Consolidated Livelihood Exercise for Analysing Resilience

Assessing climate change impacts on food security in Nepal

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Government of Nepal
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Foreword

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July 4, 2024

The Government of Nepal has set provision of nutritious and adequate food at all times as one of the fundamental rights of its citizens in the constitution and already enforced the Right to Food and Food Sovereignty Act. In accordance with Sustainable Development Goals (SDG), the government has set targets for ending hunger and malnutrition, doubling the agricultural productivity and income, ensuring sustainable food systems, and executing resilient agricultural practices by maintaining agricultural diversity.

The National Planning Commission (NPC) plays a coordination role with government and various non-government organizations for overall food system and most importantly food and nutrition security. The government is enforcing the Agriculture Development Strategy (ADS), Multi-sector Nutrition Plan (MSNP) III (2023-2030), and Zero Hunger Challenge National Action Plan (2016-2025) aiming to improve food and nutrition security status of the people. The Fifteenth Plan (2019/20-2023/24) has highlighted on the improvement of food and nutrition security. The National Planning Commission has developed a Food Systems Transformation Strategic Plan (2022-2030), a national policy, to transform Nepal's food Systems that is more resilient, equitable and sustainable and contributes to achieve SDGs.

The government has formulated Disaster Risk Reduction National Policy, 2018, aiming to significantly reduce the risk posed by disasters on means of livelihoods including agriculture, industry, road, communication, drinking water supply system and other important infrastructures and build the resilience of the means of livelihoods. The government has also formulated Disaster Risk Reduction National Strategic Act (2018-2030) which has prioritized the inter-agency coordination for the climate risk analysis, improved resilience and disaster related information collection and management effectively.

From 2019 to 2022, the National Planning Commission with technical and financial support from the United Nations World Food Programme and the UK Met undertook the Consolidated Livelihood Exercise for Analysing Resilience (CLEAR) exercise and has produced this publication. On behalf of NPC, I am very pleased to endorse the report which highlights the inter-linkage between livelihood, climate change and food security. The study is one of a kind for Nepal and has mapped out the livelihood zones, their characteristics and the disaster impact linking with the livelihoods, the rural economy along with its diversity. It also has measured the sensitivity and resilience capacity of each livelihood zone also providing insights for consideration by stakeholders in the design of livelihood focused resilience building policies and programmes.

Results of the study support to decision makers to identify the livelihoods and communities are at most vulnerable to medium- and longer-term impacts of climate change which ultimately inform them the priority sectors and geographic areas. It also supports to select the geographically relevant food security monitoring indicators for performing food security analysis. Gathered evidence of climate change impact on the rural economy are the very critical information for the government as a record and to advocate for the adverse impact of climate change happening in Nepalese economy.

Potential climate scenarios disaggregated at various seasons and months for 2050s produced in this study really give us a better understanding on the future climate risk to livelihoods and more specifically potential climatic impacts on livelihoods and subsequently food security. These plausible scenarios and anticipatory impacts really guide us to formulate the informed policies related to livelihood and food security improvements and disaster risk reduction. The recommended adaptation options of this study pave the way to design climate change adaptation programmes and projects considering livelihoods of rural economy.

It is my strong belief that the study will be very helpful for government and non-government organizations who work in the livelihoods and food security, agriculture development and disaster management sectors in Nepal. I would like to sincerely thank the United Nations World Food Programme and UK Met Office for collaborating with National Planning Commission to carry out this important study.

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Message

Nepal has extreme geographic diversity, from the subtropical lowlands in the south, to the Himalayan mountains in the north. Many areas of the country have fertile land and abundant water supplies, and agriculture supports the livelihoods of the majority of the population. However, Nepal is extremely vulnerable to the impact of climate change and climate-related disasters. Rising temperatures, erratic rainfall, drought, flooding, landslides and forest fires negatively impact agricultural productivity, livelihoods and food security, with women, children and marginalized groups frequently experiencing the greatest impact.

The Consolidated Livelihood Exercise for Analysing Resilience (CLEAR) study is an analytical approach designed to enhance understanding of the linkages between livelihoods, climate risk and food security. The first of its kind in Nepal, the study maps livelihood zones, predicts future climate risks to livelihoods and food security, and details potential adaptation options for each livelihood. By focusing on livelihoods, the study helps us understand how climate and climate risks affect people, rather than geographic areas, and provides practical adaptation methods which can help guide stakeholders and enhance knowledge and planning.

I would like to sincerely thank the National Planning Commission for leading the process and providing guidance and support in developing and finalising the study, and the UK Met Office for their technical and financial contribution.

Robert Kasca

Representative and Country Director
World Food Programme, Nepal

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Special thanks also go to the Provincial Planning Commissions of all seven provinces, the Ministry of Land Management, Agriculture and Cooperatives, Sudurpaschim Province, district coordination committees and local governments all over Nepal who coordinated to organize consultative workshops at the province and district levels.

Thanks go to Scriptoria Sustainable Development Solutions of the United Kingdom for editing and proofreading and Faustina Masini of Energy Link, Italy for her support with design and layout of the report.

1. Contents

Acronyms

AR	Assessment Report
ARRCC	Asia Regional Resilience to a Changing Climate
CanESM2	Canadian Earth System Model version 2
CLEAR	Consolidated Livelihood Exercise for Analysing Resilience
CMIP	Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Modelling Downscaling Experiment
COVID-19	Coronavirus disease 2019
DHM	Department of Hydrology and Meteorology
ECDF	Environment Conservation and Development Forum
ERA5	ECMWF Atmospheric Reanalysis version 5
FAO	Food and Agriculture Organization
GAEZ	Global Agro-ecological Zones
GDP	Gross domestic product
GLOF	Glacial lake outburst floods
HDI	Human Development Index
HPI	Human Poverty Index
ICIMOD	International Centre for Integrated Mountain Development
IIASA	International Institute of Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM5A-MR	Institut Pierre-Simon Laplace Mixed Resolution
LHZs	Livelihood zones
MoALD	Ministry of Agriculture and Livestock Development
MoFE	Ministry of Forests and Environment
MPI-ESM-LR	Max Planck Institute Earth System Model Low Resolution
mVAM	Mobile Vulnerability Assessment and Mapping
NTFP	Non-timber forest product
RCA4	Rossby Centre Regional Atmospheric Model version 4
RCP	Representative concentration pathway
RegCM4	Regional Climate Model version 4.6.1
REMO2009	Regional Model 2009
UK Met Office	The United Kingdom Meteorological Office
UNDP	United Nations Development Programme

UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollars
WFP	World Food Programme

Executive summary

Climate change is a significant factor affecting livelihoods and food security, and understanding the interlinkages between all three is crucial to solving the global problem of hunger. Although numerous studies have been conducted on climate change, few have explored the relationship between climate change, livelihoods and food security. This CLEAR study, the first of its kind in Nepal, focused on:

1. **livelihood zoning and profiling**, including climate resilience and vulnerability;
2. **future climate risks** to livelihoods and food security; and
3. potential **adaptation options** for each livelihood.

Livelihood profiles

- Nepal has seven broad livelihood zones – cereal crops, cash crops, vegetables, fruits, livestock, non-timber forest products (NTFP) and non-agricultural groups – within which there are 30 unique major livelihoods.
- The dominant livelihood is cereal crop-based, covering all of Nepal, while other major livelihoods are location-specific and influenced by factors such as access to markets, roads, climate and favourable physical conditions. Income-generating livelihoods are confined to smaller geographic areas, such as high-value crops-based livelihoods found in the eastern part of the country, tourism-based livelihoods found in smaller parts of the Mountain region, and seasonal labour migration-based livelihoods found in districts of the western Hill region.
- Analysed by ecological belt, livelihoods of the Mountain region are mainly based on apple, maize, cardamom farming, livestock rearing, NTFP collection and tourism; livelihoods of the Hill region mainly depend on maize, paddy, vegetable farming and livestock rearing; whereas livelihoods of the Terai region are predominantly based on paddy farming.

- Highly climate-resilient livelihoods are those with good access to land and markets, those which are highly diversified and those which do not rely on rainfed agriculture.
- Livelihoods based on NTFP, chino, barley and naked barley in more remote mountainous regions are among the least resilient due to the rugged terrain and remoteness, which limit access to land and alternative livelihood activities. Maize-dependent livelihoods have low resilience, paddy- and livestock-based livelihoods have a medium level of resilience, whereas non-agricultural-based income-generating activities that have fewer links with climate shocks and good market access enhance community resilience, so these are among the most resilient livelihoods.

Future climate risks

Three plausible representative projected climate scenarios for the 2050s were developed from climate models, and their impacts on livelihoods and food security were assessed:

- In *Scenario 1*, a lower-end projection, the annual average temperature is projected to be 1.5°C higher on average, and the annual average precipitation 10 percent higher than baseline values. The increase in temperature will lead to more prolonged higher temperatures across the country, especially at higher altitudes, and heatwave conditions, increasing the heat stress impact on crop production and livestock health. The small projected increase in mean precipitation will intensify heavy precipitation, increasing the risk of flash flooding, landslides and GLOF events.
- In *Scenario 2*, a higher-end projection, the annual average temperature is projected to be 3°C higher on average, and the annual average precipitation 25 percent higher than baseline values. Heat stress impacts on crops and livestock will be greater than in Scenario 1, particularly in the hottest regions where the levels of heat stress will be more severe, and larger areas will be affected. In addition, the intensity of heavy precipitation events will increase, exacerbating the risk of flash flooding, landslides and GLOF events.
- *Scenario 3* represents a hotter and drier climate for Nepal, with an annual average temperature increase of 2°C and an annual average precipitation decrease of 10 percent compared to baseline values. This scenario presents the highest risk of water stress impacts on crops and livestock across the country and throughout the year. The study also highlights that the risk of forest fires and the subsequent impacts on crop production and pollution levels will also increase.

Adaptation options

To mitigate the negative impacts of climate change on livelihoods and food security, the CLEAR report recommends that:

- Livelihood zones should be used as an entry point to implement disaster risk reduction activities, adaptation options, strategies and programmes at all administrative levels and in all ecological belts.
- Seasonal weather forecasting systems, in-season crop monitoring systems and geographic location-based agro-advisory systems need to be strengthened and new ones developed where there are gaps, for use by the relevant stakeholders.
- Climate-smart adaptation options based on plausible projection scenarios should be developed, revisited and reviewed regularly.
- Diversification of livelihoods, increased access to land for marginalized and landless groups and promotion of access to markets can enhance the resilience of livelihoods.

1. Introduction

The results of the last Climate Change Assessment Report developed by the Intergovernmental Panel on Climate Change (IPCC) state that human-induced warming has affected the productivity of the agricultural sector over the previous 50 years, with negative impacts in middle and low latitudes. The sector's direct climate-related challenges include instability and poor quality of crops, grassland and harvests, which has negatively impacted productivity and caused a sudden increase in food production losses since at least the mid-twentieth century (IPCC, 2022a).

Overall, agriculture and other sources of livelihood are also being impacted by an increasing number of extreme weather events such as droughts, floods and heatwaves. These have also contributed to reduced food availability, increased food prices and migration that have, in turn, hindered the efforts of vulnerable communities to meet their basic needs and increased undernourishment – this is especially true for South and Southeast Asia (IPCC, 2022b).

Increasing competition over critical resources (i.e. land, energy and water) has also been documented as a driving factor exacerbating climate change impacts (IPCC, 2022a). For this reason, Nepal has been working in several areas to address the increasing number of extreme weather events and their impact on livelihoods. The Government of Nepal, in line with the Sustainable Development Goals, has prioritized food and nutrition security as a key sector to end hunger and malnutrition, increase productivity and income, guarantee sustainable food production systems, and implement resilient agricultural practices that can allow diversification of agricultural products. As part of its Country Strategic Plans, the World Food Programme (WFP) in Nepal, in close coordination with the Government of Nepal, carries out several assessments (e.g., Essential Needs Assessment , Food Security Atlas , Small Area Estimation of Food Insecurity and Undernutrition), rapid assessment of disaster impact through a 72-hour approach[1] (2015 to date), and other regular activities (e.g., regular mobile Vulnerability Analysis and Mapping [mVAM] surveys, remote household surveys for monitoring the food security situation) to support the country achieve its goal of zero hunger. However, the changing climate, especially localized extreme weather events, threatens the efficiency of the interventions and hampers the continuous efforts of communities to meet their basic needs.

Therefore, national systems require scientific information to understand the past, present and future vulnerabilities of and risks to communities in a changing climate. This will allow adjustment of national

[1] 72-hour assessment: WFP's tool that provides a snapshot impact assessment before (when possible) and in the first three days after a disaster and informs to emergency operations in a short timeframe.

policies and their translation into effective local adaptation plans that empower and increase the resilience of communities to the increasing impacts of climate change.

In response to this, in January 2021, Government of Nepal and WFP , with support from the Asia Regional Resilience to a Changing Climate (ARRCC) programme, funded by the United Kingdom's Foreign, Commonwealth and Development Office and managed by the United Kingdom Meteorological Office (UK Met Office), started the implementation of WFP's Consolidated Livelihood Exercise for Analysing Resilience (CLEAR). CLEAR intends to support national systems to understand better how food security is affected by climate risks and consequently inform policy decision making at the national and provincial levels. In turn, this climate and food security analysis identifies the main livelihoods in Nepal, how they are vulnerable to the changing climate and how these risks may continue to change in the future. The approach involves a combination of consultations with national, regional and local stakeholders, complemented by an analysis of livelihoods and climate data. Through a combination of qualitative and quantitative methods, key livelihood and climate information is analysed, with a view to interpreting the potential impacts of climate change on the main livelihoods in the country in terms of vulnerability, sensitivity, adaptive capacity and overall resilience. Adaptation options are suggested to inform national and sub-national policies and programmes that can be later mainstreamed to communities to increase their adaptive capacities.

2. Livelihoods in Nepal

Nepal has a population of nearly 30 million inhabitants spread over an area of 147,181 km^2 (Government of Nepal, 2014) and ranks 144 out of 191 countries in the Human Development Index (HDI) (UNDP, 2021/2022. In 2019, about 17 percent of the population are multidimensionally poor (CBS and OPHI, 2021). While progress has been made in terms of poverty reduction in recent years, mainly due to the inflow of remittance through labour migration to foreign countries, however, evidence shows that the distribution of income is not equal, undermining the overall poverty reduction potential of the economic growth.

As the economy diversifies, agriculture remains a key economic sector, where almost 66 percent of Nepal's population is directly engaged in subsistence farming, mostly integrated with livestock rearing. About 30 percent of Nepal's total land area is used for agricultural purposes. The agriculture sector mainly consists of cropping, vegetable and fruit farming, and forestry activities. Altogether, this sector is the second biggest contributor to Nepal's gross domestic product (GDP); it constitutes a quarter of GDP with some fluctuation from year to year (Nepal Rastra Bank 2021). Due to the climate sensitivity of the agricultural sector, without climate-smart action, the income and well-being of the population may be negatively affected in the long run, undermining efforts to eradicate poverty and hunger. The key sectors that constitute agriculture in Nepal are discussed in more detail below.

2.1 Livelihood zones and profiles

The livelihood profile in Nepal is very diverse and dynamic due to the topographic and climatic variations in a relatively small area, socio-cultural diversity and limited resources. Figure 1 presents the livelihood zones of Nepal divided into the main livelihood activities, based on the outcomes of consultations conducted as part of this study.

Overall, the findings indicate that it is customary for households to rely on multiple sources of livelihood to ensure that they can sustain their needs. Due to the relatively small-scale production of a particular crop, farmers usually hold small land areas; this results in variation of soil types within a short distance, a subsistence type of farming, and dominance of rainfed agriculture systems.

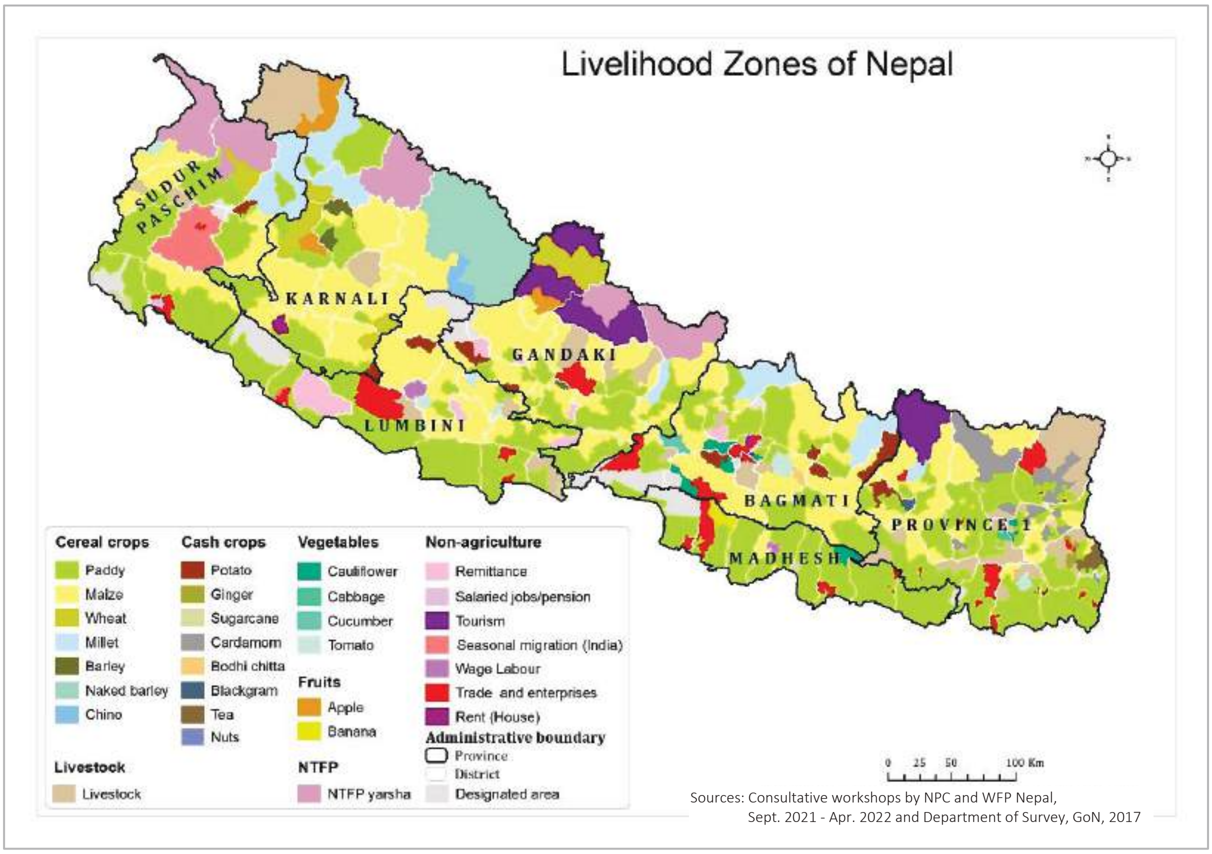

***Figure 1**: Livelihood zones of Nepal.*

Nepal can be broadly divided into three ecological belts, each of which has different climatic conditions: the Mountain, Hill and Terai zones (see Figure 2). Additionally, a second division can be made between east and west. Province 1, Bagmati and Madhesh Provinces are located in the east of the country, while Gandaki, Lumbini, Karnali and Sudur Paschim provinces are in the west. On average, the eastern part of the country receives more precipitation than the west. Taking this into consideration, Figure 3 shows the main agricultural products that each region produces.

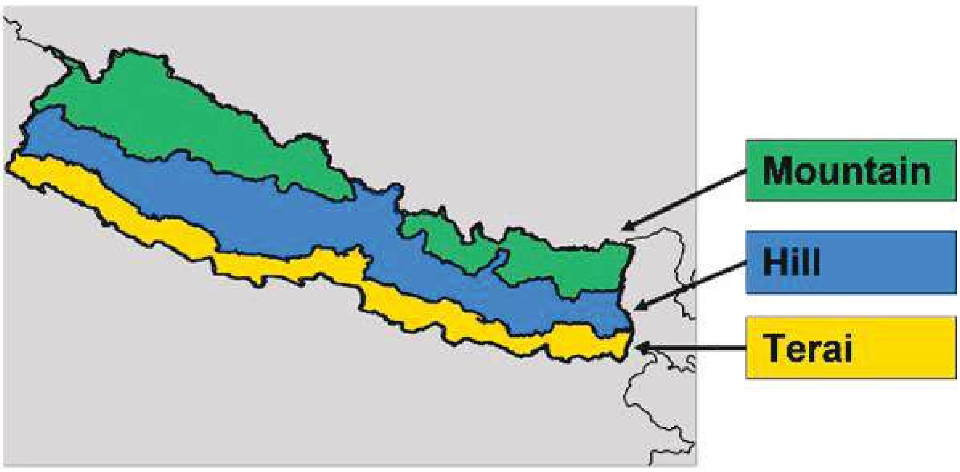

***Figure 2**: Ecobelt division of Nepal, as defined by the Government of Nepal (1996).*

The eastern side of the Hill zone produces cash crops and vegetables as its main livelihood. This might be due to higher precipitation and good connectivity to the Indian market, which allows an increased demand for products. On the western side, cereal crops are more predominant (in addition to paddy and maize, which are available in all regions). Descriptions of the main livelihoods in Nepal based on the outcome of consultations and a review of relevant literature are presented in the following section.

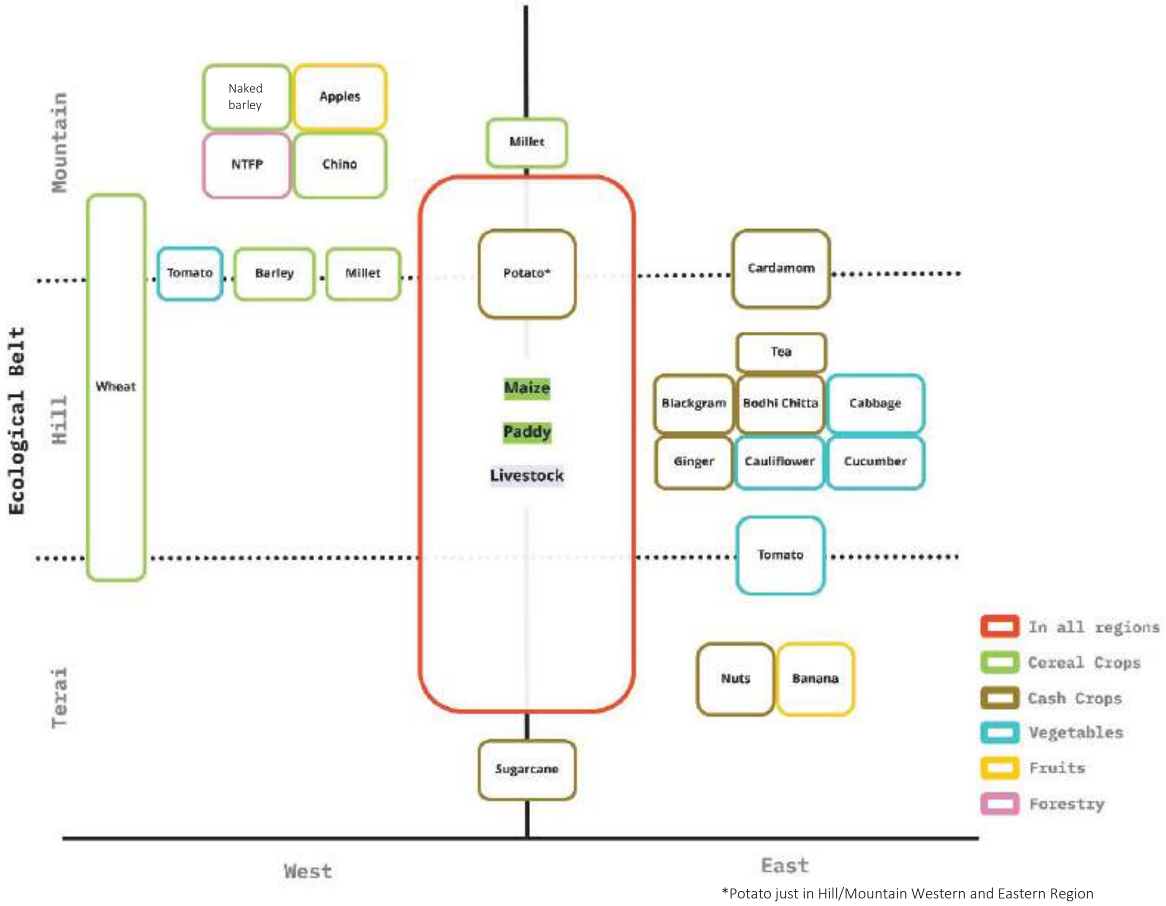

Figure 3: Schematic representation of the predominant livelihood activities in each zone of the ecological belt, divided into western and eastern sections.

2.1.1 Cereal crops

Cereal crops are the primary source of livelihood – an integral part of the Nepalese economy. They are grown across Nepal; however, productivity vastly differs from the Terai plain to the Hill and Mountain regions. The farmers mainly grow paddy, maize, wheat, millet, barley, naked barley, buckwheat and chino. Paddy, the staple food of Nepalese society, is grown from the Terai plain to the Hill and up to the Mountain zones. In contrast, maize, wheat and millet are grown mainly in the Hill and Mountain regions and barley, naked barley, buckwheat and chino are grown only in the Mountain region. These crops are grown mainly in rainfed systems, which are highly vulnerable to climate-related shocks.

Paddy alone contributes about 13 percent to the agricultural GDP and about 3 percent to the total GDP (MoALD, 2022). The farmers are smallholders, and the farming system is subsistence in nature. Due to seasonal labour migration, large farm fields of cereal crops are usually left as fallow lands.

Paddy

Paddy production is the major source of livelihood and accounts for a significant percentage of cultivated farmland (Devkota and Paija, 2020). This is partly because rice can grow across diverse climatic and topographic conditions. While it is the predominant crop in the southern Terai plain area, the communities from the Hill and Mountain regions also depend on paddy farming. Paddy farming in Nepal is subsistence in nature and done mostly through traditional practice with a low degree of mechanization. In general, however, those communities with larger areas of flat land around streams and river basins, who reside at lower altitudes, are most likely to rely on paddy production as a primary means of livelihood. Owing to the fertile land, good irrigation and bigger land parcels, paddy productivity is higher in the southern plain of the Terai region than in the Hill and Mountain regions. At higher altitudes – generally further north – adverse topographical conditions and lack of ready inputs such as irrigation result in a marked decrease in paddy productivity.

The communities from this paddy-based livelihood zone also normally produce other cereal crops – wheat and maize mainly in the southern belt of the Hill region and millet in the northern belt of the Hill and the southern belt of the Mountain region. Livestock rearing has supplemented the paddy-based livelihood, although vegetables (cauliflower, cabbage, tomato, potato etc.), cash crops (sugarcane, mustard, lentils, turmeric etc.), fruit (banana, mango, jackfruit, pineapple, litchi etc.) and poultry farming are also alternative livelihoods. Communities with paddy production also engage in rearing buffalo, goats, sheep, pigs and cows for milk products and compost fertilizer for use in the production of paddy. People in the Terai region also use buffalo for ploughing the fields and for transportation, whereas the people from the Hill and Mountain regions rear oxen for ploughing the fields.

Together with labour migration to India, Gulf countries and Malaysia, the sale of livestock and its products, cash crops and, to some extent, cereal crops from better-off families are the primary income sources for these communities. Some of the communities within this area, customarily marginalized and disadvantaged groups, depend on daily wage labour.

Paddy farming is sensitive to variations in temperature. For example, in Kailali and Morang, data compiled over 39 years shows that an increase in maximum temperature has reduced the rice yield by 259 kg/ha and 141 kg/ha, respectively (Karn, 2014). Conversely, increases in average monthly minimum temperature favour the rice yield. This suggests that paddy rice needs an adequate temperature for its production. Karn (2014) found a positive relationship between rice yield and minimum temperature, with rice yield increasing up to a critical threshold of 29.9°C. When the maximum temperature goes beyond this threshold, rice yield declines.

Rainfall variability also plays an important role. Literature suggests (Devkota and Paija, 2020; Government of Nepal, 2014) that an increase in rainfall of 1 percent increases rice yields by 0.65 percent. However, Karn (2014) indicates that while this is true, increasing precipitation during the nursery stage (first 25 days, pre-establishment) harms the crop. Paddy production is linked with access to markets and roads as farmers purchase chemical fertilizer from the market; hence if these are negatively affected by high levels of precipitation, for example damage to roads, farmers might not be able to realize the increased production brought about by increased precipitation.

Wheat

Wheat is one of the main cereal crops in Nepal. It is widely produced in the country, including in the Terai, river basins, mid-hills and high hills (Gauli et al., 2021). Some communities from the western Mountain and Hill regions and a very small number from the western Terai mainly depend on wheat farming. Overall, lack of flat land, bigger land parcels and irrigation facilities are the primary factors driving farmers into wheat production as paddy farming is practised on flat land. Selection of agricultural crops and practices is directly guided by available resources such as land or terrain and, most importantly, availability of irrigation and market facilities. Livestock (buffalo, cows and goats) and service (government, non-governmental and private) are the alternative livelihoods of these communities. They rear livestock mainly for milk products and compost fertilizers, but they also sell livestock and its products as income sources. In addition, they get income from service sectors, though this is limited.

Wheat production is similar to paddy production with regard to sensitivity to temperature. It is considered a winter crop (November–April) with an optimal temperature during the growing stage of 20°C to 25°C. As temperature increases, so does the wheat yield, with the caveat that at a certain temperature (30°C), production decreases again. This temperature increase is beneficial for those crops at higher elevations but has a negative impact in the lowlands (Devkota and Phuyal, 2016; Thapa-Parajuli and Devkota, 2016).

Precipitation also plays an important role. Delays in the post-monsoon rain during wheat planting have been reported by farmers during the consultations and this has been the trend over the past 5 to 10 years depending on the geographic area. Consequently, there is a chance of severe loss of crops and seed quality if rainfall or snowfall occurs during the maturity or harvesting stages.

Maize

As with paddy, maize production occupies a large agricultural area of Nepal. It is typically grown in a subtropical to cool temperate climate (18°C to 21°C). Therefore, most communities from the eastern hills and mountains to the western hills and mountains of Nepal mainly depend on maize farming, due to the significantly smaller amount of flat and fertile land, average landholding size and lack of irrigation facilities. However, communities also produce other cereal crops such as paddy, wheat and millet in the southern belt and barley in the northern belt. The land used to grow maize is less productive than land used for paddy and wheat but more productive than land where millet and barley are grown. Maize needs 500–600 mm cumulative precipitation during its growing period, typically during the pre-monsoon season (March–August). Yet rainfall during the maturity and harvesting seasons can lead to diseases such as turccicum leaf blight (Nayava and Gurung, 2010).

As with paddy farming livelihoods, the maize-based livelihood is also supplemented by livestock – where communities rear buffalo, goats, sheep, pigs, cows and oxen for milk products, compost fertilizer and to plough the fields. They also engage in growing vegetables (cauliflower, cabbage, tomato, potato), cash crop production (ginger, black pepper, onion, turmeric, mustard, cardamom etc.) and fruit farming (banana, apple, orange, lemon, litchi etc.). Because of the minimal economic opportunities and limited resources, there are marginalized and disadvantaged groups of people within these areas, mainly dependent on labour migration to India. Some people also go to Gulf countries and Malaysia.

The sale of livestock and its products, cash crops, fruits and labour migration are the primary income sources for these communities. Relatively better-off communities from this zone sell cereal crops such as maize and millet.

Millet

Millet farming is practised only in the Hill and Mountain regions as it is more suited to the cold climatic zone and steep slopes. There are different varieties of millet across Nepal; however, Kodo (finger millet) is predominant and is the fourth major crop after paddy, wheat and maize (Upadhya, 2021). This variety is rich in micronutrients, gluten-free and high in fibre, vitamins and protein. It can also be stored for longer periods of time since it is less sensitive to pests and high temperatures, and it can overcome challenges posed by climate change as it grows where most crops fail (Luitel et al., 2019).

Regardless of its high nutrient content and climate-resistant characteristics, consumption patterns of millet are changing and currently it is mainly used to produce alcohol (Upadhya, 2021). Some communities from the eastern and western Hill and Mountain regions chiefly engage in millet production; however, they also produce maize, paddy and wheat in smaller quantities. Livestock rearing (goats, buffalo and cows) as an everyday activity has supplemented millet farming. People from this zone also engage in vegetable production. Marginalized and disadvantaged groups depend on labour migration, mainly to India but also to Gulf countries and Malaysia. Remittance and the sale of livestock and its products are the primary income sources for people in this zone, though they also earn a little income by selling cash crops, mainly potato, and tomato, cauliflower and cabbage.

Barley

Barley production is mainly located in the western Hill and Mountain regions. Thus, it is considered a winter crop, highly sensitive to a decline in winter precipitation (WFP, 2012). It has an ideal growing temperature of between 10°C and 15°C and up to 30°C during maturity (Timalsina, n.d.). However, there have been cases where late frost has caused severe damage to the crop; other impacts may come from epidemics of stripe rust due to humid weather (Riley and Singh, 1991). Communities use barley for several purposes; the straw is used to feed the livestock, and the grain is used to prepare bread (roti) or porridge (champa) (Riley and Singh, 1991).

Naked barley

Naked barley is typically cultivated during winter; it is predominant in the western part of the mountainous region. One of its main characteristics is its high-nutrient fodder value, so that during winter when other options are scarce, naked barley has an advantage. Naked barley needs a cool, moist climate between 5°C and 26°C during its growing stage – being highly sensitive to hot and dry climates (Barsila, 2018).

Chino

Communities from the Dolpa district in the western Mountain region produce chino crops in significantly smaller volumes, because farmers hold small areas of land located in steep slopes. This crop can be grown in an area with low temperatures and minimal rainfall volume. Chino is a source of food used for making bread and paste. Animal husbandry is an alternative means of livelihood. Additionally, chino producers also generate income by selling animals, animal products, working as porters and guides for tourists, and running small hotels.

2.1.2 Cash crops

Most cash crops, grown for export mainly to India and China, are expanding in terms of geographic area. These crops are primarily grown in the eastern part of Nepal despite a lack of mechanization. This crop group comprises potato, ginger, sugarcane, cardamom, black gram and tea. Sugarcane and tea are processed in factories in Nepal. Some of the farmlands previously used for cereal crops have been switched to cash crops; however, the markets and prices are volatile, so their production fluctuates every year. Potato, ginger and black gram are highly vulnerable to climate-related shocks but less so than cereal crops.

Potato

Potato is one of the essential food crops of Nepal and is a staple crop in the Hill and Mountain regions of the country. In colder areas, potatoes are a fundamental part of the meal; they are an excellent option to meet nutrition targets as they contain high levels of starch, protein, vitamin C, potassium and essential amino acids (Bajracharya and Sapkota, 2017; Phulara et al., 2021). The higher altitude best suits potato farming and small landholding sizes, steep slopes and better market prices are additional factors that attract the communities to potato farming. Thus, while primary production occurs in the hilly and mountainous areas, potatoes are also cultivated in the Terai region. The communities that produce potatoes also produce maize, millet, barley and wheat in smaller quantities. The primary source of income for this livelihood is selling potatoes, though households also earn money by selling livestock (pigs, goats and sheep) and animal products. At higher altitudes, households also produce fruits such as apples, walnuts and black pepper (*timur*) and make the income by selling them.

Communities that produce potatoes have reported losses in their crops due to lack of rainfall, and most of these producers do not have irrigation systems. Excess rain has also been reported as damaging production due to fungus development, leading to late blight disease. This spreads fast and affects the leaves, stems and fruit, leading to total loss of the crop.

Ginger

People from Ilam district, in the eastern Hill region, depend on ginger production as a high-value crop. Ginger is one of the most popular spices in South Asia; in addition, it is taken as an anti-inflammatory agent and used in cold and flu prevention.

Ginger is one of the main export crops grown in Nepal. A good network of marketing agents, reasonable prices, lower production costs and protection from monkey encroachment are the major factors that attract people to farming ginger. Along with ginger, communities in this area also produce cardamom.

In addition to ginger and cardamom production, people produce cereal crops (maize, paddy, wheat and millet) and vegetables and rear livestock. Sale of cash crops, vegetables, livestock and its products, wage labour and remittance are the main income sources for these communities.

Sugarcane

There are some sugar mills in the Terai region as communities from West Nawalparasi, Mahottari and

Kanchanpur districts mainly engage in sugarcane production. Favourable climatic conditions, flat land, good access to roads and markets, and lack of a reliable irrigation system are the major factors attracting people to this type of farming. Communities from this area also engage in cereal crop (paddy and wheat) production, fruit farming (banana), vegetable farming (cauliflower, potato, tomato etc.) and rearing livestock (cows, buffalo and goats). People sell sugarcane as one of their major income sources and complement their incomes with the sale of other cash crops such as banana, cauliflower, potato, tomato, and livestock and its products.

Cardamom

In the eastern Hill and Mountain regions, communities produce cardamom as a high-value cash crop. The farmland needs good soil moisture, so trees are planted to provide shade for the cardamom plants. This crop is mainly exported overseas and used as a spice, but sometimes people face problems exporting it due to frequent changes in trade policies in India.

Viral diseases such as chirke and furkey and poor soil conditions reduce the yield of cardamom. The International Centre for Integrated Mountain Development (ICIMOD) and the Rural Livelihoods and Climate Change Adaptation in the Himalayas (Himalica) are working in partnership with the Environment Conservation and Development Forum (ECDF) to address the issue of declining cardamom production through identifying and promoting sustainable production practices.

People also engage in the production of cereal crops (paddy, maize, millet, wheat), vegetables (cauliflower, cabbage, onion), potatoes and fruits (kiwi and lemon) and animal husbandry. In addition to cardamom, sale of these cash crops, remittance, wage labour, animals and their products are the other sources of income.

Bodhi chitta

Some communities from Kabhrepalanchok district, in the central hills, are adopting bodhi chitta farming as a high-value cash crop. Bodhi chitta grown in this area is found to be of better quality than in other areas of Nepal. It is produced in warm temperate zones; however, the elevation and climate of this area are best suited for this plant. Bodhi chitta is an export product, through agents in Kathmandu, but exactly where it goes is officially unknown. It is said to be exported overseas to countries such as Japan and Indonesia and used for making bracelets. The high demand, reasonable market price and good agent network are the major factors attractive to farmers.

This area also engages in poultry rearing, vegetable farming and tourism. Sale of bodhi chitta, cash crops, livestock and its products, wage labour, remittance and tourism are the primary income sources for these communities.

Black gram

Farming of black gram is a significant livelihood activity for the people from one of the municipalities of Okhaldhunga, an eastern Hill district. This crop is used as a pulse and grown as a cash crop. The farmland is upland and unsuitable for cereal crops such as paddy, maize and wheat. Reasonable prices with good access to the market and lower production costs are the major attractions of black gram production.

People in this area also produce cereal crops such as maize, paddy and buckwheat and rear livestock. They generate income by selling black gram, animals and their products and from remittance and wage labour.

Tea

Some communities from Ilam district, an eastern Hill region, engage in tea production as a high-value cash crop, which is exported to India. The gentle slopes, temperate climate, good connectivity to India and establishment of tea processing factories are the factors favouring tea cultivation in this region.

In addition to tea, people engage in vegetable and ginger production, labour migration and animal husbandry. Sale of tea, vegetables, livestock and its products, remittance and the tourism industry are the main sources of income for the community.

Nuts

A community from the eastern Terai region, in Jhapa district, produces betel nuts, a high-value cash crop mainly exported to India. The factors favouring betel nut farming are the subtropical climate, good connectivity to India, reasonable price and low farming cost.

People in the area also engage in vegetable and cereal farming, livestock rearing and seasonal migration abroad. Sale of betel nuts, livestock and its products, and cereal crops as well as remittance and wage labour are the primary income sources for the community.

2.1.3 Vegetables

Vegetables as kitchen garden products are produced in most rural households with good access to irrigation. However, they are produced in large volumes as commercial products only in areas with good access to markets, seeds, fertilizers, pesticides and water. Yet markets and good prices are volatile, so vegetable production fluctuates every year. The sector comprises mainly cauliflower, cabbage, cucumber and tomato. Vegetables are grown in season, out of season, in summer and winter seasons.

Cauliflower

The main productive region for cauliflower is the eastern Hill region. Though vegetable farming is practised mostly for consumption, some communities from the Dhanusha district are mostly engaged in commercial farming of cauliflower. The major advantages of cauliflower farming are favourable climatic conditions, good access to roads and markets, and support from the Prime Minister Agriculture Modernization Project and the Ministry of Agriculture and Livestock Development.

These communities also engage in potato production, livestock rearing (buffalo and goat) and poultry farming. Some of the communities within this area engage in trade and enterprise activities.

Their main income source is the sale of cauliflower; however, to a certain extent, they also get income from the sale of livestock and livestock products. Trade and business are the main income sources for people residing in urban areas within this zone.

Cabbage

Communities from Dhankuta, an eastern mid-Hill district, mainly engage in the production of cabbage and other vegetables such as green leaves and peas. Good access to a water supply and a market with reasonable prices are the major factors supporting cabbage production in these communities.

In addition to vegetables, they also engage in animal husbandry, foreign employment and cereal production. Sale of cabbage, green leaves, peas, livestock and livestock products and remittance are the major income sources for these communities.

Cucumber

Some of the communities from the Dhading district in the central Hill region engage in vegetable farming, mainly cucumber. Good access to a big market in Kathmandu valley is a major attraction of farming cucumber. People also produce beans, bitter gourd and tomato as well as engaging in animal husbandry, poultry farming and growing fruit such as oranges and bananas. Sale of vegetables, livestock and its products, labour migration abroad and wage labour are the primary income sources for these communities.

Tomato

In Nepal, tomato production is a primary activity in the eastern Terai and Hill regions, but it can also be found in the western Hill and Mountain regions. This diversity allows balanced production over the year, because at higher altitudes peak production occurs during summer, while off-season production occurs at lower altitudes. The main communities that engage in tomato farming are from Darchula, Pyuthan, Gulmi, Kathmandu, Kabhrepalanchok, Morang and Dhankuta districts. It is considered a warm-season crop and prefers well-drained soils (high sensitivity to wet soils and frost). Optimal temperature conditions are between 23°C and 27°C, and the crop suffers from heat stress above 35°C (Bhandari et al., 2016).

Favourable climatic conditions, good access to roads and markets, support from the Prime Minister Agriculture Modernization Project and the Ministry of Agriculture and Livestock Development are the major attractions of tomato farming. These communities grow cereal crops (maize, paddy and wheat) and rear livestock (goats, buffalo, cows and pigs) as alternative activities. People from these communities engage in labour migration mainly to India but also to Gulf countries and Malaysia. People receive income by selling tomatoes and, to some extent, livestock and its products, and from remittance.

2.1.4 Fruits

There is potential for various fruits to be grown in Nepal, but only apples, oranges, mangoes and bananas are produced commercially in large volumes. Apple farming is practised only in the western Mountain region, orange farming in mid-Hill region, whereas banana farming is only practised in the Terai region.

Apple

Apple is considered a temperate fruit, which has been adopted in the upper mountains of Nepal, with their mild summers and chilling climate (WFP, 2021). In addition, apples need semi-humid conditions (200–250 mm), which occur in the mid- and far-western regions (Devkota, n.d.). During the flowering stage, apples are sensitive to frost and hailstones. This product has become very common as a sun-dried fruit, and for alcoholic products that are also post-processed locally.

Communities in Garma have reported a decrease in the number of apple trees and the quality of those remaining: the apples are colourless, small and sour. The ones that are a little better are used to make alcoholic products.

Communities also engage in tourism, cereal crops (maize, millet, wheat, buckwheat, naked barley and paddy), potato and bean farming, animal husbandry and foreign employment. They rear goat, sheep, cow, yak and donkey for meat, wool and milk products. They also use animals as a means of transport. Sale of apple, tourism, animals and its products and remittance are the major income sources for these communities.

Banana

Although banana farming is found in both Terai and Hill regions, it is communities from a small geographic area of the Bara district that mainly engage in banana farming. Favourable climatic conditions, good access to roads and markets and lack of reliable irrigation systems attract people to this type of farming. Together with coffee, expansion of banana production has increased during recent years. Optimal conditions for bananas range from 26°C to 30°C with a water demand of 2,000 mm or higher (Ranjitkar et al., 2016). In addition, local varieties have been proved to be resistant to pests.

People from this zone also produce cereal crops (paddy and maize) and rear livestock (buffalo, goats and cows).

The sale of bananas, livestock and its products and remittance are the primary income sources for these communities.

2.1.5 Livestock

The livestock sector is crucial to the country because crop-producing households use it as a means of farming. Every livestock farmer rears at least two to three animals to consume their products and produce compost fertilizers. The sector comprises buffalo, cows, oxen, goats, pigs, sheep, chickens, donkeys and horses. Buffalo, cows, oxen and goats are kept mainly in the Terai and Hill regions, and sheep, goats, donkeys and horses in the Mountain region. Chickens are the most common across all regions. Grazing and pastoral lands are critical for livestock; vegetation and water sources would be susceptible to hotter and drier conditions.

Although livestock raising is a common activity in all Nepalese communities, it is a major activity for some of the communities from the Mountain, mid-Hill and Terai regions. People from the Mountain region raise goats, sheep, cows, oxen, yaks, horses and donkeys; those from the Hill region raise buffaloes, cows, oxen, goats, sheep, pigs and poultry; and those from the Terai region raise buffaloes, cows, goats, pigs and poultry and also engage in fish farming. The availability of fodder, financial and technical support through various livestock projects launched by the Ministry of Agriculture and Livestock Development and other non-governmental organizations, and good access to markets with, to some extent, reasonable prices are the influential factors that encourage these communities to farm livestock.

These communities also engage in production of cereals (paddy, wheat and maize), vegetables (cauliflower, tomato, cabbage, potato etc.), cash crops (sugarcane, turmeric, mustard) and fruit (banana). Some people from these communities engage in labour migration to India, Gulf countries and Malaysia. People generate income mainly by selling livestock and its products and cash crops. Remittance is also one of the essential income sources for these communities.

Livestock production is highly sensitive to climate change; the Government of Nepal (2014) recognizes in its Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) that there is a non-linear relationship between changes in climate and livestock productivity. For example, as the temperature increases, so does the lignification of plant tissues, reducing their digestibility for livestock and, consequently, meat and milk production. In addition, heat stress affects the cattle's bodies, reducing their feed intake and metabolism. Another attenuating factor is the potential decrease in the number of ponds that certain animals need to access for bathing and drinking, thus decreasing their longevity.

2.1.6 Non-timber forest products (NTFP)

NTFP are products that come from the forest, with the exception of timber, and they are typically used by rural communities to support their other livelihood activities. Communities from the western mountains, in Gorkha, Manang, Mugu, Bajhang and Darchula districts, depend on the collection and sale of yarshagumba. This fungus is commonly only seen at elevations of 3,000 to 5,000 m, and it is very high market price (thousands of US dollars per kilogram) spurs many to engage in its collection. Yarshagumba fungus is considered a medicinal herb and is harvested between May and June, just before the monsoon starts. Tens of thousands of people flock to the Himalayan foothills in northwestern Nepal to collect the fungus. They travel for days to the highlands and live there for a couple of months in makeshift tents. However, the profit made by middlemen purchasers often substantially reduces the income that goes back to individual pickers of yarshagumba.

In addition to yarshagumba collection, these communities also engage in tourism, animal husbandry and remittance. Sale of yarshagumba, livestock and its products, the tourism industry and foreign employment are the primary income sources for these communities.

2.1.7 Non-agricultural activities

Non-farm activities are spreading across Nepal but, as a principal income source, they are limited to a significantly smaller geographic area. Yet, this sector contributes about 74 percent of Nepal's total GDP. It comprises trade and enterprise, remittance, seasonal labour migration (India), wage labour, house renting, tourism and salaried jobs. Trade and enterprise are found in district/provincial/national headquarters and more extensive urban areas. Remittance is generated by those labour migrants who are employed mainly in Asian countries but also in other continents. Seasonal labourers go to India between sowing, transplanting and harvesting cereal crops. Rural people engage in agricultural wage labour, while those from urban areas engage in other types of wage labour. House renting is becoming an income source for urban dwellers, and tourism generates income for communities in and around naturally beautiful mountains and cultural heritage sites.

Remittance

To maximize their earnings, Nepali youths are highly attracted to labour migration, mainly to Gulf countries, India, Malaysia, Korea, Japan and European countries. Members of households from marginalized and disadvantaged groups with limited land resources and poor economic status go to India, but families whose financial situation is better and who can afford the cost go to other countries. The push factors are the lack of employment opportunities in the agrarian rural economy, lack of wage labour opportunities due to low agricultural production, and frequent natural shocks. In contrast, existing solid migrant networks and the high number of employment opportunities for unskilled labour in other countries are the pull factors for migration.

As an alternative means of livelihood, people from almost every part of Nepal engage in foreign employment; however, some communities from Banke, Myagdi, Baglung, Syangja, Palpa, Arghakhanchi, Nuwakot and Panchthar districts use it as a primary means of livelihood.

People in this area also engage in cereal crop (maize, paddy and wheat), cash crop (ginger and mustard) and livestock (goat, buffalo, cow and pig) production.

Salaried jobs and pensions

Some areas of Kailali, Kathmandu and Sankhuwasabha districts are characterized by urban livelihoods, with communities often engaging in salaried employment (with the Government or international/national non-governmental organizations and in the private sector). This is also true to an extent in the main cities of Doti and Jumla districts.

Tourism

People engage in tourism in various parts of the country, particularly communities from the Manang and Solukhumbu districts that are mainly dependent on tourism. The roof of the world, Mt Everest, attracts a substantial number of tourists to Solukhumbu district. Mt Fishtail and Annapurna, located close to the city of Pokhara, attract significant numbers of tourists to Manang district.

Seasonal migration

Seasonal migration is the main activity in western Nepal's high Hill and Mountain regions and an alternative activity in the lower Hill and Terai regions. However, communities from the Banke district cluster are highly dependent on this activity. Small landholders with low agricultural production become unable to grow enough food for a whole year, so they go to India, mainly in two seasons: (i) after finishing crop sowing and planting activities in Nepal, they go to India to earn money and return home during the harvest season; and (ii) after harvesting the crops in Nepal, they again go to India and return home during the crop sowing and planting season. A lack of employment opportunities and wage labour in the rural economy and very small landholding size with small-scale agricultural production are the push factors, while migrant networks and wage labour opportunities available throughout the year in India are the pull factors for seasonal migration to India. Cereal crop production is an alternative activity for these communities, but this is on a very small scale, enough to feed the households for only a few weeks to months.

Wage labour

People from marginalized and disadvantaged groups, and very small landholders, normally engage in wage labour because they have very limited land resources, which would enable them to produce enough food for only a few weeks to months. People from slum areas also engage in wage labour in agricultural and non-agricultural sectors. Some of the communities in Pyuthan and Sarlahi districts depend heavily on wage labour in both agricultural and non-agricultural sectors.

These people engage in agricultural wage labour during the planting and harvesting seasons and in the construction sectors (roads and building construction). They also engage in cereal crop (maize, paddy and wheat) and livestock (goat, buffalo and cow) production as an alternative activity. Due to minimal landholding size, they have a significantly smaller volume of agricultural output. People also engage in seasonal labour migration to India, where daily wage labour is available throughout the year.

Trade and enterprise

Most of Nepal's cities have small core urban area and the outskirts remain predominantly rural, so most people, even those from the cities, engage in rural livelihoods; however, people from the central areas of the cities engage in trade and business. Some urban areas of bigger cities are characterized by urban livelihoods of trade and enterprise as their primary activity.

House renting

House renting is one of the income sources for urban dwellers in the more prominent cities of Nepal; however, urban dwellers from Birendranagar city of Surkhet district and Damak city of Jhapa district mainly depend on house renting as their primary source of income and livelihood. They also engage in trade and enterprise, cereal crop and vegetable farming, and remittance.

2.2 Climate resilience and vulnerability analysis of the main livelihoods in Nepal

The main focus of the CLEAR approach is the characterization of the resilience and vulnerability of predominant livelihoods, and how these may be impacted under a changing climate. In this study, outcomes from stakeholder consultations helped to identify the climate resilience, sensitivity, adaptive capacity and vulnerability of livelihood systems across Nepal (Figures 4 – 7; details on the methods used are provided in appendix A). These are then used to inform the assessment of the impacts of climate change on livelihoods in Nepal presented in section 4.

3.1.3 Climate resilience

The resilience of livelihoods across Nepal is very varied, as presented in Figure 4. Resilience refers to the ability of a system to absorb disturbances without losing its identity (Folke, 2006) and its capacity to absorb perturbations while maintaining essential structures and functions (Holling, 1973). The resilience analysis in this study is defined as the capability of communities to remain food secure with respect to access and availability of food, socioeconomic resources, access to infrastructure, and the diversity and sensitivity of livelihoods (for detailed methodology see appendix A).

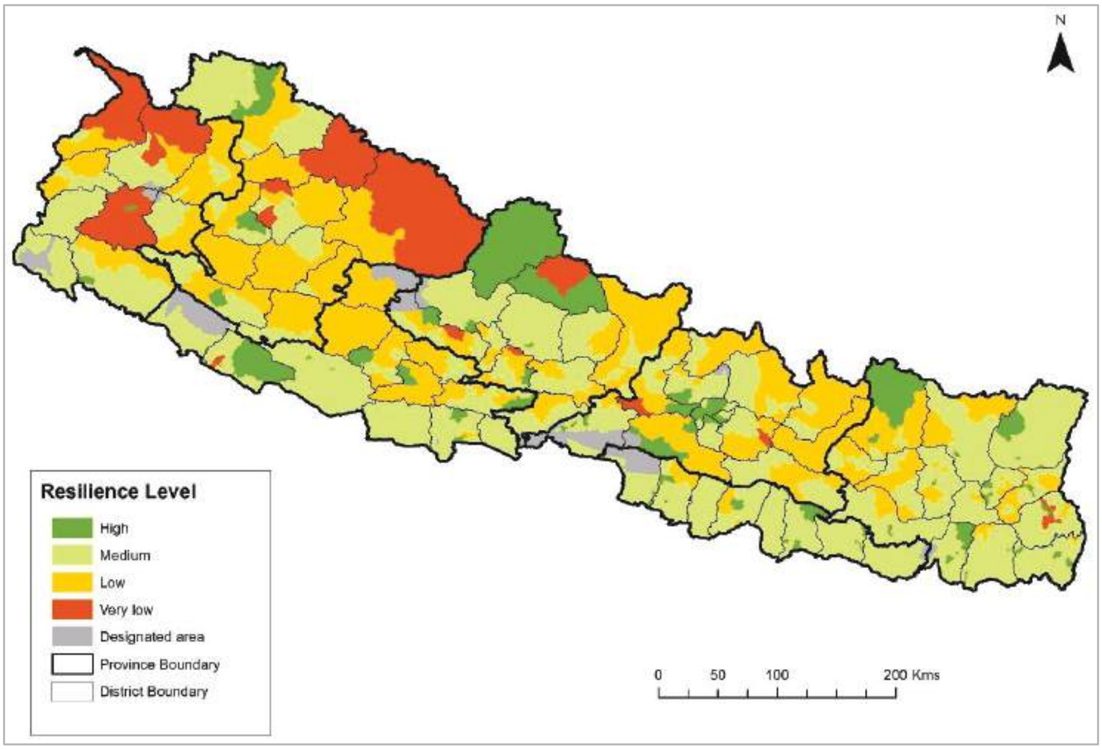

Figure 4: Resilience of the main livelihoods of Nepal.

Since the majority of livelihoods across Nepal are primarily agriculture-based, the availability of land resources, land and crop types, access to market centres and topography play key roles in determining levels of resilience. Many livelihoods, mostly from the mountainous regions and a few from hilly regions, have very low resilience.

Livelihoods based on non-timber forest products with yarshagumba as the major product, cereals such as naked barley or barley as the major crop, cash crops with cucumber as the major crop, and seasonal migration to India are the least resilient. This is due to low land productivity, small landholding size, poor market access and lack of stable non-farm activities.

Most livelihoods from the Hill region and a few from the Mountain region that are mainly based on cereals with maize, wheat or millet as the major crop, cash crops with potato or cabbage as the major crop, and seasonal migration to India have a low level of resilience. The prevalence of subsistence agriculture, small landholding size, relatively poor market access and lack of stable non-farm activities are major drivers of low resilience for these livelihoods. Seasonal migration, as an irregular and low income-generating activity, is a form of coping mechanism that indicates the community's underlying fragility.

Livelihoods based on cash crops of black gram, cardamom, sugarcane, tea, tomato, cereal with paddy, and livestock have a medium level of resilience. Non-farm-based livelihoods, with the main livelihood relying on seasonal migration (to Gulf states and Malaysia), wage labour, trade and enterprise, and salaried work, directly generate income and are more reliable. Considering these activities are less sensitive to climatic phenomena and have generally good access to markets (with exception of seasonal migration), they are highly resilient, compared to other livelihoods in Nepal.

3.1.3 Climate sensitivity

The findings show that Nepal's livelihoods are sensitive to climate at various levels; however, owing to the dominance of agriculture-based livelihoods, the climate sensitivity of Nepal's livelihoods is mostly high to medium, as presented in Figure 5. Sensitivity generally refers to the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001). Climate sensitivity as presented in this study is derived from information on exposure to climate-related multi-hazard recurrences, vulnerable population and livelihood diversity (detailed methodology in appendix A).

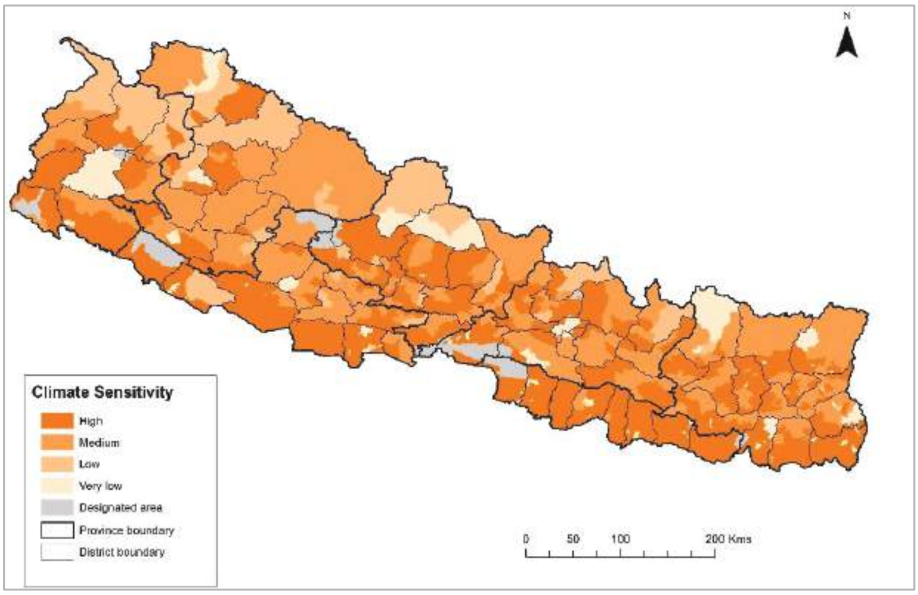

Figure 5: Climate sensitivity of the main livelihoods of Nepal.

Agriculture in Nepal is mostly rainfed and relies largely on traditional practices and crops that are highly dependent on rainfall and temperature, resulting in high climate sensitivity. Natural hazards, mainly floods and landslides, also disrupt the supply of agricultural inputs and outputs, contributing to high climate sensitivity for livelihoods in disaster-prone areas.

Paddy- and vegetable-based livelihoods have the highest level of climate sensitivity. Livelihoods based on maize, livestock and some cash crops such as potato, sugarcane and nuts have a medium level of climate sensitivity. Some cereal-based livelihoods such as millet, wheat, chino and naked barley and some based on cash crops such as tea and cardamom have a low level of climate sensitivity because these crops can be produced with low amounts of rainfall, and the communities have other alternative means of livelihood that are less sensitive to climate. All the other non-agricultural based livelihoods have very low levels of climate sensitivity.

3.1.3 Adaptative capacity

In line with resilience and climate sensitivity, the CLEAR study shows high variability in the adaptive capacity of Nepal's livelihoods, as presented in Figure 6. The adaptive capacity of a livelihood refers to the ability to adjust to potential damage and loss, to take advantage of, or to cope with, the consequences of climate change. In this assessment, adaptive capacity is a function of livelihood diversity, non-farm economic activities, sources of food, market access and landholding size.

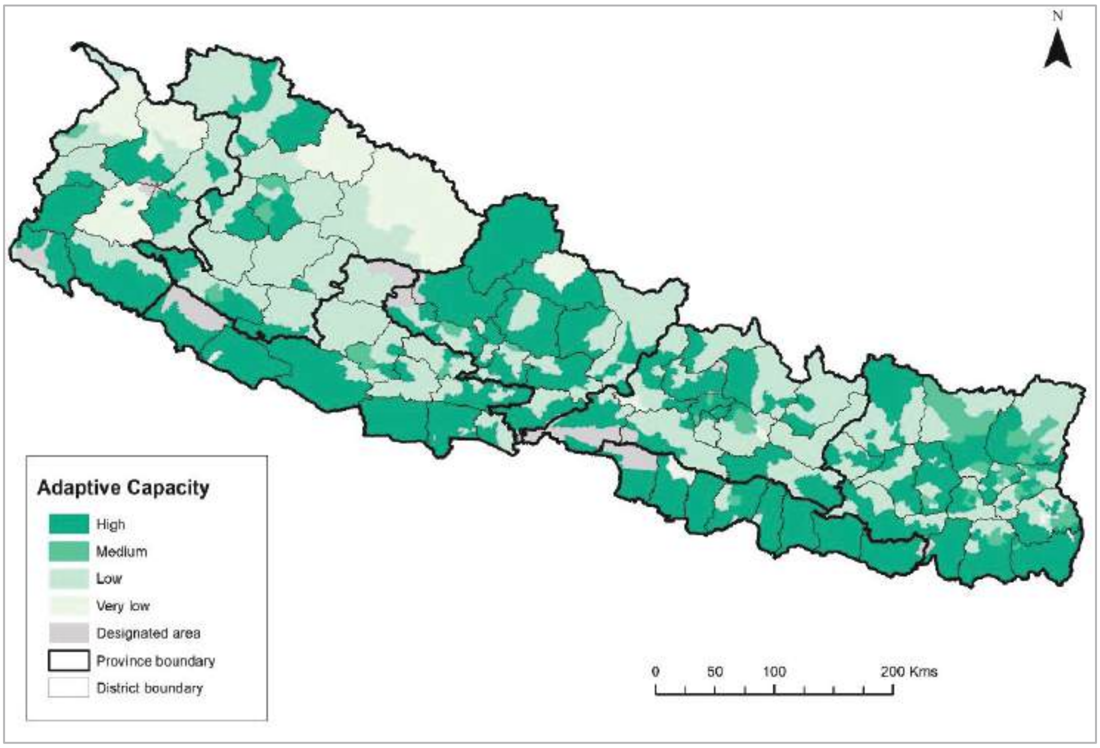

Figure 6: Adaptive capacity of the main livelihoods of Nepal.

Livelihoods dependent on seasonal migration to India, negative barley farming and non-timber forest products (NTFP) from the western Hill and Mountain regions have very low adaptive capacity as they are associated with less diverse income sources, very small landholding size and agricultural production, poor market access, and difficulty in generating income through both farm and non-farm economic activities. The maize farming livelihood covering a large area of the Hill and Mountain regions and the livestock-based livelihood have low adaptive capacity in terms of climate risk. Smaller landholding size with poor land quality and agricultural production and very few non-farm economic activities are the main reasons for the lower adaptive capacity of communities dependent on maize farming. Diverse means of livelihood, bigger landholding size with good quality land and larger-scale agricultural production, and high-value crops are reinforcing the adaptive capacity of livelihoods based on cash crops, mainly ginger and cardamom, vegetables and apple farming.

Paddy-based livelihoods have high adaptive capacity, benefiting from bigger landholding size, good quality land with larger-scale agricultural production, better access to markets and opportunities to engage in more non-farm economic activities.

3.1.3 Vulnerability

The livelihood vulnerability, a function of climate sensitivity and adaptive capacity presented above, is equally varied as shown in Figure 7. Vulnerability differs widely among communities as well as over time and space. Vulnerability is defined as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006).

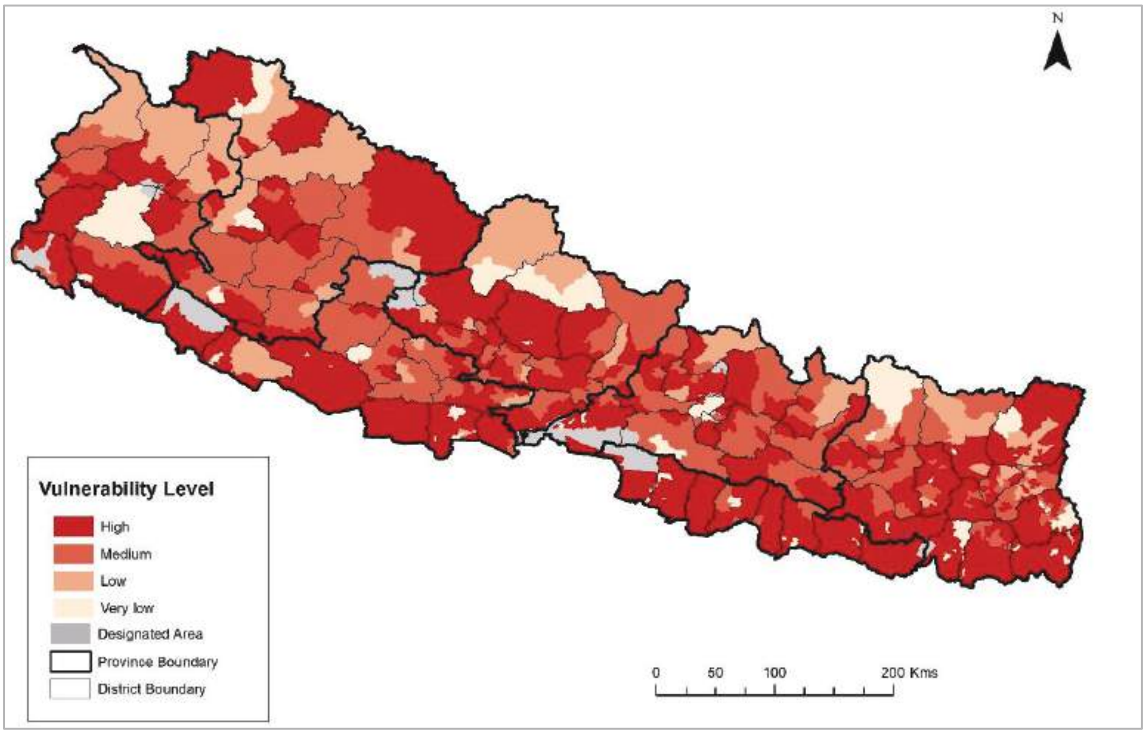

Figure 7: Vulnerability of the main livelihoods of Nepal.

Paddy-based livelihoods from almost all the Terai, some parts of the Hill, and a few parts of the Mountain regions are highly vulnerable due to a combination of high recurrences of multiple hazards (floods, drought, landslides, hailstones, windstorms) and a high degree of sensitivity to climatic phenomena, as they are mostly rainfed and require an adequate amount of rainfall to be sustained.

Livelihoods based on potato, barley, naked barley, banana, cucumber and livestock are also highly vulnerable. Communities have limited and less productive resources, which combined with their remoteness and minimal access to markets means they are unable to adequately address adverse conditions and risks, have fewer alternatives, and are thus more susceptible to food security shocks.

Livelihoods with maize as a major crop have a medium level of vulnerability. These communities are generally smallholder farmers with relatively poor access to land and markets and non-farm activities. Livelihoods based on cash crops with tomato, cauliflower, cabbage, ginger or sugarcane as a major crop are also at a medium level of vulnerability. These communities are facing recurrent climatic risks such as drought, pests and diseases, and this is compounded by the limited availability of non-farm activities.

Communities particularly dependent on cereal crops with millet, wheat or chino as the major crop, cash crops of nuts or cardamom, NTFP with yarshagumba as the major product, and remittance are less vulnerable in terms of climatic shocks as these activities are less sensitive to climate. The communities whose income is based on trade and enterprise, house renting, salaried employment, tourism, seasonal migration to India and wage labour are the least vulnerable. These are relatively more stable non-farm activities with direct, reliable and regular sources of income. As apple and tea are the least sensitive high-value crops, these livelihoods are also the least vulnerable.

3. Defining baseline climate and relationship with livelihoods in Nepal

3.1 Nepal climate overview

Nepal is a land-locked country spanning from the Indo-Gangetic Plain to the foothills and high mountain regions of the Himalayas. It shares a border with the People's Republic of China to the north and with India to the east, south and west. From east to west, it stretches 885 km , and its climate varies from a tropical climate at its lowest elevations (below 500 m) to a tundra and arctic climate above 5,000 m (MoFE, 2018; Figure 8).

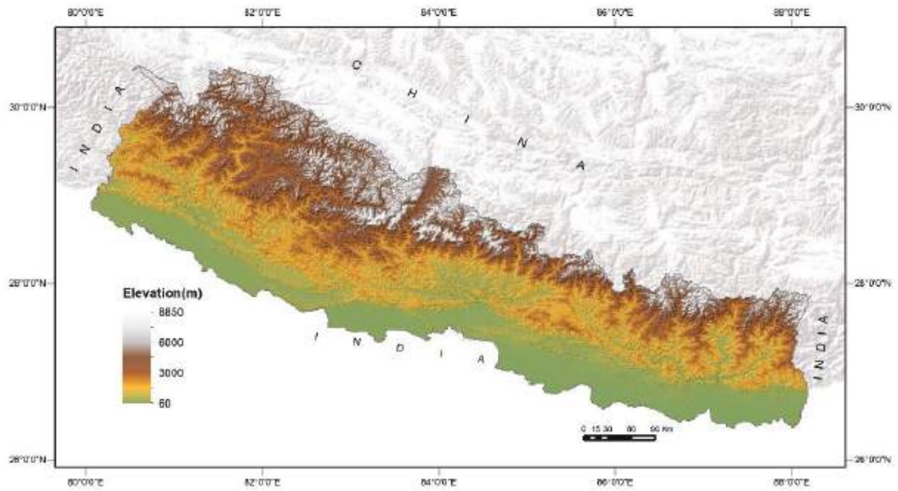

Figure 8: Topography of Nepal.

Data sources: Survey department, Government of Nepal, 1996 & Environmental Systems Research Institute, United States Geological Survey, National Oceanic and Atmospheric Administration.

Nepal receives around 1,500 mm of annual precipitation, on average, which is unevenly distributed through the year and across the country. Eighty percent of the annual precipitation occurs during the south easterly summer monsoon (June–September), with more precipitation occurring in the east on average due to the east–west progression of the monsoon. The remaining precipitation occurs during the pre-monsoon season (April–May) and from western disturbances during winter (December–February), which typically affect the northwestern regions. Precipitation patterns are strongly influenced by the country's diverse topography (Figure 8).

Multiple studies have assessed the current climate of Nepal using observational datasets, quantifying the current climate and observed trends by the five physiographic zones and by district-based administrative boundaries (e.g., MoFE, 2018; DHM, 2017). For the purpose of this study, we characterize the current climate by the Mountain, Hill and Terai zones as defined by the Ecological belt division of Nepal (Figure 2). These larger zones reflect the key differences in climate across the country and enable us to qualitatively combine gridded climate data and the livelihood zoning analysis, which is required for assessing the impacts of future climate change on livelihoods and food security. Maps and annual cycles of precipitation and mean temperatures are shown in Figure 9 and Figure 10, respectively, and show the differences in climate across the three zones.

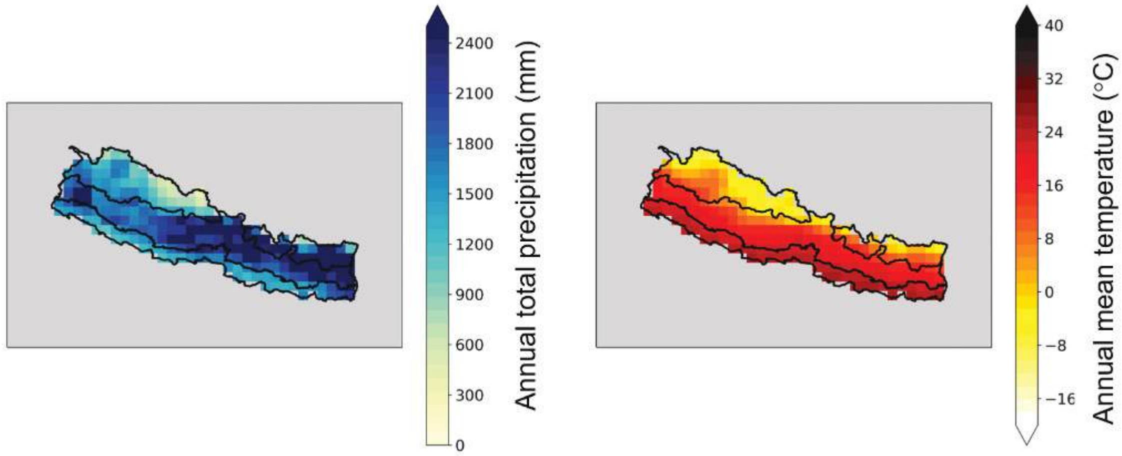

Figure 9: Maps of the annual average total precipitation (left panel) and annual average daily mean temperature (right panel) from the ERA5 dataset (Hersbach et al., 2020) in Nepal for the baseline period 1981–2010. The Ecobelt zones are plotted for reference (Government of Nepal, 1996).

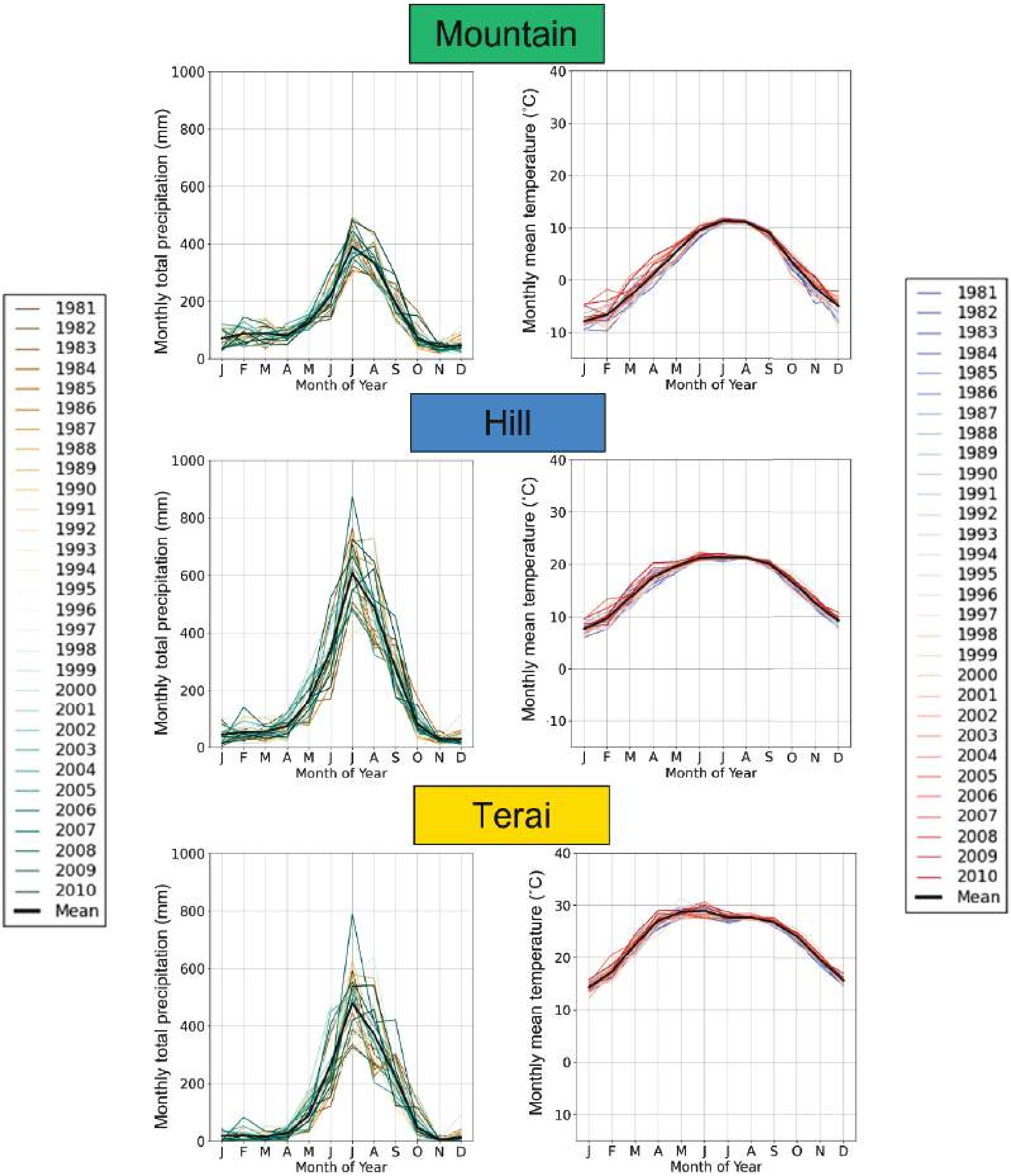

Figure 10: Annual cycles of monthly total precipitation (left panels) and mean temperature (right panels) for the baseline period (1981–2010) for the Mountain zone (top panels), Hill zone (middle panels) and Terai zone (bottom panels). Individual years from 1981–2010 are shown with coloured lines (ranging from brown to blue for rainfall, and blue to red for temperature), and the mean monthly values are shown in black. This highlights the year-to-year variability in rainfall and temperature values.

3.1.1 Mountain zone

The Mountain zone is the coolest and driest of the three zones. The climate type varies from cool temperate to warm temperate. Average daily maximum temperatures range from −2°C during winter months (December – February) to 15°C during June – August. Average daily minimum temperatures range from −15°C in winter up to 8°C during the monsoon season (June – September). Most of the precipitation falls in the monsoon season, with the peak occurring in July with a monthly average of 400 mm. This region also receives around 50 mm per month outside of the monsoon, which predominantly falls as snow. Amounts and timings of the monsoon rains and winter precipitation vary from year to year. This region is exposed to climate-related hazards such as landslides, drought, hailstones, windstorms, excessive snowfall and glacial lake outburst floods (GLOFs).

3.1.2 Hill zone

The Hill zone is the wettest of the three zones. The climate type varies from cool temperate in the higher altitude regions to warm temperate in the lower hills and valleys. Average daily maximum temperatures range from 13°C during winter months (December – February) to 25°C during April – September. Average daily minimum temperatures range from 3°C in winter up to 19°C during the monsoon season (June – September). Most of the annual rainfall falls in the monsoon season, with the peak rainfall occurring in July with a monthly average of 600 mm. The amount and timing of the monsoon rains vary from year to year, and the migration of the monsoon rains from east to west means that the eastern part of the zone receives more rainfall as the monsoon season starts earlier. The region is exposed to climate-related hazards such as landslides, hailstorms, windstorms and drought.

3.1.3 Terai zone

The Terai zone is the hottest of the three zones. The climate type in this zone is subtropical and it represents the hottest part of the country. Average daily maximum temperatures range from 20°C during the winter months (December – February) to 35°C during the pre-monsoon season (March – May). Average daily minimum temperatures range from 8°C in winter up to 25°C during the monsoon season (June – September). Most of the annual rainfall falls in the monsoon season, with the peak rainfall occurring in July with a monthly average of 500 mm. The amount and timing of the monsoon rains vary from year to year. This region is exposed to climate-related hazards such as riverine flooding, flash flooding, drought, cold waves, heatwaves and wildfire. The flooding risk is the highest in Nepal compared to the other zones (MoFE, 2021).

3.2 Observed climate trends

Analysis of observed climate trends for Nepal for the period 1971–2014 by the Department of Hydrology and Meteorology (DHM, 2017) found an observed warming trend but no clear trend in mean precipitation. A summary of the main findings is provided below.

Annual maximum temperatures increased by approximately 0.5°C per decade in all districts and in all seasons, except those located in the Terai and Siwalik regions during the winter season (DHM, 2017).

The largest trend occurred in higher altitude regions. There was no trend in minimum temperature at the national scale, but there were regional differences: there was a positive trend in regions up to 3,000 m and a negative trend during the winter season in the high Himalayas.

The number of warm days and nights and the duration of warm spells showed significant positive trends in most districts. In contrast, the number of cold days was decreasing across most of the country. The number of cold nights had increased in the northern regions and significantly reduced in the southern regions. The duration of cold spells only showed a significant increase in the far west.

In general, precipitation trends over the period assessed were not significant in any season. However, in the northwest, the number of days with precipitation increased and the frequency of consecutive dry days decreased. In northern districts, very high precipitations days decreased.

3.3 Linking climate and livelihood analysis in Nepal

This assessment draws together specific analysis of the baseline climate in each of the climate zones with information about the dominant livelihoods and how sensitive and resilient they are to climate-related shocks (as presented in section 2). Table 1 presents a summary of this key information used to assess the differences in the way people live and the climate they experience across the Mountain, Hill and Terai zones.

Source: Content from sections 2 and 3, and the Central Bureau of Statistics, 2011.

Table 2 summarizes the key climate sensitivities and how they impact the main livelihood groupings of Nepal (cropping, livestock, forestry and non-agricultural activities). This information is used to inform the interpretation of future climate change on livelihoods and food security in Nepal, presented in section 4.

Table 1: Summary of the different characteristics of the Mountain, Hill and Terai zones

ZONE	GEOGRAPHY	POPULATION	CURRENT CLIMATE	MAIN LIVELIHOODS	SENSITIVITY, RESILIENCE AND ADAPTIVE CAPACITY OF THE MAIN LIVELIHOODS
Mountain	• Comprises high mountains and Himalayas. • Located above an altitude of 2,500 m. • Covers 35% of total land area.	• 6% of the population. • Higher population density in the east (35 persons/km^2) compared to the west (54 persons/km^2).	• Coolest zone: daily maximum temperatures range from −2°C to 15°C on average through the year. • Driest zone: ~400 mm per month at peak of monsoon • Climate-related hazards include landslides, drought, hailstones, windstorms, excessive snowfall and GLOFs.	• Mix of agricultural and non-agricultural livelihoods. • Agricultural livelihoods include wheat, naked barley, chino, apples and livestock. • NTFP livelihood only occurs in this zone.	• The Mountain zone has the lowest climate sensitivity. • Agricultural livelihoods have low resilience and adaptive capacity, NTFP livelihoods are the lowest. • Non-agricultural livelihoods have high resilience and adaptive capacity.
Hill	• Comprises hills and middle mountains. • Altitudes range from 200 to 2,500 m above sea level. • Covers 42% of total land area.	• 40% of the population. • Higher population density in the east (727 persons/km^2) compared to the west (150 persons/km^2). • Population density also varies with altitude; lower hills and valleys are more densely populated.	• Daily maximum temperatures range from 13°C to 25°C on average through the year. • Wettest zone: ~600 mm per month at peak of monsoon. • Climate-related hazards include landslides, hailstorms, windstorms and drought.	• Mostly cereal crops: paddy-based livelihoods dominate at lower altitude, maize-based livelihoods dominate in the hills, some livestock, vegetables and cash crops. • Some non-agricultural livelihoods.	• The Hill zone has a medium level of climate sensitivity. • Resilience and adaptive capacity are low in the west and for maize-based livelihoods at higher altitudes. They are higher in the east and for paddy-based and non-agricultural livelihoods.

ZONE	GEOGRAPHY	POPULATION	CURRENT CLIMATE	MAIN LIVELIHOODS	SENSITIVITY, RESILIENCE AND ADAPTIVE CAPACITY OF THE MAIN LIVELIHOODS
Terai	• Comprises flat plains and the Chure range to the north. • Altitudes mostly range from 60 to 200 m above sea level. • Covers 23% of total land area.	• 54% of the population. • Highly populated area with 512 persons/km^2.	• Hottest zone: daily maximum temperatures range from 20°C to 35°C on average through the year. • ~500mm per month at peak of monsoon. • Climate-related hazards include riverine and flash flooding, drought, cold waves, heatwaves and wildfire.	• Mostly cereal crops: paddy-based livelihoods dominate. • The region accounts for 56 percent of the total arable land.	• The Terai zone has the highest climate sensitivity. • Resilience is medium and adaptive capacity is high.

Source: Content from sections 2 and 3, and the Central Bureau of Statistics, 2011.

Table 2: Summary of the main climate sensitivities and impacts for each of the main livelihoods in Nepal

LIVELIHOOD	CLIMATE SENSITIVITY	IMPACT
Cropping	Heat stress	Yields decline in most crops if optimum temperature thresholds are exceeded. Paddy produced in the Terai region is already exposed to temperatures above the optimum range.
	Water stress	Lack of required water can reduce yield, damage the crop or cause crop failure. Maize is particularly vulnerable to the impacts of water stress.

LIVELIHOOD	CLIMATE SENSITIVITY	IMPACT
	Heavy precipitation	Heavy precipitation can cause flooding, hailstorms and landslides, which can damage crops, agricultural land and infrastructure. Damage to the transport network can impact access to markets.
	Rainfall variability	Most crops in Nepal are rainfed and are therefore vulnerable to specific rainfall amounts and timings. Delays in the monsoon can result in shifts in the growing season and exposure to very high temperatures in the hottest regions. Crops are also vulnerable to variability within the monsoon, such as dry spells, and rain during the harvest period can also damage crops and seed quality.
	Pests and disease	The pests and diseases affecting crops often require certain temperatures or rainfall during certain stages of the growing season, e.g., turccicum leaf blight affects maize crops when there is rainfall during the maturity and harvesting seasons.
Livestock	Heat stress	Heat stress impacts livestock health and reduces milk and meat production.
	Water stress	Water stress impacts the availability of water for drinking, bathing, pasture and fodder.
	Rainfall variability	Drier years and delays in the monsoon can increase the incidence of heat stress and water stress in livestock.
	Pests and diseases	Certain climate conditions are conducive to pests and diseases affecting livestock.
Forestry	Habitable conditions	The formation and abundance of NTFPs, such as yarshagumba, are sensitive to temperature and humidity and as such the specific location and altitude where the products are found.
Non-agricultural activities	Heavy precipitation	Heavy precipitation can cause flooding and landslides, which can damage infrastructure and transport networks and subsequently affect access for non-agricultural livelihoods.

Source: Content from sections 2 and 3, and the Central Bureau of Statistics, 2011.

4. Scenarios of Projected climate change and outcomes for livelihoods in the 2050s

Based on climate model projections for Nepal, there is high confidence that temperatures will continue increasing over the twenty-first century. There is less confidence in the direction and extent of projected changes in precipitation, with a majority of model simulations projecting an increase in annual average precipitation but some projecting a decrease; amounts range from around −10 percent to 30 percent compared to the recent past (1981 – 2010). For the purpose of this study, three plausible scenarios of projected climate change for Nepal in the 2050s have been considered. Scenarios are not predictions but are a sample of what is plausible across the range of modelled changes. They provide a useful basis for exploring what different levels of climate change might mean for future food security in Nepal.

The scenarios were chosen to represent three different possible futures that sample the range of projected outcomes. The scenarios are results from analysis of three regionally downscaled global climate model simulations for the 2050s (2041–2070) under one moderate (RCP4.5) and one high (RCP8.5) pathway of greenhouse gas concentrations (van Vuuren et al., 2011). These scenarios are presented in this section, along with assessments of the associated pressure on livelihoods and indications for food security. More detail on the methods and choice of scenarios is given in appendix B.

4.1 Summary of the three climate change scenarios

The projected climate change in Nepal for each of the scenarios considered is summarized below. Along with the projected trends in each of these scenarios, year-to-year variability will continue to bring hotter, cooler, wetter and drier years as a result of natural variability in the climate system (Figure 11).

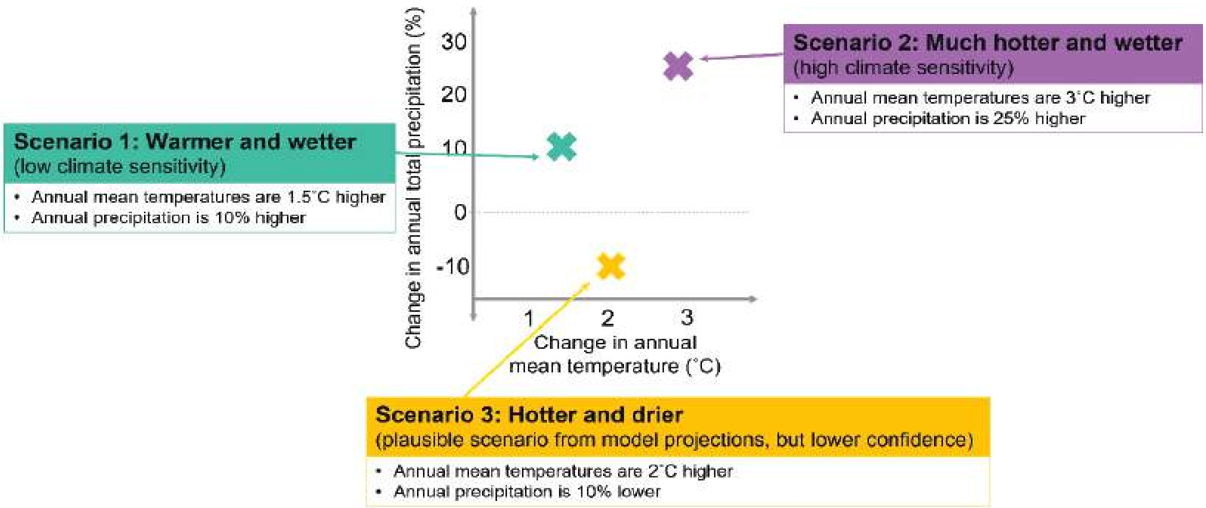

Figure 11: The three climate change scenarios for the 2050s considered in this assessment.

- Scenario 1 represents a future that is warmer and wetter compared to the baseline climate. Annual mean temperatures are 1.5°C higher than in the baseline climate, resulting in higher levels of heat stress, more frequent and intense heatwaves and an increase in evaporation. Annual precipitation is 10 percent higher on average, with the increase occurring during the monsoon season and little change in other seasons. Heavy rainfall events are more intense compared to the present day, which can exacerbate flooding risks.

- Scenario 2 represents a future that is much hotter and much wetter compared to the baseline climate. Annual mean temperatures are 3°C higher than in the baseline climate, resulting in much higher levels of heat stress, more frequent and intense heatwaves, and an increase in evaporation relative to the baseline and in comparison with Scenario 1. Annual precipitation is 25 percent higher on average, but this increase does not occur in all seasons: the pre-monsoon, monsoon and post-monsoon seasons are wetter than the present day, with larger increases in the pre- and post-monsoon seasons, whereas the winter season is drier than the present day. Heavy rainfall events during the monsoon are more intense compared with the present day and compared with Scenario 1, further exacerbating flooding risks.

- Scenario 3 represents a future that is hotter and drier compared to the baseline climate. Annual mean temperatures are 2°C higher than in the baseline climate, resulting in higher levels of heat stress, more frequent and intense heatwaves, and an increase in evaporation relative to the baseline and Scenario 1, but with lower impacts than in Scenario 2. Annual precipitation is 10 percent lower on average, with decreases in all seasons and larger decreases during the winter season. Despite the decrease in average rainfall, heavy rainfall events during the monsoon are more intense compared to the present day.

4.2 Detailed assessment of climate change scenarios and outcomes for livelihoods

3.1.3 Scenario 1

Most climate models project a warmer and wetter climate for Nepal in the 2050s and Scenario 1 represents the lower end of these projected changes. In Scenario 1, annual mean temperatures are projected to be 1.5°C higher on average and the annual average precipitation is projected to be 10 percent higher compared to the baseline values, when averaged across the whole of Nepal. Maps of the projected changes from a climate model simulation representing this scenario are shown in Figure 12 and projected changes on seasonal timescales are shown in Figure 13; note the scales are the same for all subsequent figures to allow comparisons. These figures show there is little variation across the country in the projected changes in precipitation and that precipitation is projected to increase in the pre-monsoon, monsoon and post-monsoon seasons, whereas a small decrease is projected in the winter season.

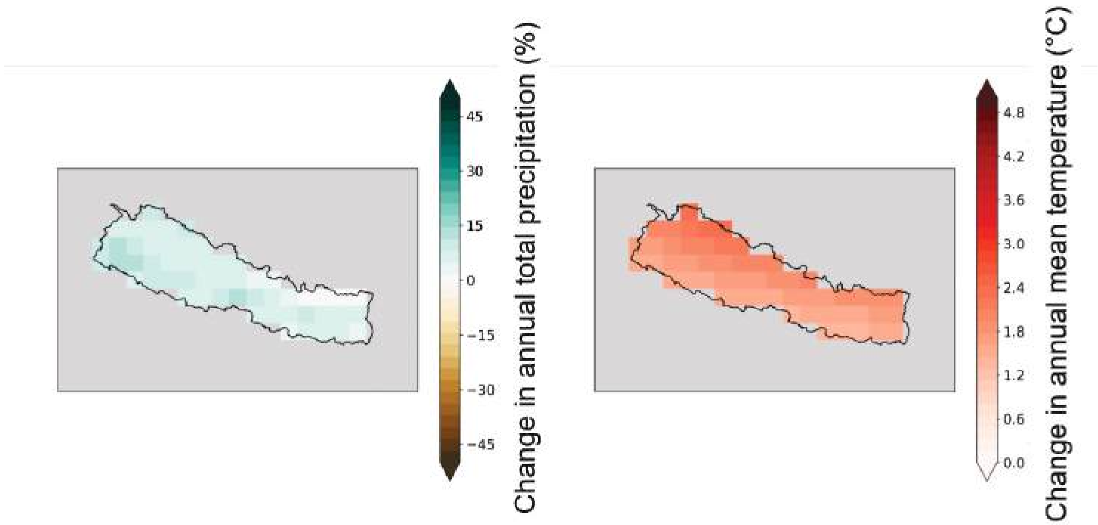

Figure 12: Projected changes in annual average rainfall and daily maximum temperature in Scenario 1 for the 2050s (2041–2071) relative to the baseline (1981–2010).

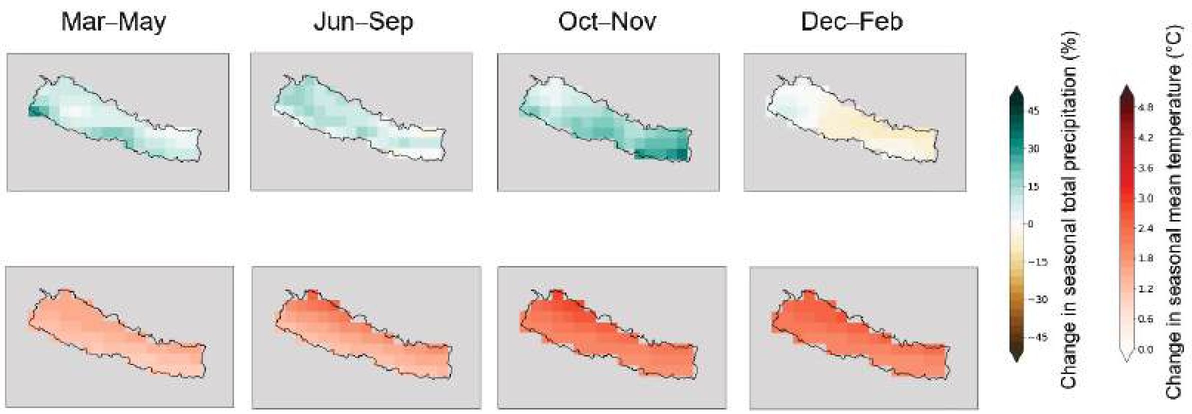

Figure 13: Projected changes in seasonal total rainfall (top panels) and seasonal average daily maximum temperature (bottom panels) in Scenario 1 for the 2050s (2041–2071) relative to the baseline (1981–2010).

The projected increase in temperature in Scenario 1 will result in higher temperatures on average across the country, and larger increases at higher altitudes. This will mean that current peak temperatures will be exceeded earlier in the year and for longer through the year. Heatwave conditions will therefore increase in frequency and intensity. This will increase heat stress impacts on crop production where optimum temperatures may be exceeded (e.g., for paddy rice) and health impacts on livestock, particularly in the hottest regions. However, warmer temperatures will also reduce the impacts of frost damage on certain crops, such as apples, and may also increase the habitable area and varieties of NTFPs (Shrestha and Bawa, 2014).

As temperatures rise, evaporation rates will also increase. This means that the small projected increase in annual precipitation in Scenario 1 may result in little change in water availability overall. During the winter season, water scarcity may increase due to the combined effect of warmer temperatures and reduced precipitation (Figure 13), which will negatively affect production of winter crops and also pasture availability for livestock, particularly in drier years. However, a warmer climate will mean that more precipitation will fall as rain rather than snow at higher altitude and accelerated melting of snow and glaciers may affect the seasonality of river flows and water availability.

As well as the projected increase in mean precipitation, the intensity of heavy precipitation events is also projected to increase, exacerbating the risk of flash flooding, landslides and GLOF events relative to the baseline climate. This will increase the risk of damage to crop production and agricultural land, affecting crop- and livestock-based livelihoods, and also damage to infrastructure and transport networks resulting in disruption to market access and supply chains.

Continued variability in precipitation amounts and timings may result in shifts in crop seasons, causing risk to local crop varieties such as paddy, wheat, maize and fruits, and heat stress impacts will be exacerbated in years when the monsoon rains are delayed.

The combined effect of warmer temperatures and increased precipitation may also increase risk of pests and diseases affecting most crops and livestock.

3.1.3 Scenario 2

Scenario 2 represents the higher end of projected climate change for Nepal in the 2050s. In Scenario 2, annual mean temperatures are projected to be 3°C higher on average and the annual average precipitation is projected to be 25 percent higher compared to the baseline values, when averaged across the whole of Nepal. Maps of the projected changes from a climate model simulation representing this scenario are shown in Figure 14 and projected changes on seasonal timescales are shown in Figure 15. These figures show little variation across the country in the projected changes in precipitation and that precipitation is projected to increase most during the pre-monsoon and post-monsoon seasons, with smaller increases during the monsoon. A large decrease is projected in the winter season. This suggests a potential earlier start and lengthening of the monsoon season.

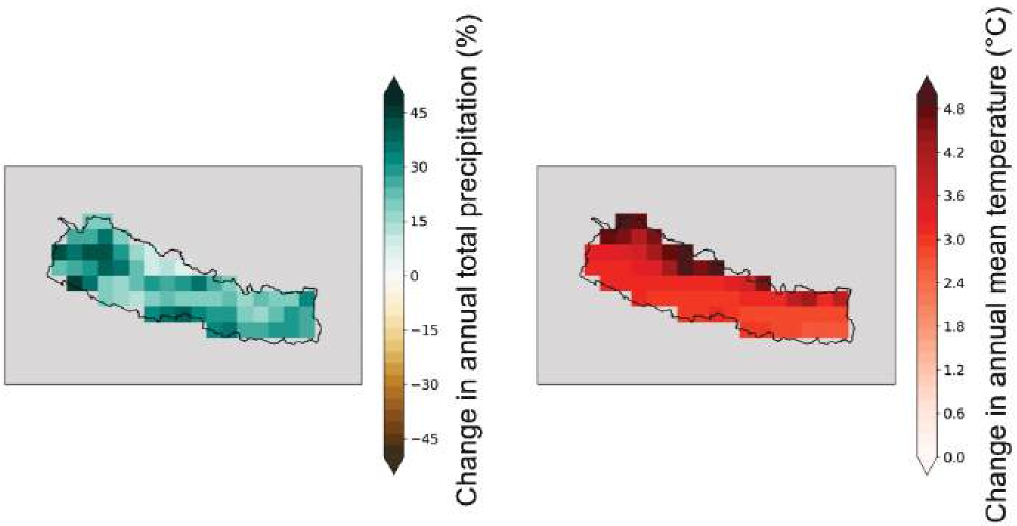

Figure 14: Projected changes in annual average rainfall and daily maximum temperature in Scenario 2 for the 2050s (2041–2071) relative to the baseline (1981–2010).

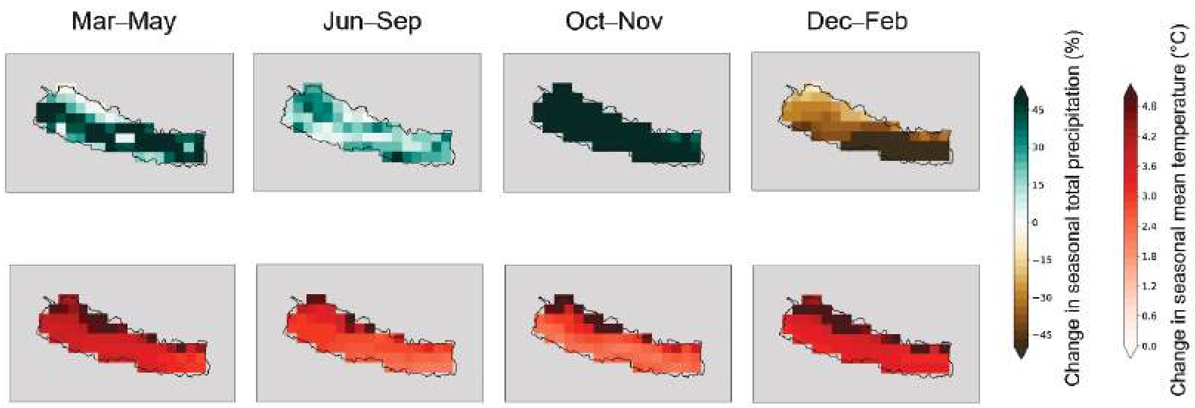

Figure 15: Projected changes in seasonal total rainfall (top panels) and seasonal average daily maximum temperature (bottom panels) in Scenario 2 for the 2050s (2041–2071) relative to the baseline (1981–2010).

The projected increase in temperature in Scenario 2 is larger than in Scenario 1 and as such will result in much higher temperatures on average across the country and, similarly, larger increases at higher altitude. This will mean that current peak temperatures will be exceeded even earlier in the year and for longer through the year. As such, heatwave conditions will increase in frequency and intensity both compared with the baseline climate and compared with Scenario 1. Heat stress impacts on crops and livestock will be larger in Scenario 2 than in Scenario 1, with higher levels of heat stress in the hottest regions and larger areas affected. As in Scenario 1, warmer temperatures will also reduce the impacts of frost damage to certain crops, such as apples, and may also increase the habitable area and varieties of NTFPs.

As in Scenario 1, evaporation rates will increase with rising temperatures, and with larger increases in temperature the evaporation rates will also be larger. In Scenario 2, the projected larger increase in precipitation during the pre-monsoon and post-monsoon seasons will result in overall increases in water availability during these seasons, but the smaller increases during the monsoon season may result in little change in water availability in some areas due to the higher temperatures. The combined effect of large increases in temperature and large decreases in precipitation during the winter season will result in increases in water scarcity relative to the baseline climate and compared with Scenario 1, exacerbating water stress impacts on winter crops and pasture availability for livestock.

The much higher temperatures and larger reductions in winter precipitation in Scenario 2 may have additional long-term implications for water availability compared with Scenario 1. With more precipitation falling as rain at higher altitudes, a higher rate of snow and glacial melt due to higher temperatures, and reductions in winter precipitation, the seasonality of river flows and water availability downstream will be more affected in this scenario. An additional impact of the higher temperatures is that the snowmelt will likely begin earlier in the year, and this combined with the increases in pre-monsoon precipitation could result in very full rivers and increase the risk of riverine flooding.

As well as the projected increase in mean precipitation, the intensity of heavy precipitation events is also projected to increase both relative to the baseline climate and in comparison with Scenario 1, further exacerbating the risk of flash flooding, landslides and GLOF events in this scenario and the associated damage to crops, infrastructure and access to markets and supply chains.

Other impacts on crops and livestock are larger in Scenario 2 compared with Scenario 1, such as shifts in cropping seasons linked with precipitation variability, increases in heat stress in years when the monsoon rains are delayed, and the incidence and habitable areas of pests and diseases.

3.1.3 Scenario 3

Although most climate models project a wetter climate on average for Nepal in the 2050s, there are some plausible climate model simulations that project a drier climate on average. Scenario 3 represents this hotter and drier future climate and is an example of a high impact, low likelihood future for Nepal. In Scenario 3, annual mean temperatures are projected to be 2°C higher on average and the annual average precipitation is projected to be 10 percent lower compared to the baseline values, when averaged across the whole of Nepal. Maps of the projected changes from a climate model simulation representing this scenario are shown in Figure 16 and projected changes on seasonal timescales are shown in Figure 17. These figures show little variation across the country in the projected changes in precipitation and that precipitation is projected to decrease in the pre-monsoon, post-monsoon and winter seasons and there is little change projected during the monsoon season.

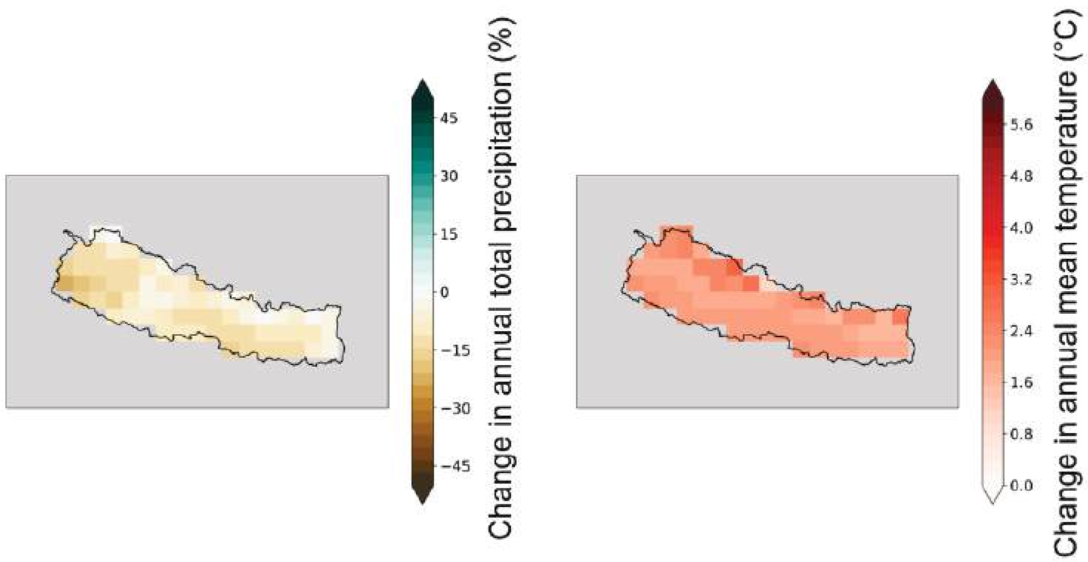

Figure 16: Projected changes in annual average rainfall and daily maximum temperature in Scenario 3 for the 2050s (2041–2071) relative to the baseline (1981–2010).

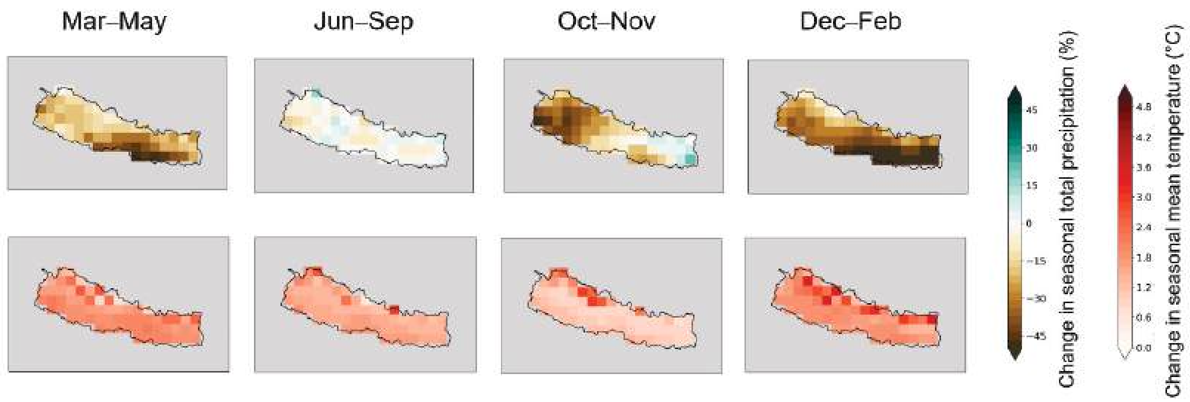

Figure 17: Projected changes in seasonal total rainfall (top panels) and seasonal average daily maximum temperature (bottom panels) in Scenario 3 for the 2050s (2041–2071) relative to the baseline (1981–2010).

The projected increase in temperature in Scenario 3 is greater than in Scenario 1 and less than in Scenario 2, resulting in similar heat stress impacts on crop and livestock livelihoods, which are scaled between those in Scenarios 1 and 2. As in Scenarios 1 and 2, warmer temperatures will also reduce the impacts of frost damage on certain crops, such as apples, and may also increase the habitable area and varieties of NTFPs.

However, due to the projected drier climate in Scenario 3 and the increase in evaporation associated with higher temperatures, increases in heat stress will be higher in this scenario. Water scarcity will increase across the country in all seasons. Reduced precipitation in the winter season and also the pre- and post-monsoon seasons combined with higher temperatures will further exacerbate the impacts of accelerated melting of snowpack compared with Scenarios 1 and 2, with long-term implications for water availability and seasonality of river flows. In addition, a hotter and drier climate on average will mean that groundwater sources will not be recharged as in the other scenarios, causing long-term depletion and reduction in water availability. This will particularly impact water availability during the drier seasons, and with continued year-to-year variability in precipitation amounts and timings, dry years will be much drier in this future scenario, resulting in an increase in drought conditions. This scenario presents a higher risk of water stress impacts on crops and livestock across the country and throughout the year. These conditions are also more conducive to forest fires, and the risk of these and subsequent impacts on crop production and pollution levels will also increase.

Despite the drier climate on average, the intensity of heavy precipitation events is still projected to increase due to the changing nature of precipitation in a warmer climate (UK Met Office, 2022. These increases are most likely to occur during the monsoon season, further exacerbating the risk of flash flooding, landslides and GLOF events and resulting in similar damage to crops, infrastructure and access to markets as other scenarios.

4.3 Climate change outcomes by livelihood

Table 3 summarizes the potential impacts of a changing climate on the main livelihoods (listed in section 2) for the climate change scenarios presented.

Table 3: Summary of climate change outcomes by livelihood

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE
Cropping	Heat stress	Increasing temperatures, found across all scenarios, will increase the risk of heat stress on crops. The larger the temperature increase, the larger the impact will be on crop yields, though precipitation changes may modify responses. Higher maximum temperatures will be experienced for longer through the year, larger areas will be exposed to higher temperatures, and more crops will exceed their optimum thresholds, such as maize in higher altitude areas. Paddy produced in the Terai and maize in the Hill regions are most likely to be negatively affected; however, people with maize-based livelihoods are most at risk as they are less able to adapt due to their reliance on maize and limited alternatives. One benefit of increasing temperatures is the reduction in frost, which may improve growing conditions for crops sensitive to frost, such as apples, or open up new regions for production.
	Water stress	Under all scenarios considered, the risk of water stress is likely to increase for winter crops, particularly in the drier regions. This risk will be higher in a hotter and drier future climate (Scenario 3) when water stress may also impact crops during the pre- and post-monsoon seasons. The seasonality of river flows and water availability will also be affected in a future climate due to changes in the timing and amount of snow and glacial melt, particularly in Scenario 3 where there may be longer-term implications due to accelerated melting and insufficient snowfall to replace the snowpack.
	Heavy precipitation	The frequency and intensity of heavy precipitation events is projected to increase in all scenarios considered. This will increase the risk of flash flooding and subsequently the risk of damage to crops, agricultural land and infrastructure. The risk of flooding and landslides is higher in a climate that is wetter on average (Scenarios 1 and 2), as is the associated damage, causing greater impacts on access to markets, which will particularly affect livelihoods with poor market access. It is not clear how the risk of hailstorms may change. Although heavy precipitation events are projected to increase, rising temperatures will mean that more precipitation falls as rain rather than snow or ice. Similarly, changes in the timing and increases in the amount of snow and glacial melt, combined with an increase in heavy precipitation events, will also contribute to the risk of riverine flooding.

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE
	Rainfall variability	Variability in rainfall amounts and timings will continue in the future climate, alongside the projected trends. In years where the monsoon is delayed, this will exacerbate heat stress impacts on crops and may also affect agricultural labour productivity. The risk of water stress may increase in years when there are delays in the monsoon or dry spells, particularly in a drier future climate (Scenario 3), and the risk of flash and riverine flooding and associated impacts may increase in wetter years, particularly in a wetter future climate (Scenarios 1 and 2).
	Pests and disease	The risk of pests and diseases affecting crops may increase in a changing climate, as rising temperatures open up new areas with habitable conditions and increases in flooding may increase the incidence and spread of certain pests and diseases.
Livestock	Heat stress	Heat stress impacts on livestock will increase under all future climate scenarios. The impacts scale with the increase in temperature; larger increases will result in more severe impacts in the hottest regions and larger areas exposed to the risks of heat stress on livestock.
	Water stress	The risk of water stress is likely to increase during the winter season in all scenarios considered, causing stress on the availability of water and pasture for livestock, particularly in drier regions. In a hotter and drier future climate (Scenario 3) the risk will increase throughout the year, exacerbating these stresses.
	Rainfall variability	Continued year-to-year variability in rainfall alongside the long-term trends will mean that in years when the monsoon rains are delayed, heat stress impacts on livestock are more severe. In a hotter and drier future climate (Scenario 3), heat and water stress impacts will be further exacerbated in drier years.
	Pests and diseases	The risk of pests and diseases affecting livestock may increase in a changing climate as rising temperatures open up new areas with habitable conditions and increases in flooding may increase the incidence and spread of certain pests and diseases.
Forestry	Habitable conditions	With increasing temperatures, the habitable area of NTFPs such as yarshagumba will change, with extensive areas being potentially suitable for production.
Non-agricultural activities	Heavy precipitation	Increases in the frequency and intensity of heavy precipitation events under all future scenarios will increase the risk of flooding and landslides and the associated damage to infrastructure, transport networks and subsequent impacts on access for non-agricultural livelihoods.

Source: Content from sections 2 and 3, and the Central Bureau of Statistics, 2011.

5. Adaptation options

The following section presents the proposed adaptation options developed based on district consultations regarding climate trends and future climate change analysis. The options presented here reflect and are aligned with the “Vulnerability and Risk Assessment and Identifying Adaptation Options” study carried out by the Ministry of Forests and Environment in 2021 for the National Adaptation Plan. Additionally, provincial and national consultations were held to identify which options were better suited for different regions and at which administrative level they should be implemented.

5.1 Policy level

- Revise and improve current agriculture-related policies to account for the latest climate scenarios. In line with these, the revision and development of corresponding institutional arrangements and regulations that enable their coordinated implementation at different levels (federal, provincial and local levels).
- Promote the integration and articulation of the latest scientific and country-specific information into plans that are periodically evaluated and revised.
- Promote the risk transfer mechanisms guidelines and mechanisms such as crop, livestock and fisheries insurance covering mostly the marginalized and smallholder farmers.

5.2 Capacity strengthening

- Assess the capacities of different institutions to manage climatic risks.
- Develop country-specific awareness-raising programmes and approaches on climate change and its potential impacts to sensitize the population to the potential climate risks and how to adapt to them.
- Integrate climate change into the curriculum of schools and universities.
- Support the organization of innovation fairs to document and promote technology and practices, including local knowledge.
- Strengthen agricultural extension services; promote flood-, landslide- and drought-resilient crop varieties; stimulate nature-based solutions for hazard mitigation; and develop reliable early warning systems for risk communication.
- Document and disseminate farmers’ perceptions of climate change and adaptation techniques.

5.3 Value chain

- Integrate sustainable and climate-resilient approaches to value chain development to address potential impacts of inflation on agriculture.
- Strengthen the linkage between the local community and regional markets for easy access to flood- and drought-resilient crop species and technical, non-technical and financial support mechanisms for alternative livelihood opportunities.

5.4 Climate risk financing

- Promote and scale up early warning systems.
- Ensure availability and access to better forecasting information; change or improve processes and technologies.
- Improve farming design; individual/cluster insurance; use indigenous or non-reproducing stocks to minimize climate change impacts.
- Promote weather-index-based crop insurance to compensate for the loss caused by extreme weather events and climate hazards.
- Promote agrometeorological forecasting targeting smallholder and marginalized farmers.
- Establish a mechanism for credit for institutions and cooperatives to invest in profitable agricultural activities.
- Establish financial schemes and policy instruments to promote sustainable agriculture.
- Assess the loss and damage in the agriculture sector and devise a strategy to mitigate it.

Table 4: Summary of proposed adaptation measures for each livelihood and climate sensitivity

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE	ADAPTATION MEASURES (aligned with MoFE, 2021[2])	REMARKS

Cropping	Heat stress	• **Increasing temperatures**, found across **all scenarios**, will increase the risk of heat stress on crops. The larger the temperature increase, the larger the impact will be on **crop yields**, though precipitation changes may modify responses.
		• Higher maximum temperatures will be **experienced for longer periods** through the year, larger areas will be exposed to higher temperatures, and **more crops will exceed their optimum thresholds**, such as **maize** in **higher altitude areas**.
		• **Paddy** produced in the **Terai** and **maize** in the **Hill** regions are most likely to be negatively affected, people with **maize**-based livelihoods are **most at risk as they are less able to adapt** due to their reliance on maize and limited alternatives.
		• A benefit of increasing temperatures is the reduction in frost which **may improve growing conditions for crops sensitive to frost**, such as apples, or open up new regions for production.
			• Support and work with farmers in tailoring major staple crop calendars (i.e., paddy, maize and wheat) to account for the current climate trends and crop's temperature thresholds.
			• Introduce alternative heat-tolerant crop varieties.
			• Promote agricultural diversification that considers suitable products for new climatic conditions.
			• Increase country-specific research on:
			  o local heat-resistant alternatives for the major staple crops (i.e., paddy, maize and wheat); and
			  o health problems in humans due to heat stress.
			• Establish e seed gene banks, especially in the Himalayan region, to preserve local varieties of across country from heat stress.
			
			• Promote conservation agriculture practices (e.g., cover crop, mixed cropping, crop rotation, mulching, legume integration) to preserve water moisture in the soil and increase yield.
			• Promote the creation of climate-proof post-harvest storage and processing facilities.
			• Develop guidelines and training for smallholder farmers to improve their homestead agriculture practices.
			• Strengthen national climate services to produce advisory information on preparing for
				• Regardless of the scenario, longer periods with high temperatures are expected.
				• Paddy in the Terai, and maize in Hill and Mountain regions should be prioritized.

[2] MoFE (2021). Vulnerability and Risk Assessment and Identifying Adaptation Options: Summary for Policy Makers. Ministry of Forests and Environment, Government of Nepal. Kathmandu, Nepal.

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE	ADAPTATION MEASURES (aligned with MoFE, 2021[2])	REMARKS
			water stress periods and ensure this reaches the end user (i.e., farmers).	
	Water stress	• Under **all scenarios** considered, the risk of **water stress** is likely to increase for **winter crops** and particularly in the drier regions. • This risk will be higher in a **hotter and drier** future climate (Scenario 3) when water stress may **also impact** crops during the **pre- and post-monsoon seasons.** • The **seasonality** of river flows and water availability will also be **affected** in a future climate due to the changes in the **timings** and **amounts** of snow and glacial melt, particularly in Scenario 3 where there may be longer-term implications due to **accelerated melting and insufficient replacement of snowpack.**	• Adjust crop calendars to new precipitation regimes (considering the water need thresholds for different crops), promoting agricultural diversification. • Introduce short-duration and drought-tolerant crops and varieties to avoid drought during maturity periods. • Introduce micro-irrigation (drip irrigation, sprinkler irrigation), Bursha propeller pump. • Increase research and implementation of programmes that focus on aquifer storage and recovery. • Snow harvesting for recharge and agricultural production. • Promote water tapping and multiple-use water systems: grey/wastewater ponds in kitchen gardens, plastic ponds, maintenance of traditional ponds and water sources, groundwater trenching, rainwater harvest.	• Activities in the Mountain and Hill regions should be prioritized.
	Heavy precipitation	• The **frequency and intensity** of heavy precipitation events are projected to **increase** in **all scenarios** considered. • This will increase the **risk of flash flooding** and subsequently the **risk of damage to crops**, agricultural **land** and **infrastructure**. • The risk of flooding and **landslides** is higher in a	• Construct embankments for river channels and tree plantations along the banks to protect farmlands (Mountain, Hill, federal, provincial) • Promote and scale up early warning systems. • Strengthen national climate risk information to support the generation of early warning systems.	• Activities in the Mountain and Hill regions should be prioritized.

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE	ADAPTATION MEASURES (aligned with MoFE, 2021[2])	REMARKS
		wetter on average climate (Scenarios 1 and 2), as is the associated damage, causing greater **impacts** on **access to markets**, particularly affecting livelihoods with poor market access. • It is not clear how the risk of hailstorms may change as although heavy precipitation events will increase, rising temperatures will mean that **more precipitation falls as rain** rather than snow or ice. • Similarly, changes in the **timing** and **increases** in amount of **snow and glacial melt**, combined with increases in heavy precipitation events, will also contribute to the risk of **riverine flooding.**	• Promote research on flood modelling with an emphasis on flash floods, to develop risk maps that account for future climate conditions. • Revise and update land use regulations that consider flood zones for flash flooding. • Promote practices for soil management and protection and crop variation to prevent soil erosion. • Introduce improved cattle, goat and poultry sheds and climate-smart housing.	
	Rainfall variability	• **Variability in rainfall amounts** and timings will continue in the future climate, alongside the projected trends. • In years where the **monsoon is delayed** this will exacerbate heat stress impacts on crops and may also **affect agricultural labour productivity.** • The risk of water stress may increase in years when there are delays in the monsoon or dry spells, particularly in a drier future climate (Scenario 3), and the risk of flash and riverine flooding and associated impacts may increase in wetter years, particularly in a wetter future climate (Scenarios 1 and 2).		
	Pests and disease	• The risk of **pests and diseases affecting crops may increase** in a changing climate as rising temperatures open up new areas with habitable conditions. • Increases in flooding may increase the incidence and spread of certain pests and diseases.	• Introduce alternative crop varieties (drought-tolerant, disease-resistant), agricultural diversification, and shifting agriculture/crop calendars. • Monitor pest populations and behaviour, prioritizing areas where changes in temperature are higher.	
Livestock	Heat stress	• **Heat stress** impacts on **livestock will increase** under **all future climate scenarios**. • The impacts scale with the increase in temperature;	• Increase country-specific research on: ○ breeds resistant to heat, drought and harsh environments;	

LIVELIHOOD	CLIMATE SENSITIVITY	POTENTIAL IMPACTS UNDER A CHANGING CLIMATE	ADAPTATION MEASURES (aligned with MoFE, 2021[2])	REMARKS
		larger increases will result in more severe impacts in the hottest regions and larger areas exposed to the risks of heat stress on livestock.	○ fodder and forage resistant to heat and drought. • Promote a shift in species and breeds to those better suited to the agroclimatic zones. • Promote agroforestry and crop-livestock systems.	
	Water stress	• The **risk of water stress** is likely to **increase** during the **winter season** in **all scenarios** considered, causing stress on availability of water and pasture for livestock, particularly in **drier regions**. • In a hotter and drier future climate (**Scenario 3**) the risk will **increase throughout the year**, exacerbating these stresses.		
	Rainfall variability	• Continued **year-to-year variability in rainfall** alongside the long-term trends will mean that in years when the monsoon rains are delayed, heat stress impacts on livestock are more severe. • In a hotter and drier future climate (Scenario 3), heat and water stress impacts will be further exacerbated in drier years.		
	Pests and diseases	• The risk of **pests and diseases affecting livestock may increase** in a changing climate as rising temperatures open up new areas with habitable conditions. • Increases in **flooding may increase the incidence and spread of certain pests and diseases**.	• Monitor pest populations and behaviour, prioritizing areas where changes in temperature are higher and flood-prone areas.	
Forestry	Habitable conditions	• With increasing temperatures, **the habitable area of** NTFPs such as yarshagumba **will change**, with **more large areas being potentially suitable for production**.	• Promote fire management to control woody thickening.	• Activities in the Mountain and Hill regions should be prioritized.
Non-agricultural activities	Heavy precipitation	• **Increases in the frequency and intensity** of **heavy precipitation** events under **all future scenarios** will increase the risk of **flooding** and **landslides** and associated **damage to infrastructure and transport networks** and subsequent impacts on access for **non-agricultural livelihoods.**	• Identify flood- and landslide-prone areas and prepare hazard maps. • Promote and scale up early warning systems, including strengthening rapid response teams and empowering communities to take efficient actions. • Promote the use and adoption of climate proof infrastructure. climate proofed.	

6. Conclusion and recommendations

The CLEAR study reveals the interconnection between climate change, livelihoods and food security in Nepal. The impact of climate change on livelihoods and food security is a significant issue that requires immediate attention from policymakers, planners and other stakeholders. The analysis found that the most resilient livelihoods are those that are highly diversified and have good access to land. However, livelihoods in remote mountainous regions are among the least resilient due to rugged terrain and limited access to land and alternative livelihood activities. The CLEAR study also identified potential future climate scenarios, with varying degrees of temperature and precipitation changes. The scenarios project an increase in heat stress impacts on crops and livestock, higher levels of heat stress in the hottest regions, and a greater risk of flash flooding, landslides and GLOF events. CLEAR's recommendations for developing climate-smart adaptation options, revisiting and reviewing them regularly, and implementing disaster risk reduction activities, strategies and programmes are critical for building resilience to future climate change impacts.

Based on the findings and conclusions of the analysis, the following recommendations are proposed[3]:

- Develop and implement climate-smart adaptation options: The development of climate-smart adaptation options is crucial to building resilience to future climate change impacts on livelihoods and food security. The options should consider plausible projection scenarios and be revisited and reviewed regularly.
- Increase access to land: Access to land is critical to building resilient livelihoods. Explore ways to increase access to land, particularly for vulnerable populations such as women and marginalized groups.
- Diversify livelihoods: Highly diversified livelihoods are more resilient to climate change impacts. Continue to explore ways to promote livelihood diversification, including income-generating activities that have fewer linkages with climate shocks and good market access.
- Promote access to markets: Good market access is crucial to enhancing community resilience. Promote access to markets, including developing geographic location-based agro-advisory systems and other market-oriented approaches.
- Implement disaster risk reduction activities: Disaster risk reduction activities should be implemented at the livelihood zone level to enhance resilience to future climate change impacts. Seasonal weather forecasting systems and in-season crop monitoring systems are recommended to be developed and communicated to the respective stakeholders.

[3] Matrix of Proposed Actions and Agencies is presented in Appendix-C, in order to take the actions forward.

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Appendix A – Methods and data

The analysis presented in this report, to assess the impact of projected climate change on livelihoods and food security in Nepal, has been a collaborative effort across climate science and food security disciplines. The approach taken here is based on a combination of Consolidated Livelihood Exercise for Analysing Resilience (CLEAR) methodology (WFP, 2014; Figure A1) and the Climate in Context methodology, where a more narrative approach is taken to the food security analysis due to constraints of data availability. Figure A1 shows CLEAR's main components, designed to understand how food security and nutrition are and will be affected by climate change. The steps build on each other yet can be carried out individually.

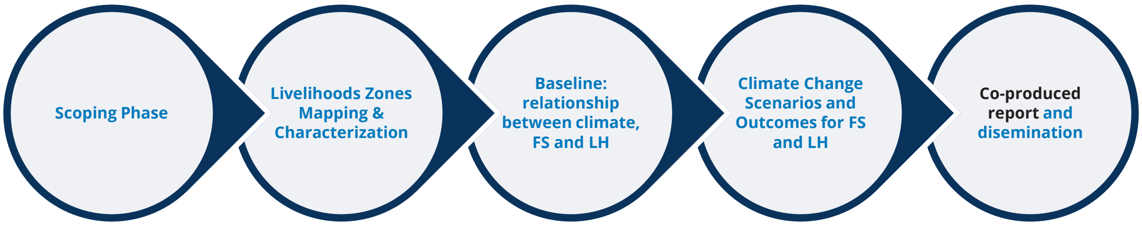

Figure A1: Main components of CLEAR. FS, food security; LH, livelihoods.

The first step was to ensure a good understanding of the baseline climate and its relationship with current livelihoods and food security. Three plausible scenarios of projected climate change were then analysed, and the impact on livelihoods and food security were assessed in the context of the potential change from the present day. This section describes the methods and data used for this analysis.

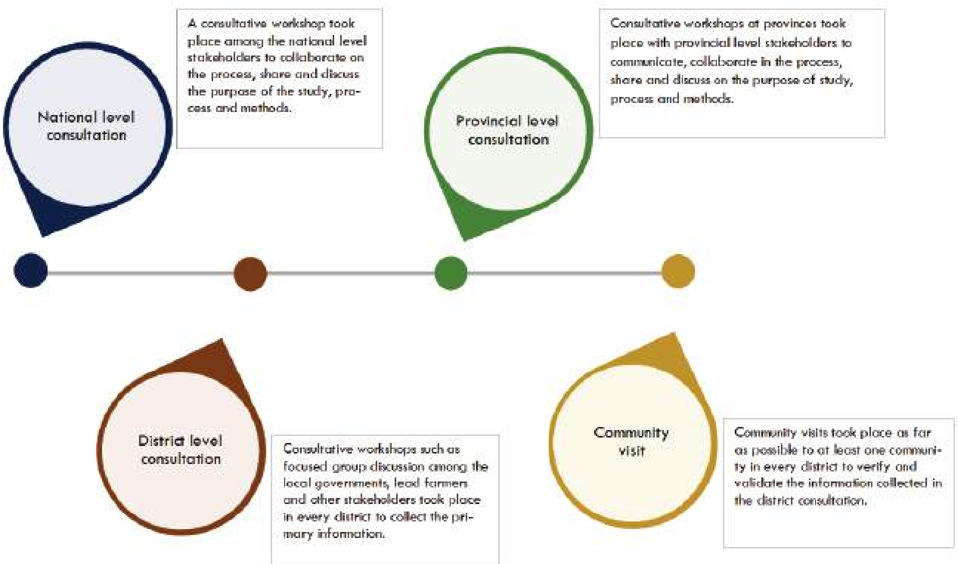

Figure A2: Livelihood mapping.

A1: Livelihood resilience and vulnerability analysis methods

Table A1: Indicators of resilience and vulnerability

Analysis	S. N.	Indicators
Resilience	1.	Land access
	2.	Market access
	3.	Stable non-farm economic activities
	4.	Livelihood diversity
	5.	Livelihood sensitivity
Vulnerability		
Sensitivity	1.	Multi-hazard recurrences
	2.	Vulnerable population (households headed by women + disabled + pregnant and lactating woman + >59 years age + children <5 years)
	3.	Livelihood sensitivity
Adaptive capacity	1.	Livelihood diversity
	2.	Income sources
	3.	Food access
	4.	Market access
	5.	Land access

Transformation of indicator values

The zero to one scoring transformation method, as used by the United Nations to compute the Human Development/Poverty Indices (HDI and HPI; UNDP 2004) and by ICIMOD to compute District Development Indicators (1997), was used to compute the scores for the indicators and composite index. The method transformed the values of the indicators to a score between 0 to 1. The values 0 and 1 denote the poorest and the best condition, respectively. There were two categories of indicators in relation to resilience and vulnerability. The first category of indicators was inversely proportional, and the second category was directly proportional.

The values of the indicators were in different measurement units and positive and negative relationships, so they were transformed to percentile rankings and, to align the indicators in the same direction, they were then converted to unitless values using the following equations:

In the case of the indicators that were directly proportional

$$dij = \frac{(Xij - \min j)}{(\max j - \min j)} \quad \textit{Equation 1}$$

In the case of the indicators that were inversely proportional

$$dij = \frac{(\max j - Xij)}{(\max j - \min j)} \quad \textit{Equation 2}$$

where
dij = the score corresponding to Xij
Xij = the actual value of the j^{th} indicator
min j = minimum value of the j^{th} indicator
max j = maximum value of the j^{th} indicator
All scores were free from a unit of measurement and varied from 0 to1.

Composite index

A composite index was calculated for a set of indicators falling under a particular domain.

$$Cij = \frac{\sum_{i=1}^{n} TV}{n} \quad \textit{Equation 3}$$

where
Cij = composite index
TV is the unitless transformed value of the i^{th} indicator having a numerical value between 0 and 1.
According to IPCC AR5, vulnerability is a function of sensitivity and adaptive capacity.

$$V = S - AC \quad \textit{Equation 4}$$

where
V is the vulnerability indicator
S is the sensitivity component of vulnerability
AC is the adaptive capacity component of vulnerability

Land access

Land is an important resource for agriculture dominant livelihoods of Nepal. In this context, the climate resilience of the households or communities mainly depends on access to good quality land and its size. Land resources are categorized into two groups: (i) upland – sloping, non-irrigable and less fertile, and (ii) low land – flat, irrigable and fertile. The access to land resources for a particular livelihood zone was measured taking into consideration the type of land and its size.

Market access

Only those market centres where food items were available were considered. The travel time to market centres for each municipality was estimated considering the majority of people. All types of mode of travel were taken into account to estimate the travel time.

Stable non-farm economic activities

Activities other than those in the agricultural sector that could regularly generate income were considered as stable non-farm activities. This indicator represented the poverty status of the livelihood zones. The ratings of these activities were differentiated based on their contribution as primary, secondary, tertiary and quaternary means of livelihood.

Livelihood diversity

Every livelihood zone's maximum four major livelihood activities and its sub-activities were s listed out . From this, a score was calculated to measure how diverse a livelihood is.

Income sources

Diverse sources of income were considered as one of the indicators, assuming that the more diverse the income sources, the higher the resilience and the better the adaptive capacity of the livelihoods.

Livelihood sensitivity

Climate sensitivity was measured based on crop sensitivity to climate variability (changes in rainfall and/or temperature conditions) according to the Global Agro-ecological Zones (GAEZ3.0) analysis prepared by IIASA and FAO in 2012. The livelihood activities were ranked from most to least sensitive with a score from 4 to 1 respectively.

Table A2: Sensitivity ratings of livelihood activities

Livelihood means	Primary	Secondary	Tertiary	Quaternary
Paddy/vegetables	4	3	2	1
Maize/millet/wheat/naked barley/buckwheat/barley/chino/kaguno/ Potato/mustard/peas/legumes/black gram/oil seed/ ginger/garlic/onion/lentil/pulses/bean/ soya bean/turmeric/mushroom	3	2	1	0.75
Fruits/tea/coffee/amliso/sugarcane/ cardamom/tobacco /NTFP/nuts/bodhi chitta/wood/livestock/poultry/fishery/ fishing/bee farming/floriculture	2	1	0.75	0.5
Tourism/jobs/seasonal migration/remittance/trade/business/ wage labour/rent	0	0	0	0

Source: Adapted from Global Agro-ecological Zones (GAEZ3.0) analysis prepared by IIASA and FAO, 2012.

Recurrence of multi-hazards

This indicator denotes the climate sensitivity of the communities. Recurrences of multiple hazards including flood, landslide, winter drought, summer drought, hailstones, windstorm, frost etc. within the last 5 years in a locality or municipality were considered as elements of this indicator. These hazards were weighted with a score from 10 to 1 taking into account the scale of their consequences and a composite score was made for each municipality and livelihood zone.

Table A3: Hazard rating

Hazard	Weighting of hazard
Flood	10
Drought	9
Landslide	8
Snowfall/avalanche	8
Hailstones	7
Insects	6
Wild animal encroachment	6
Windstorm/storm	5
Frost	4
Fire/wildfire	3
Cold wave	3
Heatwave	2

Source: Community perception, consultative workshops, 2019–2022.

Food access

Food access was measured through sufficiency of a community's own production for 12 months and food scarcity problems. The higher the sufficiency of their own production and the lower the food scarcity, the higher the level of food access was considered to be. It was assumed that food scarcity may happen in a community or household due to a combination of lack of their own production, being economically unable to purchase the food, and unavailability of food in market centres due to disruption in supply mechanisms.

Vulnerable population

Households headed by women, the elderly population and children below 5 years of age were considered as a group to comprise the vulnerable population. This vulnerable population was used as one element of exposure to calculate sensitivity.

A2: Climate analysis methods

The climate analysis undertaken in this report considers two time periods. The first is an assessment of the baseline climate, covering the period 1981–2010 to represent the present day. Due to the sparsity of reliable direct observations of climate across the region, this assessment is based on reanalysis data (a blend of observed weather data and model data of the past climate to provide gridded historical climate data). The analysis then goes on to consider projected changes in climate from climate model outputs for the period 2041–2070, as representative of the climate in the 2050s.

To define the baseline climate of Nepal, monthly temperature and precipitation data from the ERA5 reanalysis dataset (Hersbach et al., 2020) were analysed over the baseline period. For the future projections, changes in these variables from two climate models were analysed for the future time period. Further detail about climate model projections and the use of individual models as scenarios of future climate change is given in appendix B.

Due to the spatial resolution of the baseline and future climate data (i.e., the size of the data grid boxes relative to the area of the individual LHZs), it was not statistically meaningful to provide climatology data for individual LHZs. Instead, climatology data were grouped into three zones that represent regions of similar climatological rainfall amounts. The zones relate to the Ecobelt division of the country into districts representing the Terai, Hill and Mountain zones (Government of Nepal, 1996) and the dominant livelihoods within these zones were identified using the livelihood zone map shown in Figure 1.

A.3: Constraints and limitations

Livelihood zones and their characteristics were identified through a consultative process by engaging with representatives from 753 municipalities of 77 districts. Four predominantly agricultural livelihood strategies were identified within Nepal: cropping (including cereals, cash crops, fruits and vegetables), livestock, forestry and non-agricultural activities. The Mountain, Hill and Terai zones that were used for the climate analysis each represent distinctly different climates and, as such, naturally align with different livelihood strategies.

Within each of the zones (and thus, LHZs) the climate-sensitive aspects are linked to potential pressures that have a bearing on the performance of specific crops and livestock. Thus, climate change will have a direct link to livelihood success and, consequently, food security.

This analysis has been carried out using LHZs as a scale over which impacts of climate change on food insecurity are assessed. However, there are a limited number of sources that have data aggregated in this way, and hence a qualitative approach was taken to bring together the range of different types and scales of information available in the most robust way possible.

A further limitation in our understanding of the specific meteorological characteristics of the region is the ability of the reanalysis and climate model data to accurately represent the climatology of the region. However, the limited observational record means that reanalysis offers the best source of information on the present-day climate, by making use of the available observations. An added advantage is that it is compatible with the climate model data against which it is compared.

Climate data is low resolution, both temporally and spatially and, while trends are well represented, specific weather events in individual locations and years are not. The climate data is a useful way of identifying the scale and direction of change; viewed in the context of the relationship between climate and food security in the present day, this information can help guide understanding of the scale of the challenge that climate change presents.

This report makes use of scenarios for future climate. These are not predictions but are a sample of what is plausible across the range of modelled changes, which provide a useful basis for exploring what different levels of climate change might mean for future food security in Nepal.

Finally, based on the highly consultative nature of the process, many different opinions and perspectives were received, and not all could be validated through the literature review. To the extent possible, all feedback received was triangulated with other data sources to ensure accuracy, but some limitations to this approach are recognized.

Appendix B – Use of climate model projections

Climate models are a mathematical representation of the physical processes that govern the Earth's climate and are used to provide projections of climate change under different pathways of future greenhouse gas concentrations, known as representative concentration pathways (RCPs; van Vuuren et al., 2011). However, there is no unique way of representing the key processes or solving the mathematical equations, meaning that there is inevitably some uncertainty in climate projections. It is, therefore, extremely important to quantify that uncertainty in order to provide context for climate projections. Indeed, many climate modelling groups around the world have developed their own climate models. Each model has strengths and weaknesses with some performing better than others in certain geographical regions (McSweeney et al., 2015).

To be able to robustly compare outputs from different models, the models have to be run with the same experimental set up. This is achieved through the Coupled Model Intercomparison Project (CMIP), which promotes a standard set of model simulations so that models can be compared and evaluated. Climate projections from multiple models from the CMIP5 (Taylor et al., 2012) and CMIP6 (Eyring et al., 2016) sets of climate projections are used to inform the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports, AR5 (IPCC, 2013) and AR6 (IPCC, 2021), where the mean of the multi-model ensemble and spread across the models is used to communicate the projected change. One benefit of using many different models is that the spread of projections obtained provides a range of uncertainty for each variable of interest. For some variables, such as surface temperature, the projections from different models indicate a similar direction and magnitude of change. However, some other variables, such as rainfall for example, are more complex to model and the magnitude and direction of projected change may differ among different climate models.

For Nepal, there is high confidence that temperatures are projected to increase as all models in the CMIP5 ensemble show a projected increase in temperature, but there is uncertainty across the models as to the exact value of the increase. For example, by the 2050s (2041–2070), the multi-model mean of the projected increase in the average value of daily maximum temperature is around 2.5°C above the baseline period (1981–2010) under the RCP8.5 greenhouse gas concentration scenario, with a 5 to 95 percent range of around 2°C to 3.7°C (Figure B1, top panel). In contrast, the projected changes in rainfall across the models show large uncertainty in the direction and magnitude of the projected changes (Figure B1, bottom panel). In this case, focusing only on the multi-model ensemble mean does not reflect the full range of uncertainty in the direction and magnitude of the projected changes.

In addition to the multi-model mean not representing the full range of uncertainty in the projected changes, the multi-model mean also gives equal weight to all models, even those that are known to perform less well for certain geographic regions, such as Africa (McSweeney et al., 2015). A different way of presenting model projections is to take a scenario-based approach, where the outputs of individual models (selected based on criteria relevant to the task in hand) are considered as plausible scenarios of future change.

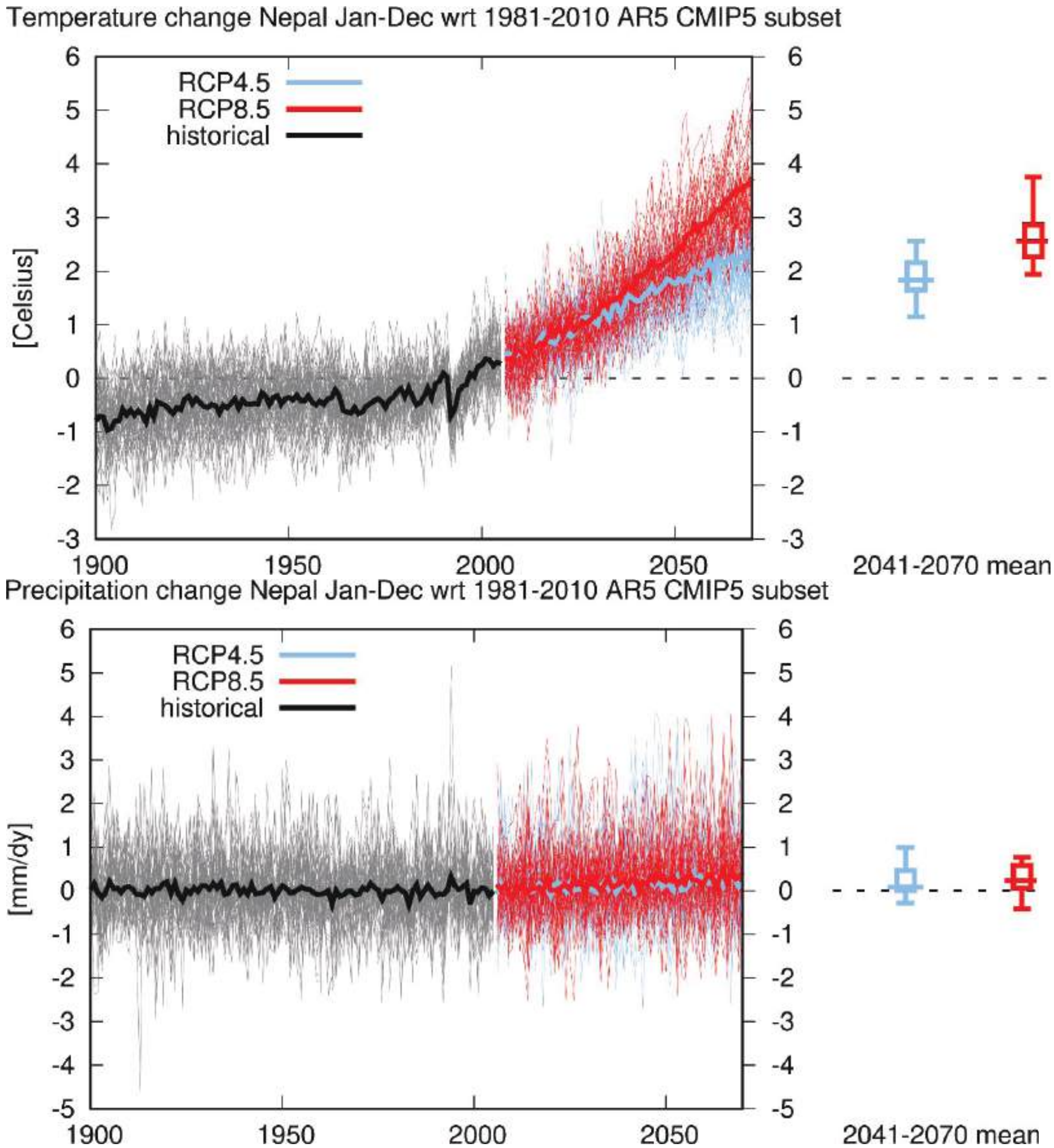

Figure B1: Time series of historical (black) and projected change in daily maximum temperature (top panel) and precipitation rate (bottom panel) relative to the 1981–2010 baseline period for Nepal for the CMIP5 model ensemble. One line per CMIP5 model is shown for both the RCP2.6 (blue) and RCP8.5 (red) greenhouse gas concentration scenarios, and the multi-model mean is shown as a thick line. The box-and-whisker plots on the right show the range values for the 2041–2070 period across the models; the box represents the 25%–75% range of the model values, the whiskers represent the 5%–95% range, and the 50% (median) is denoted by the horizontal line. Source: KNMI Climate Change Atlas.

For the analysis in this study, climate projections from 30 of the CMIP5 model simulations were analysed, as well as 17 dynamically downscaled projections from the Coordinated Regional Climate Modelling Downscaling Experiment (CORDEX; Giorgi & Gutowski, 2015) for the South Asia domain. The regional climate model simulations from CORDEX take the output from a subset of the CMIP5 global climate models and provide higher resolution output accounting for local factors such as topography in more detail compared to their driving models. These regional climate models have not yet been used to downscale the latest available global climate model projections from CMIP6.

The range of projections in daily mean temperature and annual precipitation amounts for the 30 CMIP5 model simulations and 17 CORDEX model simulations for the 2050s under the RCP4.5 and RCP8.5 greenhouse gas concentration pathways are shown in Figure B2.

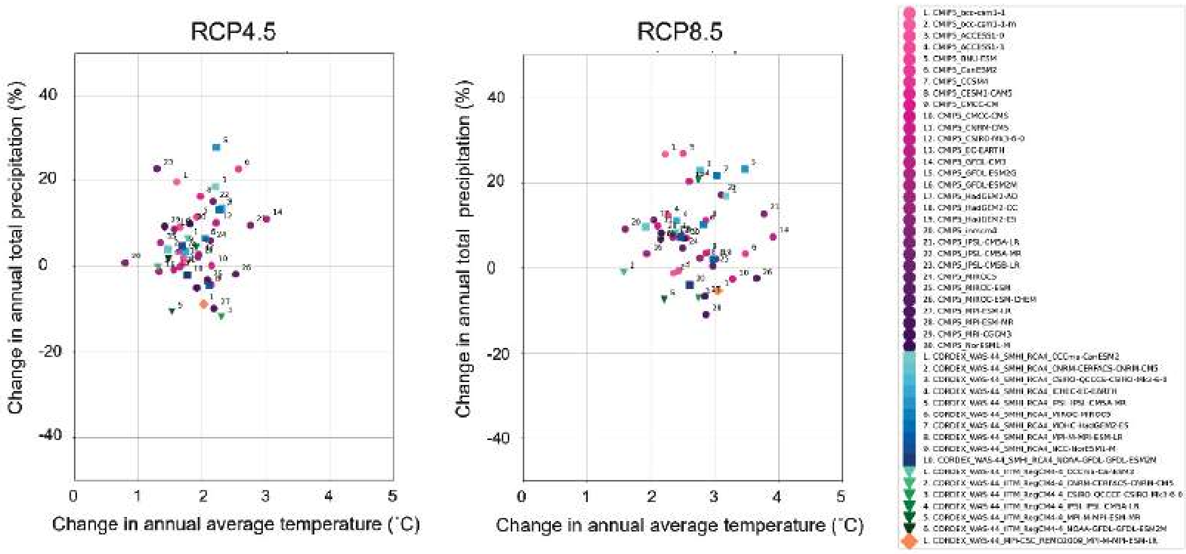

Figure B2: Scatter plots of projected changes in annual average temperature and annual total precipitation from 30 CMIP5 global climate model simulations (pink dots) and 17 downscaled projections from CORDEX (other icons) under a medium greenhouse gas emissions pathway (RCP4.5; left panel) and a very high greenhouse gas emissions pathway (RCP8.5; right panel) for the 2050s (2041–2070) relative to the baseline (1981–2010).

Three model simulations were selected to represent the range of plausible scenarios of future climate for Nepal in the 2050s based on that shown in Figure B2. These were selected based on the following criteria:

- Resolution of the model simulations – the higher resolution CORDEX model simulations were selected but the resolution of the original CMIP5 model simulations was also taken into consideration when assessing the range of plausible projections.
- Sample the range of regional climate model projections in the CORDEX ensemble – three regional models were used to downscale a subset of the CMIP5 projections and therefore to avoid double counting of model projections the scenarios should include different CMIP5 driving conditions and different regional models.
- Model performance should be in the region of the original CMIP5 model simulations (UK

Met Office, 2021).

- Models should reflect the scale and direction of trend across the majority of model projections (i.e., most models project a hotter and wetter to varying degrees of magnitude).
- Low likelihood scenarios (i.e. model simulations with different direction of future trends to the model consensus) should be considered if deemed plausible and relevant to food security and livelihoods (i.e. some plausible model simulations project a hotter and drier future).

Based on these criteria, the following model simulations were selected:

- Scenario 1: the RegCM4-4 downscaling of CanESM2 under the RCP4.5 greenhouse gas concentration pathway was selected to represent the low climate sensitivity scenario: the lower end of projected increases in annual average temperature and annual total precipitation.
- Scenario 2: the RCA4 downscaling of IPSL-CM5A-MR under the RCP8.5 greenhouse gas concentration pathway was selected to represent the high climate sensitivity scenario: the higher end of projected increases in annual average temperature and annual total precipitation.
- Scenario 3: the REMO2009 downscaling of MPI-ESM-LR under the RCP4.5 greenhouse gas concentration pathway was selected to represent the low likelihood scenario of a hotter and drier future.

Appendix C – Proposed Actions

Key Actions	Responsible agencies
Policy and Planning	
• Revise/formulate agriculture-related policies and agriculture development plans considering future climate scenarios and the risk of impact on agriculture-based livelihoods	National Planning Commission (NPC) and Ministry of Agriculture and Livestock Development (MoALD)
• Produce/update livelihood zones and profiles at the local level	Ministry of Federal Affairs and General Administration (MoFAGA) and Local Governments
• Update climate risk analysis and conduct scientific studies integrating livelihood, food security and nutrition components, and use the results to update and revise periodic, medium- and long-term plans and strategies related to agriculture development, livelihood improvements, food security and nutrition	NPC/MoALD/Ministry of Forest and Environment (MoFE)
• Promote risk transfer mechanisms to expand usage to additional livelihood sources such as crops, livestock, fruit, fisheries, vegetable farming and agro-forestry	MoALD/MoFE/NPC
Capacity strengthening	
• Assess the capacity of government institutions to manage and reduce the climatic risk to livelihoods	NPC/MoALD/MoFAGA/MoFE
• Organize awareness-raising programmes on climate change and its potential impact on livelihoods for stakeholders at various levels	MoFE/Province/Local Governments
• Strengthen the capacity of agricultural extension centers to deliver services to reduce the risk posed by weather and climate risks	MoALD

Key Actions	Responsible agencies
• Research on flood, landslide and drought resilient crop varieties and promote usage amongst farmers	MoALD
• Implement disaster risk reduction activities at the livelihood zone level to enhance resilience to the future impact of climate change	Ministry of Home Affairs (MoHA), National Disaster Risk Reduction and Management Authority (NDRRMA) and MoALD
• Simulate nature-based solutions for hazard mitigation	MoFE
• Promote innovation, science and technology including local/indigenous knowledge and good practices to reduce the impact of climate change across livelihood zones	MoFAGA/Local Government
• Promote and scale-up a reliable early warning system for timely risk communication	Department of Hydrology and Meteorology (DHM)/MoHA
• Promote the linkages between farming communities and regional markets to facilitate easy access to flood-and-drought-resilient crop species and agricultural inputs	MoALD/Ministry of Industry, Commerce and Supplies (MoIC)
• Establish appropriate market systems and financial support mechanisms for alternative livelihood opportunities	MoALD/Nepal Rastra Bank
• Develop/adapt approaches to identify vulnerable/disadvantaged households in vulnerable livelihood zones to target interventions to the most affected households	MoFAGA/Local Government/MoALD
Climate risk financing	
• Establish weather monitoring stations in various locations to capture micro-climatic hazards	DHM
• Use remote sensing data to promote weather-index-based crop insurance to compensate for loss and damage caused by extreme weather events	MoALD
• Establish agrometeorological forecasting systems and advisory mechanisms targeting smallholder and marginalized farmers	DHM/MoALD

Key Actions	Responsible agencies
• Establish financial schemes and policy instruments to promote profitable and sustainable agriculture • Use remote sensing data to monitor crop growth, estimate crop yield, assess loss, and damage in the agriculture sector and inform strategies	NPC/MoALD MoALD
Technological development • Improve farming systems, promote crop species conservation activities and post-harvest storage techniques • Introduce heat-resistant and disease-resistant crop varieties • Develop geospatial tools to map out hazard prone areas considering current and future climate scenarios • Establish a system to monitor pest population and behavior in areas identified as more vulnerable to temperature changes • Plausible climate projection scenarios revisited and reviewed regularly • Develop seasonal weather forecasting systems and in-season crop monitoring systems and communicate to respective stakeholders	MoALD/NARC MoALD/Nepal Agricultural Research Council (NARC) DHM/MoFE MoALD MOFE/DHM MoALD/MoFE/DHM

Government of Nepal
National Planning Commission

Met Office

WFP
World Food Programme