It generates short-term benefits and alternative sources of income that alleviate the immediate pressures of economic crisis and offer food and nutrition security (Gupta et al., 2021). However, in the long term, it exacerbates food security challenges by reducing agricultural productivity (Roy et al. (2016). The loss of agricultural labour exacerbates food production and land abandonment challenges, creating obstacles to fulfilling domestic demand for food and agricultural products. This cycle adds another barrier to achieving the SDGs and mitigating the adverse effects of climate change. There is an urgent need to bridge the gap between advocacy and practical implementation to safeguard the agricultural sector, ensure food security, and attain the SDGs in the face of climate change and rural migration.

This thesis adopts a pioneering approach to address significant research gaps. Existing studies have explored the drivers of climate change adaptation strategies (Tiwari et al., 2014; Bhatta & Aggarwal, 2016), household food security

(Khanal & Wilson, 2019; Karki et al., 2021), and migration (Abebaw et al., 2020; Kim et al., 2019). However, they often overlook the intrinsic linkages between these critical issues. The multifaceted implications of climate change—notably its severe effects on agriculture—require an integrated approach that encompasses its broader spectrum. This study centres on three key dimensions: climate change, food security, and migration. Our holistic approach responds to the complex realities of agriculture and smallholder farmers in rural Nepal to provide essential insights into the challenges Nepal's rural households face. The findings can guide strategies to improve rural households' climate resilience and food security in other countries facing similar complex challenges.

The empirical analysis chapter is divided into three sub-chapters. Each sub-chapter comprehensively explores a specific aspect of the complex and dynamic relationship between climate change, food security, and migration among smallholder farmers in Nepal. We explore how climate-induced vulnerabilities trigger adaptive responses, including the pursuit of off-farm activities and the temporary migration of vulnerable farmers. Adaptation strategies have a dual impact: they significantly improve food security and influence migration decisions. The migration element yields positive results for migrant household food security in the short term. However, long-term consequences like land abandonment and reduced agricultural productivity ultimately (negatively) affect food security.

While the existing literature focuses on discrete aspects of climate-induced vulnerability, this study explores their complex interplay. It fills a research gap by examining the linkages between climate change, adaptation strategies, food security, and migration in rural smallholder farming households. We highlight the dual impact of adaptation strategies that influence food security and migration decisions. The (underexplored) long-term consequences of rural out-migration include land abandonment and reduced agricultural productivity.

The following sections of the thesis are structured as follows: Chapter 2 provides a comprehensive literature review, Chapter 3 articulates the objective, and Chapter 4 describes the methodology. The empirical analysis and findings are detailed in Chapter 5. Chapter 6 provides a general discussion and reviews the study's limitations. Chapter 7 offers a comprehensive conclusion.

2 Literature review

The literature review serves three primary purposes. First, it provides a contextual basis for the study by synthesising existing knowledge on climate change, food security and migration. Second, it identifies gaps, limitations, or areas for further research in the current literature. Third, it informs the theoretical framework, shapes the conceptual framework, and identifies research questions, methodology and crucial factors to consider for further research. This chapter examines the global and Nepalese context of the climate, agriculture, food security and migration. It reviews Nepal's climate change action plan and agricultural policies. The chapter also outlines specific strategies for adapting to climate change, focusing on Nepal. Finally, it explores the complex concepts of climate change, food security and migration.

2.1 Concept of climate change

Climate change represents the long-term variations in weather conditions, encompassing factors like temperature and precipitation (Nicholls et al., 2021; Roy et al., 2023; Simpson et al., 2021). These changes can range from a few decades to several thousand years, illustrating the different timescales over which these changes manifest themselves (Nicholas and Golledge, 2020; IPCC, 2013). Human activities have significantly impacted the climate since the industrial revolution (Abbass et al., 2022).

The impact of climate change is evident globally, affecting crucial sectors like agriculture, human health, food and water security, transportation, ecosystems, energy, and migration (Raihan, 2023; Singh et al., 2023). Agriculture, in particular, faces increasing challenges due to climate interruptions, with increased severity (Abbass et al., 2022). This changing climate presents formidable obstacles to agricultural practices, affecting vital aspects such as crop yields, water availability, and overall food production (Gardezi et al., 2022; Maraseni et al., 2021).

2.1.1 Observed climate change

Global temperatures have risen significantly during the 20th century. Sea levels have risen globally, and snow and ice cover reductions have been observed (IPCC, 2020). Changes in atmospheric and oceanic currents and regional weather patterns have affected seasonal precipitation conditions (World Bank, 2021). In the future (2021-2040), global warming is expected to continue to increase, mainly due to escalating cumulative CO2 emissions. According to the report of IPCC (2023), there's a high probability that global temperatures will exceed 1.5°C. The ongoing emissions will continue to affect all climate system components. With each incremental increase in global warming, extreme changes will become more evident. The report of IPCC (2023) predicts that continued warming will increasingly affect global hydrology, including its variability and global monsoon rainfall. The impact of climate change on the agricultural sector in the least developed countries and in developing countries is observed more (Khanal et al., 2018).

In the context of Nepal, a Himalayan country, the effects of climate change are particularly sharp (Manandhar et al., 2011; Aryal et al., 2020). The glaciers are melting rapidly, increasing the risk of glacial lake outburst floods, and threatening mountainous and hilly communities (Shrestha et al., 1999). In addition, rainfall patterns are disrupting established agricultural practices, leading to increased landslides and floods, particularly threatening the plains and their communities (Aryal et al., 2020). However, in Nepal, an analysis of observed temperature and precipitation is limited. Over the past five decades, studies have revealed a remarkable trend of Nepal's temperature (Shrestha et al., 1999; Manandhar et al., 2011). These studies' findings indicate that the average annual temperature increase between 1977 and 1994 was 0.06°C per year. It has also been found that the warming is more pronounced in the winter than in other seasons.

2.1.2 Indicators of climate change

Global warming extends the potential growing season, allowing earlier planting and faster crop maturation (Marklein et al., 2020). In Nepal, a temperature increase of 1.0-1.3°C is observed between 1900-1917 and 2000-2017, with a projected increase of about 0.9°C by 2045 under medium emissions (World Bank, 2021). Studies in the Himalayan region suggest an even higher rate of warming (Pokharel et al., 2020). Higher temperatures lead to accelerated crop growth and early maturity (Olesen & Bindi, 2002).

Climate change poses a rainfall threat and disrupts overall seasonal rainfall patterns. Agriculture, especially in semi-arid regions, highly depends on water resources (Olesen & Bindi, 2002). There has been an escalation of extreme rainfall events in Nepal since the late 20th century (World Bank, 2021). Despite this, western Nepal has experienced a notable decline in mean seasonal rainfall (World Bank, 2021). This erratic rainfall pattern increases vulnerability to landslides and floods (World Bank, 2021).

Climate variability leads to reduced agricultural productivity, damage to livelihoods, and adverse impacts on human health (Chhetri et al., 2020). Over the past four decades, floods, landslides, and droughts have become the most recurrent hazards, and their frequency is expected to increase as climate change intensifies (Amadio et al., 2022; Dhakal & Dhakal, 2015). Southern and urban communities in Nepal are more vulnerable to the adverse impacts of floods and heat stress. At the same time, northern regions face increasing challenges such as erosion, landslides, water stress, and glacial lake outbursts (Vij et al., 2020).

2.1.3 Effect of climate change on agriculture in Nepal

Climate change poses a significant threat to agriculture. It affects crop yields, livestock health and overall food production (Amadio et al., 2022). Adapting agricultural practices and implementing sustainable measures are critical to mitigate these challenges and ensure global food security and better livelihoods. The vulnerability of agriculture is compounded by its dependence on weather and climate conditions, with the sector already experiencing negative impacts from higher temperatures, erratic rainfall, and extreme weather events (Asare-Nuamah, 2021; Shahzad et al., 2021).

The Intergovernmental Panel on Climate Change (IPCC) Assessment Report AR5 states that changing climate has more negative impacts than positive (IPCC, 2014). Around 66% of the total population of Nepal is employed in the agricultural sector. It contributes a third of the country's GDP and the national economy (FAO, 2023). Nepal is vulnerable to recurrent natural disasters such as Glacial Lake Outburst

Floods (GLOFs), floods, droughts, landslides, diseases, and pest outbreaks. Subsistence farming continues to dominate the agricultural sector in the country, resulting in a limited level of productivity (FAO, 2023). The impact of climate change is much more direct on the agricultural sector, mainly through changes in cropping patterns due to increases in temperature and rainfall patterns in the country, (Aryal et al., 2020). Despite an agro-based economy, country is a net importer of many agricultural products, and this trend is increasing every year (Adhikari et al., 2021). In addition, the climate change is making Nepal's farming communities more vulnerable. In response to these changing conditions, it is imperative for Nepalese farmers to proactively seek adaptation strategies that can help mitigate the impacts of climate change. Furthermore, the government of Nepal developed policies to mitigate and adapt to climatic hazards.

2.1.4 Farmers awareness of climate change in Nepal

Farmers are at the forefront of adaptation in the face of escalating climate challenges, dealing with the severe impacts of changing weather patterns and extreme events (Uprety et al., 2017). Awareness and active response to climate change are essential to making farming systems more resilient (Jha & Gupta, 2021). Nepalese farmers encounter significant challenges in maintaining agricultural production because of limited access to information sources that can enhance awareness (Manandhar et al., 2011). Awareness of climate change is critical for farmers to plan activities, programs, and policies to reduce associated risks (Fahad et al., 2020). Many studies show that farmers' awareness of climate change influences agricultural production and its outcomes (Cosmas et al., 2017; Gartaula et al., 2012; Manandhar et al., 2011). Moreover, farmers' awareness of climate change is the first step towards successful adaptation (Fahad et al., 2020). The likelihood of farmers adopting climate change adaptation strategies increases with climate change awareness (Jha & Gupta, 2021).

2.1.5 Climate change adaptation strategies in Nepal

With the growing challenges of climate change, adaptation strategies are essential to reduce the negative impacts on agriculture (Rijal et al., 2022; Thoai et al., 2018). As global temperatures and erratic rainfall increase, extreme weather events are becoming more frequent, and adaptation helps to reduce the negative impacts (Thoai et al., 2018). Effective adaptation strategies are essential to protect agriculture and ensure sustainable development (Ojo & Baiyegunhi, 2020; Tesfaye & Nayak, 2022).

Nepal has actively pursued various climate change adaptation strategies to protect its agriculture, ecosystems, and economy from increasing climate-related risks (Bhattarai et al., 2021). These strategies include crop diversification, intercropping, drought-resistant crops, new crop varieties and agroforestry (Muench et al., 2021). Farmers in the country have reduced growing crops highly susceptible to temperature and water stress and instead introduce more resilient crops to their land (Karki et al., 2020). The country's crop shift pattern favours high-value crops such as fruits and vegetables over water-intensive options such as rice (Hussain et al., 2016). The shift from cereals to vegetables has increased household incomes and effectively addressed the challenges of climate change (Merrey et al., 2018). Vegetable production has become a critical adaptation strategy in the mountainous regions of the country (Karki et al., 2020; Krupnik et al., 2021). Farmers in these regions have adopted practices such as rainwater harvesting, using surplus drinking water for vegetable production, and maintaining ponds (Tiwari et al., 2014). Drought has been identified as a major challenge, making irrigation programmes crucial for local farmers to reduce drought-related problems (Karki et al., 2020). Several studies show that agroforestry is a preferred adaptation strategy among Nepalese farmers to cope with climate extremes such as droughts, landslides, and floods (Jones & Boyd, 2011; Tiwari et al., 2014; Neupane et al., 2002). In the face of increased vulnerability to natural hazards, smallholder households have diversified their income sources through off-farm activities and temporary migration to sustain their livelihoods (Kandel et al., 2023). This adaptive approach highlights the importance of understanding the determinants of climate change adaptation strategies, which are critical to building resilient communities (Fahad et al., 2020; Manandhar et al., 2011).

In Nepal, the determinants of climate change adaptation strategies are diverse and include various socio-economic, institutional, and geographical factors. Farmers' awareness and perception of climate change, communication channels and economic incentives play a crucial role in adopting climate change adaptation strategies (Manandhar et al., 2011). In addition, age, gender, education, income, land tenure, social status, exposure to climate hazards, geographical location, and access to credit and markets play a crucial role in shaping their adaptation strategies (Atube et al., 2021; Piya et al., 2013; Ullah et al., 2020). More details on climate change adaptation strategies and their determinants among Nepalese smallholder farmers are provided in subchapter 1 of the empirical analysis, results, and discussion chapter.

2.2 Concept of food security

The term 'food security' originated in the 1970s during the World Food Conference (1974). It was initially defined as ensuring staple foods' availability and price stability at both international and national levels (FAO 2006). It was widely accepted as a standard definition at the 1996 World Food Summit. According to the 1996 World Food Summit, food security exists "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2008). Achieving food security requires households and individuals to have an adequate supply of nutritious food, consistent access to food, and satisfactory quality (Ilboudo Nébié et al., 2021; Nagoda, 2015). Food security is based on the four main key pillars: food availability, food accessibility, food utilization and food stability (FAO,2001). In the context of climate change, each pillar of food security faces increased challenges and complexity. These pillars are graphically highlighted in Figure 1 below.

The first pillar, food availability, is significantly affected by climate change through agricultural productivity and food production systems. Rising temperatures, variability in rainfall patterns and the increased frequency of extreme weather events such as droughts, floods and landslides disrupt crop yields and livestock production. These changes lead to the reduction of food availability both locally and globally (Gebre & Rahut, 2021; Sam et al., 2021a). For example, shifting climate zones may make certain areas unsuitable for traditional crops, requiring costly adaptations or transitions to different agricultural practices. In addition, changing climate conditions may affect the availability of water resources, which are critical for irrigation, further exacerbating the challenge of food production (Poudel & Kotani, 2013; Radeny et al., 2022).

The second pillar, food accessibility, is also significantly affected by climate-related disasters, which can severely disrupt transport routes, infrastructure, and markets, hindering physical and economic access to food (FAO,2001). Vulnerable populations, particularly those in low-income countries and regions prone to climate extremes, face increased food insecurity risks as their capacity to purchase or access food is reduced due to price spikes or supply disruptions (Alpízar et al., 2020). In addition, marginalised communities, such as smallholder farmers or indigenous groups dependent on specific ecosystems, are disproportionately affected, exacerbating existing food access inequalities (Poudel & Kotani, 2013; Radeny et al., 2022).

The third pillar, food use, is also directly affected by climate change through impacts on nutritional quality and diversity. The changes in temperature and rainfall patterns impact the distribution and abundance of crops (FAO, 2001). In addition, extreme weather events can disrupt food processing and storage facilities, compromising food safety and increasing the risk. Ensuring the proper biological use of food during these disruptions becomes increasingly challenging, requiring innovative strategies to maintain dietary diversity and nutritional adequacy in the face of changing environmental conditions (Hussain et al., 2016; Shah et al., 2020).

Food stability, the fourth pillar, emphasises the need for individuals or households to have consistent access to sufficient and appropriate food without the risk of losing access (FAO, 2001). Climate variability and extremes introduce uncertainty and volatility into food systems, undermining the food stability for individuals and households. Sudden shocks such as crop failures, livestock losses or market disruptions triggered by climate-related events can push households into food insecurity, especially those without adequate resilience measures. Building resilience to climate impacts is essential to improve food security. It includes measures such as diversified livelihoods, enhanced early warning systems, climate-smart agricultural practices, and social protection mechanisms to buffer against shocks and ensure continued food stability (Poudel & Kotani, 2013; Radeny et al., 2022).

To tackle these challenges, a multi-faceted approach that integrates strategies to adapt to the effects of climate change with food security practices is required. This includes investing in sustainable agricultural practices, enhancing the food system, and promoting resource access. Smallholder farmers benefit from adopting a holistic approach to addressing the adverse effects of climate change on food security (Taylor et al., 2019; Kogan et al., 2019).

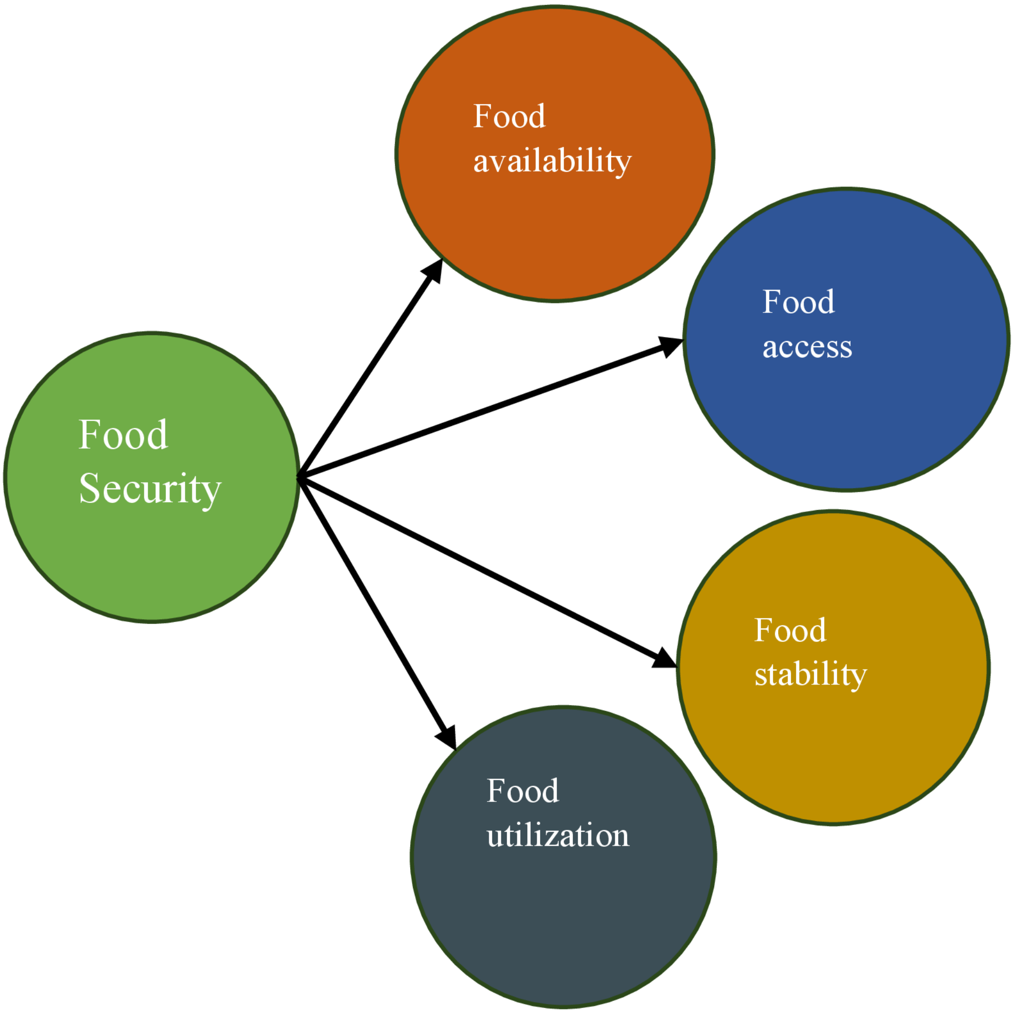

Figure 1 Components of food security

Source: Author owns construction based on FAO dimensions of food security (FAO, 2001)

2.2.1 Climate change and food security in Nepal

Climate change is a significant factor in global food insecurity, affecting the four pillars of food security (Hussain et al., 2016; Shah et al., 2020). Rising temperatures and erratic rainfall can reduce food availability by affecting crop productivity (Poudel & Kotani, 2013; Radeny et al., 2022).

Market disruptions, prices, infrastructure, and income shifts affect food access and stability (FAO, 2001). The direct effects of climate change on the use of food include an increase in mycotoxins in food due to extreme climate events (FAO, 2001). Climate extreme events like drought, floods and landslides directly affect the stability of food supplies through disruption of transport and markets (Alpízar et al., 2020). Vulnerable households, especially those heavily dependent on agriculture with limited livelihood diversification, face significant challenges to food security due to extreme climate conditions (Ilboudo Nébié et al., 2021).

Regarding Nepal, the nexus of food security and climate change is critical (Thapa & Hussain, 2021). With around a quarter of the population living in poverty, the country's vulnerability to food security is exacerbated (Thapa & Hussain, 2021). Climate-related hazards have caused nearly 5% of household land in Nepal to become unproductive over the past decade, amounting to 30,845 hectares (FIAN, 2022). Over the past two decades, cultivated areas in Nepal have been adversely affected by erratic rainfall patterns, rising temperatures, droughts, flash floods and landslides, significantly affecting production (Rijal et al., 2022). Furthermore, Nepal faces challenges overcoming its vulnerable state due to topographical variability, monsoon variability and inadequate infrastructure (Rijal et al., 2022; Thapa & Hussain, 2021). The recent flash floods of 2017, which affected 80% of the southern agricultural region and caused significant agricultural and human losses, illustrate the country's vulnerability to climate-related hazards (Government of Nepal, 2017). All three agro-ecological zones of Nepal (Mountain, Hills, and Terai) have been affected by climate change, resulting in agricultural systems that have led to new insects, pests, and diseases of crops and animals (Karki et al., 2020). Farmers are actively implementing adaptation strategies to ensure sustainable food security despite climate change (Kandel et al., 2023).

2.2.2 Indicators to measure food Security

Food security measurement involves assessing various dimensions to understand food availability, access, utilization, and stability within a population (Taylor et al., 2019). This analysis occurs at two levels: the micro level, which comprises individual and household levels, and the macro level, encompassing national, regional, and global scales. At the household level, key indicators such as demographics, income, livelihoods, assets, and expenditure contribute to a comprehensive understanding of food security (Thapa & Hussain, 2021). In addition, key indicators for measuring food security include food consumption and coping strategies, measured by scales such as FCS, CSI, IDDS, and HDDS (Vhurumuku, 2014).

Table 1 Food security indicators

Dietary diversity and food frequency	**Consumption behaviors**
a) Food Consumption Score (FCS) b) Household Dietary Diversity Scale (HDDS) c) Food expenditure d) Undernourishment	a) Coping Strategy Index (CSI) b) Reduced Coping Strategy Index (rCSI) c) Household Food Insecurity and Access Scale (HFIAS) d) The Household Hunger Scale (HHS) e) Self-assessed measure of food security (SAFS).

Source: Author owns construction based on Vhurumuku, (2014)

Food diversity is a crucial element of a nutritious diet. A diverse diet which includes all the food groups, such as vegetables, fruits, cereals, meat, and dairy products, is essential for reaching nutrient adequacy (WFP, 2008). Dietary diversity is the number of foods or groups consumed over a provided recommendation period (Nachvak & Abdollahzad, 2017). At the same time, consumption behaviours measure capture food security indirectly by evaluating behaviours associated with food consumption (WFP, 2008).

2.3 Concept of migration

As per the International Organization of Migration (IOM), migration refers to "*persons or groups of persons who, for compelling reasons of sudden or progressive changes in the environment that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either permanently or temporarily, and move either abroad or within their home country*" (IOM, 2017). Migration is a complex phenomenon influenced by economic, social, geographical, political, and climatic factors and often results in individuals or households moving from one place to another. It plays a significant role in shaping demographic and cultural values in global society (Zhao et al. 2022).

2.3.1 Climate change and migration

Climate change has profoundly reshaped global migration dynamics, as highlighted by recent international agreements such as the Agenda for Humanity and the Global Compacts on Migration and Refugees and the 2030 SDGs (Nielsen et al., 2008; Kaczan et al., 2020). These frameworks emphasise the critical link between climate action (SDG 13) and the promotion of orderly and safe migration. There has been a notable increase in awareness and understanding of the complex challenges posed by climate-induced migration, as evidenced by international agreements and policy initiatives.

However, despite this increased awareness, accurately measuring the scale of climate-induced migration remains an ongoing challenge. Studies suggest significant numbers, ranging from hundreds to tens of millions annually, underscoring the issue's urgency (Debnath & Kumar Nayak, 2022; Epstein et al., 2022). Nevertheless, understanding the nuanced dynamics of migration requires more sophisticated analytical approaches.

While earlier literature often tended towards environmental determinism, more recent research offers profound insights into the multifaceted nature of climate-induced migration (Debnath & Kumar Nayak, 2022; Epstein et al., 2022; Muller et al., 2014); Mahmood et al., 2019). Over the past decade, empirical studies have shed light on the factors beyond climate - such as socio-economic conditions, cultural norms, conflict, and topographical structures - that significantly shape migration decisions (Muller et al., 2014; Kim et al., 2019; Mahmood et al., 2019; Debnath & Kumar Nayak, 2022; Epstein et al., 2022).

2.3.2 Climate change and migration in Nepal

Migration due to climate change is considered a subset of environmental migrants. Climate change migrants refer to "*persons or groups of persons who for compelling reasons of sudden or progressive changes in the environment as a result of climate changes that adversely affect their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either permanently or temporarily, and move either abroad or within their home country*" (Duda et al., 2018; Ocello et al., 2015). Climate change pushes smallholder farmers in many developing countries to resort to migration as an adaptation strategy (Duda et al., 2018; Ocello et al., 2015). Prolonged drought and land degradation drive seasonal and permanent migration in Africa (Debnath & Kumar Nayak, 2022; Epstein et al., 2022; Hermans & Garbe, 2019). In Pakistan by (Muller et al., 2014); Mahmood et al., 2019) and in

Nepal by (Kim et al., 2019) revealed that climate shocks notably influence long-term rural out-migration, particularly among male household members. Analysing the situation in India, a study by Roy et al. (2016) identified three main drivers of migration: environmental, economic, and social factors. Of these, environmental factors emerged as the most influential, with 86.67% of households reporting migration as a direct or indirect result of climate change. Various manifestations of climate change, including increased temperatures, rising sea levels, unpredictable rainfall, and premature snowmelt, contribute to droughts and the degradation of agricultural land. Similarly, floods destroy land, infrastructure, and human territories, ultimately resulting in migration (Das et al., 2020; Zhao & Jiang, 2022).

2.4 Framework for understanding climate change, food security and migration

Climate change, food security and migration are interlinked challenges, highlighting the complex relationship between livelihoods and environmental sustainability. The impact of climate change on agriculture threatens food security, especially for vulnerable smallholder farmers (Debnath & Kumar Nayak, 2022; Kaczan & Orgill-Meyer, 2020). Adaptation to climate change may reduce vulnerability and increase food security and livelihoods of rural smallholder farmers (Das et al., 2020; Zhao & Jiang, 2022). However, vulnerable smallholder farmers are disadvantaged because they lack robust adaptability (Sadiddin et al., 2019). An integrated perspective is needed to fully understand and develop effective, sustainable development solutions. A prerequisite is a framework to address the interaction between climate change, food security and migration to provide a holistic perspective on these interrelated concepts. This approach identifies the complex relationships between these concepts and highlights the importance of a comprehensive strategy to tackle these challenges effectively. Below in Figure 2 is an illustration of the integrated approach needed to understand and develop effective, sustainable solutions to the interlinked challenges of climate change, food security and migration.

In Figure 2 below, climate change indicators such as rising temperatures and erratic rainfall have increased the frequency of extreme events such as GLOFs, droughts, landslides, and floods. Extreme climate events affect the productivity of crops, reducing food availability and access. In addition, due to extreme events, disruptions in markets, infrastructure, production, and trade, coupled with potential price increases, lead to reduced food access and stability. Moreover, due to extreme events, the presence of mycotoxins in food reduces overall food utilization. Therefore, climate change directly impacts all four pillars of food security and smallholder farmers' overall food security status. Smallholder farmers use different adaptation strategies to cope with climate change and food insecurity. The adaptive capacity of smallholder farmers influences their adaptation strategies. The adaptive capacity of smallholder farmers depends on various factors such as socio-demographic, farm, financial, institutional and farmers awareness.

On the other hand, extreme events impact land degradation and destruction of farmland, infrastructure, and housing, directly influencing smallholder farmers. Those smallholder farmers with limited adaptive capacity often move for off-farm activities or migrate to diversify their livelihoods. Migration appears to be an emerging coping strategy for climate change and a means to enhance livelihood diversification, with significant implications for food security. Due to limited access to land, credit and information, vulnerable smallholder farmers opt for migration, which includes short-term, seasonal, long-term, and permanent migration. In the context of Nepal, short-term and seasonal migration seems particularly compelling (Kim et al., 2019). Through migration, households ultimately achieve food security and improve their livelihoods (Sadiddin et al., 2019). This framework clarifies the complex links between climate change, food security and migration, demonstrating their interdependence and highlighting their intricate relationships.

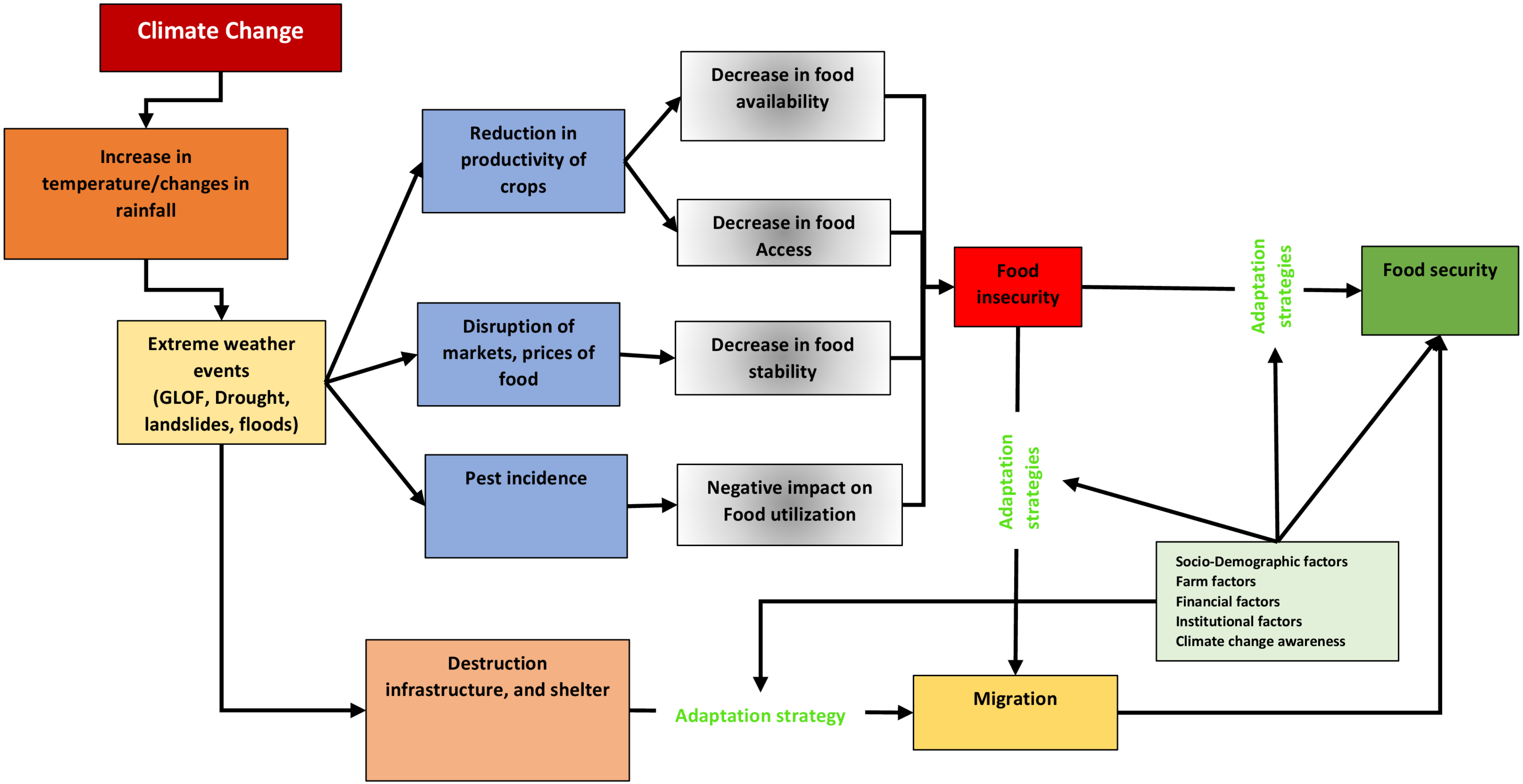

Figure 2 conceptual framework of climate change, food security and migration

Source: Author owns construction

3 Aim of the thesis

3.1 Objectives of the study

As the introduction and literature review emphasises, this dissertation adds significant depth to the existing knowledge on climate change adaptation strategies, food security and migration. The primary objective of this study is to analyse the complex relationships between these factors, shedding light on how climate change affects food security and migration dynamics. At the same time, it aims to explore the interrelationship by examining how food insecurity drives migration and, conversely, how migration affects the food security status of rural smallholder farmers. The links between climate change, food security and migration have been completely overlooked in the existing literature. The significance of closing this gap is particularly evident in developing countries like Nepal, where the challenges of climate change, food security and migration are pressing. Moreover, the growing importance of migration as a long-term issue underscores the importance of addressing these interlinked challenges. Hence, this research contributes to the broader discourse on sustainable development and resilience strategies for vulnerable communities facing these interlinked challenges. The specific objectives guiding this study are as follows:

1. Factors influencing climate change adaptation strategies:

    1.1. To examine the impact of agro-ecological zones on adopting CCA strategies.

    1.2. To examine the impact of social groups in adopting CCA strategies.

2. Factors influencing food security:
    2.1. To assess the impact of climate-related extremes, particularly drought, on food security.
    2.2. To determine the impact of smallholder adoption of climate change adaptation strategies on food security.
3. Factors influencing migration:
    3.1. To assess the role of climate change in driving migration.
    3.2. To determine migration's impact on rural households' food security.

These three overarching objectives are closely linked to their respective sub-chapters within the empirical analysis chapter. Sub-chapters 1, 2 and 3 deal with the first, second and third overarching objectives, respectively. Each sub-chapter draws on empirical evidence from Nepal and deeply explores specific aspects within the overarching goals. This approach enhances the depth of understanding of the dynamics in the Nepalese context and lays the groundwork for sophisticated research with cross-national applicability and global contribution.

The findings of sub-chapter 1 are relevant to sub-chapter 2, particularly concerning the influence of climate change adaptation strategies and farmers' adaptive capacity on the food security status of smallholder farmers. Similarly, the findings of sub-chapters 1 and 2 are relevant to sub-chapter 3. In this context, farmers experiencing food insecurity tend to migrate abroad or to urban areas in search of better employment opportunities. Correspondingly, the findings of sub-chapter 3 have implications for sub-chapters 1 and 2, highlighting migration as a strategy adopted in response to climate change and food insecurity. Nevertheless, the collective findings of all three sub-chapters point to a persistent challenge of long-term issues such as land abandonment and reduced agricultural productivity due to a shortage of productive labour in the agricultural sector.

3.2 Abstract of the sub-chapters

Table 2 below provides a basic classification of the three sub-chapters from the empirical analysis chapter, highlighting their specific objectives, keywords, and survey methods employed.

Table 2 Basic classification of the three chapters

Chapters	**Objectives**	**Keywords**	**Methods**
Building resilience to climate change: Examining the impact of agro-ecological zones and social groups on sustainable development	1. To identify agro-ecological zones' impact in adopting CCA strategies among smallholder farmers in Nepal. 2. To identify the impact of the social groups in adopting CCA strategies among smallholder farmers in Nepal.	Agro-ecological zones, climate change, multivariate probit model, social groups, sustainable development	**Instrument**: Quantitative Survey **Sampling**: Multistage, purposive sampling to select 3 districts and snowball sampling **Analysis**: Multivariate Probit Model (MVP)

Food Security and Sustainability through Adaptation to Climate Change: Lessons Learned from Nepal	1. To assess the impact of climate-related extremes (drought) on food security. 2. To determine how adopting CCA strategies by smallholders affects food insecurity.	Climate change adaptation, drought, food security, socio-economic and institutional factors, sustainable development, vulnerability, Nepal	**Instrument**: Quantitative Survey **Sampling**: Multistage, purposive sampling to select 3 districts and snowball sampling **Analysis**: Ordered Logit Model
From Fields to New Horizons: Smallholder Farmers' Rural-Out Migration and Its Impact on Food Security	1. To investigate the factors affecting migration of rural smallholder farmers in Nepal. 2. To assess the impact of migration on the food security status of rural households in Nepal.	Climate change, food security, migration, sustainable development goals, remittances, agro-ecological zones	**Instrument**: Quantitative Survey **Sampling**: Multistage, purposive sampling to select 3 districts and snowball sampling **Analysis**: Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR) models

The first sub-chapter within the empirical analysis chapter focuses on climate change and its drivers for adaptation strategies, particularly building resilience. It examines the impact of agro-ecological zones and social groups on sustainable development in the context of climate change. Moreover, the analysis extends to other socio-economic factors to capture their combined influence on adopting climate change adaptation strategies. It integrates two theories, namely "An action theory of adaptation" and the "Intersectionality framework", to enhance this sub-chapter and support identifying vulnerable households and their difficulties in adopting CCA strategies. An action theory of adaptation proposes a way of thinking about adaptation that emphasises the interconnectedness of complex activities that address the social consequences of climate change and considers multiple actors in different roles. At the same time, the intersectionality framework examines different forms of inequality within society, providing insight into the complex combination of inequalities that need to be addressed. This theory suggests that different forms of inequality can disadvantage individuals and households. In this study, an intersectionality framework seeks to raise awareness of social inequalities concerning adaptive capacity to climate change and to strengthen the resilience of Mountain and Sudra farmers. An intersectional lens helps address the vulnerability of these disadvantaged (Mountain farmers) and discriminated (Sudra farmers) households. The use of sophisticated analytical models, such as a multivariate probit model (MVP), further enhances the value of this study.

Simultaneously, the second sub-chapter within the empirical analysis chapter assesses smallholder farmers' food security status. It examines how climate change adaptation strategies affect smallholder farmers' food security and sustainability, particularly in climate change extremes. This sub-chapter meticulously investigates farmers' choices regarding their climate change adaptation strategies. These choices revolve around whether to stay in agriculture or move away to improve their food security and livelihoods. This sub-chapter also integrates two theoretical frameworks to provide in-depth insights into the complex dynamics of climate change and food security. This comprehensive approach incorporates FAO food security indicators, such as the food consumption score (FCS) and the reduced coping strategies index (RCSI). In addition, the study considers the IPCC dimensions of vulnerability to climate change, which include exposure, adaptive capacity, and sensitivity. This combination of theoretical frameworks provides a holistic understanding of climate change and food security. We employed an ordered logit model to analyse data for its capacity to break down food security indicators into more detailed perspectives. This analytical approach enabled us to capture a comprehensive variation within the food security status of smallholder farmers.

Finally, the third sub-chapter within the empirical analysis chapter examines rural out-migration issues in the context of climate change and food security. In this sub-chapter, rural out-migration refers to the involvement of at least one family member, internal or external, in the last ten years or more. This sub-chapter aims to go deeper and identify two critical aspects: the factors influencing rural out-migration, and its impact on household food security. It also integrates two theories: the push-pull theory and the neo-economics of labour migration (NELM). In the context of rural out-migration in Nepal, push factors include environmental degradation, climate-related challenges, or limited economic opportunities in the current location. In contrast, pull factors include improved economic opportunities, favorable climatic conditions for agricultural production and better living standards in the new destination. On the other hand, the NELM focuses on the economic aspects of migration, emphasising the role of income differentials and labour market conditions in shaping migration patterns. In the context of this study, NELM provides insights into the impact of migration on household food security. It examines how remittances and changes in employment status affect households' ability to access and maintain adequate food resources. By integrating these two theories, this sub-chapter provides comprehensive information on the complex dynamics of rural migration in Nepal. In addition, econometric methods such as binary probit, propensity score matching, and endogenous switching regression enrich the study's understanding of migration dynamics.

4 Methodology

Many scientific papers from databases such as Web of Science and Science Direct were examined to ensure a broad scope of climate change, food security and migration. In addition, reports from international organizations such as FAO, IPCC, WFP, IOM, FANTA, and USAID were reviewed. Articles published by the Government of Nepal and other governmental organizations were reviewed for a specific understanding of the Nepalese context. Various modelling approaches were assessed to develop a clear methodology. This section provides details of the study area, sampling technique and data collection methods, all designed to meet the objectives mentioned in Subchapter 1.1 of the introduction chapter.

4.1.1 Study area

Nepal's diverse topography, complex geology and high altitude expose it to many natural hazards. With a population of about 30 million (Central Bureau of Statistics of Nepal, 2022), nearly 80% of whom depend on agriculture for their livelihoods (Y. Liu et al., 2023) . Nepal is one of the top 20 multi-hazard countries in the world (Gautam et al., 2021). The country's limited domestic economy, geographical dispersion, dispersed population, and diverse caste groups contribute to increased social vulnerability to disasters (Amadio et al., 2023). More than 80% of the population is vulnerable to various natural hazards, including droughts, floods, landslides, extreme temperatures, and glacial lake outburst floods (Government of Nepal's Disaster Risk Reduction Status Report 2019).

This study was conducted in three different agro-ecological regions of Nepal, namely the Mustang district

(Mountain region), Baglung district (Hilly region), and Chitwan district (Terai or Plain region). The selection of these agro-ecological regions (districts) was based on the topographic diversity and climate change disasters. The data were collected from 195m to 3800m above sea level. Farming in the three districts is largely small-scale predominantly inhabited by crop farmers. The Government of Nepal, (2019) and figure below (Figure 3), clearly shows through the country's district vulnerability map that the selected study areas are vulnerable to climate change extremes. The Mustang district is characterized by high altitudes, where climatic events such as GLOF and drought are common. The Baglung district, on the other hand, represents the mid-altitude region, where events such as landslides and drought are common. Finally, the Chitwan district symbolizes the lowlands, where climatic events such as floods and droughts are common (Figure 3).

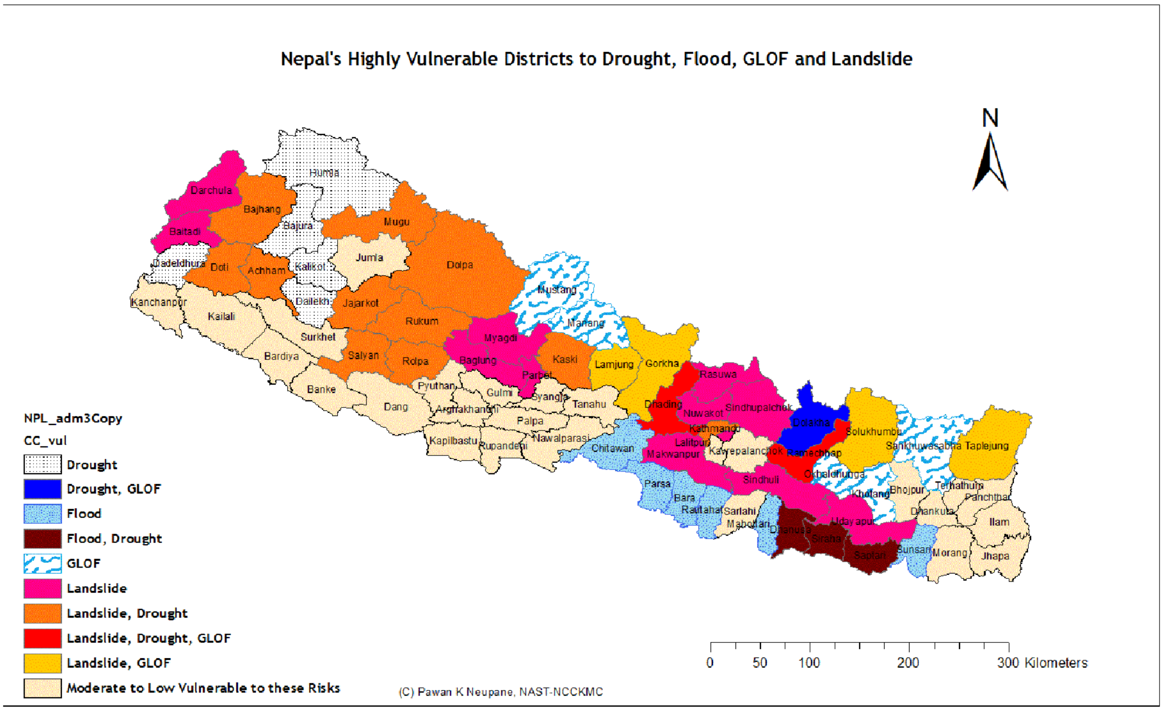

Figure 3 Map of Nepal showing vulnerable districts to climate change

Source: Nepal academy of science and technology (*http://www.ncckmcnast.org.np/publications/nepals-highly-vulnerable-districts-drought-flood-glof-and-landslide accessed on 21/03/2020*)

Figure 4 below shows the study area map. Mustang District lies at latitudes 29° N and longitudes 84° E, Baglung district lies between latitudes 28° N and longitudes 83° E and Chitwan district lies between latitudes 27° N and longitudes 84° E. Three different rural municipalities, Thasang, Gharapojung, and Baragaun Muktikshetra, were selected from the Mustang district. One rural municipality, Tarakhola from Baglung district, and Ratnanagar municipality from Chitwan district were selected. Farmers in the study area are implementing various adaptation strategies to cope with the effects of climate shocks while improving food security (Karki et al., 2020). Migration stands out as one of the prevailing strategies (Karki et al., 2020).

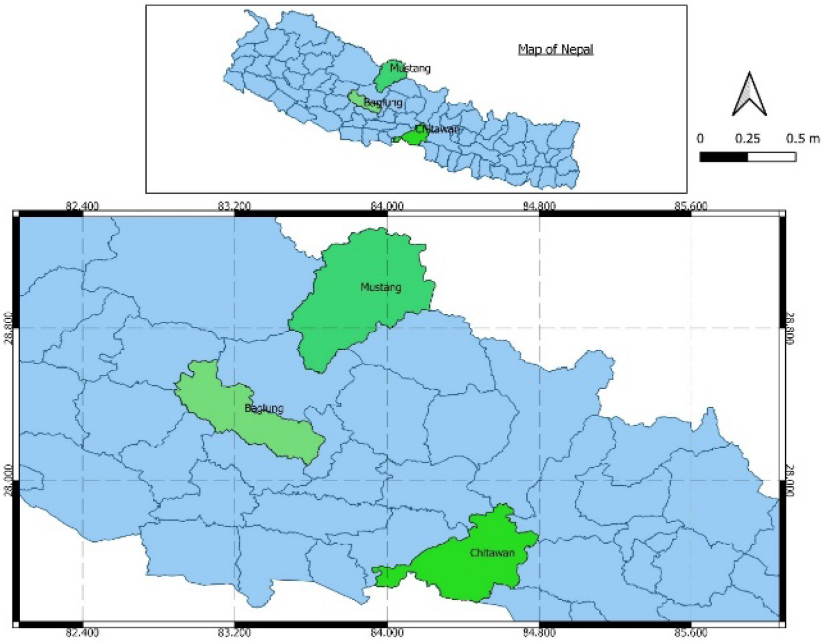

Figure 4 Map of Nepal showing the agro-ecological zone and study area

4.1.2 Sampling technique

A multistage sampling technique was applied to select the respondents. In the first stage, three districts, Mustang district from the mountainous region, Baglung district from the hilly region and Chitwan district from the Terai/plain region, were purposively selected to include respondents from all three AEZs. In the second stage, we also used a purposive sampling technique to select one rural municipality (the lowest administrative unit within the government structure in Nepal) in each district to include respondents from different altitudes. The villages of three rural municipalities, Thasang, Gharapojung and Baragaun Muktikshetra, were selected from Mustang district, and Bhuskat, Hila and Tara (Tarakhola Municipality) from Baglung district. Similarly, three villages, Lanku, Ratnanagar and Sharadpur, were selected from Chitwan district. Finally, snowball sampling was used to select 180 smallholder farmers from the Hill region, 150 from the Hill region and 70 from the Terai region (table 3). The snowball sampling technique helps to access hidden populations while being cost and time-efficient (Dudovskiy,2018). The selected sample represents approximately 7–10 percent of the total population of smallholder farmer households in each rural municipality. A total of 400 farmers were selected. Due to the low response rate and population of smallholder farmers, different respondents were interviewed in each region.

Table 3 Sampling and sampling size

Agro-ecological zone	Districts	Villages	No. of sampling households
Mountan	Mustnag	Thasang	60
		Gharapojung	60
		Baragaun	60
Hill	Baglung	Bhuskat	50
		Hila	50
		Tara	50
Terai/plain	Chitwan	Lanku	25
		Ratnanagar	20
		Sharadpur	25
Total			**400**

4.1.3 Data collection methods

Primary data were collected from households in the three agro-ecological zones using a structured questionnaire survey. A structured questionnaire was developed based on the conceptual background presented in section 3.1. Recent studies such as those by Ansah et al. (2019), Aryal et al. (2020), Karki et al. (2020), Selod & Shilpi, (20210, Shrestha & Aryal, (2011), Tesfaye & Nayak, (2022) helped to improve the questionnaires further. In addition, the survey content was adapted based on a focus group discussion with a local farmers' group. We conducted a pilot test by randomly selecting 28 respondents (12 from the mountain region, 10 from the hill region and 6 from the terai/plain region) from the study region to check the clarity of the questionnaire.

The comprehensive questionnaire covers a range of information, including farmers' socio-demographic details, farm characteristics, access to credit and markets, and institutional factors. It also covers aspects related to climate change, including awareness, information sources, perceptions, and experiences over the past decade. The questionnaire explores climate adaptation strategies, such as adjusting planting dates and crop rotation, using drought-resistant and early maturing varieties, agroforestry, off-farm activities, and temporary migration. A special section of the questionnaire focuses on food security, using indicators such as the food consumption score and the index of reduced cropping strategies. The questionnaire also includes questions on migration and concludes with questions on the impact of COVID-19 on food security.

Data were collected from March 2021 to July 2021 using a multistage sampling. First, the mayor and secretary of the village in each study area were contacted to obtain permission to collect data. Village staff made the initial contact with smallholder households and, in some cases, the secretary and mayor. In addition to the lead author, 15 (5 in the mountain region, 5 in the hill region and 5 in the terai/plain region) well-trained enumerators were employed to assist in conducting the interviews with the smallholders. All questionnaires were administered on paper and were based solely on face-to-face interviews with farmers. The questionnaire was developed in English and translated into Nepali prior to fieldwork.

5 Empirical analysis and results

Within this thesis's empirical analysis, results, and discussion chapter, three distinct sub-chapters address critical aspects of the complex relationship between climate change, adaptation strategies, food security and migration among rural smallholders. The first sub-chapter comprehensively examines the factors influencing adaptation strategies to climate change. This includes a detailed examination of the social, economic, and geographical barriers that affect adopting these strategies. It also sheds light on the preferences of the most vulnerable farmers, who show a tendency towards strategies that take them away from farming. These include participation in off-farm activities and temporary migration, providing a unique perspective on the dynamics of adaptation. The second section examines the impact of extreme climate events on the food security status of rural smallholder farmers. In particular, it assesses the effectiveness of climate change adaptation strategies in improving food security. A key finding is that adopting CCA strategies has significantly improved the food security status of these farmers. The third subsection shifts the focus to an in-depth examination of the drivers of migration and their subsequent impact on farmers' food security. It identifies the direct influence of perceptions of climate change on smallholder farmers' migration decisions. It also highlights the critical role that the migration of one household member plays in improving the overall food security status of such households. These three sub-chapters provide a nuanced understanding of the vulnerabilities faced by smallholder households that migrate away from agriculture while implementing CCA strategies to improve short-term food security and livelihoods. However, a critical observation emerges, highlighting that the long-term consequences of agricultural migration exacerbate the problem of land abandonment, with direct implications for agricultural productivity.

5.1 Building resilience to climate change: examining the impact of agro-ecological zones and social groups on sustainable development

5.1.1 Introduction

Nepal is one of the countries highly exposed to climate-related hazards due to its fragile topography, climate-sensitive subsistence livelihoods and low adaptive capacity of farmers (Shrestha & Aryal, 2011; Piya et al., 2013; Government of Nepal, 2021). It was also ranked as the fourth most climate-vulnerable country in the world by Maplecroft's Climate Change Vulnerability Index in 2011 (Eckstein et al., 2019). Continued temperature rise, rainfall variability and extreme events such as droughts and floods are increasing at a higher rate in Nepal than in other countries (Jørgen E.Olesen, 2002; Paudel et al., 2020; World Bank, 2021). A report by the Asian Development Bank estimates that climate change will reduce Nepal's GDP by 2.2 per cent annually by 2050 (ADB, 2021). Nepal's GDP predominantly depends on agriculture, contributing 25.8% to the national economy (Government of Nepal, 2021). Climate-related shocks have severely affected the agricultural sector's productivity and smallholder farmers' livelihoods (Ryghaug, 2011; Ahmed et al., 2014; Aryal et al., 2020). Various adaptation strategies, such as crop diversification, new crop varieties, agroforestry and off-farm activities, help reduce vulnerability to climate shocks (IPCC, 2012; Beltrán-Tolosa et al., 2020; Mahmood et al., 2020). Climate change adaptation strategies are effective when site- and context-specific (Makate et al., 2019; Mogomotsi et al., 2020; Diwakar & Lacroix, 2021; Tenali & McManus, 2022).

Agricultural systems in Nepal vary according to agro-ecological zones (AEZs) (Liliane & Charles, 2020). The country has three representative agro-ecological zones, namely Mountain, Hill and Terai/Plain, which are characterised by different altitudes, climate, and agricultural production systems (World Bank, 2017). The consequences of climate change, such as reduced yields, are a more pressing issue in the Mountain region than in the Hill and Terai/Plain regions (FAO, 2015; Nepal Academy of Science and Technology, 2018; World Bank, 2021; Ginbo, 2022). Mountainous farmers are biophysically limited to a maximum of two cropping seasons per year, while Terai/Plain farmers have three (Poudyal et al., 2021). Farming systems in the mountains of Nepal are more based on cattle and yak (livestock) production, and farmers there have less diversified sources of income than those in the plains. Mountain farmers also need more access to human, financial and physical capital (Choden et al., 2020; Poudyal et al., 2021). Smallholder farmers in the mountain region have fewer options for CCA strategies than their counterparts in the hill and terai/plain regions due to lower adaptive capacity (Gupta et al., 2020; Choden et al., 2020; Poudyal et al., 2021).

Adaptive capacity also differs among social groups (Adger et al., 2003; Smit & Wandel, 2006; IPCC, 2012; Asante et al., 2021; Aslany & Brincat, 2021). In Nepal, there are four social groups: Brahmin, Kshatriya, Vaishya, and Sudra. The allocation of farm work and land resources in the communities of Nepal is based on these social groups. The contribution of Brahmins in designing strategies to reduce the impact of climate shocks is comparatively higher than the other groups (Nagoda & Nightingalea, 2017). Similarly, a few Sudra farmers could also have higher levels of adaptability. However, the Sudra households usually cultivate land owned by the Brahmins and receive a negotiated share of the harvested crops. Although most Sudra farmers are disadvantaged, some Brahmin farmers may face challenges due to their lower economic status. Sudra farmers are usually tenant farmers and depend on daily labour for their livelihoods. These sources of income are highly volatile in the face of climate change and increasing disasters.

In some cases, Sudra farmers are marginalised from decision-making on agricultural production, including adopting new technologies such as purchasing machinery for sharing within the community (Ravera et al., 2016; Poudel et al., 2021). The government provides farming equipment, improved seed varieties and other benefits to the farming groups in the local communities, which should be distributed equally. However, the Sudra groups have less control over them or are given the last chance to use them (Bapuji & Chrispal, 2020). Because of this inequality, unequal distribution of resources and access to information and institutions, Sudra farmers have less adaptive capacity. They are more vulnerable to climate change (Nagoda & Nightingalea, 2017).

Previous studies have suggested CCA strategies and factors influencing their adoption in different countries such as in Nepal by Tiwari et al. (2014), Bhatta & Aggarwal, (2016); Uprety et al. (2017), in Pakistan by (Mahmood et al. (2020), in

Ghana by (Antwi-Agyei et al. (2021), in Bangladesh by Alauddin & Sarker, (2014), and in India by Jha & Gupta, (2021). However, to our knowledge, research has yet to be conducted to assess the impact of agro-ecological zones and social groups on farmers' CCA strategies. To fill this gap, this study examines the impact of agro-ecological zones and social groups on smallholder farmers' CCA strategies in Nepal. The study identifies location- and social group-based CCA strategies at the household level in Nepal and suggests comparable solutions for other countries with similar characteristics. It will also promote the adoption of CCA, leading to improved rural livelihoods, increased crop productivity and a systematic shift towards sustainable development. The study aims to accomplish the following objectives:

1. To identify the impact of agro-ecological zones on adopting CCA strategies among smallholder farmers in Nepal.
2. To identify the impact of the social groups in adopting CCA strategies among smallholder farmers in Nepal.

To date, the action theory of adaptation and the framework of intersectionality have been used separately. This study contributes to theory building by combining the action theory of adaptation and the framework of intersectionality. Understanding how AEZs and social groups influence the adoption of CCA strategies will help policymakers, donors, and extension agents prioritise the most vulnerable household farmers and increase their capacity to adapt to climate change.

5.1.2 Conceptual framework

An Action theory of adaptation and framework of intersectionality:

As a theoretical background for this study, we integrated an action theory of adaptation by Eisenack & Stecker (2011) with the concept of intersectionality. An action theory of adaptation proposes a way of thinking about adaptation that emphasises the interconnectedness of complex activities that address the social consequences of climate change and considers multiple actors in different roles (Eisenack & Stecker, 2011). Exposure units are climate shocks from temperature and precipitation variability (Figure 5). It negatively affects agricultural production and the livelihoods of farm households. In our context, smallholder farmers (operators) are exposed to and respond to climate shocks. As smallholders experience the benefits of adaptation, such as improved food security and livelihoods, they are the receptors. The actor needs resources, knowledge, and power to implement the adaptation strategies. Resources, knowledge, and power depend on the characteristics of individuals and households (Eisenack et al., 2011). The characteristics of individuals and households are examined through the lens of intersectionality.

Crenshaw's (1991) framework of intersectionality looks at different forms of inequality in society. It also helps to understand the combination of complex forms of inequality to address. Intersectional theory argues that different forms of inequality can disadvantage individuals and households. In our context, the concept of intersectionality aims to raise awareness of social inequalities in terms of adaptive capacity to climate change and to strengthen the capacity of mountain and Sudra farmers. An intersectional lens supports addressing the vulnerability of these disadvantaged (mountain farmers) and discriminated (Sudra farmers) households.

Previous literature by Onta & Resurreccion, (2011), Amran et al. (2011), Ravera et al. (2016), Lawson et al. (2020), Azong & Kelso (2021) and IPCC (2022) reported that smallholder farmers' adaptation capacity relies on geographical and social characteristics. Crenshaw's (1991) intersectionality approach addresses the interconnectedness of CCA strategies with geographical and social conditions (Collins & Bilge, 2020). Inequalities based on agro-ecological zones are geographically embedded. In contrast, social groups in Nepal's agriculture-dependent communities are socio-economically embedded.

Along with agro-ecological zones and social groups, various other intersecting factors such as age, education, off-farm occupation, income, landholding, land size, access to market, access to irrigation, access to credit, and access to information also influence farmers' ability to adopt CCA strategies (Onta & Resurreccion, 2011; Kaijser & Kronsell, 2014; Ravera et al., 2016; Lawson et al., 2020; Azong & Kelso, 2021).

Previous studies have used the action theory of adaptation and the theory of intersectionality separately (Eisenack et al., 2011; Jordanoska, 2018; Griese et al., 2021; McArdle, 2021; Maia et al., 2022; Sharma et al., 2022). In this study, we combine these theories to understand the complexity of CCA drivers better.

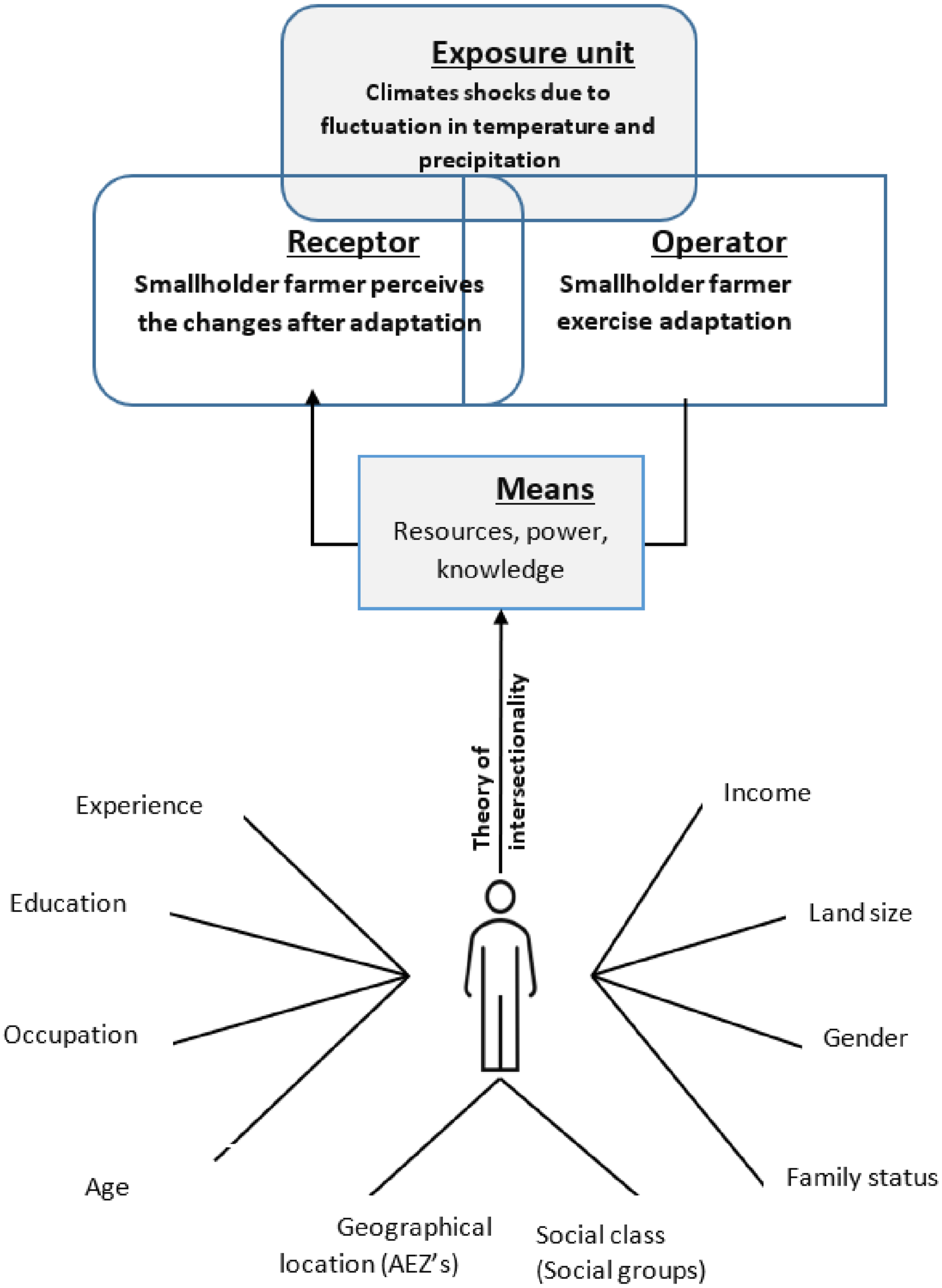

Figure 5 Concepts of an action theory of adaptation and framework of intersectionality

Source: Author formulation based on (Eisenack & Stecker, 2011; Crenshaw, 1991)

5.1.3 Analytical tools

5.1.3.1 Multivariate probit model

A multivariate probit (MVP) model was used to capture smallholder farmers' decision to adopt multiple CCA strategies. The MVP model was used because farmers rely on adopting multiple CCA strategies rather than relying on one option to reduce the impacts of climate change. Previous literature suggests that the MVP model is the most appropriate option when the responses of the dependent variables are interdependent and correlated (Trinh et al., 2018; Abid et al., 2019; Aryal et al., 2020). The correlation between the different multiple adaptation options is the main source of the correlation between the error terms (Trinh et al., 2018; Aryal et al., 2020). However, the multivariate probit model eliminates these correlations (Gebregziabher et al., 2016; Trinh et al., 2018). In addition, the MVP model allows a flexible correlation structure for the unobservable variables (Trinh et al., 2018; Aryal et al., 2020).

The formula of the multivariate probit model for observation i and equation m is as follows (Cappellari & Jenkins, 2003; Trinh et al., 2018; Tesfaye & Nayak, 2022):

$Y_{im} = 1$ if $Y_{im}^* > 0$ and 0 otherwise ($i = 1, 2, \ldots, N$; $m = 1, 2, \ldots, M$)

$Y_{im}^* = X_{im}^*\beta_m + \varepsilon_{im}$

Where: N is number of observations, M is number of options, X_{im} is matrix of explanatory variable, β_m is matrix of parameters, and ε_{im} is matrix of error terms.

Simulated Maximum Likelihood (SML) using the Geweke-Hajivassiliou-Keane (GHK) simulator developed by Cappellari & Jenkins, (2003) was used to estimate the MVP model. The SML estimator is consistent as the number of observations and draws tends to infinity. STATA 14.2 software is used to analyse the data, which is appropriate for this dataset. A correlation test is performed to avoid multicollinearity between different explanatory variables. However, certain variables were initially measured in the category and transformed into a dummy. Because the variable type is initially category, the following variables were omitted from the model and used as a reference group. These are non-formal education as part of education, earning less than 150,000 Nepalese rupees as part of income, Terai region from agro-ecological region and Sudra from social groups.

5.1.3.2 Selection of variables

5.1.3.2.1 **Dependent variables**

The CCA strategies were initially identified based on the basis of previous literature. The pilot test in each study area further clarified the appropriateness of the CCA strategies. Initially, farmers were offered a choice of 14 main adaptation strategies from which they were instructed to select their main strategy. Of the 14 adaptation strategies, six were significant. These were off-farm activities, new crop varieties, early-matured varieties, small-scale irrigation systems, agroforestry, and temporary migration, which were used as dependent variables (Table 4).

5.1.3.2.2 **Explanatory variables**

The selection of explanatory variables included in this study is based on the theoretical framework and a review of existing literature. Previous literature suggests that socio-demographic characteristics such as gender, age, education, social class, ethnic group, household size and farm experience positively affect farmers' adaptation choices (Trinh et al., 2018; Aryal et al., 2020; Tesfaye & Nayak, 2022). Furthermore, the literature suggests that farm characteristics such as land size and institutional factors such as access to farmer groups significantly affect farmers' adaptive capacity and adaptation choices (Piya et al., 2013; Abid et al., 2019). Access to information through the internet and farmer groups are other important factors reported by previous researchers (Vaughan et al., 2019; Ullah et al., 2022b). Several researchers have noted that experiences of climate change, such as temperature increases and erratic rainfall, also significantly influence farmers' adaptation choices (Trinh et al., 2018; Tesfaye & Nayak, 2022). Previous research has also shown that agro-ecological zones significantly influence the choice of CCA strategies (Aniah et al., 2019; Karki et al., 2020). Therefore, we include these climate change experience variables in our model.

5.1.3.2.3 **Variables of Interest**

There is a lack of knowledge about how different agro-ecological zones and social groups influence the adoption of adaptation strategies. Nepal provides a perfect opportunity to study this, as it is located at different altitudes, resulting in different farming systems, and the society is divided into social groups. Mustang district represents mountainous regions, Baglung district represents hilly and mid-altitude regions, and Chitwan represents terai/plain and low altitude regions. Similarly, the social groups included in this research have a hierarchy of Brahmin, followed by Kshatriya, Vaisya, and Sudra.

5.1.4 Results

5.1.4.1 Sample description

The results of our descriptive statistics are presented in Table 4. Approximately 72 percent of households were male headed. The average age of the household head was 50.31 years. In terms of education, 36 percent of the farmers had primary education, 27 percent had secondary education and 3 percent had postgraduate education. The average farming experience of the respondents was 23.8 years. The average household size was 5.80 members, while the average size of land owned by smallholder farmers was 13.16 ropani (1 ropani=0.051 ha). About 12 percent of the farming households had access to informal credit for agriculture. About 7 percent of the households earn more than 150,000 Nepalese Rupees (Rs), equivalent to $1250 ($1 = Rs.120 as of May 2021) per year from their farm. Most farmers were aware of climate change (i.e. 92 percent), while 84 percent and 58 percent perceived an increase in temperature and erratic rainfall, respectively, in the last 10-15 years. About 62.0 percent and 42 percent of smallholder farmers reported having access to weather information through the Internet and farmers' groups, respectively.

Table 4 Descriptive statistics of variables used in regression

Variables	Description	Mean	Std Dev
Dependent variables			
Off-farm activities	Dummy=1 if household implemented off-farm activities as an adaptation measure, 0 otherwise	0.53	0.50
New crop varieties	Dummy=1 if household implemented new crop varieties as an adaptation measure, 0 otherwise	0.41	0.49
Early-matured varieties	Dummy=1 if household implemented early-matured varieties as an adaptation measure, 0 otherwise	0.43	0.50
Small-scale irrigation system	Dummy=1 if household implemented small scale irrigation system as an adaptation measure, 0 otherwise	0.46	0.50
Agroforestry	Dummy=1 if household implemented agroforestry as an adaptation measure, 0 otherwise	0.31	0.46
Temporary migration	Dummy=1 if household implemented temporary migration as an adaptation measure, 0 otherwise	0.62	0.49
Independent variables			
Gender	Dummy= 1 if the household head is male, 0 otherwise	0.72	0.45
Age	Continuous, household age in years	50.32	13.99
Education	Dummy=1 if education level is "primary" 0 otherwise	0.36	0.48
	Dummy=1 if education level is "higher secondary" 0 otherwise	0.27	0.44
	Dummy=1 if education level is "graduate" 0 otherwise	0.03	0.16
Household size	Continuous, number of the family members in the household	5.80	2.88
Farm experience	Continuous, farming experience of HH in years	23.78	14.29
Land size	Continuous, total land owned by the household	13.16	17.86
Access to informal credit	Dummy=1 if the household accessed informal credit, 0 otherwise	0.12	0.32

Table 4 Descriptive statistics of variables used in regression

Variables	Description	Mean	Std Dev
Independent variables			
Farm income	Dummy =1 if household earns more than 150,000 Rs from the farm, 0 otherwise	0.07	0.26
Awareness of CC	Dummy= 1 if HH is aware of climate change, 0 otherwise	0.92	0.27
Temperature rise	Dummy =1 if farmers perceived temperature rise, 0 otherwise	0.84	0.36
Erratic rainfall	Dummy =1 if farmers perceived an increase in erratic rainfall, 0 otherwise	0.58	0.49
Access to information via internet	Dummy =1 if farmers have access to climate change information via. the internet, 0 otherwise	0.62	0.49
Access to information via farmers' group	Dummy =1 if farmers have access to climate change information via farmer's group, 0 otherwise	0.42	0.49
Variable of Interest			
Agroecological zone (Altitude)	Dummy=1 if agroecology zone is Mountain "highland", 0 otherwise	0.46	0.50
	Dummy=1 if agroecology zone is Hill "midland",0 otherwise	0.38	0.48
Social groups	Dummy=1 if social group is "Brahmin" 0 otherwise	0.24	0.43
	Dummy=1 if social group is "Kshatriya" 0 otherwise	0.01	0.11
	Dummy=1 if social group is "Vaisya" 0 otherwise	0.61	0.49

Ropani= A unit of the area measured in Nepal, 1 Ropani=0.051 hectare
NPR= Nepalese Rupee (Currency of Nepal), 1$=120NPR as of May 2021

About 46 percent of the farming households belong to the Mountain AEZs and 38 percent to the Hill AEZs. In the study area, 24 percent of the farmers are Brahmins, while 1.25 percent and 60.5 percent are Kshatriyas and Vaisyas, respectively.

5.1.4.2 Adaptation strategies

In Table 5, adaptation strategies are presented based on the agro-ecological zones of Nepal. The majority of farmers in the Mountain region use agroforestry (76.23 percent), followed by small-scale irrigation (53.01 percent) and temporary migration (48.39 percent). Farmers in the Hilly region prefer adopting early-matured varieties (59.06 percent), followed by temporary migration (37.9 percent) and off-farm activities (37.14 percent). Correspondingly, 64.2 percent of farmers in the Terai region adopted new crop varieties, followed by small-scale irrigation (14.8 percent) and temporary migration (13.7 percent).

Table 5 Farmers' adaptation strategies based on the agro-ecological zone (N=400)

Variables		**Adopters (in percentage)**		
		Mountain Region	**Hilly Region**	**Terai Region**
Adaptation strategies	Off-farm activities	51.43	37.14	11.4
	New crop varieties	8.64	27.16	64.2
	Early-matured varieties	30.99	59.06	9.94
	Small-scale irrigation system	53.01	32.24	14.8
	Agroforestry	76.23	10.66	13.1
	Temporary migration	48.39	37.9	13.7

Table 6 below presents adaptation strategies based on the social groups. Among the six adaptation strategies, the Brahmin farmers, were highly adopting early-matured varieties and temporary migration by 57.29 percent each, followed by new crop varieties (56.25 percent) and off-farm activities (48.96 percent). Among the Kshatriya farmers, temporary migration (60 percent) was highly adopted and followed by new crop varieties (40 percent) and early-matured varieties (20 percent). The majority of farmers in the Vaisya group also used temporary migration (61.57 percent) and followed by small-scale irrigation (52.48 percent) and off-farm activities (51.65 percent). The Sudra farmers adopted highly temporary migration (71.93 percent) and followed by off-farm activities (66.67 percent) and early-matured varieties (33.33 percent). Table 6 Farmers' adaptation strategies based on the social groups (N=400).

Table 6 Farmers' adaptation strategies based on the social groups (N=400)

Variables		**Adopters (in percentage)**			
		Brahmin	**Kshatriya**	**Vaisya**	**Sudra**
Adaptation strategies	Off-farm activities	48.96	0.00	51.65	66.67
	New crop varieties	56.25	40.00	37.19	28.07
	Early-matured varieties	57.29	20.00	39.67	33.33
	Small-scale irrigation system	39.58	0.00	52.48	31.58
	Agroforestry	14.58	0.00	38.43	26.32
	Temporary migration	57.29	60.00	61.57	71.93

5.1.4.3 Determinants of farmers' adoption of adaptation strategies to climate change

The results of the MVP model are shown in Table 7. Our results show that the model fits the data well (Table 8). The adaptation strategies implemented are not mutually exclusive; the adoption of one CCA strategy does not mean that other strategies could not be adopted. To better understand which CCA strategies are often used in combination, we looked at the correlation matrix obtained from the MVP model (Table 8). A positive coefficient indicates complementarity between the two practices, meaning that the adoption of one practice is related to the other. A negative correlation coefficient indicates that the two practices are substitutes or compete for the same scarce resources. The chi-squared test of the model is statistically significant (Wald $\chi 2$ (126) = 390.13, p = 0000), confirming that the explanatory variables taken together are significant in explaining the variation in farmers' adoption of the six adaptation options in the study regions. The likelihood ratio test rejects the hypothesis that the adaptation options considered are independent ($Chi^2(15) = 129.758$, $p<0.000$), indicating that the multivariate regression generates more reliable information than separate univariate regressions. The results show that demographic, socio-economic, biophysical, institutional and climate change risk factors are significant determinants of CCA measures.

Table 7 Multivariate probit regression results

Variables	Off-farm activities	New crop varieties	Early-matured varieties	Small scale irrigation system	Agroforestry	Temporary migration
Gender	-0.026(0.155)	0.302(0.166)*	-0.187(0.157)	0.065(0.158)	-0.088(0.176)	0.089(0.152)
Age	-0.003(0.008)	-0.004(0.008)	0.008(0.008)	0.011(0.008)	0.002(0.008)	0.008(0.007)
Primary education	0.303(0.173)*	0.027(0.188)	0.122(0.18)	0.236(0.177)	0.051(0.202)	0.217(0.172)
Higher secondary education	0.646(0.209)***	-0.256(0.226)	-0.185(0.214)	0.068(0.21)	0.48(0.23)**	0.107(0.205)
Graduate education	0.753(0.438)*	0.243(0.484)	0.024(0.441)	-0.091(0.452)	1.164(0.502)**	0.516(0.453)
Household size	0.027(0.026)	-0.008(0.029)	-0.028(0.027)	-0.003(0.027)	0.028(0.031)	0.027(0.025)
Farm experience	0.006(0.008)	-0.008(0.008)	-0.004(0.008)	-0.004(0.008)	0(0.008)	-0.016(0.007)**
Land size	-0.005(0.004)	0.006(0.005)	0.002(0.005)	-0.014(0.005)***	-0.001(0.006)	0.001(0.005)
Access to informal credit	0.175(0.216)	0.062(0.226)	-0.438(0.233)*	-0.107(0.228)	-0.575(0.298)*	0.607(0.229)***
Farm income	-0.232(0.257)	0.147(0.276)	0.38(0.259)	0.102(0.264)	0.666(0.283)**	-0.428(0.256)*
Awareness of CC	0.669(0.276)**	0.916(0.307)***	0.359(0.266)	-0.084(0.266)	0.576(0.316)*	0.177(0.248)
Temperature rise	0.103(0.193)	-0.094(0.208)	-0.124(0.201)	-0.081(0.2)	-0.444(0.219)**	0.013(0.189)
Erratic rainfall	0.23(0.138)*	0.095(0.149)	0.333(0.141)**	-0.202(0.14)	-0.199(0.155)	-0.013(0.136)
Access to information via internet	-0.075(0.154)	-0.335(0.165)**	0.079(0.157)	0.717(0.159)***	-0.051(0.179)	0.236(0.154)
Access to information via farmers group	-0.354(0.145)**	0.31(0.154)**	0.283(0.147)*	0.351(0.146)**	0.373(0.161)**	0.012(0.144)
Variable of interest						
Agro-ecological zone "Mountain"	2.026(0.766)***	-0.008(0.814)	0.444(0.804)	-1.869(0.828)**	-1.898(0.864)**	3.172(0.796)***
Agro-ecological zone "Hilly"	1.455(0.572)**	1.107(0.606)*	1.421(0.6)**	-1.313(0.618)**	-2.503(0.662)***	2.31(0.592)***
social groups "Brahmin"	-0.257(0.276)	0.769(0.303)**	0.573(0.282)**	0.511(0.281)*	-0.136(0.33)	-0.194(0.27)
social groups "Kshatriya"	-5.211(129.017)	0.759(0.588)	-0.163(0.655)	-4.554(145.143)	-4.531(165.162)	-0.117(0.632)
social groups "Vaisya"	-0.422(0.22)*	0.248(0.231)	0.11(0.213)	0.415(0.221)*	0.221(0.231)	-0.225(0.219)

Table 8 Correlation of error terms of selected climate adaptation measures

Correlation	**Coefficient (standard Error)**	**P- value**
ρ21	0.1(0.088)	0.258
ρ31	0.092(0.085)	0.283
ρ41	0.082(0.082)	0.319
ρ51	0.164(0.091)*	0.072
ρ61	0.436(0.072)***	0.000
ρ32	0.652(0.062)***	0.000
ρ42	0.155(0.085)*	0.068
ρ52	0.105(0.096)	0.276
ρ62	0.18(0.085)**	0.035
ρ43	0.222(0.081)***	0.006
ρ53	0.205(0.088)**	0.02
ρ63	0.159(0.084)*	0.058
ρ54	0.35(0.086)***	0.000
ρ64	-0.095(0.084)	0.26
ρ65	0.143(0.089)	0.108
ρ43	0.22(0.081)***	0.006
ρ53	0.203(0.088)**	0.021
ρ63	0.158(0.084)*	0.06
ρ54	0.349(0.085)***	0.000
ρ64	-0.098(0.084)	0.245
ρ65	0.143(0.089)	0.109
Log-likelihood	-1269.0041	-
Wald chi2(126)	390.13	-
Prob > chi2	0.0000	-
Number of observations	400	-

Likelihood ratio test of H0 ρ21 = ρ31 = ρ41 = ρ51 = ρ61 = ρ32 = ρ42 = ρ52 = ρ62 = ρ43 = ρ53 = ρ63 = ρ54 = ρ64 = ρ65 = 0:
chi2(15) = 129.758 Prob > chi2 = 0.0000
Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively.
ρ1 =Off-farm activities
ρ2 = New crop varieties
ρ3 = Early-matured varieties
ρ4 = Small scale irrigation system
ρ5 = Agroforestry
ρ6 = Temporary migration

Results from the MVP model show that the gender of the household head has a significant and positive effect on the adoption of new crop varieties as an adaptation strategy. Male-headed farmers are more likely to adopt these CCA strategies than female-headed farmers. The model results showed that education is a significant factor in the adoption of CCA measures. This variable had a positive and significant impact on the use of off-farm activities and agroforestry. The decision to adopt agroforestry is significant for farmers with higher secondary and tertiary education, while the adoption of off-farm activities was significant for all farmers with education (primary, higher secondary and tertiary) (Table 7). The farming experience of the head of the household has a significant and negative effect on the likelihood of temporary migration as an adaptation measure. Land size also has a significant and negative effect on the adoption of small-scale irrigation (Table 7). Unexpectedly, access to informal credit, such as borrowing from friends and relatives, is significantly and negatively associated with the likelihood of adopting early-matured varieties, agroforestry, and temporary migration. Farm income significantly affects the adoption of agroforestry and temporary migration. Farmers earning more than 150,000 Nepalese rupees per year are more likely to adopt agroforestry and less likely to adopt temporary migration.

We found that the adoption of adaptation strategies is influenced by awareness of climate change. Farmers who are aware of climate change use off-farm activities, new crop varieties and agroforestry. Farmers' perceptions of rising temperatures and erratic rainfall also affect the adoption of adaptation strategies. The perception of rising temperatures has a significant but negative effect on the use of agroforestry. The perception of erratic rainfall has a significant and positive effect on the use of off-farm activities and early-matured varieties. Access to climate-related information significantly influences the implementation of adaptation strategies. Farmers with internet access are less likely to adopt new crop varieties and more likely to adopt small-scale irrigation. Similarly, farmers involved in local farmer groups and receiving climate change information through farmer groups significantly influence the adoption of off-farm activities, new crop varieties, early-matured varieties, small-scale irrigation, and agroforestry, but not temporary migration.

5.1.5 Discussion

5.1.5.1 CCA strategies in different agro-ecological zones

Our study revealed that (Table 5), farmers in three agro-ecological zones have adopted different adaptation strategies due to different farming systems and climatic conditions in each zone. The majority of farmers in the mountainous region have adopted agroforestry (Table 5) as a climate change adaptation strategy, which is consistent with previous studies by Ullah et al. (2022) and Ullah et al. (2023), who reported that most farmers in mountainous regions have adopted agroforestry as a CCA strategy. Agroforestry is a system that integrates crop production with trees. Adopting agroforestry reduces the risks of climate change and increases the adaptive capacity of farmers (Ullah et al., 2022). Farmers in the hilly region prefer to adopt early-matured varieties as a CCA strategy. This is also consistent with the previous studies by Manandhar et al. (2011) who reported that farmers in the hilly regions prefer adopting early-matured and less water demanding varieties as a CCA strategy. Accordingly, most of the respondents in the terai region adopted new crop varieties as a CCA strategy. Our results are in line with the previous findings of Karki et al. (2020) who found similar results from the study region as they reported that most farmers in the terai region adopted new crop varieties as a climate change adaptation strategy.

Results from our MVP model showed that different agro-ecological zones in Nepal influence farmers' adoption of different CCA strategies. A farmer in the mountain agro-ecological zone (Mustang district) is less likely to adopt small-scale irrigation and agroforestry practices than a farmer in the Terai region. The adoption of small-scale irrigation and agroforestry may be affected by the low rainfall in the study area (Khadka, 2018). The average annual rainfall in the area is around 260 mm, which is one of the lowest in the country, limiting the availability of water for irrigation (Khadka, 2018). Previous findings from Nepal have reported similar results as by Paudel et al. (2022) and Kattel & Nepal, (2022) found that a farmer in mountainous agro-ecological zone is less likely to adopt agroforestry and irrigation system. They suggested that the non-adoption of agroforestry may be due to limited knowledge about the practices and their proper implementation. Similarly, farmers from the hill agro-ecological zone are more likely to adopt off-farm activities and temporary migration than those from the terai/plain agro-ecological zone (Table 8). Compared to the terai/plain agro-ecological zone, the agricultural production in the mountainous agro-ecological zone often does not provide sufficient livelihood to the farmers (disadvantaged farmers in terms of intersectionality theory), which pushes these farmers to engage in off-farm activities and temporary migration to overcome the problems they face due to low productivity and climate change (Ullah et al., 2021). This is similar to the previous findings of Ullah et al. (2021) who reported that instead of adopting CCA practices such as agroforestry and irrigation, they migrate to other regions for off-farm activities.

Our results showed that farmers in the hilly AEZ were less likely to adopt small-scale irrigation and agroforestry practices than those in the terai AEZ. This is consistent with previous findings by Deressa et al. (2009) and Piya et al. (2013), who reported that farmers in the hilly AEZ usually did not adopt such practices or adopted them on a limited scale. Several studies in different countries, such as in Ethiopia by Tesfaye & Nayak, (2022); in Pakistan by Abid et al. (2019), in coastal Bangladesh by Aryal et al. (2020), and in Andean-Amazonian foothill households in Colombia and Peru by Beltra'n-Tolosaet et al. (2022), have reported that farmers' CCA strategies vary across agro-ecological zones.

Farmers in the mountainous and hilly regions of Nepal grow mainly traditional food crops such as millet, buckwheat, indigenous beans, barley, rice, potatoes, and vegetables. Agriculture is mainly rain-fed, with a few exceptions such as micro-irrigation systems fed by springs and snowmelt. There are now a variety of climate change impacts, including positive and negative effects on rainfall, temperature, snowfall, and snowmelt patterns. Households are adapting to the changing climate by adjusting agricultural practices, integrating livestock with agriculture, and taking up off-farm income-generating activities (Merry et al., 2018).

Our results confirm that AEZs are one of the key determinants of smallholders' choice of appropriate CCA. Therefore, policies to support the diffusion of different adaptation strategies need to be locally specific. Farmers in mountainous or hilly agro-ecological zones (AEZs) face several challenges, including adverse climatic conditions, limited opportunities for income diversification and limited access to financial resources. As a result, they face greater difficulties in adapting to climate change, as predicted, and explained by intersectionality theory. Similar studies, particularly in Nepal, such as by Poudel & Kotani, (2013), Merrey et al. (2018), Thapa & Hussain, (2021), also reported that CCA strategies in Nepalese agriculture should be tailored based on the AEZs.

5.1.5.2 CCA strategies among different social groups

Our study found (Table 7) that most farmers in the Brahmin group adopted different climate change adaptation strategies compared to the Sudra farmers. These findings are similar to other findings in the CCA literature. For example, studies by Deressa et al. (2009) and Tesfaye & Nayak, (2022) in Ethiopia, Makuvaro et al. (2018) in Zimbabwe, and Trinh et al. (2018) in Vietnam showed that social systems influence the adoption of new crop varieties, and that small-scale irrigation systems, agroforestry, and early planting and early-matured varieties are important adaptation strategies. Studies by Aryal et al. (2020) in coastal Bangladesh and Kundu & Mondal, (2022) in the Lower Gangetic Plain of India found that seeking off-farm activities and temporary migration were highly used CCA strategies among vulnerable social groups.

Our results from the MVP model also show that social groups significantly influence the adoption of different CCA strategies. Respondents from the Brahmin group are more likely to adopt new crop varieties, early-matured varieties and small-scale irrigation than farmers from the Sudra group. In addition, farmers reported that the social system in Nepal is historically linked to the governance system, in which the Brahmins have long controlled the majority of official positions of power and privilege. As the dominant privileged caste group has dominated these institutions in Nepal, policies have been created to favour the Brahmins rather than the Sudra groups. Farmers from the Kshatriya social group were unlikely to adopt any adaptation measures. This may be because they were mostly dependent on agriculture for their livelihoods. We also found a significant influence of Vaisya farmers on the adoption of different CCA strategies. Our results suggest that Vaisya farmers are less likely to adopt off-farm activities and more likely to adopt small-scale irrigation than Sudra farmers. Since Vaisya farmers were initially employed to work on farms, whether owned or rented, they may be less likely to adopt off-farm activities. This is because they have fewer opportunities to engage in non-farm activities. Households in the Vaisya group are more likely to engage in flat farming, where access to irrigation water is easier, compared to Sudra farmers, who mostly engage in terrace farming (Pariyar et al., 2018).

It was also reported by (World Bank, 2011) that the Sudra group has been marginalized and denied access to crucial governmental structures and institutions, affecting farmers' adoption of CCA strategies. Therefore, caste-based discrimination is most likely to be enforced and experienced harshly by Sudra farmers in their local community. Our findings are consistent with the intersectionality theory. That means Sudra farmers were more vulnerable to climate change because of their lower CCA capacity and the need to deal with multiple problems simultaneously. A similar study conducted by Coulier & Wilderspin, (2016) reported that ethnic minority groups and a study by Pariyar et al. (2018) reported that Sudra farmers in Nepal were highly affected by climate change and had less capacity to implement CCA measures.

5.1.5.3 Impact of other drivers on adoption of CCA strategies

Our study shows that gender is an important factor in influencing the adoption of new crop varieties. It also means that male-headed households are more likely to adopt new crop varieties as a CCA measure than female-headed households. This may be because women have limited access to information and other resources due to traditional social constraints or because they contribute more to household activities than to agricultural activities. This finding is consistent with previous studies by Deressa et al. (2009), Trinh et al. (2018), and Aryal et al. (2020), which reported that male-headed households were more likely to adopt new crop varieties as a CCA strategy.

Our study suggests that formal education has a significant and positive impact on the adoption of off-farm activities and agroforestry. This may be because the adoption of off-farm activities and agroforestry requires specific training and knowledge, which is insignificant without education. Our findings are consistent with previous studies from Ethiopia by Deressa, et al. (2009), in Bangladesh by Alam et al. (2016), Aryal et al. (2020), and in Nepal by Khanal et al. (2018). These studies reported that education plays a positive role in the adoption of off-farm activities and agroforestry.

The farming experience of household heads was another significant and negative variable influencing the adoption of temporary migration as a CCA strategy. More years of farming experience is often associated with older age. Older farmers tend not to shift their livelihoods from on-farm to off-farm activities, which has a negative impact on temporary migration (Rigg et al., 2020). For different adaptation strategies such as agroforestry, small-scale irrigation, soil and water conservation, findings by Trinh et al. (2018), Abid et al. (2019), Aryal et al. (2020) and Tesfaye & Nayak, (2022) reported that households with more years of farming experience were more likely to adopt these adaptation strategies.

Our results show that farm size has a significant negative impact on farmers' adoption of small-scale irrigation practices. This means that farmers with large landholdings are less likely to adopt small-scale irrigation. This may be because farmers from the study area are highly dependent on rain-fed agriculture and the cost of adopting an irrigation system is higher for the large land size. This finding is similar to a previous study in Nepal by Piya et al. (2013) and in Pakistan by Abid et al. (2019), who reported that adoption of small-scale irrigation is negatively affected by land size.

In our study, access to informal credit has a significant and negative impact on farmers' adoption of early-matured varieties and agroforestry as a CCA strategy. Farmers with access to informal credit are less likely to adopt early-matured varieties and agroforestry practices. This may be because farmers who borrow small amounts of money from relatives, neighbors or local moneylenders are struggling to meet their subsistence needs rather than productive agricultural investments. The poor farmers who do not adopt CCA strategies usually borrow money from informal credit sources. Moreover, our study found that access to informal credit increases the likelihood of adopting temporary migration as a CCA strategy. This statement is also supported by several studies, such as Timsina, (2015) and Bhattarai, (2020), which examined the process of borrowing money from banks in Nepal. Conceivably, this is the reason why temporary migration was positively influenced by access to informal credit. Studies such as Piya et al. (2013), Trinh et al. (2018), Aryal et al. (2020) and Tesfaye & Nayak, (2022) also reported that access to informal credit had a significant and negative impact on the adoption of early-matured varieties and agroforestry as CCA strategies.

The results of our MVP model show that farm income has a significant and positive impact on the adoption of agroforestry practices. This means that the higher the farm income, the higher the probability of adopting agroforestry as a CCA strategy. This result is consistent with the study by Ojo & Baiyegunhi, (2020) and Tesfaye & Nayak, (2022) who reported that farm income increases the probability of adopting CCA strategies including agroforestry. In addition, our results showed that the higher the farm income, the lower the likelihood of temporary migration, suggesting that farmers with lower farm income are forced to migrate to secure their livelihoods. This finding is consistent with a study by Deressa et al. (2009) and Sam et al. (2020). Their studies reported that farm income increases the financial capacity to produce different crops to maintain and improve their farm productivity from climate change losses.

Farmers' awareness of climate change (such as droughts, floods, and landslides) has a significant impact on the adoption of CCA strategies. In our study, awareness of climate change positively influenced off-farm activities, new crop varieties and agroforestry. This suggests that farmers who are aware of climate change are more likely to adopt off-farm activities, new crop varieties and agroforestry as a CCA strategy. Our findings are consistent with the previous studies in the central region of Vietnam by Trinh et al. (2018), in Bangladesh by Aryal et al. (2020) and in Ethiopia by Tesfaye & Nayak, (2022). These studies reported that awareness increases the adoption of off-farm activities, new crop varieties and agroforestry.

We found that farmers' perceptions of temperature rise significantly and negatively influenced the adoption of agroforestry. Similarly, our results showed that farmers' perceptions of the increase in erratic rainfall significantly and positively influenced the adoption of off-farm activities and early-matured varieties. This suggests that household heads who were aware of the rise in temperature did not adopt agroforestry, whereas those farmers who perceived erratic rainfall realised the greater need to adopt off-farm activities and early-matured varieties. Since agroforestry in Nepal is mainly apple based, an increase in temperature will affect apple production and reduce agroforestry adoption. Similarly, farmers who perceived an increase in erratic rainfall (in the last 10-15 years) go for off-farm activities and adopt early-matured varieties. The probable reason for engaging in off-farm activities due to erratic rainfall could be that farmers don't want to take the risk of adopting new crop varieties. However, planting early-matured varieties helps to reduce harvest and post-harvest losses due to erratic rainfall, so the likelihood of adopting early-matured varieties increases with the perception of erratic rainfall in the study area. This finding is also supported by Lawson et al. (2020), Azong & Kelso, (2021) and Tesfaye & Nayak, (2022) who indicated that the perception of climate indicators such as temperature rise, and erratic rainfall increases the likelihood of adopting early-matured varieties and agroforestry.

We found that farmers' access to information via the internet had a significant and negative effect on the adoption of new crop varieties, whereas it had a significant and positive effect on the adoption of small irrigation systems. This means that new crop varieties were less likely to be adopted by farmers with access to the internet, whereas small irrigation systems were more likely to be adopted. The probable reason for this could be that farmers are less likely to search for information on new crop varieties on the Internet. This is because new crop varieties depend on local biophysical conditions, whereas farmers often search for information on different irrigation systems (Sedeek et al., 2019). As irrigation systems are relatively easy to search for, accurate information is easily accessible on the internet (Zinkernagel et al., 2020).

Access to information through farmer groups has had a significant and positive impact on the adoption of new crop varieties, early-matured varieties, small-scale irrigation, and agroforestry. However, it had a negative effect on the adoption of off-farm activities. The significant and positive effect of access to information through farmer groups on the adoption of new crop varieties, early-matured varieties, small-scale irrigation systems and agroforestry suggests that information from local groups appears to be valuable to farmers. In addition, the information shared by the farmer groups only covers climate change and farming practices, not off-farm activities. Many studies have found similar results that access to climate change information through the internet and farmer groups increases the likelihood of farmers adopting early-matured varieties, small-scale irrigation, and agroforestry (Deressa et al., 2009; Piya et al., 2013; Ravera et al., 2016; Lawson et al., 2020 and Tesfaye & Nayak, 2022).

5.1.6 Conclusion and recommendations for policy implications

The study uses a multivariate probit regression model to examine the influence of agro-ecological zones (AEZs) and social groups on the adoption of climate change adaptation (CCA) strategies at the household level in Nepal. The results of this study indicate that 53%, 41%, 43%, 46%, 31% and 62% of the surveyed households have adopted six key CCA strategies, namely off-farm activities, new crop varieties, early-matured crops, small-scale irrigation, agroforestry, and temporary migration, respectively.

The research validates that agro-ecological zones determine farmers' adaptation strategies. The most preferred CCA strategies among mountain farmers were off-farm activities and temporary migration. Hill region farmers preferred the use of off-farm activities, early-matured varieties, new crop varieties and temporary migration. Farmers in the

Terai region preferred the use of small-scale irrigation and agroforestry.

Social group is an important determinant of the decision to adopt off-farm activities, new crop varieties, early-matured varieties, and small-scale irrigation as adaptation options. The preferred CCA strategies of Brahmin farmers were new crop varieties, early-matured varieties, and small-scale irrigation. While the preferred CCA strategies of Sudra farmers were off-farm activities and temporary migration.

Access to climate change information through farmer groups is another important factor in the decision to adopt all strategies except temporary migration. In addition, access to informal credit, such as borrowing from friends and relatives, also determines farm households' decision to adopt early-matured varieties, agroforestry, and temporary migration as adaptation strategies. This result suggests that farmers with better access to information and finance have a higher adaptive capacity. The results are consistent with the action theory of adaptation and the intersectionality framework, which predict lower adaptive capacity of farming households in the disadvantaged geographical location and disadvantaged social groups.

The results show that both off-farm activities and temporary migration are strategies used by disadvantaged farmers (Mountain and Sudra group farmers). Therefore, to empower disadvantaged farmers and support them to stay in agriculture, policies need to support the dissemination of updated climate change adaptation information to all farmers, including to farmers leaving in remote rough terrains and those belonging to vulnerable social groups. The study recommends that in case the government want to prevent/reduce migration and keep agricultural production, consideration be given to providing subsidies to Mountain and Sudra farmers to help them cope with climate shocks and to support them in maintaining their farming activities. Similarly, access to credit is an important factor influencing the choice of adaptation strategies. Therefore, easy access to credit (perhaps microfinance credit) needs to be made available to farmers, especially disadvantaged farmers (Mountain and Sudra farmers), which will allow them to increase their adaptive capacity. Furthermore, educating, and sensitizing farmers to adopt multiple combinations of strategies rather than relying on a single adaptation option will diversify the livelihoods of disadvantaged farmers and motivate them to stay in agriculture.

5.2 Food security and sustainability through adaptation to climate change: lessons learned from Nepal

5.2.1 Introduction

Global climate change exacerbates the challenge to eliminate hunger (Kogo et al., 2021). In particular, extreme climate-related events contribute to a steady increase in global food insecurity (World Bank, 2022; Roy et al., 2022). With the advent of climate change, these extreme events are occurring regularly, intense, random, and persistent, exacerbating their impact on different regions (Pradhan et al., 2022). According to the FAO (1996), food security is achieved 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". This definition portrays the concept of food security as one that includes various dimensions, such as food availability, access, utilization, and stability (FAO, 1996; Taylor et al., 2019; Kogan et al., 2019).

In June 2022, approximately 345 million people worldwide were acutely food insecure (World Bank, 2022). Acute food insecurity occurs when individuals or communities face severe and immediate deprivation of sufficient, safe, and nutritious food due to conflict, disaster, or emergency (Brück & d'Errico, 2019). It poses an immediate threat to lives and livelihoods, leading to malnutrition and disease (Tirado et al., 2022). Food insecurity was higher among household's dependent on agriculture especially smallholder farmers than among households engaged in non-farm activities (Kogan et al., 2019). Despite SDG2 aims to eradicate hunger by 2030, approximately 670 million people will still endure hunger and food insecurity (FAO, IFAD, WFP & WHO, 2022). Particularly in low-income, agriculture-dependent countries, the number of food-insecure people is expected to exceed 30 million by 2030 (FAO, 2022). Increasing food insecurity in agriculture-dependent countries is due to climate extremes, population growth and changing lifestyles (FAO, 2015; FAO, 2018; World Bank, 2022).

Smallholder farmers are more vulnerable to food insecurity because they rely heavily on agriculture for their income and livelihoods (Ado et al., 2019). Simultaneously, smallholder farmers are disproportionately affected by climate change and extreme events due to several factors, including limited land area, challenging socio-economic conditions, limited access to information, outermost dependent on rain-fed agriculture, and low capacity to adapt (Atube et al., 2021; Ansah et al., 2023). Crop productivity is declining significantly due to changes in temperature, rainfall patterns, extreme weather events and the inability of smallholder farmers to adapt to climate change (Harkness et al., 2020). Reduced smallholder productivity increases food insecurity and poverty (Ogunniyi et al., 2021). Enforcing strategies to improve adaptation to climate change is critical to increasing agricultural productivity and improving food security for smallholder farm households (Mahmood et al., 2019; Matavel et al., 2022). Many developing countries, including Nepal, are proactively formulating climate change adaptation strategies to address climate change challenges. These strategies ensure the long-term sustainability of agricultural productivity and household food security (Pawlak & Kołodziejczak, 2020).

Nepal is characterised by a predominantly smallholder farming system coupled with high levels of poverty and food insecurity (Gartaula et al., 2017; Thapa & Hussain, 2021). Food insecurity is a daily problem, especially for households living in remote areas of the country (Pandey & Bardsley, 2019a; Randell et al., 2021) . Access to food for all citizens is a fundamental right in Nepal, yet the country ranks 74th in terms of food insecurity (Global Food Security Index, 2022). The affordability, quality, safety, and sustainability of food are low among rural households living under poor socio-economic conditions (Global Food Security Index, 2022). Nepal is highly dependent on imported food (about 21%), mainly from India and neighbouring countries (Adhikari et al., 2021).

Compared to their urban counterparts, smallholder farmers in Nepal's rural mountain, hill, and Terai regions are farther vulnerable to food insecurity (Pandey & Bardsley, 2019). This is due to limited access to modern agricultural technology, infrastructure, markets and financial services, adverse climatic conditions, and higher dependency on rain-fed agriculture (Khanal & Wilson, 2019; Karki et al., 2020; Karki et al., 2021; Masud et al., 2017). Consequently, the study area has a low level of adaptation to climate change, contributing to high levels of food insecurity (Randell et al., 2021a). In addition, farmers in these regions face significant yield gaps, with up to 78% of their income spent on food (Pandey & Bardsley, 2019b; Pradhan et al., 2015). However, agricultural production in the remote mountainous and hilly regions of the country is critical for food security (Randell et al., 2021).

Some smallholder farmers are adopting various climate change adaptation options to increase crop productivity and household income and improve food security (Dirani et al., 2021; Cole et al., 2018). These adaptation options involve either staying in agriculture or avoiding it to improve household food security status (Ansah et al., 2019). The impact of assuming and adopting such practices on food security has yet to be sufficiently explored in previous studies. However, as per the findings by Jambo et al. (2021), small-scale irrigation adoption helps to increase agricultural productivity, resulting in improved food security status in Ethiopia. The Indonesian smallholder farmers and smallholder farmers in Pakistan showed that the consequence of adopting climate adaptation strategies such as agroforestry contributed to food security as well as income, health, and environmental stability (Duffy et al., 2021; Harkness et al., 2023). In addition, research by Smith & Wesselbaum (2020) reported that the distribution of food insecurity influences migration decisions, including rural-urban migration and international migration. Temporary migration is one of the adaptation strategies that coexist with vulnerable households in managing family food needs throughout the year (Alam et al., 2020; Hussain et al., 2016). In developing countries such as Nepal, enhancing off-farm activities has been identified as essential to address climate change, improving food security and diversifying livelihoods (Merrey et al., 2018). A study in rural sub-Saharan Africa indicates that off-farm income correlates significantly better with food security (Dzanku, 2019). The study also shows that male-headed households and those living in wealthier regions have a firmer link between off-farm activities and food security than female-headed households and those living in economically disadvantaged regions.

The links between climate-related factors and smallholder food security are increasingly being explored (Nagoda, 2015; Ilboudo-Nébié et al., 2021; Randell et al., 2021; Thapa & Hussain, 2021; Ayinu et al., 2022). These investigate show that traditional adaptation strategies, such as adopting water harvesting in rainfed dry farming and diversifying herds and incomes, do not meet the constraints of climate change in food-insecure rural communities (Nagoda, 2015). Smallholder farmers in Nepal use a variety of approaches to CCA. These include crop diversification, adoption of new crop varieties, irrigation, agroforestry, temporary migration, and off-farm employment. These measures are designed to mitigate the effects of climate change and address the resulting food security challenges (Karki et al., 2020; Amare & Balana, 2023). Studies conducted in different countries for instance in Ethiopia by Hilemelekot et al. (2021), in Tanzania by Randell et al. (2022), in Nigeria by Balana et al. (2022) and in Nepal by Joshi & Joshi, (2016) show that demographic factors like gender, age and education play a dominant role in food security. Similarly, a study from Tanzania by Randell et al. (2022) revealed that households led by females were more vulnerable to food insecurity compared to those led by males. Research conducted in Ethiopia found that the accessibility of information, including radio broadcasts and neighbours, was identified as a critical factor influencing climate change adaptation and the achievement of food security (Di Falco et al., 2011).

To date, most research efforts have focused on identifying factors that influence food security. In addition, existing literature has often narrowly examined either the impact of climate extremes or CCA strategies on household food security. These studies have mainly examined individual CCA strategies, such as agroforestry or small-scale irrigation, and analysed their impact on food security. However, these studies have often lacked a holistic perspective, neglecting the possibility that farmers may use a combination of adaptation strategies. Research has also failed to consider strategies that enable farmers to sustain their agricultural activities or lead them to alternative livelihoods. To fill this gap, this study examines the outcomes of integrating multiple adaptation strategies on smallholder farmers' food security. Our knowledge base indicates a need for previous research on how smallholder farmers can improve their food security status through adaptive agricultural practices or by exploring non-farm alternatives under the impacts of climate change. Therefore, this paper aims to provide a comprehensive overview of climate change extremes, CCA strategies and their impacts on food security. We also highlight the implications of these approaches and suggest avenues for future research. As such, this study aimed to address the following specific objectives to address the research gaps identified above.

i) To investigate the factors affecting the food security of rural smallholder farmers in Nepal.
ii) To assess the impact of climate-related extremes (drought) on food security.
iii) To determine how adopting CCA strategies by smallholders affects food insecurity.

This study will help to identify suitable CCA strategies to improve household food security in Nepal and propose analogous solutions for countries with similar features. The aim is to encourage the adoption of CCA strategies, thereby improving food security, crop productivity, livelihoods, and overall sustainability. Understanding how smallholder farmers adopt CCA strategies to improve food security and income diversification will help policymakers, donors, and extension agents to target CCA interventions that benefit vulnerable households, strengthen their adaptive capacity to the changing climate, and climate extremes and enhance food security.

5.2.2 Conceptual framework

FAO food security indicators and IPCC climate vulnerability dimensions:

Figure 6 shows the conceptual framework of this study. Our study integrates the FAO recommended measures of food security indicators such as Food Consumption Score and Reduced Coping Strategies Index (Devereux, 2006; FAO, 2003; WFP, 2008) with the IPCC dimensions (exposure, adaptive capacity, and sensitivity) of climate change vulnerability (IPCC, 2012). FAO has proposed to combine different food security indicators such as FCS and RCSI to capture the overall status of household's food security. From the perspective of a developing nation (such as Nepal), determining the food security status of households requires consideration of various factors. These encompass demographic, socio-economic, and geographical factors, as well as access to information, climate variability and strategies related to climate change (FAO, 2008; IPCC, 2007). These determining factors of food security will vary depending on the extent of vulnerability to climate change (IPCC, 2007; Sam et al., 2019).

Vulnerability is defined in the IPCC framework as: "the degree to which an environmental or social system is sensitive to and unable to cope with the adverse impacts of climate change and extreme events" (IPCC, 2007). Vulnerability is a “consequence of a system's exposure and sensitivity to climatic stimuli and its capacity to adapt” (IPCC, 2007). The IPCC defines “exposure” as the “presence of people and their economic, social, and cultural resources in areas that may be adversely affected by the impacts of climate change”, such as drought. Adaptive capacity describes the “ability of a system to successfully cope with the adverse effects of climate change” (IPCC, 2007). Sensitivity describes the “extent to which extreme climatic events, such as drought, can damage a system and the ability of an individual or household to cope with them” (IPCC, 2007).

Looking at these dimensions at the household level, food security status is influenced by vulnerability to climate change (Gebre & Rahut, 2021; Sam et al., 2021a). The exposure dimension is the perceived impact of the drought on farm production and household livelihood (Sam et al., 2019, 2021a). Whereas households’ adaptive capacity to cope with climate change depends on their various factors such as demographic, social, economic, geographical and access to information characteristics (Burchi & de Muro, 2016; Gebre & Rahut, 2021; Ilboudo Nébié et al., 2021; Randell et al., 2022; Sam et al., 2019, 2021). Moreover, building the adaptive capacity of smallholder farmers facilitates their adoption of multiple CCA practices, thereby reducing their vulnerability to climate change impacts (Sam et al., 2019, 2021). In contrast, households with higher adaptive capacity are less vulnerable to climate change, and vice versa. As household sensitivity increases, household food security status decreases. As household sensitivity increases, household food security status decreases. Therefore, in light of these findings and the literature reviewed, and following the work of (Gebre & Rahut, 2021; Islam & al Mamun, 2020; Sam et al., 2021), this research conceptualises the links between climate change vulnerability and the food security status of smallholder households.

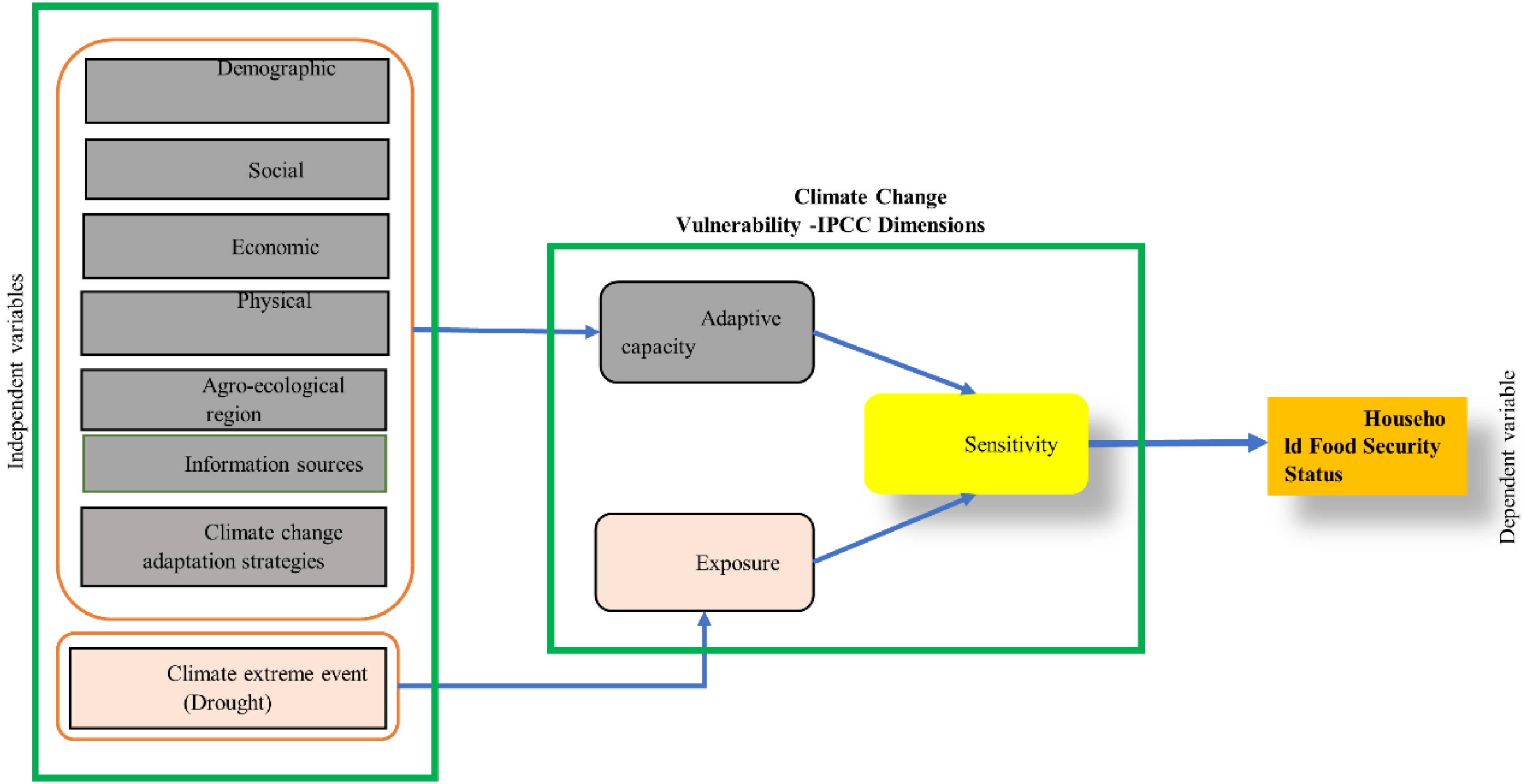

Figure 6 Conceptual framework for addressing household food security using the IPCC dimensions of vulnerability
Source: Author established construction on FAO Food Security Indicators and IPCC Climate Vulnerability Dimensions

5.2.3 Analytical tools

5.2.3.1 Data analysis

We used Stata 14.2 for data analysis. The ordered logit model is most appropriate for a dependent variable when it is on an ordinal scale (Sam et al., 2019; Tu et al., 2021). The ordinal logit model estimates the cumulative probability of being in a particular category compared to all other categories. This model allows analysis of the relationship among different predictors and the ordered categories of food security status. The ordered logit regression model is well suited to analysing data where food security is often determined on an ordinal scale indicating different levels of food security. In addition, this model helps to identify the factors that influence food security outcomes and given the ordered nature of the response categories, provides an understanding of the influence of independent variables on different levels of food security (Polimeni et al., 2018). It has been widely used in studies by researchers in similar contexts across diversified fields (Nkomoki et al., 2018; Sam et al., 2019; Balana et al., 2022;). As defined in section 3.4.1.1 and Table 1, our study defines the household FCS and RCSI indicator as an ordered outcome variable with three categories. A household may come under one of the three FCS conditions and one of the three RCSI conditions (dependent variable y). The ordered categories can be coded as $j = 1, \dots, m$, where m is the total number of categories. Within our analysis, we let y_i assume values $j = 1,2,3$ which indicate the FCS and RCSI category for the household. We classify y_i^* as the latent unobserved measure of the i^{th} household's FCS and RCSI status which gradually intersects significant thresholds. Then, we introduce an index model for y_i^* for each individual i as in Eq. 1 (Cameron & Trivedi, 2010;Williams, 2021):

$$y_i^* = x_i'\beta + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where the x_i' stands as a vector of regressors, β represents parameters to be assessed and ε_i denotes the error term. In accordance with Eq. 1, higher values of y_i^* indicates the acceptable food security category for FCS and high coping strategies for RCSI model of the household. For a three category ordered variable, a household's FCS and RCSI category j can be defined as $y_i = j$ if $\alpha_{j-1} < y_i^* \leq \alpha_j$, for $j = 1, \ldots, 3$.Where α_j signifies the threshold values for the j^{th} FCS and RCSI category. The likelihood that the i^{th} household falling into the j food insecurity category p_{ij} can be represented as shown in Eq. 2:

$$p_{ij} = p(y_i = j) = p(\alpha_{j-1} < y_i^* \leq \alpha_j) = F(\alpha_j - x_i'\beta) - F\alpha_{j-1} - x_i'\beta) \ldots\ldots\ldots \text{(2)}$$

Using the approach outlined by Cameron and Trivedi (2010, p.528), the marginal effects of the covariates can be obtained, where F is the cumulative distribution function (cdf) of ε_i and ε_i is expected to have a logistic cumulative distribution function with $F(z) = \frac{e^z}{1} + e^z$ .The parameters β and the threshold parameters, α_j, are estimated by maximizing the log-likelihood using the maximum likelihood estimator. A correlation test was performed to account for possible multicollinearity between different explanatory variables. However, certain variables were first categorised before being transformed into dummy variables. Subsequently, certain variables were excluded from the model and referred to as reference groups due to their initial categorisation. These include informal education under the demographic factor and Sudra social grouping under the social factor. Similarly, agricultural households with incomes below 150,000 Nepali rupees and the Terai region within the agro-ecological zone factors were also excluded from the model.

5.2.3.2 Selection of variables

5.2.3.2.1 Dependent variables

Our study used two indicators to assess household food security: the Food Consumption Score (FCS) and the Reduced Coping Strategies Index (RCSI). In 1996, the World Food Programme (WFP) introduced a Food Consumption Score (FCS) index. This index considers the variety and frequency of food groups consumed over the previous seven days and assigns weights based on the nutritional value of the food groups consumed. For example, food groups containing nutrient-rich items such as animal products are weighted more heavily than those containing less nutritious foods such as tubers (WFP, 2008). The calculation of FCS follows below approach (WFP, 2008).

$$FCS = a1b1 + a2b2 + \cdots + a9b9 \ldots\ldots\ldots\ldots\ldots (3),$$

where a = frequency (1-week recall period), 1–9 = food group, and b = weight.

The weighting scheme is as follows: meat, milk, and fish = 4, pulses = 3, staples = 2, vegetables and fruits = 1, oil and sugar = 0.5, and condiments = 0. The FCS divides households into the following groups based on cut-off points: poor (< 21.5), borderline (21.5–35), and acceptable (> 35) (World Food Programme, 2008).

RCSIs are household food security indicators that measure household head responses to inadequate access to food (Maxwell, et al., 2003). The RCSI is determined by assessing a concise set of five food-related coping strategies used in the previous seven days. During this period, households were asked how often they used these five short-term food-related coping strategies when they did not have enough food or the financial means to buy food. Each of the five strategies is assigned a different weight that reflects its severity. The RCSI is calculated as follows: (WFP, 2008; Maxwell et al., 2008).

$$RCSI = a1b1 + a2b2 + \cdots + a5b5 \ldots\ldots\ldots\ldots\ldots \text{(4)},$$

where a = frequency (1-week recall period), 1–5 = food related coping strategies, and b = weight. These weights are, "relying on less favoured and less expensive foods =1, limiting portion size at mealtimes =1, reducing the number of meals eaten in a day =1, borrowing food or relying on help from relatives or friends =2, restricting consumption by adults for small children to eat =3. The cut-off points for the RCSI that classify households into one of the following categories are no or low coping (CSI= 0-3), medium (CSI = 4-9), and high coping (CSI ≥10)" (Maxwell et al., 2008).

5.2.3.2.2 Explanatory variables

The selection of explanatory variables used in the ordered logit model was based on an extensive analysis of the existing literature. We made assumptions about the expected impact of each explanatory variable on food security (Table 9). Our assumptions applied only to the overall coefficient of food security; they did not apply to specific categories. In addition, an idea established by Sam et al, (2019), we divided the independent variables into main components and sub-components to provide a better explanation. Both food security indicator models (FCS, RCSI) have 8 major components and 28 sub-components (Table 9). The eight main components are demographic, social, economic, geographical, access to information, CCA strategies, extreme climatic events, and agro-ecological zones. The demographic components that either positively or negatively affect food security include gender, age, education, household size, number of children, adolescents and adults, agricultural experience, and household food choices (Nagoda, 2015; Nkomoki et al., 2018; Gwada et al., 2020a; Ilboudo Nébié et al., 2021; Acheampong et al., 2022; Ayinu et al., 2022; Balana et al., 2022;). Social components include social groups and informal credit (borrowing from friends, borrowing from farmer groups), while economic components include farm income and remittances (Gwada et al., 2020a; Acheampong et al., 2022; Balana et al., 2022). The geographical components include land size and distance to the nearest market. Similarly, access to information is divided into five categories: access to information through the internet, radio, television, research institutes and universities, and mobile phones (Cole et al., 2018). Climate-induced drought, classified as an extreme climatic event, was included in the analysis because of its expected negative impact on food security (Sam et al., 2019; Qtaishat et al., 2022a; Randell et al., 2022; Demont, 2022). Drought was chosen as a representative indicator of climate change extremes because it is frequently perceived and widespread across all agro-ecological regions of Nepal. While several studies such as (Nagoda, 2015; Nkomoki et al., 2018b; Enkuahone Kassie & Alamirew Alemu, 2021; Hilemelekot et al., 2021; Jambo et al., 2021a; Dope Setsoafia et al., 2022) showed that CCA strategies like small-scale irrigation, agroforestry, temporary migration, and off-farm activities showed a dual influence on food security, encompassing both positive and negative effects. Mountainous and Hilly regions are two subcomponents of the agro-ecological region (Nagoda, 2015; Cosmas et al., 2017a; Theriault et al., 2018; Karki et al., 2020; Hilemelekot et al., 2021; Acheampong et al., 2022).

5.2.4 Results and discussion

The findings of this study are presented in three tables below. Table 9 provides the definition and descriptive statistics of the variables employed in the ordered logit regression model. Table 10 and Table 11 elaborate on the results of the ordered logit regression analysis for FCS and RCSI, respectively.

5.2.4.1 Descriptive statistics of model variables

The mean FCS of the poor, borderline and acceptable categories were 4.25, 7.25 and 88.50 respectively. These values suggest that the majority of smallholder households in the study area are food secure. Similarly, the mean RCSI value of no or low coping, medium coping and high coping was 78.50, 9.25 and 12.25 respectively. The results from the RCSI model show that a few households were struggling with food security. Our two consistent models indicate that smallholder farmers in the study area are food secure and less likely to use no or low coping strategies.

In terms of the gender of the household head, 72% of households were headed by men. Our findings are consistent with the World Bank (2016) report on the Nepal Demographic and Health Survey. According to the World Bank and Ministry of Health, Nepal (2016) report, the number of female-headed households in Nepal is increasing and currently stands at 31.3%, while in our study area, 28% of households were female-headed. The mean age of the head of household was 50.32 years. The level of education showed that 65% of the household heads had formal education. The World Bank (2018) report for Nepal stated that the literacy rate of Nepal is 67.91%, which is identical to our result from the selected study area.

The average household size was 6 members. According to the Census Nepal Report, the average family size in the country is 5 members per household (Census Nepal Report., 2021).

Table 9 Definition and measurement of variables used in ordered logit regression model

Major components	***Sub-components (variable)***	***Explanation***	***Mean/Percent***	***Std Dev***	***Expected sign***
Dependent variables					
Food security indicators	Food Consumption Score (FCS)	Ordered category Poor (<21.5), Borderline (21.5–35), Acceptable (>35) 0=Poor 1=Borderline 2=Acceptable	4.25 7.25 88.50		
	Reduced Coping Strategies Index (RCSI)	Ordered category: No or low (0-3), Medium (4-9), High (>9) 0=No or Low coping 1=Medium coping 2=High coping	78.50 9.25 12.25		
Independent variables					
Demographic	Gender	Dummy= 1 if household head is male, 0 Otherwise	0.72	0.02	(-)
	Age	Continuous, household head age in years	50.32	0.70	(+)
	Education	Dummy= 1 if household head has formal education, 0 Otherwise	0.65	0.02	(+)
	HH size	Continuous, total family members in the household	5.80	0.14	(+)
	Number of children	Continuous, total number of children in the household	1.40	0.07	(-)
	Number of youths	Continuous, total number of youths in the household	3.69	0.10	(+)
	Number of adults	Continuous, total number of adults in the household	0.71	0.05	(+)
	Experience (farming)	Continuous, total years of farming experience of HH	23.78	0.71	(+)
	Food decision in household	Dummy= 1 if decision what will be eaten for next meal is by is male, 0 Otherwise	0.06	0.01	(-)
Social	Social groups	Dummy=1 if household belongs to social group is "Brahmin" 0 Otherwise	0.24	0.02	(+)
	Borrow money from friends	Dummy=1 if the household borrow money from friends (access informal credit), 0 Otherwise	0.12	0.02	(+)

Table 9 Definition and measurement of variables used in ordered logit regression model

Major components	*Sub-components (variable)*	*Explanation*	*Mean/Percent*	*Std Dev*	*Expected sign*
	Borrow money from farmers group	Dummy=1 if the household borrow money from farmers group (access to information credit), 0 Otherwise	0.07	0.01	(+)
Economic	Income from farm	Dummy =1 if annual earning of household from farm more than 150,000 Rs ($1,250), 0 otherwise ($1 = Rs.120 as of May 2021)	0.93	0.01	(+)
	Remittances	Dummy=1 if family receives remittances, 0 otherwise	0.30	0.02	(+)
Physical	Land size	Continuous, total amount of land size owned by households (in Ropani, 1 Ropani=0.051 hectare)	13.16	0.89	(+)
	Distance to the close market	Continuous, closest market in hours	1.61	0.12	(+)
Information sources	Internet	Dummy =1 if households have access to the internet, 0 Otherwise	0.62	0.02	(+)
	Radio	Dummy =1 if households have access to the radio, 0 Otherwise	0.52	0.03	(+)
	Television	Dummy =1 if households have access to the television, 0 Otherwise	0.68	0.02	(+)
	Research institutes/university	Dummy =1 if households have access to the Research institutes/University, 0 Otherwise	0.25	0.02	(+)
	Mobile	Dummy =1 if households have access to the Mobile phones, 0 Otherwise	0.79	0.02	(+)
Climate extreme events	Drought impact	Dummy= 1 if the household's perception on adverse impact of drought on farm production in last 5 years, 0 otherwise	0.59	0.03	(-)
CCA strategies	Small-scale irrigation	Dummy=1 if households adopted small scale irrigation system as a CCA strategies, 0 Otherwise	0.46	0.02	(+)
	Agroforestry	Dummy=1 if households adopted agroforestry as a CCA strategies, 0 Otherwise	0.31	0.02	(+)
	Temporary migration	Dummy=1 if households adopted temporary migration as a CCA strategies, 0 Otherwise	0.62	0.02	(+)
	Off-farm activities	Dummy=1 if household adopted off-farm activities as CCA strategies, 0 Otherwise	0.53	0.03	(+)
Agro-ecological region	Mountain region	Dummy=1 if household belong to the agro-ecological zone Mountain "Highland", 0 Otherwise	0.46	0.02	(-)
	Hilly region	Dummy=1 if household belongs to the agro-ecological zone Hill "Midland",0 Otherwise	0.38	0.02	(-)

According to the same data, the average size of children, youth and adults in the households was 1, 4 and 1, members respectively. This indicates that the active labour force in the study area is high. A similar finding by the World Bank (2022) reported that the age dependency ratio (active labour force) in Nepal was 51.47% in 2021. In our study area, the average farming experience was 24 years. Only 6% of men decide on the next meal to be eaten in the household. This suggests that women play a major role in determining the next meal in the household. In addition, women in Nepal are more involved in household activities than men.

In our study, we divided the social groups into Brahmins and others. And the Brahmin social group accounted for 24%. Access to informal credit was divided into borrowing money from friends and farmer groups. Borrowing from friends and farmer groups accounted for 12% and 7% respectively. Farm income was divided into earning more and less than 150,000 Nepalese rupees per year. The 93% of farmers earn more than 150,000 NPR per year from their farms. Similarly, another source of income was remittances and 30% of the households' received remittances. A study by Narayan (2019) and a report by the World Bank (2022) stated that remittances contribute to 30% of Nepal's GDP on average, which is similar to what we found in our study.

The average size of smallholder farms was 13.16 *ropani* (0.67 hectares). The average distance to the nearest market was 2 hours, but the majority were categorised as more than 4 hours away. Access to information sources in the study area through internet, radio, television, research institutes and university, and mobile phones was 62%, 52%, 68%, 25% and

79% respectively, showing that farmers in the study region have adequate access to information sources.

In the study area, the negative impact of drought was reported by 59% of the households. This shows that the selected study area is highly vulnerable to drought. As a climate change adaptation strategy, small-scale irrigation was adopted by 46% of households, while agroforestry, temporary migration and off-farm activities were adopted by 31%, 62% and 53%, respectively. According to a report by the Government of Nepal (2022), about 40% of the total agricultural land is irrigated. However, irrigated agriculture still faces several challenges that require significant improvement and expansion. Similarly, a study by (Neupane et al., 2002) found that agroforestry supported about 50% of the households in the Hill region of Nepal. About 46% of the respondents were from the Mountainous region and 38% from the Hilly region.

5.2.4.2 Factors affecting food security

Tables 10 and 11 present the calculated coefficients of the ordered logit model of household food security in Nepal. Table 10 presents the results of the FCS model, while Table 11 presents the results of the RCSI model. Notably, a significant number of the estimated coefficients are statistically significant and in the expected direction.

5.2.4.2.1 Demographic aspects and food security

Household demographics play a critical role in determining household food security status in Nepal. In the context of the FCS model, household food security status likely varies with the age of the household head. The relationship of the household head age variable was statistically significant and positive for the FCS. This is consistent with a prior expectation reported in Table 9. In the FCS model, the marginal effect indicates that a one-year increase in household head age reduces the probability of being in the poor and borderline food security categories by 0.1% each. In addition, our results indicate that a one-year increase in the age of the household head increases the probability of being in the acceptable FCS category by 0.2%. This implies that as the age of the household head increases, so does the likelihood of the household being food secure. Given that the head of household holds significant decision-making authority within the family, age is of considerable importance in the context of household food security (Muche et al., 2014). Our results align with the research conducted by Sam et al. (2021), who used the Food Security Index (FSI) as an indicator of food security to identify factors influencing it in India. Their finding demonstrated that as the age of the household head increases, so does the knowledge and experience of agricultural activities, which helps increase food security status. In contrast, our study's outcomes differ from those in sub-Saharan Africa. There, age was reported to have a significant and negative impact on the food security of farming households (Cosmas et al., 2017; Gwada et al., 2020). Their investigations indicated that household heads' economic role in enhancing well-being or food security declined beyond a certain age. With an increase in the age of household heads, their capacity to alleviate food insecurity diminished, attributed to a reduction in productive capabilities.

Regarding the formal education level, the estimated relationship was found to be statistically significant and positive at the 1% significance level. Our results show that the formal education level of a household head increases the likelihood of Nepalese smallholder farmers being food secure (acceptable) while decreasing the likelihood of them being food insecure (poor). This implies that as the household head's formal education level increases, the household's likelihood of achieving food security increases. In the FCS model, the marginal effect of the formal education level of the household head indicates that it reduces the likelihood of being in the poor and borderline food security categories by 1.3% and 4.3%, respectively. In addition, our results indicate that the level of formal education increases the probability of being in the acceptable FCS category increases by 5.6%. Higher levels of formal education enable individuals to make more informed and effective investments, leading to higher income generation. This increase in income correlates with higher levels of food security (FAO; 2006). This finding is similar to that of Nkomoki et al. (2018) and Acheampong et al. (2022), who also used FCS as an indicator of food security to identify the determinants of food security in Zambia and Ghana, respectively. A similar study in Nigeria by Balana et al. (2022) reported that farmers with formal education had better dietary diversity scores than other households. Another study in Kenya by Cosmas et al. (2017) and in Ethiopia by Ayinu et al. (2022) reported the positive impact of education. They further explained that the formal education increases the innovativeness of the household head, which enables access to productive resources.

In our RCSI model, men deciding on the next meal is statistically significant. The marginal effect shows that having the men in the household decide on the next meal reduces the likelihood of a household being in the low or no coping category by 14.1% and increases the likelihood of being in the medium coping category by 6.3% and the high coping category by 7.7%. This suggests that when men decide on the next meal, the household is more likely to be food insecure. This could reflect the fact that women are more involved than men in producing food crops, mainly for home consumption. In addition, women tend to take more responsibility than men for food selection, planning, and preparation. This role difference may explain why men fall into the high coping strategies group within the RCSI model. A similar study by Acheampong et al. (2022) found that male-headed households had higher probability to fall into the category of food insecure.

5.2.4.2.2 Social aspects and food security

Our results found that the borrowing money from friends has a statistically significant impact on household food security for the RCSI model at the 5% significance level. Households that borrowed money from friends for agricultural investment were 14.3% less likely to be in the no or low coping RCSI category. In comparison, they were 6.5% and 7.8% more likely to be in the medium and high coping RCSI categories than those who did not borrow money from friends for agricultural investment. Borrowing from friends appears to have a negative impact on food security in the study region, although it may be perceived as a temporary tactic to improve household food security. This may be because borrowing from friends was used for purposes other than household food consumption. In the villages, access to formal capital, such as banks and financial institutions, is complicated and bureaucratic for smallholder farmers, so they borrow money from friends and relatives (Ullah et al., 2020). Social associations, social networks and social integration significantly increase household food security (Claasen & Lemke, 2019). In rural communities in Nepal, borrowing from the kinship network is well practised. They favour borrowing money within the kinship network instead of reaching banks and financial institutions due to excessive interest rates (Kumar et al., 2015). In contrast to our findings, studies in India by Sam et al. (2021) and in Zambia by Nkomoki et al. (2018) reported that borrowing money from friends, neighbours, and relatives is essential for food security.

Table 10 Results of an ordered logistic regression of the factors affecting the food security of households in Nepal (FCS model)

Variables		**FCS Coef (Std error)**	**FCS**		
			Poor	**Borderline**	**Acceptable**
Demographic	Gender	-0.661(0.474)	0.00 3(0.002)	0.011(0.008)	-0.015(0.01)
	Age	0.071(0.029) **	-0.001(0) *	-0.001(0.001) **	0.002(0.001) **
	Education	1.639(0.501) ***	-0.013(0.007) *	-0.043(0.021) **	0.056(0.026) **
	HH size	-0.121(0.267)	0.001(0.002)	0.002(0.005)	-0.003(0.007)
	Number of children	0.354(0.295)	-0.002(0.002)	-0.007(0.006)	0.009(0.008)
	Number of youths	0.047(0.267)	0(0.001)	-0.001(0.005)	0.001(0.007)
	Number of adults	0.311(0.272)	-0.002(0.002)	-0.006(0.006)	0.008(0.007)
	Farming experience	-0.027(0.027)	0.001(0.001)	0.001(0.001)	-0.021(0.002)
	Food decision	-1.288(1.036)	0.013(0.018)	0.044(0.054)	-0.057(0.071)
Social	Social groups	0.937(0.584)	-0.004(0.003)	-0.015(0.009)	0.019(0.012)
	Borrow money from friends	-0.091(0.551)	0.001(0.003)	0.002(0.011)	-0.002(0.015)
	Borrow money from farmers group	-0.382(0.826)	0.002(0.006)	0.009(0.022)	-0.011(0.028)
Economic	Income from farm	-0.073(1.028)	0(0.006)	0.001(0.021)	-0.002(0.027)
	Remittances from migrants	-0.013(0.005) **	0.001(0.002) *	0.001(0.002) **	-0.002(0.004) **
Physical	Land size	0.012(0.014)	-0.001(0.002)	-0.001(0.021)	0.002(0.023)
	Market	-0.091(0.084)	0.001(0.001)	0.002(0.002)	-0.002(0.002)
	Internet	-0.14(0.454)	0.001(0.002)	0.003(0.009)	-0.003(0.011)
	Radio	0.611(0.423)	-0.003(0.003)	-0.012(0.01)	0.016(0.012)

Table 10 Results of an ordered logistic regression of the factors affecting the food security of households in Nepal (FCS model)

Variables		FCS Coef (Std error)	FCS		
			Poor	**Borderline**	**Acceptable**
Information sources	Television	-0.399(0.495)	0.002(0.003)	0.007(0.009)	-0.009(0.011)
	Research institutes/university	1.875(0.756) **	-0.007(0.004) **	-0.026(0.01) ***	0.034(0.013) **
	Mobile phone	-0.544(0.556)	0.003(0.003)	0.009(0.009)	-0.012(0.011)
Climate extreme events	Drought impact	-0.744(0.246) ***	0.004(0.002) **	0.014(0.006) **	-0.019(0.008) **
CCA strategies	Small-scale irrigation	1.211(0.477) **	-0.007(0.004) *	-0.023(0.011) **	0.03(0.015) **
	Agroforestry	-0.579(0.563)	0.004(0.004)	0.013(0.014)	-0.016(0.018)
	Temporary migration	0.915(0.458) **	-0.006(0.004)	-0.02(0.013)	0.026(0.017)
	Off-farm activities	-0.882(0.456) *	0.005(0.003)*	0.017(0.01) *	-0.022(0.013) *
Agro-ecological region	Mountain region	-0.05(1.357)	0(0.007)	0.001(0.026)	-0.001(0.034)
	Hilly region	-3.692(1.303) ***	0.052(0.038)*	0.15(0.085) *	-0.202(0.119) *
	/cut1	-4.784(1.835)			
	/cut2	-3.234(1.809)			
	Observations	400			
	Chi-square	113.912			
	Prob > chi2	0.000			
	R-squared	0.329			

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively. The averages marginal effects are reported, and the standard errors are in parentheses.

Table 11 Results of an ordered logistic regression of the factors affecting the food security of households in Nepal (RCSI model)

Variables		*RCSI* *Coef (Std error)*	*RCSI*		
			No or low coping	*Medium coping*	*High coping*
Demographic	Gender	-0.109(0.321)	0.014(0.042)	-0.007(0.02)	-0.007(0.021)
	Age	-0.024(0.018)	0.003(0.002)	-0.002(0.001)	-0.002(0.001)
	Education	-0.181(0.333)	0.023(0.043)	-0.011(0.021)	-0.012(0.022)
	HH size	0.001(0.214)	-0.002(0.027)	0.001(0.014)	0.001(0.013)
	Number of children	0.153(0.242)	-0.019(0.03)	0.009(0.015)	0.01(0.015)
	Number of youths	0.132(0.209)	-0.016(0.026)	0.008(0.013)	0.008(0.013)
	Number of adults	0.37(0.227)	-0.046(0.028)	0.023(0.014)	0.023(0.014)
	Farming experience	0.005(0.018)	-0.002(0.002)	0.001(0.001)	0.001(0.001)
	Food decision	0.874(0.529) *	-0.141(0.104)*	0.063(0.043)*	0.077(0.062)*
Social	Social groups	-0.359(0.382)	0.042(0.042)	-0.021(0.022)	-0.021(0.021)
	Borrow money from friends	0.908(0.378) **	-0.143(0.072)**	0.065(0.031)**	0.078(0.043)*
	Borrow money from farmers' group	0.417(0.507)	-0.059(0.08)	0.028(0.037)	0.031(0.043)
Economic	Income from farm	-0.3(0.698)	0.034(0.072)	-0.017(0.037)	-0.017(0.035)
	Remittances from migrants	-0.003(0.004)	0.001(0.001)	0.001(0.001)	-0.002(0.002)
Physical	Land size	-0.033(0.013) ***	0.004(0.002)***	-0.002(0.001)**	-0.002(0.001)**

Table 11 Results of an ordered logistic regression of the factors affecting the food security of households in Nepal (RCSI model)

Variables		*RCSI Coef (Std error)*	*RCSI*		
			No or low coping	*Medium coping*	*High coping*
	Market	-0.148(0.084) *	0.018(0.01)*	-0.009(0.005)*	-0.009(0.005)*
Information sources	Internet	0.106(0.372)	-0.013(0.046)	0.007(0.023)	0.007(0.023)
	Radio	0.347(0.328)	-0.043(0.041)	0.021(0.02)	0.022(0.021)
	Television	-0.896(0.356) **	0.126(0.055)**	-0.06(0.026)**	-0.066(0.031)**
	Research institutes/university	0.177(0.389)	-0.023(0.052)	0.011(0.025)	0.012(0.027)
	Mobile	0.753(0.442) *	-0.081(0.041)**	0.041(0.022)*	0.04(0.02)**
Climate extreme event	Drought impact	-0.437(0.175) **	0.055 (0.022)**	-0.027(0.011)**	-0.028(0.011)**
CCA strategies	Small-scale irrigation	-0.646(0.314) **	0.079(0.038)**	-0.039(0.019)**	-0.04(0.02)**
	Agroforestry	-1.388(0.451) ***	0.146(0.038)***	-0.073(0.021)***	-0.073(0.02)***
	Temporary migration	-0.026(0.319)	0.003(0.04)	-0.002(0.02)	-0.002(0.02)
	Off-farm activities	0.082(0.314)	-0.01(0.039)	0.005(0.019)	0.005(0.02)
Agro-ecological region	Mountain region	-1.058(0.559) *	0.129(0.068)*	-0.063(0.034)*	-0.066(0.036)*
	Hilly region	-0.553(0.474)	0.066(0.055)	-0.033(0.028)	-0.033(0.028)
	/cut1	-0.703(0.985)			
	/cut2	0.158(0.985)			
	Observations	400			
	Chi-square	95.929			
	Prob > chi2	0.000			
	R-squared	0.18			

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively. The averages marginal effects are reported, and the standard errors are in parentheses.

5.2.4.2.3 Economic aspects and food security

Our FCS model shows that remittances received from the migrant members of the households have a statistically significant effect on the food security status of the farm households. This finding is contrary to our previous expectations (Table 9). This may be because a household's remittances are used for other purposes, such as paying for their children's education, spending in the construction of a house, or buying land in a better location, instead of buying food. Nepal has one of the highest ratios of remittances to GDP in the world; in 2021/22, remittances contributed 30% of national GDP (Government of Nepal, 2022). Globally, and in Nepal in particular, labour migration is widely seen as an essential strategy for improving the food security of farming households (Gartaula et al., 2012). Remittances are one of the main reasons for the decline in poverty in Nepal, from 42% in 1995/96 to 21.6% in 2016 (Government of Nepal, 2022). However, the most desperate and unskilled migrants tend to receive the lowest remittances. And those households that migrated first had to borrow money to go abroad. Because they are unskilled workers, their income is relatively low, and they still have to pay a high interest rate. So, households spend all their remittances on paying their debts but can't afford to buy quality food. In contrast to our findings, studies by Sam et al. (2019) in India and Abdullah et al. (2019) in Pakistan report that household members with migrants are more food secure than households without migrant members.

5.2.4.2.4 Geographical aspects and food security

In our RCSI model, the coefficient of land size was statistically significant at the 1% level of significance. As estimated, land size is positively related to food security. Furthermore, the marginal effect shows that one Ropani (1 Ropani=0.051 hectare) increase in land size increases the likelihood of a household being in no or low coping categories by 0.4%. It also increases the likelihood of a household being in high coping categories by 0.2% of the RCSI model. This indicates that households with more land are more prone to achieving food security than those with smaller land holdings. This trend may be because farming households with larger landholdings often have a wider variety of crops, contributing to a more varied and nutritious diet than households with smaller landholdings. Another likely reason is that households with larger landholdings have greater potential to increase productivity to achieve better food security. Physical capital helps to reduce community food insecurity by increasing the level of bonding and bridging social and economic capital (Chriest & Niles, 2018). Our findings are similar with Nkomoki et al. (2019); Balana et al. (2022); and Randell et al. (2022), who reported that land size increases household food security status.

Our results showed a statically significant and negative relationship between access to the nearest market (in hours) and household food security. This indicates that households closer to the market are more likely to be food secure than those further away. The marginal effect indicates that distance to the nearest market increases by one hour, decreases by 0.9% to be in the high and medium coping categories, respectively, while it increases by 0.18% to be in the no or low coping category of the RCSI model. Our findings are in line with Akukwe, (2020) and Mustapha et al. (2016), who reported that a unit increase in distance to the market decreases the likelihood of being food insecure.

5.2.4.2.5 Information sources aspects and food security

In Nepal, our research has shown that access to information is another important factor contributing to food security. The FCS model showed that access to information through research institutes and universities reduced the probability of a smallholder household being in the poor category by 0.7%, while such a household was 2.6% less probable to be in the borderline category and 3.4% more probable to be in the acceptable category. In our RCSI model, we found that access to information through television and mobile phones has a significant impact on food security. According to the RCSI model, access to information through television led to a 6.6% decrease in the probability of a smallholder household being in the high coping category. In addition, such households were 6% less probable to be in the medium coping category and 12.6% more probable to be in the no or low coping category. According to Ullah et al. (2020), the availability of information is critical to improving food security. Our finding is consistent with studies by Ogunniyi et al. (2021), and Wang et al. (2021), who found that access to information increases farmer productivity and income, leading to food security and poverty alleviation.

However, in our RCSI model, access to information through mobile phones increased the likelihood of a smallholder household falling in the high coping category by 4%, while such a household was 4.1% more probability to be in the medium coping category and 8.1% less likely to be in the no or low coping category. This may be due to the fact that the information received via mobile phone is difficult for farmers to understand, as not all farmers are well educated and experienced with mobile devices. In addition, smallholder farmers in Nepal continue to depend on the traditional approach to farming and believe in tradition and culture more than the information they receive over the phone. In contrast to our findings, a study by Ogunniyi et al. (2021) reported that access to mobile phone communication promotes food security by reducing the probability of being in the food insecure category by 15%.

5.2.4.2.6 Drought aspects and food security

Our study found that the impact of drought has a statistically significant and adverse association with the food security of the sampled households for both models. Our study of the FCS model found that the impact of drought was significant and negative at the 1% significance level. It was found that 0.4% and 1.4% of the smallholder households had a higher probability of falling into the poor and borderline categories, respectively, and that 1.9% of the smallholder households had a lower probability of falling into the acceptable categories. The impact of rising temperatures leads to severe drought, which damages crops and increases disease and irrigation costs (Qtaishat et al., 2022). This suggests that as the impact of drought intensifies, smallholder households are more likely to fall into the food insecure category.

Similarly, our results from the RCSI model indicate that drought has a statistically significant and negative relationship with food security. It shows that drought-affected households are 5.5% more likely to be in the no or low coping category, while 2.7% and 2.8% less likely to be in the medium and high coping categories, respectively. Our study is in line with Sam et al. (2019); Debnath & Kumar Nayak, (2022); and Qtaishat et al. (2022), who reported that drought-prone households are more vulnerable to food security and insisted that drought is one of the climate risk factors for the smallholder household food security.

5.2.4.2.7 Climate change adaptation strategies aspects and food security

Our results showed a significant and positive association between adopting climate change adaptation strategies and the food security status of small farm households. The small-scale irrigation adoption was statistically significant with both food security indicators. About 0.7% and 2.3% of small-scale irrigation adopters were found in FCS's poor and borderline categories, respectively. At the same time, 3% of households who adopted small-scale irrigation were to be in the acceptable category of FCS. Similarly, the RCSI model showed that small-scale irrigation increased the probability of a smallholder household being in the no or low coping category by 7.9%, while such households were 3.9% and 4% less likely to be in the medium and high coping categories, respectively. This finding is consistent with studies in Ethiopia by Enkuahone Kassie, Alamirew Alemu and Jambo et al. (2021), who concluded in their paper that irrigation significantly and positively impacts household food security. They also recommended continued investment in smallholder irrigation for poverty reduction. To achieve sustainable food security, adaptation to climate change helps to mitigate its adverse impacts (Chandra et al., 2016; Mahmood et al., 2019; Ajani & Geest, 2021; Muench et al., 2021). Furthermore, a study by Kandel et al. (2023), in Nepal found that economically marginalised farmers, especially those living in geographically difficult mountainous areas and belonging to lower socio-economic strata are more likely to adopt off-farm strategies as a pragmatic approach to changing climate. These strategies may serve livelihood diversification and contribute to food security.

Regarding adopting agroforestry, the RCSI model found that adopting this strategy increases the likelihood of a smallholder household being in the no or low coping category by 14.6%, while it reduces the probability of being in the medium or high coping category by 7.3% each. This means that adopting agroforestry improves crop yields, positively influencing household food security. It furthermore enhances the adaptive capacity of smallholder farmers by providing multiple benefits such as food sources, additional income, and environmental protection (Ullah et al., 2022). Our results align with the findings of Nkomoki et al. (2018), who reported that agroforestry contributed to in reducing the number of food insecure households in Zambia.

Adopting temporary migration as a CCA strategy reduced smallholder households' probability of being in the FCS model's poor and borderline categories by 0.6% and 2%, respectively. Meanwhile, temporary migration increased the likelihood of smallholder households being in the acceptable category of the FCS by 2.6%. This is in line with Debnath &

Kumar Nayak, (2022); and Demont, (2022), who reported that extreme climate events push household members into seasonal migration, exerting a favourable influence on food security.

Contrary to our assumption, off-farm activities significantly and negatively impact food security in our FCS model. The result indicates that 0.5% and 1.7% of smallholder households were more likely to be in the poor and borderline categories, respectively, while 2.2% of smallholder households were less likely to be in the acceptable category of the FCS. This suggests that engaging in off-farm activities had a negative impact on food security. This may be because the income from off-farm activities was not sufficient to cover the cost of food purchases. In addition, in Nepal, farmers who engage in off-farm activities are less likely to focus on their farms, leading to food insecurity. Adopting off-farm activities helps farmers escape a broader state of food insecurity (Kassegn & Endris, 2021). In contrast to our findings, Tien Thanh et al. (2020) reported that off-farm activities positively influence household food security. Moreover, a study by Kassegn & Endris, (2021) reported that off-farm activities increase food security status and promote livelihood diversification.

5.2.4.2.8 Agro-ecological zone and food security

Regarding location, our results from both models showed that farm household food security was correlated with all regions. The results from the FCS model showed that farm households in the Hilly region had a significant and negative relationship with food security at the 1% significant level. The results showed that farm households in the Hilly region are 5%

and 15% more likely to be in the poor and borderline categories than those in the Terai region. On the other hand, they are 20.2% less likely to be in the acceptable category than farmers from the Terai region. This suggests that smallholder farmers from the Hill region were more food insecure than those from the Terai region. This may be because weather conditions were only sometimes favourable for farmers in the Hills. As a result, farmers in the Hills could not produce enough food for their consumption and sale, which would have given them income to buy other food items than in the Terai region.

Our RCSI model results showed that mountain farmers' probability of being in the no or low category increased by 12.9% while decreasing the probability of being in the medium and high coping categories by 6.3% and 6.6%, respectively. This is contrary to our previous expectation, but because Mountain farmers engage in temporary migration and off-farm activities as a livelihood diversification that supports households in the food security category. In addition, the Mountain region is a tourist area that provides short-term jobs for local people, which helps smallholder farmers to diversify their incomes. During our face-to-face interview, some farmers reported working as porters during the tourist season and earning some money. Several previous researchers, Theriault et al. (2018), Karki et al. (2020) and Acheampong et al. (2022) reported that agro-ecological zones play significant role in food security.

5.2.5 Conclusion and recommendations for policy implications

Agricultural production and food insecurity are adversely affected by the increasing frequency and severity of climate extremes like drought. In the context of smallholder farmers' vulnerability to climate change's challenges, this study aimed to examine the factors influencing food security in Nepal. The demographic, social, economic, and geographical attributes of households hold significant sway in mitigating food insecurity, especially when faced with the worsening impacts of climate change extremes in Nepal. The results suggest that the impact of drought has pushed households into the food insecure category. However, household's adaptive capacity plays crucial in reducing food insecurity. Our findings revealed that the higher smallholder adaptive capacity significantly enhances food security status. Strengthening climate change adaptation strategies as an influential intervention ultimately reduced their food insecurity status. Households showed different levels of food insecurity, with those in the Hill AEZs reporting more food security than their Hill and Terai AEZs counterparts. Hill farmers implemented temporary migration and off-farm activities to improve their food security by generating more income.

The results of our research highlight the urgent need to formulate policies, programmes and strategies aimed at empowering smallholder farmers. These initiatives should focus on reducing their vulnerability to climate variability while addressing food insecurity issues. Policymakers can promote climate change adaptation strategies and diversify livelihoods through education, especially among households that lack formal education. Non-formal education campaigns may prove effective in engaging uneducated and illiterate households. Moreover, it is strongly recommended that concerted efforts increase agricultural productivity, leading to improved food security outcomes. To achieve this, it is imperative to prioritize improved access to comprehensive weather and climate information, including accurate forecasts, for farmers in the region. This proactive approach has the potential to catalyze positive changes in both agricultural sustainability and the overall well-being of farming communities. Furthermore, adaptation strategies need to be carefully designed to fit the underlying biophysical, socio-economic, climatic, and institutional structures of each agro-ecological zone. Collaborative action is paramount and requires the active involvement and coordination of governments, non-governmental organisations, and all relevant stakeholders. This collective effort empowers smallholder farmers to effectively cope with and adapt to existing and future climate impacts and related challenges and, ultimately, to assure food security.

5.3 From fields to new horizons: smallholder farmers' rural-out migration and its impact on food security

5.3.1 Introduction

Rural out-migration (both internal and external) continues on a large scale in less developed countries (Selod & Shilpi, 2021). In Nepal, the rural out-migration rate was 4.35 per 1000 population in 2022, an increase of 19.72% compared to 2021. The rural out-migration rate in 2021 was 3.64 per 1,000 population, an increase of 24.52% compared to 2020 (World Bank, 2023). This high level of rural out-migration has primarily affected the country's agricultural sector since approximately 85% of the rural population in Nepal are engaged in agriculture, primarily in smallholder farming. Smallholders have frequently helped themselves by temporarily migrating to other places within and outside the country. They see migration as a more fruitful strategy in the face of harsh climatic conditions, reduced yields, and food insecurity (Kandel et al., 2023). For Nepalese smallholder farmers, rural-out migration is a key driver of economic growth and food security.

While rural out-migration is enhancing the food security status of smallholder farm households, it has also adversely affected agricultural productivity.(Kim et al., 2019). Accomplishing SDG1 and SDG2 (no poverty and zero hunger) in the context of a growing population will require a continues attention to food production. This is because these two goals are top priorities for ending poverty in all its forms and hunger, thereby achieving food security, and sustainability in the agriculture sector. Moreover, these two SDGs are intricately linked to other goals. For instance, SDG1 is related to health (SDG Goal 3) and climate action (SDG Goal 13) whereas food security (SDG Goal 2) is linked to decent work and economic growth (SDG Goal 8) and reducing inequality (SDG Goal 10). Therefore, the achievement of the first two SDGs can contribute significantly to the realization of other interconnected goals as well.

On the one hand, agricultural growth holds utmost important for the country's food security (Rijal et al., 2022). Conversely, smallholder farmers struggle to sustain their livelihoods solely through agriculture (Karki et al., 2021). While engaged in farming, they primarily produce staple foods and face challenges in generating a substantial income from their farm endeavours (Christiaensen et al., 2021). Owing to prevailing poverty, mostly smallholder farmers continue to rely on traditional production methods, which contribute to decrease in their crop productivity levels (Kamau et al., 2022). The reduced yield from agricultural sector leads to inability of smallholder farmers to adequately provide for their families, thereby exacerbating issues of food insecurity (Asare-Nuamah, 2021). However, remittances from rural out-migration play a crucial role in alleviating household poverty and ensuring food security (Gupta et al., 2021). Remarkably, these remittances constitute a significant portion (27%) of Nepal’s GDP, reflecting their substantial impact on the country’s economy (World Bank, 2023). For smallholder farmers, these remittances stemming from rural-out migration serve as an indispensable source of employment and income (Piras et al., 2018).

With respect to motives and determinants, migration has been primarily defined by age, gender, and marital status. Most empirical findings confirmed the dominance of young, male, and the married moving out from the rural areas to take advantage of better job opportunities (Abebaw et al., 2020; Kim et al., 2019; Mergo, 2016; Sadiddin et al., 2019). Mainly poor households tend to send their male children to less distant destinations to search for jobs (Nguyen et al., 2015). In contrast, the dominant form of migration for high-income households is intercontinental (Ayanie et al., 2020). Education is another determinant factor of migration (Duda et al., 2018; Epstein et al., 2022). Migrants from developing countries are often poorly educated and have no or limited skills (Segal, 2019). They find themselves underpaid and irregularly paid in informal jobs. (Epstein et al., 2022). Previous studies have shown that people with higher education tend to choose cities as their destination, while lower education was associated with rural-rural migration (Bierkamp et al., 2021; Malamassam, 2022; Selod & Shilpi, 2021). In addition, social groups, such as ethnic majority or minority groups, have a significant impact on rural out migration (Bierkamp et al., 2021; Epstein et al., 2022b; Karki et al., 2022). Due to access barriers to other sources of income, ethnic minority households intend to migrate in order to improve their living conditions (Bierkamp et al., 2021; Debnath & Kumar Nayak, 2022; Epstein et al., 2022). The self-employment and other forms of off-farm activities on migration has been mixed influence. According to their study in Tanzania, off-farm activities enhance the food security and diversification of livelihoods of rural smallholder households (Duda et al., 2018). In Vietnams, Nguyen et al. (2015) households with non-agricultural activities were found to be less likely to migrate than households with agricultural activities (Nguyen et al., 2015). Another factor contributing to rural out migration is the reduction in crop yields due to climate change (Black et al., 2011; Duda et al., 2018; Ocello et al., 2015). According to (Jacobson et al. (2019)perceived reduction in crop yields due to climate shocks increases the tendency of household members to migrate Location is another important variable in migration (Debnath & Kumar Nayak, 2022; Jacobson et al., 2019). The impact of migration depends on different agroecological zones. People in remote agro-ecological zones have much lower crop productivity and soil fertility and are more prone to migration (Black et al., 2011). A study by Dupre et al. (2022) in Guatemala reported that access to sources of information is an important factor of the migration. They argued that having access to information provided a strong insight into farming practices and prevented farmers from looking to work in other areas.

Previous empirical studies of the migration-food security nexus in developing countries have been mixed results. Studies in Vietnam by Nguyen & Winters, (2011), in Ethiopia by Abebaw et al., (2020), in Tanzania by Duda et al., (2018), in Tajikistan by Azzarri & Zezza, (2011), reported positive effects of rural out migration on food security. On the contrary, others (Kim et al., 2019b; Sunam & Adhikari, 2016)have found that rural out-migration only improves food security on a short term and can have adverse effects on food security in the long run (Kim et al., 2019b; Sunam & Adhikari, 2016),.

Comparatively less attention has been paid to the impact of rural out-migration on household food security. Nepal is the most appropriate study area to examine the relationship between rural out-migration and household food security status. Despite Nepal's progress in poverty reduction in recent years, food insecurity continues widespread in the country, affecting several million households (FAO, 2021). To our knowledge, this is the first paper to bring together different pull and push factors of migration, such as household, social, climate, location, and access to information sources. Therefore, in this paper, we quantitatively examine the impact of rural out-migration on household food security in Nepal. We address the identified gaps in the literature by posing two main research questions.

1) What are the factors affecting migration of rural smallholder farmers in Nepal?

2) What is the impact of rural out migration on food security status of rural smallholder farmers in Nepal?

In four important respects, our discoveries support important information. First, it contributes to and promotes the UN's 2030 Sustainable Development Agenda, as migration is explicitly considered in 8 of the 17 SDGs. Second, our research is expected to shed light on the impact of migration on development. Such a contribution is important as food insecurity remains a widespread development problem in Nepal. Third, by using a large and unique dataset of 400 rural Nepalese households, we add to the body of empirical literature that specifically considers immigration from the perspective of the country of origin. Most datasets are inadequate for the study of migration due to a lack of information on the links between rural households and their migrants, or the inclusion of only officially registered migrants, such as those identified in household living standard surveys. Finally, the potential contribution of rural out-migration to improving household food security in the face of climate shocks and other constraints is often overlooked in in-country policy discussions. Therefore, understanding the drivers of rural out-migration and its impact on food security will enable policymakers, donors, and advisors to strategically target policies and funding. By understanding the drivers of rural out migration and its impact on food security, policymakers, donors, and extension agents can design tailored interventions to support the most vulnerable household farmers. This proactive strategy will increase their adaptive capacity to cope with food insecurity and promote sustainable progress within farming communities.

The paper is organized as follows: Section 2 briefly introduces the data and the methodology. In Section 3, the results of the data analysis are presented and discussed. Finally, Section 4 summarizes the findings and concludes by drawing some policy implications.

5.3.2 Conceptual framework

Push-pull theory and New Economics of Labour Migration (NELM):

Various theories and models have been developed in regard to migration issues. For the scope of this study, we have employed the push-pull theory of migration and the New Economics of Labour Migration (NELM).

The push-pull theory, initially purposed by Lee (1966) is closely linked to the neoclassical theory of migration (Zeng et al., 2021). This theory conceptualises migration as a result of unfavourable (push) factors in the place of origin and favourable (pull) factors in the destination (Lee, 1966; Zeng et al., 2021). Push factors encompass motivations such as political, social, or economic insecurity along with inadequate employment opportunities, driving smallholders to migrate. Conversely, pull factors encompass social, economic, political, and environmental incentives in the destination. These include job opportunities, better education and living conditions (Niu, 2022). This approach distinguishes between push and pull influences, as well as potential barriers to migration, such as moving costs and legal barriers (Lee, 1966). The push-pull theory has been used in some recent demographic gravity modelling studies and is particularly applicable to the case of environmentally induced migration (Gu et al., 2022; T. Liu et al., 2022; Z. Zhao et al., 2021). Environmental considerations can impact both push and pull factors, for example, impact of climate change indicators like temperature rise, erratic rainfall, drought, floods can act as push factor, while favourable environmental conditions can act as pull factor (Sajjad et al., 2020).

The NELM theory proposed by Stark & Bloom in 1985 analyse the relationship between migration and food security. NELM views migration as a household decision aimed at reducing risk and enhancing livelihoods, rather than an individual choice. This theory assumes that the total costs or benefits of migration are shared within migrant households (Stark & Bloom, 1985). NELM provides a comprehensive perspective, exploring not only migration drivers but also its growing impact on countries of origin (Hermans & Garbe, 2019b; Taylor, 1999). Households may choose to migrate certain members in order to maximise food security and ensure sustainable livelihoods by diversifying resources such as labour. Thus, migration is seen as a sustainable strategy to mitigate household food security risks and diversify livelihoods (Abebaw et al., 2020).

However, rural out-migration can affect food security through both positive and negative channels (Abebaw et al., 2020; Sadiddin et al., 2019b). A positive aspect of rural out-migration is that it can enhance food security through remittances or money brought back by returning migrants (Obi et al., 2020). Alternatively, the departure of a household member can improve food security for those remaining by reducing the mouths to feed(Kim et al., 2019). Furthermore, rural out-migration can provide an opportunity to acquire additional agricultural knowledge that benefits the food security migrant sending households (Spangler & Christie, 2020). On the downside, the migration of active and productive workforce may lead to reduce labor availability for food and agricultural production at home, potentially worsening food security for migrant-sending households (Das et al., 2020; Vo, 2023). It is therefore difficult to predict the net effect of migration on food security as it can vary based on the circumstances (Wegenast & Beck, 2020). Thus, empirical research is necessary to determine the overall impact of migration on food security in different context (Nguyen & Winters, 2011).

5.3.3 Analytical tools

5.3.3.1 Probit model

We used a probit model to examine the factors that influence a smallholder household member's decision to migrate. The probit model is advantageous for studying migration because it allows the analysis of binary outcomes, such as whether or not households have a migrant member. Furthermore, it considers the binary nature of migration decisions while providing information on the relative impact of push and pull factors on migration decisions. The probit model was formulated as follows:

$$Y_{ik=\beta_1} x_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,

X_i represents a set of all explanatory variables presented in the study (see Table1 for the list of explanatory variables),

β_1 is a vector of estimated parameters, and

ε_i is an error term.

Y_{ik} is household with migrated members,

The system of equations that describes the binary decisions of smallholder farmers household members is as follows:

$Y_{ik} = 1 \text{ if } Y_{ik} > 0$

$0 \text{ otherwise } \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$

The estimated average marginal effects are presented in the results section.

5.3.3.2 *Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR)*

Due to observable and unobservable bias, determining the causality between rural out migration and household food security status is not straightforward. Controlling for both observable and unobservable characteristics through the random assignment of individuals to treatments is necessary for accurate impact measurement. Selection bias may arise in the absence of random assignment because observed and unobserved characteristics of individual smallholder household members may influence the likelihood of receiving treatment (migrating) as well as the outcome variable. To account for both observable and unobservable bias (i.e., the so-called endogeneity problem), we used PSM, and ESR techniques (El-Shater et al., 2016; Hu et al., 2021). The PSM and ESR methods help to eliminate selection bias (i.e., observable, and unobservable) associated with establishing conditional causality with observational data when randomised trials are infeasible (Hu et al., 2021). To determine the average difference in the outcome variable between treated and untreated households, we used the PSM to first match each treated smallholder household to a comparable untreated household. Thus, the PSM helps us to know: "What would have happened to the food security status of a smallholder household with migrated members (treated) if that same smallholder household had no migrated members (control)?". Following Imbens & Wooldridge (2009), the Average Treatment Effect on the Treated (ATT) is as:

$$ATT = E[Y(1) - Y(0)|T = 1] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

In this study, we define Y(1) and Y(0) as outcome indicators representing the food security statuses of migrated and non-migrated smallholder households. T is the treatment variable. We can estimate the food security status of a household with migrated members (treated), $E[Y(1)|T = 1]$ from our dataset but $E[Y(0)|T = 1]$ is missing. Thus, we cannot directly observe the household food security status of treated households if they had not received the treatment. Consequently, a simple comparison of household food security status between those with and without migrated members introduces self-selection bias into the estimated impacts. The extent of self-selection bias is reported in detail to provide a full understanding of its influence on the results.

$$E[Y(1) - Y(0)|T = 1] = ATT + E[Y(0)|T = 1 - Y(0)|T = 0] \ldots\ldots\ldots\ldots (4)$$

PSM diminishes bias by creating comparable counterfactual for smallholder households with migrated members. The method assumes that there are no systematic differences between treated (migrated) and non-treated (non-migrated) smallholder households once they are matched based on observed characteristics (Imbens & Wooldridge, 2009). Under this conditional independence assumption and meeting the required overlap, the ATT is computed following a specific procedure.

$$ATT = E[Y(1)|T = 1, p(x)] - E[Y(0)|T = 0, p(x)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5$$

However, in the presence of misspecification in the propensity score model, the ATT obtained from PSM may still produce biased results (Imbens & Wooldridge, 2009; Robins et al., 2007; Wooldridge, 2007; Wossen et al., 2017).

Matching techniques can effectively deal with selection bias due to observable factors, even with adjustments for misspecification bias. However, if unobservable heterogeneity, such as the inherent skill of a smallholder household member, leads to endogeneity problems, the estimates obtained by matching may still be biased. We addressed the endogeneity problem using the ESR model in the second step. The ESR considers both observed and unobserved biases (M. Liu et al., 2021; Sileshi et al., 2019a; Udimal et al., 2020) . The ESR method solves the endogeneity problem by estimating the selection and outcome equations using full information maximum likelihood (FIML) (M. Liu et al., 2021; Wossen et al., 2017a).

To ensure proper ESR identification, at least one instrumental variable is needed. The instrumental variable should affect the treatment rather than the outcome variable of interest (S. Ullah et al., 2021). We conducted a falsification test to verify the appropriateness of the instrumental variable in the model. We identified 'access to information as a potential instrumental variable for smallholder households with migrated members. To create the instrumental variable, we used a dummy variable access to information, derived from the question 'Do you have access to information sources such as internet, television, radio, etc.? The assumption is that farmers with access to information are more likely to benefit from rural migration. However, we do not assume that access to information has a direct impact on the outcome variable of interest, as access alone does not directly improve or reduce household food security (Wossen et al., 2017). We assume that a given farm household would opt for the treatment, i.e., having migrant household members, if the expected benefit of the treatment (in terms of food security status) is positive. Let F_0 be the food security status of farm households without migrant members (i.e., the control group) and let F_1 be the corresponding food security status of farm households with migrant members. The farmer's decision to choose the treatment (having migrant members) that improves food security is defined as $Y_i^* = F_1 - F_0$, which is expected to be positive. However, the actual improvement in food security status that a farmer-household derives from migrant members, treatment (Y_i^*), is a latent variable determined by the observed characteristics (Z_i) as follows:

$$Y_i* = \beta^0 + \gamma Z_i + \mu_i \text{ with } T_i = \begin{cases} 1 \text{ if } Y_i*>0 \\ 0 \text{ if } Y_i*\leq 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Vector Z represents the variables that influence the expected food security gains from rural out-migration. The conditional outcome function can be formulated as an ESR model as follows:

$$Regime1: Y_{1i} = \gamma 1 \times X1i + \varepsilon_{1i} \text{ if } T_i = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$Regime2: Y_{2i} = \gamma 2 \times X2i + \varepsilon_{2i} \text{ if } T_i = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Whereas Y_{1i} represents the outcome indicator for smallholder households with migrants (treated group), while Y_{2i} represents the outcome indicator for smallholder households without migrants (control group), and x_i denotes a vector of exogenous variables. The error term associated with the outcome variable is included in both the selection equation (i.e., equation (6) and the outcome equation (i.e., equations (7) and (8)). The error terms are assumed to have a tri-variate normal distribution with mean zero and covariance matrix (Ω) as follows:

$$\Omega = \begin{bmatrix} \sigma_u^2 & \sigma_{1\mu} & \sigma_{2\mu} \\ \sigma_{1\mu} & \sigma_1^2 & . \\ \sigma_{2\mu} & . & \sigma_2^2 \end{bmatrix}$$

where $\sigma_u^2 = \text{var}(\mu_i)$, $\sigma_1^2 = \text{var}(\varepsilon_1)$, $\sigma_2^2 = (\varepsilon_2)$, $\sigma_{1\mu} = \text{cov}(\mu_i, \varepsilon_1)$, $\sigma_{2\mu} = \text{cov}(\mu_i, \varepsilon_2)$. Moreover, σ_u^2 = is estimable up to a scale factor and can be assumed to be equal to 1 and cov(ε_1, ε_2) is not defined as Y_1 and Y_2 cannot be observed simultaneously. Moreover, the correlation between the error term of the selection equation and the outcome equation is not zero (i.e., corr(μ_1, ε_1) ≠ 0 and corr(μ_1, ε_2) ≠ 0), which creates selection bias. ESR addresses this selection bias by estimating the inverse mills ratios (λ_{1i} and λ_{2i}) and the covariance terms ($\sigma_{1\mu}$ and $\sigma_{2\mu}$) and including them as auxiliary regressors in Equations (10) and (11). If $\sigma_{1\mu}$ and $\sigma_{2\mu}$ are significant, we reject the absence of selection bias. In addition, $\sigma_{1\mu} < 0$ represents positive selection bias. The ESR model estimates can then be used to estimate ATT as follows:

$$E(Y_{1i}|T_i = 1) = \gamma_1 x_{1i} + \lambda_{1i}\, \sigma_{1\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$E(Y_{2i}|T_i = 0) = \gamma_2 x_{2i} + \lambda_{2i}\, \sigma_{2\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$E(Y_{2i}|T_i = 1) = \gamma_2 x_{1i} + \lambda_{1i}\, \sigma_{2\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$E(Y_{1i}|T_i = 0) = \gamma_1 x_{2i} + \lambda_{2i}\, \sigma_{1\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The equations (9) and (10) show the observed expectations from the sample, while equations (11) and (12) show the counterfactual expected outcome (12). Furthermore, to calculate the ATT for the treated "beneficiary" smallholder households, we determine the difference between equations (9) and (11), following the methodology outlined in (Hu et al., 2021; Miranda & Rabe-Hesketh, 2006; Sarma & Rahman, 2020; Sileshi et al., 2019).

$$ATT = E(Y_{1i}|T_i = 1) - E(Y_{2i}|T_i = 1) = x_{1i}(\gamma 1 - \gamma_2) + (\sigma_{1\mu} - \sigma_{2\mu})\lambda_{1i} \dots\dots\dots\dots (13)$$

which represents the impact of rural out-migration on the household food security status.

5.3.3.3 Selection of variables

The study uses different types of variables: treated, output, control and instrumental (see Table 12). Previous research has shown that demographic, socio-economic and institutional factors can influence the food security status of smallholder farmers. Section 2 of the study identifies several proxy variables that could potentially affect the food security status of smallholder households. These variables include age, gender, marital status, education level, social group, involvement in off-farm activities, exposure to climate change impacts, agro-ecological zones, access to information sources and households with migrant members.

5.3.4 Results and discussion

We begin this section with descriptive statistics of the whole sample and test statistics of differences in the mean of the migrated (treatment group) and non-migrated (control group) in Table 12. Table 13 shows the determinants of migration (normal probit model). In Table 14, we present the results of the treatment effect of migration on food security before and after the treatment of observable and unobservable bias with the PSM and ESR methods.

5.3.4.1 Descriptive statistics and mean difference of the model variables

The model variables used in this study are present ed in Table 12 below. The result shows that 35% of the households had at least one migrant member in the last 10 years. Regarding food security status, the non-migrated households had 6.45 FCS points more than the migrated households. The average age of the household head was 50 years. There was no considerable mean difference in the age of the heads of migrated (51.53 years) and non-migrated (49.65 years) household. Most of the households were managed by males, accounting for 72%. Our results correspond with the World Bank (2016) report on a demographic and health survey conducted in Nepal. According to the 2016 World Bank report, the rate of households in Nepal with a male head is falling, at 68.7% now. Most of the household heads were married, accounting for 85%. There is a statistically significant difference in marital status between migrated and non-migrated households. In terms of level of education, 65% of household heads had a formal education. Moreover, there is a significant difference in the level of formal education of household heads with migrated members and those without migrated. Eleven percent (11%) of households with migrated members were less educated than their counterparts. A World Bank (2016) report for

Nepal stated that the country's literacy rate was 67.91%, which is very close to our results from the selected study area. In our study, we differentiated social groups into the Brahmin and others. The Brahmin social group constitutes 24% of the total sample size. There is significant difference between migrated and non-migrated households in regards Brahmin social groups. Fifty-eight percent (58%) of the households were involved in off-farm activities. There is a statistically significant difference between the two groups in terms of their off-farm activities. Households with migrated members were more involved in off-farm activities than non-migrated member-households. The reduction in crop yields in the last five years due to climate change was measured by a 5-points Likert scale - the value 1 represents there was no reduction in crop yield due to climate change and 5 represents there was reduction in crop yield (more than five times in last 5 years) due to climate change. From the results, the migrated member-households had high perception (3.22) that their reduced crop yield in the past five years is due climate change compared to non-migrated member-households (3.03). However, there was no statistically significant difference between migrated and non-migrated member-households in terms of frequency of reduction of crop yield as a consequences of climate change. Regarding the agroecological zones of respondents, approximately 46% of the respondents were from the mountain region, while 38% were from hilly region and remaining 17% were from terai region. In all agroecological zones shows statistically significant difference between migrated and non-migrated member-households. In the Mountain and Hilly AEZ, respectively, 23% and 51% of households had at least one migrant, whereas 58% and 30% of households did not. In the Terai AEZ 26% of the households had at least one migrant member, whereas 12% did not. Regarding having access to information, 61% of households had access to various sources of information such as radio, TV, internet, etc. Most of the non-migrant households have access to different sources of information (64%) compared to the migrant households (54%).

The t-test of differences in mean in Table 12 affirms our choice of treatment effect approach. From the results of the covariates, there are statistically significant differences in the means between the migrant households and the non-migrant households. This is an indication that an estimation of the effect of migration on household food security status might be biased due to differences in characteristics of the selected treatment and control groups. We treat both the known and unknown biases in sub-section 4.3 of this chapter using the PSM and ESR methods.

Table 12 Definition of variables and descriptive statistics

Variable	Variable definition	Full sample (n=400) Mean (Std.Dev)	Migrated Household (n=141) Mean (Std.Dev)	Non- migrated Household (n=259) Mean (Std.Dev)	Diff.in mean (t-test)
Treated variable					
Migration	Dummy=1 if at least a member of household migrated in last 10 years, 0 otherwise	0.35 (0.48)			
Output variable					
FCS	Continuous, household food consumption score value	73.93 (22.51)	69.76 (20.31)	76.21 (23.35)	6.45***
Control Variables					
Age	Continuous, household head age in years	50.32 (13.99)	51.53 (14.16)	49.65 (13.89)	-1.88
Gender	Dummy= 1 if the household head is male, 0 otherwise	0.72 (0.45)	0.74 (0.44)	0.71 (0.46)	-0.04
Married	Dummy=1 if the household head is married, 0 otherwise	0.85 (0.36)	0.89 (0.31)	0.83 (0.38)	-0.07**
Education	Dummy=1 if education level is "formal" 0 otherwise	0.65 (0.48)	0.58 (0.49)	0.68 (0.46)	0.11**
Social group	Dummy=1 if household belongs to "Brahmin" social group, 0 otherwise	0.24 (0.43)	0.42 (0.49)	0.14 (0.35)	-0.28***
Off-farm activities	Dummy=1 if at least a member of household involved in off-farm activities, 0 otherwise	0.58 (0.49)	0.63 (0.48)	0.55 (0.49)	-0.08*
Reduce crop yield	Scale, frequency of reduction in crop yield occurred in last 5 years as a consequence of climate change (1-5 whereas 1= Never, and 5=)	3.09 (1.25)	3.22 (1.27)	3.03 (1.24)	-0.19
Agro-ecological zones	Dummy=1 if agroecology zone is Mountain "highland", 0 otherwise	0.46 (0.50)	0.23 (0.42)	0.58 (0.49)	0.34***
	Dummy=1 if agroecology zone is Hill "midland",0 otherwise	0.38 (0.48)	0.51 (0.50)	0.30 (0.46)	-0.21***
	Dummy=1 if agroecology zone is Terai "lowland",0 otherwise	0.17 (0.38)	0.26 (0.04)	0.12 (0.02)	-0.13***
Instrumental variable (IV's)					
Access to information sources	Dummy=1 if farmers have access to information sources, 0 otherwise	0.61 (0.49)	0.54 (0.50)	0.64 (0.48)	0.10**

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively. The averages marginal effects are reported, and the standard errors are in parentheses.

5.3.4.2 Determinants of rural out migration

Table 13 presents the results of the probit model used to analyse the determinants of rural household migration prior to the treatment effect analyses (i.e., PSM). The likelihood ratio test shows that the model estimates are significant at the 1% level. The results of the probit model indicate that age, social group (Brahmin), involvement in off-farm activities, and severity of environmental shocks on crops have a positive and statistically significant impact on the probability of a household member migrating. Formal education, and mountain agro-ecological zone have a negative and statistically significant effect on the probability of migration.

Regarding the socio-demographic characteristics, the results show that the propensity of a household member to migrate increases with the rising age of the household head. Specifically, an additional year in age increases the tendency to migrate by 1.3%. It is perhaps the older household heads may have middle-aged children that could migrate and remit funds home. The Nepalese society practice more collectivism than individualism (Porcher, 2021). Unity and altruism are valued traits in collectivist cultures; hence they are more likely to get remittance from non-relatives out of shared empathy and respect. Our results are in line with Mkrtchyan & Vakulenko, (2019) who found age group as strong determinant of migration flow since motivations of migration differs according to age. In contrast to our results, Duda et al (2018) reported that increase in age of the household head decreased the probability of migration in Tanzania. They argued that older household heads are more dependent on the direct labour of household members.

A household head having access to formal education (Primary to highest level) has a statistically significant negative effect on migration. The household heads with formal education are less likely to migrate. Particularly, the household heads with formal education have approximately 14% less chances of having a migrant member. The probable reason could be highly educated farmers have more employment opportunities within and outside the agriculture sector, hence are less likely to migrate for greener pastures. Our results conform with previous studies that argued that low level of education restricts the capability of people to get extra employment opportunities particularly in the non-agricultural industry (Abebaw et al., 2020; Lawson et al., 2020).

The effect of social groups of the household on migration was positive and statistically significant. Members of the Brahmin social group are more likely to migrate than other social groups. Specifically, farmer households from the Brahmin social groups are approximately 59% more likely to migrate than member of other social groups. The Brahmin social groups have high social network, access to resources such as land, financial capitals etc., and therefore are more capable of sending their wards abroad (Epstein et al., 2022; KC et al., 2016). In addition, we observed during the survey, that most of the Brahmin social group member-households had migrated members with education as the crucial reasons for migration. After completing their education, they find better opportunities outside of agriculture and are more likely to take advantage of these opportunities by migrating (Figure 7). Similar to our study Epstein et al. (2022) found that the Brahmin social group has benefits over other social groups, hence they are more likely to seize those opportunities by migrating for livelihood diversification.

In terms of household livelihood activities, households involved in off-farm activities such as self-employment were more likely to have a migrant than households that solely relied on farming. Specifically, involvement in off-farm activities increases a member's propensity to migrate by 35%. Off-farm activities generate more income for households and may increase their capacity to migrate. Moreover, a combination of on-and- off-farm activities would improve the economic status of households in the rural areas which was one of the primary reasons for migration based on Figure 7. Duda et al., (2018) found off-farm activities to have positive impact on the livelihood diversification and food security status of rural smallholder households in Tanzania. In contrast, households with off-farm activities in Vietnam were less likely to migrate according to (Nguyen et al., (2015). According to the authors, the household members did not migrate because they wanted to avoid the problem of labour shortages on the farms.

Crop yield reduction due to climate change related issues is another factor contributing to rural outmigration. The perceived decrease in crop yields due to climate shocks increase household members' probability to migrate by 14%. Members of the household would employ different coping mechanisms such as migration to cope with the economic impact of climate change. Our result is supported by Black et al., (2011) and Jacobson et al., (2019). In addition, studies from Tanzania (Ocello et al., 2015;Duda et al., 2018) found that environmental shocks which reduce productivity and yields in rural areas compel farmers to migrate. This is also described by Figure 7 where about 15% of the migrated individual's primary reason was climate shocks such as drought, landslides, and floods.

Living in remote mountain region decreases the propensity of a household member to migrate by 76%. Agricultural productivity and soil fertility are much lower in the study area. Yet, the mountainous area is important to the tourism industry. The remoteness and poor condition of rural road networks is a challenge for the tourism industry. As a result, smallholder farmers in the area participate in off-farm activities like porters and tourist guides during the tourist season. Funds generated from such sources help farmers maintain a better standard of living and improve their investment in agriculture. Similar study in Tanzania by Duda et al., (2018), stated that different agroecological zones have significant impact on migration due to their geographical characteristics.

Table 13 Factors affecting rural out migration

Variable	Probit	
	Coef.	Std. Err
Age	0.013*	0.006
Gender	0.034	0.161
Married	0.245	0.216
Education	-0.141*	0.077
Social group (Brahmin)	0.589***	0.196
Off-farm activities	0.345**	0.148
Reduce crop yield	0.139**	0.058
Agro-ecological zones	-	-
Mountain	-0.761***	0.246
Hill	-0.003	0.208
Cons	-1.27**	0.51
Number of observations	400	
Prob > chi2	0.0000	
Log likelihood	-219.34	

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively.

5.3.4.3 The impact of migration on household food security

Table 14 presents estimates of the effect of migration on food security status. As described in the analytical approach section, we begin the treatment effect approach with the PSM method in the first stage. We will then use the ESR method to check for potential endogeneity since the PSM fails to deal with the potential effect of unobserved bias on the outcome variable (FCS). The results from the PSM approach show that households with migrant members were worse off in terms of FCS (Table 14). More specifically, our study found that the FCS of households with migrant members would have had better FCS (i.e., food security status) if they had not migrated. The shortage of labour, which reduces crop productivity, could explain the lower food consumption score among migrant households. Most of the members of the migrant households are active labourers. When active labour migrates, the adoption of new agricultural technologies is reduced. This has direct implications for reducing agricultural output, agricultural incomes, and food consumption patterns. Nonetheless, the estimate of the PSM was not statistically significant. One of the reasons for the insignificant effect of migration on the food security (FCS) in the PSM is potential presence and effect of unobservable or hidden bias on the estimated outcome "so-called endogeneity problem". Besides, the PSM is not an efficient technique for treating endogeneity in treatment effect analysis (Issa, 2023). We therefore augmented the matching approach with an endogenous treatment effect procedure that considers both observable and unobservable bias.

Table 14 Treatment effect of migration on Food security (PSM and ESR model)

Variable	PSM				ESR			
	Treatment group	**Control group**	**Difference**		**Treatment group**	**Control group**	**Difference**	
	Coef	Coef		Std. Err (combined)	Coef	Coef		Std. Err (combined)
FCS	70.13	74.82	-4.69	3.40	69.76	61.08	8.68***	0.49

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively.

The ESR model generates average results for the treated household and corresponding counter-factual results, that is, what would have happened if the treated group had not received the treatment. The net difference between these two outcomes is the average treatment effect on the treated (ATT). These average outcomes and the estimated ATT are presented in Table 14, columns 5-8. Estimate of the ESR show that migration has a significant and positive effect on FCS. This means that households with members who have migrated are better off in terms of food security compared to households with members who have not migrated. More specifically, households with migrated members would have had 8.68 FCS points less if they had not migrated members. Our results suggest that households with migrant members in Nepal are effective in the improvement of food consumption score and for that matter, food security. Moreover, the estimate from the ESR is statistically significant and higher than the estimate from the PSM method, indicating the presence of selection bias and endogeneity of migration. It also confirms the appropriateness of the ESR model in dealing with observed and unobserved bias. These results are in line with those of Abebaw et al., (2020) in Ethiopia, who found that migration significantly improved daily calorie consumption per adult and reduced severity of food poverty. Our findings are also consistent with the growing literature on migration and its impact on food security in developing countries, where most researchers have found a positive correlation (Duda et al., 2018; Hasanah et al., 2017; M. C. Nguyen & Winters, 2011; Sadiddin et al., 2019).

5.3.4.4 Reasons for rural out migration of individuals

Figure 7 provides an overview of the main reasons for rural out-migration of individuals in households with migrant members. Of the 400 households in the sample, 141 had at least one migrant member. Both economic and non-economic factors play a role in the decision to migrate. In particular, education was the main reason for 23 percent of all migrant households, while 22 percent migrated for employment opportunities elsewhere. Climate change also played an important role in migration in the study area. Extreme climatic events such as droughts, floods and landslides accounted for about 15 percent of migrants. Improved livelihoods were the reason for about 24 percent of the total number of households that migrated. Access to arable land is another reason for rural out-migration. About 12 percent of migrant households had no or insufficient land to cultivate, or land of poor quality. The remaining 4 percent of households with migrant members cited access to better health services and family ties as the main reasons for migration.

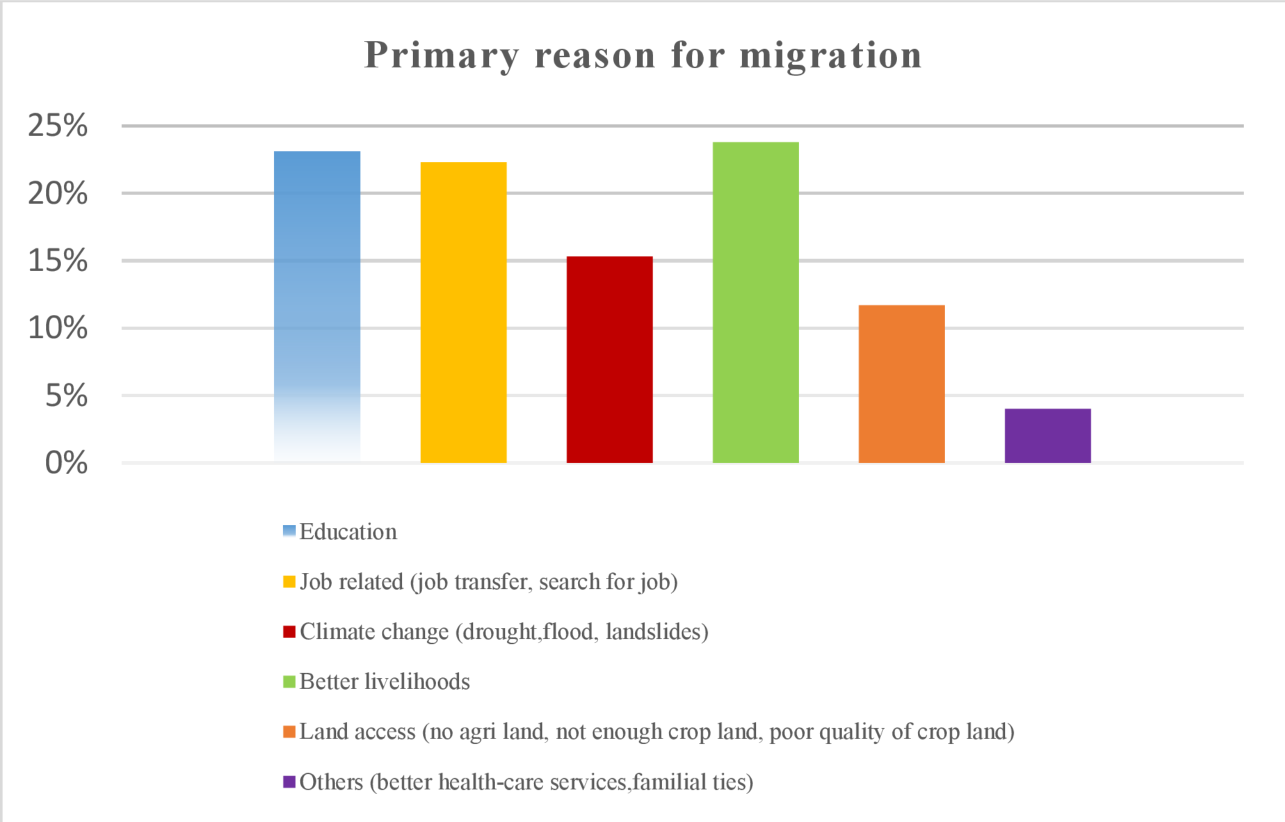

Figure 7 Reasons for out-migration of individuals (all migrants, n=141)

5.3.5 Conclusion and recommendations for policy implications

In this study, we examined two key issues related to rural out-migration. First, we examined the factors that influence a rural household member's decision to migrate. Second, we assessed whether rural out-migration can be considered an effective and viable strategy for achieving food security in rural areas. Our research focused on places of origin in three different agro-ecological zones in Nepal.

On the first question of the drivers of migration, our findings indicate that migrants tend to be older, less educated, belonging to the Brahmin social group, engaged in non-agricultural work and vulnerable to the impacts of climate change. At the household level, certain characteristics such as the age of the household head, the social group of the household and the involvement of household members in non-agricultural activities had significant and positive effects on migration. However, the educational level of the household head had a significant and negative effect on migration. In addition, at the community level, environmental factors such as the occurrence and severity of environmental shocks to crops were significant and positively correlated with migration, while being located in mountain agro-ecological zones had a significant and negative effect on the propensity to migrate. These results suggest that migration is a response to the availability of better livelihood opportunities and the challenges posed by adverse agricultural conditions in rural areas. The study confirms the notion that migration serves as a short-term coping mechanism following environmental shocks. However, it is important to recognize that the long-term consequences of climate change require permanent adaptation strategies, such as the implementation of changes in agricultural practices.

Regarding the second question, rural out-migration significantly enhances smallholder farm households' food security. The estimated effect on FCS demonstrates that migration significantly and positively impacts FCS. This means that households with migrant members are better off regarding food security than households with members who have not migrated. More specifically, households with migrated members would have had 8.68 FCS points less if they had not migrated members. Our findings show that households with migrant members in Nepal effectively enhance their food consumption scores as so food security. This paper takes a broader approach by identifying the main reasons for migration in the study area. The search for employment opportunities, the pursuit of better livelihoods, access to education, access to productive agricultural land and the response to climate change-related factors were identified as motivations for migration. This finding highlights the crucial role of rural out-migration in ensuring household food security, mainly due to the substantial remittances sent back to rural areas, which are widespread throughout Nepal.

Migration remains a common livelihood strategy in developing countries like Nepal. However, continued rural out-migration poses a risk of land abandonment due to dwindling labour availability. Despite the positive short-term effects of migration, it poses a long-term challenge to household food security. It is, therefore, imperative to implement robust and effective policies at the point of origin of migration. One promising approach is public investment in infrastructure development, particularly in creating a well-connected road network. This can facilitate better access to more prosperous labour markets and enable remaining households to engage in trading without a household member. In addition, an integrated approach to rural development that includes creating both on-farm and off-farm employment opportunities is essential. At the same time, investment in increased agricultural productivity is crucial as it will likely improve the overall situation in rural areas and reduce unnecessary migration. Migration is not only driven by poverty and food security, but also by the process of development and social transformation, although food security remains a crucial factor. These recommendations are directly linked to several SDGs, in particular 8, 10 and 11, which aim to improve opportunities for migrants in their destination regions.

In order to provide migrants with sufficient employment prospects, especially in urban areas, access to education must be supported (SDG 4). At the same time, improving current agricultural practices and increasing productivity will enable household members to secure a better livelihood through agricultural activities. Such investments will not only increase the benefits of migration, but also strengthen the resilience of households during migration by maintaining or even increasing their agricultural productivity. The adoption of advanced and regionally adapted agricultural practices will also prepare households against increasing environmental shocks and climate variability, thereby maintaining their overall level of food security. Given the significant impact of migration on rural food security, future research needs to explore the complex effects of migration on the livelihoods of both the households left behind and the migrants in their destination areas. Further exploration through panel data analysis is needed to better understand the complex relationship between migration and food security. In addition, investigating potential cases of reverse causality would be invaluable. If such causal links are established, the development of policies to support households in using migration as a coping mechanism against food insecurity becomes even more imperative. Furthermore, research on the impact of migration on household food security in migrants' destinations is recommended. To comprehensively assess migration's impact on achieving the SDGs, further research is warranted, focusing on the circumstances of migrants in their respective destinations. Such in-depth investigations will undoubtedly enrich our understanding of the multifaceted role of migration in the context of food security and broader development goals.

6 General discussions

6.1 General discussions

This dissertation explored the complex relationships between climate change, food security and migration dynamics among smallholder farmers in Nepal. A quantitative survey of 400 participants in three agro-ecological zones examined factors influencing climate adaptation strategy uptake. It also assessed how these strategies impacted food security and migration. Several key findings emerged from our analysis.

Geographically and socially marginalised farmers face significant challenges in implementing climate change adaptation strategies. These challenges are exacerbated by farmers' limited access to resources, knowledge, and infrastructure. Farmers can more easily adopt adaptation strategies when they have access to credit and climate information.

Climate change presents a growing threat to smallholder livelihoods, crop yields, food security, and income generation. Similar studies by Atube et al. (2021) and Ansah et al. (2023) also reported that smallholder farmers are disproportionately affected by climate change and extreme events due to their small farming operations, challenging socio-economic conditions, and limited access to information (Ravera et al., 2016; Lawson et al., 2020 and Tesfaye & Nayak, 2022). Manandhar et al. (2011) confirmed that limited access to information perpetuates Nepalese farmers' challenges with sustaining agricultural production.

Our first objective was analysed using a multivariate probit model guided by the action theory of adaptation and the intersectionality framework (Table 4, Table 5, Table 6, Table 7, Table 8). Farmers from the Mountain Agroecological and Sudra groups encounter barriers to adopting climate change adaptation strategies. This study highlights the critical need for tailored adaptation strategies that would support farmers in responding to climate change. Our novel integration of the action theory of adaptation and intersectionality theory offers valuable insights for future global research in similar contexts.

Secondly, climate change extremes have a significant negative impact on household food security status (e.g., drought has made many households food insecure). Similar studies from different regions have confirmed that climate change-induced extreme events have a negative impact on farmers' food security status and livelihoods (Trinh et al., 2018; Aryal et al., 2020; Tesfaye & Nayak, 2022). This study supports Sam et al. (2019), Debnath & Kumar Nayak (2022), and Qtaishat et al. (2022), who suggest that drought is a major climate risk factor affecting smallholder households' food security. We also align with Debnath & Kumar Nayak (2022) and Demont et al. (2022), who reported that extreme climate events push household members into seasonal migration. Many studies explore how climate change adaptation strategies such as small-scale irrigation, agroforestry, off-farm activities, and temporary migration can significantly improve farmers' food security. For instance, Enkuahone Kassie, Alamirew Alemu and Jambo et al. (2021) concluded that irrigation positively impacted household food security and recommended continued investment in smallholder irrigation for poverty reduction.

Climate change adaptation helps to mitigate adverse effects and achieve sustainable food security (Chandra et al., 2016; Mahmood et al., 2019; Ajani & Geest, 2021; Muench et al., 2021). Strategies like agroforestry can diversify livelihoods, contribute to food security by improving crop yields, and provide additional food sources, income, and environmental protection. These findings echo Ullah et al. (2022) and Nkomoki et al. (2018), who also demonstrated how agroforestry can improve livelihoods and reduce the number of food-insecure households. In this study, farmers who adopted off-farm activities could better escape from food insecurity by increasing their livelihoods (see also Tien Thanh et al., 2020; Kassegn and Endris, 2021)

However, implementing such strategies can be challenging for marginalised groups due to resource constraints and geographical and social barriers (see also Pariyar et al., 2018). Climate change and food security issues disproportionately affect smallholder farmers in mountainous agro-ecological zones and those belonging to Sudra social groups. These economically marginalised farmers living in rural mountain areas and belonging to lower socio-economic strata were most likely to adopt off-farm strategies and temporary migration in response to changing climate conditions. Our findings suggest that marginalised farmers are more likely to move away from agriculture to cope with climate change and food insecurity. Marginalised farmers showed the highest propensity to adopt climate change adaptation strategies—such as engaging in off-farm activities and temporary migration—revealing their increased vulnerability in the face of significant climate-related challenges.

This dissertation's second objective was achieved by applying an ordered logit model following the IPCC vulnerability framework (Tables 9, 10 and 11) to measure the impact of extreme climate events pushing smallholder farmers towards food insecurity. We emphasise the importance of supporting and implementing tailored adaptation strategies that address marginalised farmers' food security status to increase their resilience.

Thirdly, our findings indicate that rural migration is a multifaceted phenomenon with positive and negative impacts on food security. We contribute to a growing literature on the (largely positive) association between migration and food security in developing countries (Duda et al., 2018; Hasanah et al., 2017; Nguyen & Winters, 2011; Sadiddin et al., 2019). Nepalese households with migrant members do report improved food consumption scores and remittances can increase household income to facilitate access to food in the short term. These findings echo Abebaw et al.’s (2020) work in Ethiopia, where migration significantly increases daily calorie intake per adult and reduces the severity of food poverty. However, we caution that prolonged migration can lead to land abandonment and reduced agricultural productivity, posing a potential long-term threat to food security.

Two models—propensity score matching and endogenous switching regression— were employed to address the third objective. Following the push-pull theory and the neo-economics of labour migration theory, we demonstrate the dual nature of rural out-migration’s positive and negative effects (Table 12, Table 13, Table 14, Table 15). Rural out-migration has a short-term positive impact on food security and livelihoods. However, long-term problems (e.g., reduced agricultural production and food security concerns) may arise as the rural population ages and younger generations migrate away from agriculture. Therefore, this study proposes tailored adaptation strategies that involve targeted support and training for marginalised farmers. While migration may serve as a coping mechanism for some households, we must alleviate the underlying factors that drive people to leave their homes (i.e., poverty, food insecurity and lack of opportunity).

This study recommends actively promoting climate-resilient agricultural practices through knowledge dissemination, provision of finance and access to credit, and investment in research and development for climate-smart crops. Strategically allocated financial support and targeted extension services should ensure that marginalised groups have access to resources. Capacity-building programmes could also enhance the skills and capabilities of smallholder farmers in disadvantaged (especially mountainous) regions. We also recommend targeted empowerment interventions for socially excluded communities like Sudra farmer groups. Such programmes would invest in rural development, create employment opportunities, and improve access to basic services in rural areas. Otherwise, the whole nation may soon suffer from food insecurity if too many farmers leave their fields.

Finally, this dissertation underscores the importance of strengthening institutional frameworks and fostering effective collaboration between government agencies, NGOs, and research institutions. Such cooperation is essential for developing and implementing comprehensive policies and programmes that address the interlinked challenges of climate change, food security, and migration. By taking a holistic approach that considers the complex interactions between these factors, policymakers and development practitioners can develop more effective and sustainable solutions to support smallholder livelihoods and food security in Nepal and beyond.

Strategic adaptation measures are effective in mitigating food insecurity exacerbated by climate extremes; however, marginalised farmers face many barriers to implementing these strategies. This thesis also examined the nuances of rural migration on short-term food security versus long-term agricultural productivity to recommend targeted support, climate-resilient practices, and tackling the root causes of migration. Strengthening institutions and fostering collaboration to develop comprehensive and sustainable solutions can safeguard the livelihoods of smallholder farmers in Nepal and beyond. For its part, the government of Nepal should address the complex challenges posed by climate change, food insecurity, and migration while ensuring the sustainability and resilience of its agricultural sector and the well-being of its smallholder farmers—the backbone of the food production system.

6.2 Limitations of the study

The following limitations of this study can be remedied by future research:

- The COVID-19 pandemic hindered qualitative data collection. Travel restrictions and physical distance measures meant that we could not collect in-depth interviews, which are valuable for understanding the nuances of local climate change adaptation. Qualitative data would have strengthened the findings with more comprehensive perspectives on the challenges and dynamics of adaptation strategies.

- The study's cross-sectional design limited its ability to establish causal relationships. Longitudinal studies are needed to understand how relationships unfold over time.
- This study offers an overview of the factors affecting migration decisions and their impacts on food security. A more in-depth exploration of these experiences and the long-term impacts of migration on sending and receiving communities would be valuable.

6.3 Summary of policy implications

This dissertation provided critical insights into the interlinkages between climate change, food security, and migration in Nepal (particularly among smallholder farmers). These findings have important policy and practice implications that could pave the way for more appropriate adaptation strategies.

1. Enabling climate change adaptation strategies for smallholder farmers

- Facilitate smallholder farmers' access to vital resources, knowledge, and information on CCA strategies, particularly for those who are geographically (in mountainous regions) and socially (e.g., Sudra groups) marginalised. Empowerment will enhance their adaptive capacity.
- CCA strategies must be tailored to Nepalese smallholder farmers' diverse agricultural topography and socio-economic contexts. Farmers in the mountains (and among the Sudra group) tend to engage in off-farm activities and temporary migration, suggesting that they may be moving away from agriculture. To reverse this

trend and mitigate long-term problems, marginalised farmers should be given sustained support in the form of subsidies or insurance to encourage continued farming.

- Developing and disseminating tailored climate information can increase smallholder farmers' preparedness and resilience to climate variability and extremes. We must prioritise marginalised farmers by providing them with timely access to climate information, education, and training to help them understand climate change dynamics and effectively use adaptation strategies to mitigate its impacts.

2. Enhancing food security for smallholder farmers

- Prioritise investments in irrigation infrastructure and water management practices to improve agricultural productivity and food security.
- Promote agroforestry and sustainable land use practices that foster soil fertility, environment, and long-term agricultural sustainability.
- Promote income diversification initiatives by providing opportunities for off-farm activities beyond agriculture. This approach aims to strengthen the economic resilience of smallholder households and reduce dependence on agriculture as their main source of income.

3. Addressing the drivers of migration and their impact on food security

- Encourage viable economic opportunities in rural areas to reduce migration pressures and provide smallholder farmers with alternative livelihoods.
- Implement policies that encourage the productive utilization of remittances to enhance household food security and promote investments in agricultural productivity.
- Strengthen collaboration between government agencies, policymakers, and local communities to ensure that policies and interventions are grounded in local realities and effectively address the needs of smallholder farmers.

4. Prioritising the well-being of smallholder farmers—the backbone of Nepal's agriculture

- Invest in education, healthcare, and social protection programs for smallholder farmers to enhance their well-being, productivity, and resilience.
- Empower smallholder farmers through participatory decision-making processes and support the development of community-based organisations to strengthen their collective voice and influence.
- Recognise and value smallholder farmers' contributions to food security, rural livelihoods, and the preservation of Nepal's agricultural heritage.

7 General conclusion

This dissertation examined the complex links between climate change, food security, and migration for Nepalese smallholder farmers. It investigated the factors influencing smallholder farmers' climate change adaptation strategies, the impacts of climate change and adaptation strategies on food security, and the factors influencing smallholder farmer migration. The mixed-methods approach involved surveying 400 smallholder households in three agro-ecological zones of Nepal using a multistage sampling technique.

Climate change significantly affects Nepal's agricultural production and food security. Increasingly frequent and severe extreme events such as droughts, floods, and landslides lead to crop losses, reduced yields, and exacerbated food insecurity. Smallholder farmers are particularly vulnerable to these impacts, as they rely heavily on rain-fed agriculture and have limited access to resources and information. Smallholder farmers also adopt various adaptation strategies to cope with climate change, including off-farm activities, new crop varieties, early-maturing varieties, small-scale irrigation systems, agroforestry, and temporary migration. However, the effectiveness of these strategies depends on the adaptive capacity of smallholders. Factors such as social group, access to resources, and agro-ecological zone shape outcomes in Nepal.

This study also revealed that climate change extremes (e.g., droughts) negatively impact household food security. Fortunately, climate change adaptation strategies—agroforestry, small-scale irrigation, and temporary migration—

positively impacted household food security. However, migration may lead to negative long-term effects. While migrant remittances can improve household food security, migration may lead to land abandonment and labour shortages, ultimately reducing agricultural productivity.

Prompt action is needed to sustain agriculture and support smallholder farmers, who are leaving their fields in record numbers. Concrete plans tailored to the local situation can prevent farm abandonment and long-term food shortages. Policies should prioritise support for geographically and socially marginalised farmers (e.g., through subsidies, market and credit access, and climate information). Urgent steps are needed to protect the farmers and keep the agricultural sector thriving.

Climate change, food security, and migration have interconnected and complex effects in Nepal. Addressing these challenges requires a holistic approach to climate change adaptation, food security interventions, and effective migration governance. This dissertation provides valuable insights with far-reaching implications for policy and practice. The primary focus should be improving smallholder farmers' food security status and well-being through sustainable development initiatives, especially in the face of climate change-imposed challenges.

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9 Author´s scientific contributions

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10 Appendices

Appendix 1: Factors affection migration

Table 15 Factors affecting migration results from ESR model

Variable	ESR (Selection equation)	
	Coef.	Std. Err
Age	0.013**	0.006
Gender	0.030	0.162
Married	0.233	0.217
Education	-0.138*	0.077
Social group (Brahmin)	0.595***	0.198
Off-farm activities	0.341**	0.148
Reduce crop yield	0.136**	0.058
Mountain region	-0.760***	0.248
Hilly region	-0.003	0.210
Access to information sources	-0.333**	0.141
Cons	-1.24**	0.51
r1	0.22	0.32
r2	-0.34	0.41
Rho_1	0.22	0.30
Rho_2	-0.33	0.37
Number of observations	400	
Prob > chi2	0.0024	
Log likelihood	-1963.33	

Note: ***, **, *0.01, 0.05 and 0.1 significance levels, respectively. Source: Author own calculation based on the survey data

Appendix 2: Propensity score matching graph

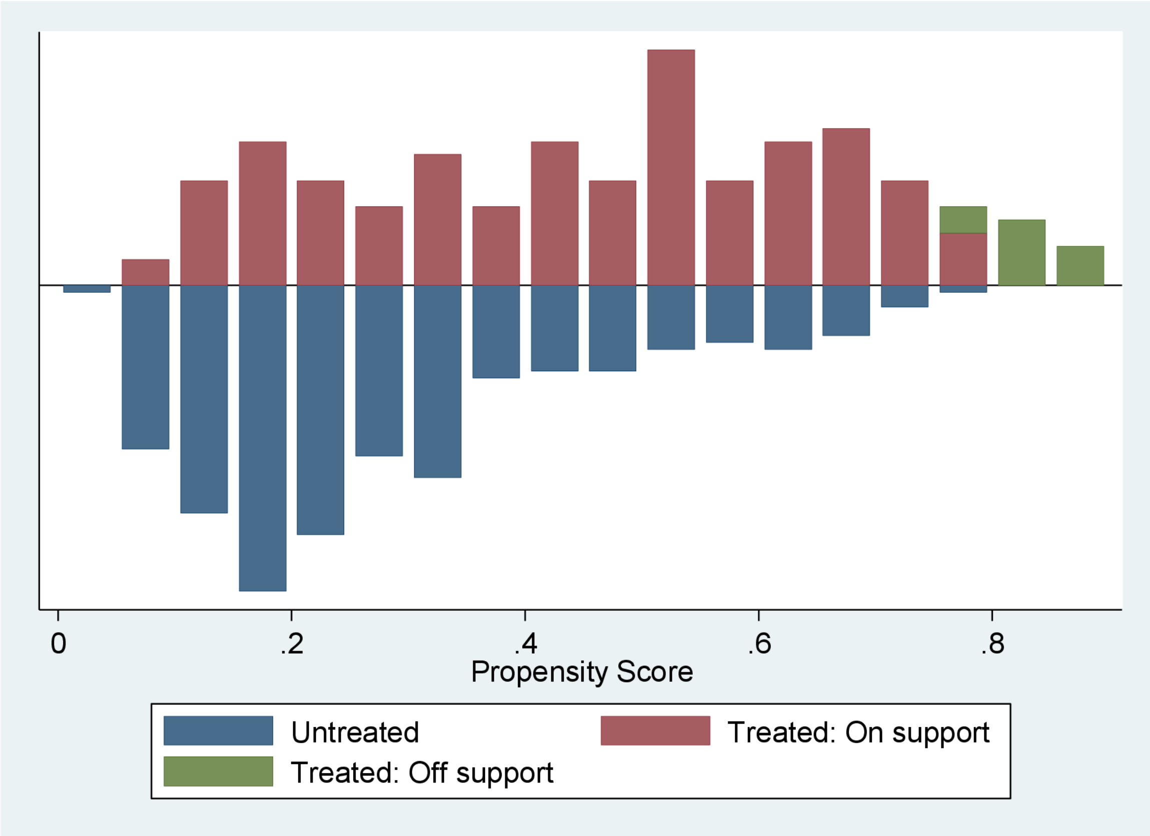

Figure 8 Propensity score matching graph

Source: author own calculation based on the survey data

Appendix 3: Survey Questionnaire

Exploring the nexus: Climate change, food security and migration dynamics among smallholder farmers in Nepal

Dear Sir/Madam,

Namaste,

I would like to ask you to fill in the following questionnaire. I am a PhD student at the Czech University of Life Sciences Prague, Czech Republic. I am conducting this study to learn more about the "***Exploring the nexus: Climate change, food security and migration dynamics among smallholder farmers in Nepal***". All the data is collected anonymously. I would appreciate it very much if you would fill in and help me to conduct this research. Thank You!

ID number (M/D/C) M= Mustang, B=Baglung, C= Chitwan	…………………………………………………………………………
Name of the respondent	…………………………………………………………………………
Phone number/email	…………………………………………………………………………
Rural Municipality name and ward number	…………………………………………………………………………
Geographical coordinates	…………………………………………………………………………
Date of the interview	…………………………………………………………………………

Section A: Household section- Socio-economic characteristics

No.	**Questions**	**Responses**
1	Sex of the HH (Household Head)	Male ☐ Female ☐
2	Current age of HH (in years)	…………….

3	What is your highest education level?	Nonformal☐ Primary☐ Secondary☐ Higher Secondary☐ Undergraduate☐ Postgraduate☐
4	What is your marital status?	Single☐ Married☐ Divorced☐ Widowed☐ others ……..
5	What ethnicity do you belong to?	Kshetri ☐ Brahmin ☐ Magar ☐ Tharu ☐ Tamang ☐ Newar ☐ Sherpa ☐ Gurung ☐ Thakali ☐ Dalit ☐ Rai ☐ Madeshi ☐ Others …..
6	What is your household size (in persons)?	………………
6a	Total number of Children (<15 years):	………………
6b	Total number of adults (16-59 years): active labor	………………
6c	Total number of adults (>59 years):	………………
6d	Total number of males in household	………………
6e	Total number of females in household	………………
7	How long have you been working as a farmer? (years)	………………
8	Are you involved in some farmers group (Krishi samuha)?	Yes☐ No ☐
8a	If yes, what kind of group it is?	Producer☐ Processors☐ Marketing☐

		Multipurpose☐ Others (specify) ……	
9	Do you own a land?	Yes ☐ No ☐	
9a	What is the total amount of land your household owns now (ha)?	………………	
9b	What is the total amount of land your household cultivated (both owned & rented) (in ha) this year?	………………	
10	What type of farming you have?	Arable farming (Crops) ☐ Pastoral farming (Livestock) ☐ Mixed farming (Arable & Pastoral)	
10a	Please indicate what are the major crops you cultivated in last 2-3 years?	**Main crops**	**In %**
		Rice	………
		Wheat	………
		Maize	………
		Millets	………
		Barley	………
		Buckwheat	………
		Oats	………
		Potato	………
		Beans	………
		Vegetables	………
		Fruits	………
		Others	………
10b	How is your food production compared to 5 years ago?	Less High No difference Don't know	
10c	Please indicate what are the major livestock you have?	**Livestock**	**Number**
		Cattle ☐	…………
		Yak/nak ☐	…………
		Horse/ Mule☐	…………
		Goat/Sheep ☐	…………
		Buffalo ☐	…………
		Pigs☐	…………
		Chicken/Duck ☐	…………
		Others	…………

Section B: Access to credit & market

1	How do you finance investment in your farm in the last year? (Multiple choice allowed)	Family saving ☐, Bank/Government loan ☐ Borrow from relatives/friends ☐ Farmers association ☐ Non-profit organizations ☐ Remittances ☐ Others (please specify) …	
1a	What share of the household income do you get by your farm (in%)?	0-25% ☐ 26-50% ☐ 51-75% ☐ 76-100% ☐	
2	Do you have an off-farm occupation?	Yes ☐ No ☐	
2a	**If yes, what are the major off farm activities?**	**Activities**	**income share (%)**
		Self-employed (Permanent work)	……..
		Self-employed (temporary work)	……..
		Retailer	……..
		Labor work	……..
		Administrative(office) work	……..
		Others	……..

How often did this happen?		**Never =(1)**	**Rarely (once a year)=2**	**Sometimes (few times a year)=3**	**Often (monthly) =4**	**Very often (weekly) =5**
	Do you sell your farm products to the market?					
a	Do you buy farm products from to the market?					
b	What is the nearest distance to the next market (in km and in hour)	…….. km ……………hours				

	How much total money did you earn from your farm in 2020 (in NPR)?	<50,000 ☐ 50,001 to 100,000 ☐ 100,001 to 150,000 ☐ 150,001 to 200,000 ☐ >200,001 ☐

		Food	Water	Shelter	Cloths	Health
a	How satisfied is your family with the satisfaction to cover the following needs from your income in last 2-3 years?	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐
		Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐
		Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐
		Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐
		Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐

	Which of the following sustainable farming practices do you use?	Rotating crops ☐, Intercropping ☐ Planting cover crops ☐, Reducing or eliminating tillage ☐, Applying integrated pest management ☐, Integrating livestock and crops ☐, Adopting agroforestry practices ☐, Use of organic fertilizer ☐, Irrigation ☐

		Seeds	**Irrigation system**	**Pesticides**	**Chemical fertilizer (eg.urea)**
	How do you perceive the price of inputs?	Extremely cheap ☐	Extremely cheap ☐	Extremely cheap ☐	Extremely cheap ☐
		Cheap ☐	Cheap ☐	Cheap ☐	Cheap ☐
		Affordable ☐	Affordable ☐	Affordable ☐	Affordable ☐
		High☐	High☐	High☐	High☐
		Extremely high ☐	Extremely high ☐	Extremely high ☐	Extremely high ☐

Section C: Climate change awareness

1	Are you aware about climate change?	Yes ☐ , No ☐
	In last 10-15 years have you experienced following changes?	
2	It is generally warmer these days,	Agree ☐ , Disagree ☐, No change ☐, Don't know ☐
3	The onset of summer these days occurs,	Earlier ☐, Later☐, No change ☐, Don't know ☐
4	Duration of winter these days are,	Longer ☐, Shorter☐ No change ☐, Don't know ☐
5	The amount of rainfall these days are,	Less ☐, More ☐ Unpredictable ☐, Don't know☐= 4
6	The onset of rainfall these days occurs,	Earlier ☐, Later☐, No change ☐, Don't know ☐
7	Snowfall these days starts,	Earlier ☐, Later☐, No change ☐, Don't know ☐
8	Incidence of drought these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
9	Incidence of fire these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
10	Incidence of floods and landslides these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
11	Incidence of avalanches these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
12	Amount of forest area these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
13	Populations of wildlife species these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐
14	Blooming time of common plants these days occurs,	Earlier ☐, Later☐, No change ☐, Don't know ☐
15	Plantation of major crops these days occurs,	Earlier ☐, Later☐, No change ☐, Don't know ☐
16	Harvesting of major crops these days occurs,	Earlier ☐, Later☐, No change ☐, Don't know ☐
17	Increase of pest and disease outbreak these days are,	Higher ☐, Lower☐ No change ☐, Don't know ☐

Section D: Climate change adaptations (1,2) strategies and vulnerability (3,4)

1	Which of the following strategies you have adopted so far?	How long are you using this strategy (in years)?
	Crop diversification (e.g., different cultivars) ☐	…………….
	Changing planting date ☐	…………….
	Changing of crop planted ☐	…………….
	Early matured varieties ☐	…………….
	Drought tolerant/resistant varieties ☐	…………….
	Irrigation system ☐	…………….
	Rainwater harvesting ☐	…………….
	Reduced tillage ☐	…………….
	Mulching ☐	…………….
	Agroforestry ☐=	…………….
	Off farm income ☐=	…………….
	Temporary migration ☐=	…………….
	Organic fertilizer=	…………….
	Other (Please specify) …………….	…………….

2	How often do you have access to the following information channels regarding weather information?				
Sources	**Never-1, Once a year-2, Once a month-3, Once a week-4, Everyday-5**				
Internet	1	2	3	4	5
Radio/Television (e.g. weather forecast)	1	2	3	4	5
Farmers cooperatives (Krishi Samuha)	1	2	3	4	5
Research Institution/University	1	2	3	4	5
Print media (e.g. newspaper)	1	2	3	4	5
Mobile phone	1	2	3	4	5
Other (please specify):	1	2	3	4	5

3	How was the influence/impact of the following factors on your farm production in last 5 years?				
Factors	**Not at all-1, slightly-2, somewhat-3, very- 4, extremely-5**				
Rise in temperature	1	2	3	4	5
Drought	1	2	3	4	5

Windstorm	1	2	3	4	5
Overflooding	1	2	3	4	5
Hailstorm	1	2	3	4	5
Crop pest and disease outbreak	1	2	3	4	5
Livestock disease outbreak	1	2	3	4	5
Decrease in soil quality	1	2	3	4	5
Other (please specify) …………………	1	2	3	4	5

4	**How often following consequences of climate change occurred in last 5 years?**				
Factors	**Never-1, Rarely (once in a 5 years)-2, sometimes (2-3 times in 5 years) -3, often (4-5 times in 5 years)-4, Always (more than 5 times)-5**				
Reduce crop yield	1	2	3	4	5
Shortage of livestock feeds	1	2	3	4	5
Dead of livestock	1	2	3	4	5
Crop pest and disease outbreak	1	2	3	4	5
Destruction of farmland	1	2	3	4	5
Destruction of habitat (human being & animal)	1	2	3	4	5
Physical injury to the family member/me	1	2	3	4	5
Dead of family member (except earthquake)	1	2	3	4	5
Lack of financial capital	1	2	3	4	5
Others (please specify …………	1	2	3	4	5
Others (please specify) …………	1	2	3	4	5

Section E: Food Security

Food consumption and food sources (FCS)			
Who decides what will be eaten?		Female☐	Male ☐
		Female	Male
	How many meals did the adults (18+) in this household eat yesterday?	1.|__|	2.|__|
	How many meals did the children between the age of 5-17 eat yesterday?	1.|__|	2.|__|

	How many meals did the children between the age of 2-< 5 eat yesterday?		1.|__|	2.|__|
	Food items/groups	**Exampl es**	**4.1. How many days over the last 7 days, did members of your household eat the following food items, prepared and/or consumed at home?**	**4.2. How was this food acquired? Write the main source of food for the past 7 days**
			Days	**Source**
	Cereals or tubers	Rice, potato, naan etc.	……………	……………
	Pulses and groundnuts	Beans, peas, Cashew nuts	……………	……………
	Milk and milk products	Fresh milk, powdered milk, yogurt, cheese, other dairy products	……………	……………
	Eggs, meat, fish, shells	Organ meat, flesh meat, fish, eggs, etc.	……………	……………
	Vegetables	carrots, spinach etc.	……………	……………
	Fruits	Apple, banana, etc.	……………	……………
	Sugar	Sugar, honey, jam, cakes, pastries, (sugary drinks)	……………	……………
	Oil	Vegetable/palm oil, butter, ghee, other fats	……………	……………
	Condiments	Spices, tea, coffee, salt, spices, tomato / sauce	……………	……………

Food acquisition codes: 01 = purchase (cash) 02 = purchase (credit) 03 = food assistance (General Food Distribution)	04 = food assistance (food card) 05 = army distributing food 06 = support from relatives/friends	07 = barter and exchange 08 = borrowing 09 = begging, scavenging	10 = gathering of wild foods (plants/insects) 11 = hunting/fishing 12 = own production

HOUSEHOLD COPING STRATEGIES (rCSI)		
	During the last 7 days, were there days (and, if so, how many) when your household had to employ one of the following strategies (to cope with a lack of food or money to buy it)?	**Frequency (number of days from 0 to 7)**
1	Relied on less preferred, less expensive food	……….
2	Borrowed food or relied on help from friends or relatives	……….
3	Reduced the number of meals eaten per day	……….
4	Reduced portion size of meals at meals time	……….
5	Restrict consumption by adults in order for young children to eat	……….

Section F: Migration

1. Household size and migrants

Variable	**Male**	**Female**
Household size excluding migrants (current)		
How many have migrated internally (inside the country) for the past 10 years		
How many have internationally (outside of the country) migrated for the past 10 years		

2	What is your tenancy agreement on this farmland?			Own ☐, Rent ☐, Both ☐		
3	Do you receive remittances or items from migrant members				Yes ☐ No ☐	
3a	If yes, how often do you receive the following items from migrants for the past 5-10 years					
		Never	**Rarely (once a year)**	**Sometimes (Few times a year)**	**Often (Monthly)**	**Very Often (Weekly)**
	Money					
	Farm input					
	Cloth & household belongings					
	Food items					
	Others……					
4	Please indicate the share of your livelihood which was covered by money or stuff sent by migrant members last year?				0-25 % ☐,26-50% ☐ 51-75% ☐, More than 75% ☐	
5	Please indicate the importance of remittances to cover the following (1 lowest importance, 5 highest importance)					
	Importance of remittances	**1-not at all important**	**2-slightly important**	**3-Neutral**	**4-very important**	**5-Extremely important**
	Buying food/ cloths					
	Education					
	Health expenses					
	Buying Seed/ fertilizer					
	Buying pesticides					
	Buying Agri tools					
	Repay debts					
	Financing migration costs of					

	additional family members					
	House construction and maintenance					
	Others…...					
6	Ideally, if you had the opportunity, would you like to move **temporarily** to another place?				Yes ☐	No ☐
6a	Ideally, if you had the opportunity, would you like to move **permanently** to another place?				Yes ☐	No ☐
7	If 6&6a is Yes, are you planning to move in the next 12 months?				Yes ☐	No ☐
8	If 7 is Yes, have you done any preparation for this move? (for eg; buy properties or making arrangements for the move)				Yes ☐	No ☐
9	If any questions from 6 to 8 is Yes, What is the primary reason you choose to move? (Multiple selection allowed)	Education ☐ Search for work ☐ Job transfer/ opportunity ☐ Family problems ☐ Better livelihoods☐ Drought ☐ Flood ☐ Do not own Agri land to work here ☐ Don't have enough land ☐ Poor quality of land ☐ Other (Please specify) …				
10	How often do your household had to deal with the lack of labor available for work in agriculture in last 5 years?	Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐				

Section G: Covid-19 in food security

COVID-19 and Food security		
1	Which statement best reflects your food situation in this pandemic time?	I increased my food intake ☐ I had no difficulties eating enough food ☐ I ate less preferred foods ☐ I skipped meals or ate less than usual ☐ I went one whole day without eating ☐
2	Does your household had/have food stock?	Yes, less than 1 week ☐ Yes, 1 week ☐ Yes, 2-3 weeks ☐ Yes, 1 months ☐ Yes, more than 1 months ☐
3	What is the situation of your household income in this pandemic time?	Increased in salary/revenue ☐ No change ☐ Job loss ☐ Reduced salary/revenue ☐ Had to resort to alternative source of income☐=5
4	Looking ahead, how do you expect your livelihood will be impacted as result of disruptions from COVID-19?	No impact ☐ Slightly impact ☐ Somewhat impact ☐ Very impact ☐ Severe impact ☐
5	In this pandemic and the lockdown started, have you received any food, cash, or other support from anyone else that you do not usually receive?	Yes ☐ No ☐
5.1	If 5=yes, could you please indicate the source?	Government ☐ Relatives ☐ Neighbors ☐ Community leaders ☐ NGOs ☐ Other (please specify) ………….
6	Is someone in your family had to return home from abroad due to COVID-19?	Yes ☐ No ☐

Appendix 4: Data collection pictures