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Enhancing the resilience of food production systems for food and nutritional security under climate change in Nepal

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Background: Climate change in Nepal has posed a considerable challenge to agricultural productivity and has threatened food and nutritional security at multiple levels. This study aims to assess the impacts of climate change on national food production and food and nutritional security as well as document issue-based prioritized adaptation options for a resilient food production system.

Methods: This study considers temperature, precipitation, and their anomalies as the key factors affecting food production in Nepal. Nationwide precipitation trends along with their association with the annual production of major cereal crops in Nepal were assessed using data from the last three decades (1990–2018). The annual productions of the major cereal crops were summed and normalized to calculate production index scores in the districts. Scores were plotted and visualized into maps using the R programming. In three ecological regions, the distribution of flood and extreme rainfall events and cases of malnutrition from 2005 to 2018 were plotted. The effects of climate change and highest priority adaptation options at the district level were documented through a review of national policies and literature studies and qualitative research based on Focus Group Discussions (FGDs).

Results: Between 1990 and 2018, the overall average production of major cereal crops in Nepal was increased by around 2,245 MT annually. In the district level index analysis, the highest production score was found for Jhapa and Morang while the lowest production score was found for Humla. Cases of malnutrition in some districts coincided with flood and heavy rainfall events, indicating that climate change and extreme climatic events have a role to play in food production and security. Growing drought-tolerant crops, changes in crop cycle, riverbed farming practices, and development of short-term strategies, such as contingency crop planning, changing plantation dates, plantation of short-duration varieties, and evacuation schemes. Similarly, long-term strategies, such as encouraging out-migration of population to safer locations, resettlement programs with transformative livelihood options, and sustainable agricultural practices were found to be key prioritized adaptation measures for a resilient food system.

Conclusion: In Nepal, climate change and the increasing frequency and magnitude of extreme climatic events adversely affect the food production system, which has become a serious threat to food and nutritional security. The implementation of evidence-based practices to build a resilient food system specific to climate-vulnerable hotspots at the district and local levels is the nation's current need.

KEYWORDS

adaptation, climate change, food security, malnutrition, nutrition, resilient

Introduction

Globally, climate change is one of the greatest threats to agriculture, food security, and human health (Gregory et al., 2005; Schnitter and Berry, 2019). Nepal is highly vulnerable to climate change. The impacts of climate change are alarming due to the country's diverse topography and corresponding climatic variations, natural resource-based livelihoods, and resource constraints to adapt to the increasing occurrence of extreme climatic events, hazards, and disasters (Rasul et al., 2020). Agriculture is one of the major sources of income and livelihood for around 60% of Nepalese households, most of which follow traditional cultivation practices and rely on monsoon rains. Fluctuations in rainfall patterns adversely affect crop production and food insecurity, leading to nutritional insecurity. Water-related threats, such as floods and droughts, account for almost 70% of all economic losses in mountainous countries like Nepal (Eriksson et al., 2009; Shrestha et al., 2010). Climate change affects agriculture, livestock, water and forest resources and, consequently has an impact on long-term food security (Rasul, 2021).

The concept of food and nutritional security is complex and multidimensional in nature. The Food and Agricultural Organization unpacks food security into availability, accessibility, utilization, and stability (FAO, 2005). Even though all these conditions are important elements for food and nutritional security, the availability of sufficient food and its accessibility by different groups of people are the foremost necessary conditions for food security, without which other elements cannot be fulfilled (Nepal and Neupane, 2022). The impact of climate change and extreme events is more pronounced on the above two pillars of food security, namely, food availability and accessibility.

The effects of droughts on agriculture and food security have significant consequences on the long-term development of a country where agriculture is a prime source of the national economy. Food security in developing countries like Nepal is mostly jeopardized by trade, population growth, climate change, deforestation, and desertification (Malla, 2008; Thakur, 2017). Climate change mainly affects two aspects of food and nutritional security such as food availability and access. Farms face droughts and increased crop diseases and pests, and frequent climate-related disasters that affect agricultural yields. The impacts of climate change are expected to reduce food production, resulting in decreased global food supply and increased food prices, making food inaccessible to poor communities. Farmers are heavily affected by climate change, which puts enormous pressure on the nation to achieve its sustainable development goal related to food and nutritional security indicators.

In Nepal, a higher proportion of agricultural land is rainfed. Climate change is expected to impact the water cycle, rainfall pattern, timing, and intensity of the rainfall, resulting in a change in production. An increase in the occurrence of climatic hazards, such as floods and heavy rain, damages cultivated crops, reduces food production and causes food insecurity (Atanga and Tankpa, 2021), and escalates the challenge of hunger and malnutrition (FAO, 2015; MoFE, 2021a). Certainly, a decline in food production increases the malnutrition rate and has serious consequences, especially among children and other vulnerable groups (Regmi and Adhikari, 2007). Frequent and intense droughts and floods have further reduced agricultural yields. In addition to climatic factors, practices, such as inappropriate farming, conversion of agricultural lands to housing, loss of soil fertility, erosion, land degradation, high reliance on pesticides, and youth migration, are making people more vulnerable to food insecurity (Bhatta et al., 2019). Climate change together with unsustainable anthropogenic practices has increased pressure on agricultural production, and food security has an impact on several national and international targets. This has led to an increase in food and nutritional insecurities among poor and marginalized communities, smallholders, pregnant and lactating women, mothers and children, and the elderly population who are already at risk from climatic hazards and food insecurity.

This paper aims to find out the impacts of climate change on agricultural production systems and nutritional security along with the identification, evaluation, and documentation of adaptation practices in response to climate change at multiple scales in Nepal.

Methods

Study area

Nepal is a landlocked country bordering India to the east, west, and south, and China to the north. It has a diverse geographic distribution in three ecological regions; Tarai (17%), Hill (62%), and Mountain (21%). Approximately 66% of the economically active population is engaged in agriculture, and this sector contributes to 25.8% of the nation's gross domestic product in 2020 (MoF, 2021). Rice, wheat, maize, barley, millet, and potato are considered the major crops produced in the country, contributing to more than 90% of the country's total food production (MoALD, 2021). Nepal's climate varies considerably in seasons and altitudes. There are four distinct seasons. The pre-monsoon season (March–May), is hot and dry, with scattered rainfall. The monsoon (June–September) is hot and humid, with overcast skies and intense precipitation. Rainfall is reduced during the post-monsoon (October–November) while the winter (December–February) is with clear skies, low temperatures, and little precipitation (Shrestha et al., 2019). Nepalese agriculture is heavily dependent on monsoon rain, with almost 67% of agriculture based on rainfed cultivation (Shrestha et al., 2013). Due to diversity in geography, Nepal is exposed to a range of climate risks and water-related hazards.

Data collection and analysis

We used the mixed method approach. Quantitative data were gathered from secondary sources, and qualitative data were collected from primary sources through focus group discussions (FGD). The data on malnutrition cases from 2005 to 2018 were retrieved from the Health Management Information System database of the Department of Health Services (DoHS, 2021). Annual food production parameters, production area (ha), food production (MT), and yield (kg/ha) of five major cereals (paddy, maize, wheat, barley, and millet) from 1990 to 2018 were obtained from the Ministry of Agriculture, Government of Nepal (MoALD, 2021). The annual average of precipitation (cm) of Nepal from 1990 to 2018 produced by the Climate Research Unit of the University of East Anglia, UK, presented at a 0.5 × 0.5° (50 × 50 km) was taken from the World Bank Group (World Bank, 2021). Similarly, flood and heavy rainfall events data in districts from 2005 to 2018 were collected from the Nepal Disaster Risk Reduction Portal of the Ministry of Home Affairs, the Government of Nepal (MoHA, 2022).

A descriptive analysis of the distribution of food production parameters of five major crops and annual average precipitation was performed. The occurrence of extreme climatic events vary in different districts and ecological regions of Nepal (MoFE, 2021b). Therefore, we calculated the mean value of floods and heavy rainfall in each region separately. Districts with higher than average hazard events and the top five districts with a higher number of malnutrition cases were identified in each ecological region. Hazard events and malnutrition cases at the district level of each ecological region were plotted. The sum of the annual average production in 77 districts of Nepal was normalized on a scale of 0–1 using the minimum–maximum formula. Data analysis was performed in Microsoft Excel (MS office version-10), and visualization in maps was performed using R programming (version 4.2.1).

Between February and June 2019, we performed 12 FGDs in six districts of Nepal, i.e., two FGDs in each district. The districts were selected in a way to represent the three ecological regions of Nepal, which consisted of Mountain (Sindhupalchowk and Dolakha), mid-Hill (Kavre and Ramechhap), and inner-Tarai (Chitwan and Makawanpur). Each FGD session consisted of seven participants. They were purposively selected from farming communities representing smallholders, women, and marginalized people. The discussion sessions were conducted in a community setting after acquiring farmers' consent to participate. Policy and program information was extracted from the published literature studies and policy documents and reports related to climate change and adaptation in Nepal.

Results and discussion

Cereal crop production trend

From the analysis of crop production data between 1990 and 2018, the highest and lowest average annual volumes of cereal production were found for paddy at 54,888 MT and barley at 438 MT, respectively. Average annual production was found to have increasing trends in paddy, maize, wheat, and millet. The cultivated land area for maize, wheat, and barley was almost the same during this period while it shrank and expanded in paddy and millet. During these three decades, the overall average production of five major crops in Nepal seems to have increased by 2,245 MT annually. The highest annual average increase in production was found in paddy (1,026 MT) while the lowest increase was found in barley (1.2 MT) (Figure 1).

In the regression model, the highest (95%) coefficient of determination (R^2) was found for wheat, which implied that wheat production was linear while the lowest (3%) R^2 was found for barley. In all the major cereals, a variation in the average annual production was found with the change in the average annual precipitation in the country. However, the highest fluctuation in average annual production of paddy and barley was marked by declining and rising trends in the average annual precipitation (Figure 1).

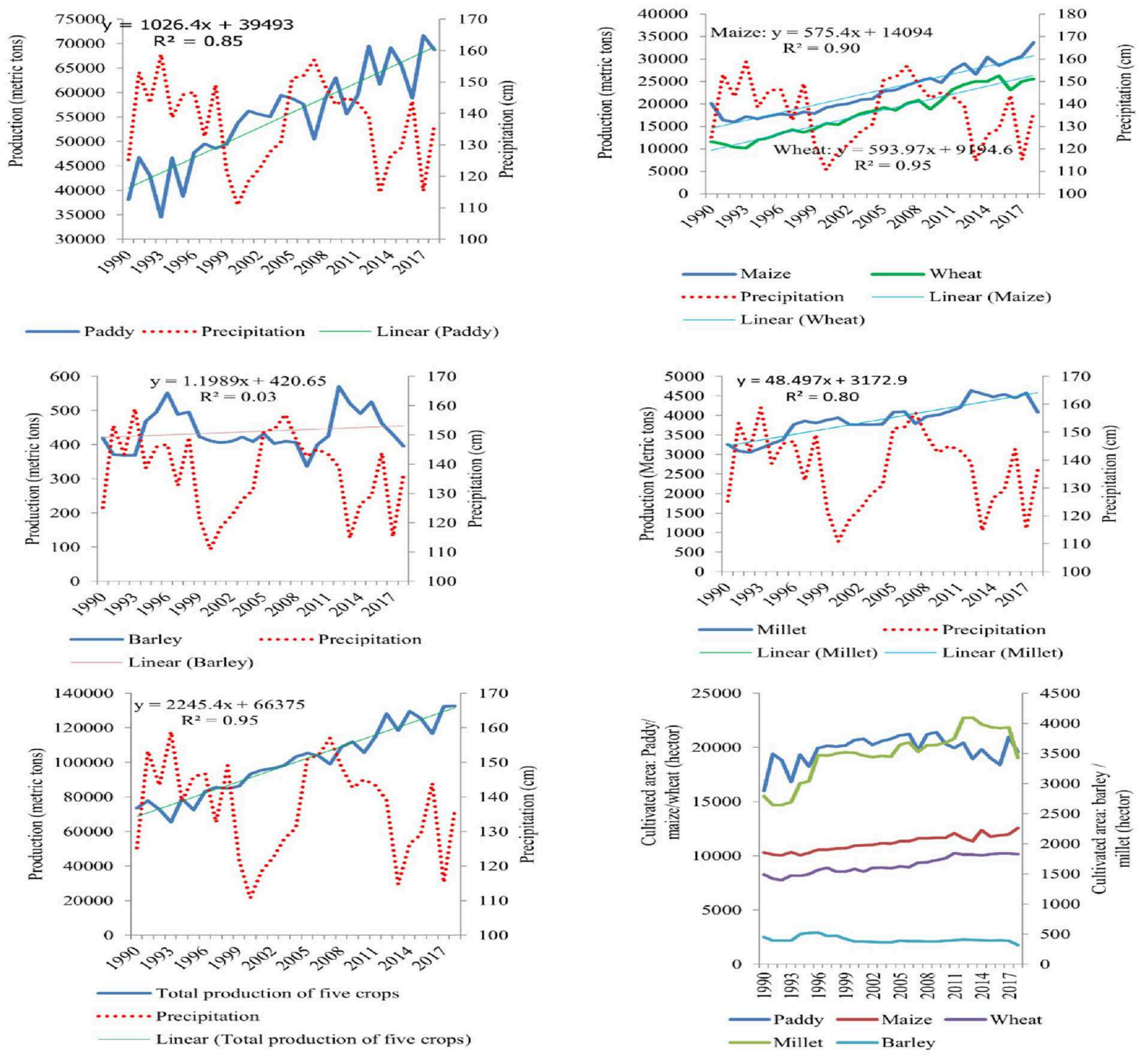

FIGURE 1
Trend of production of five major cereal crops from 1990 to 2018 vs precipitation trend.

Food production varied in the different districts of Nepal. Food production is determined by climatic factors along with non-climatic factors, such as soil quality, topography, irrigation facility, labor, technology, and the use of pesticides. In this study, index analysis at the district level shows that the highest production of the major cereal crops is found in the Bara, Morang, and Jhapa districts, while the lowest production score was found in six hill districts (Achham, Baitadi, Dadeldhura, Doti, Pyuthan, and Western Rukum) and 12 mountain districts [Bajhang, Bajura, Darchula, Dolakha, Dolpa, Kalikot, Humla, Jumla, Mugu, Mustang, Rasuwa, and Taplejung (Figure 2)]. The Food production annual average (Normalized index) for all five crops i.e. paddy, maize, wheat, barley, and millet are attached as Supplementary Figures 1–5.

Food insecurity and malnutrition under climate change

Food insecurity and malnutrition is one of the major health issues caused by climate change in Nepal, where almost 17% of the population is multidimensionally poor (NPC, 2021). Food insecurity is also associated with susceptibility to disasters, such as drought, floods, pests and diseases, and landslides, vulnerability to fluctuations in global prices, civil turmoil, disease, and poor infrastructure. In Nepal, 4.6 million people are noted to live with food insecurity, where 20% of households are reported to be mildly food insecure, 22% of households are moderately food insecure, and 10% of households are severely food insecure (Chemjong and KC, 2020).

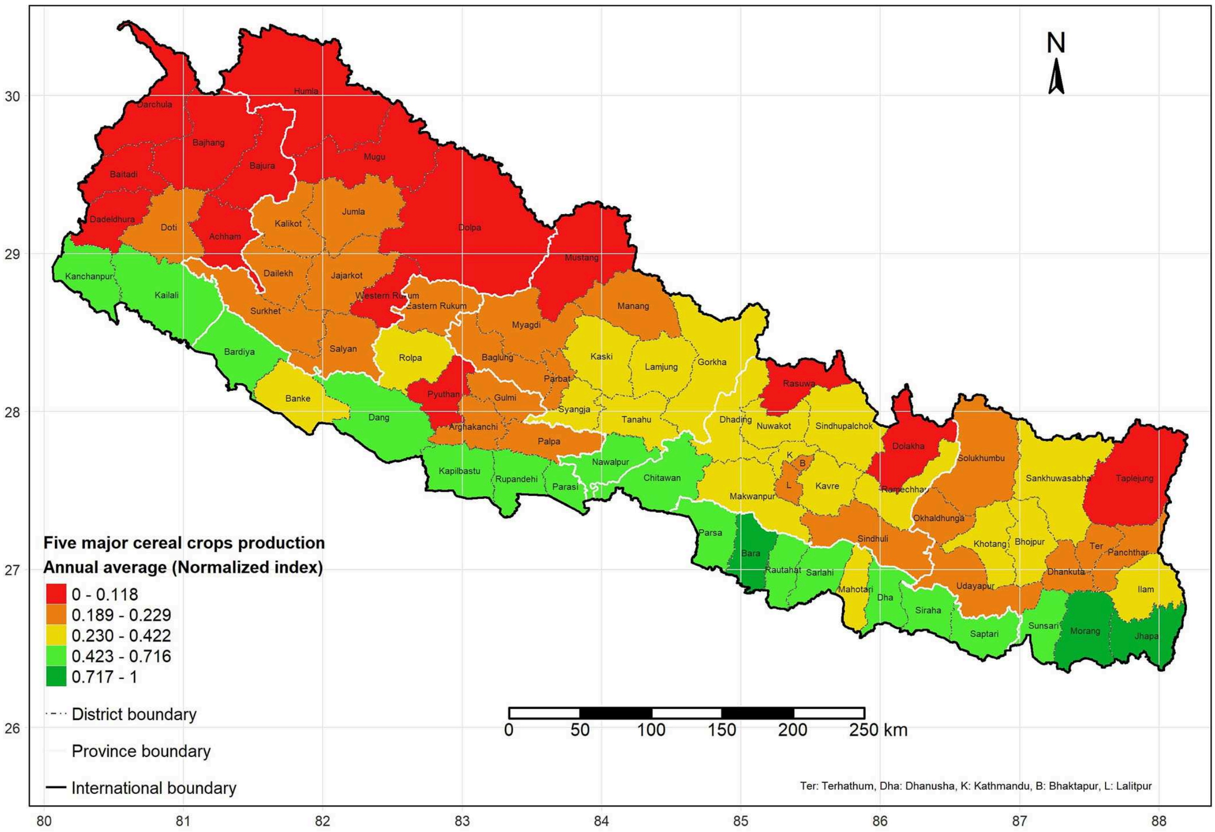

FIGURE 2
Distribution of production scores by the district of Nepal.

A rise in maximum temperature has decreased agricultural productivity, leading to an increased threat of food insecurity (Pant, 2012). In the Western and Tarai region of Nepal, many people are affected annually due to heavy rainfall, flash floods, and landslides. These disasters have a direct impact on agricultural production and food security. For instance, paddy was one of the main crops in Nepal, but it was severely affected by the prolonged drought and late monsoon (Thapa and Hussain, 2021).

Nutritional deficiency diseases, including malnutrition, are the most serious consequences of food insecurity and have a multitude of health and economic implications (Chinnakali et al., 2014). In addition to the socioeconomic factors, environmental factors, such as increased annual average precipitation, mean temperature, and drought, are linked with malnutrition cases in some districts of Nepal (MoFE, 2021b). We also noted the existence of a certain relationship between floods and extreme rainfall with malnutrition cases in most districts of three ecological regions of Nepal. Increasing the number of flood events was found to coincide with the higher number of malnutrition cases in Morang, Bajura, Kaski, and Western Rukum while increasing the incidence of heavy rainfall events coexisted with the higher number of malnutrition cases in Sarlahi, Bara, Dhading, Humla, and Jajarkot. In Rautahat and Achham, an increase in flood and heavy rainfall events was found to be somehow related with the higher number of malnutrition cases (Figure 3).

However, there are some instances where food production and malnutrition cases do not seem to coincide with floods and heavy rainfall. This could be due to humanitarian interventions in some regions (Conway et al., 2020), along with some adaptive capacity and preparedness measures adopted by farmers. Both natural and anthropogenic factors contribute to crop production, and climate change and extreme events can alter the usual trend of the overall agricultural production.

Based on the secondary data analysis, we can observe a decline trend of malnutrition cases from 2005 to 2018 in Nepal. The cases of malnutrition are decreasing in the Hill and Mountain regions while they are slightly increasing in the Tarai region. The mobilization of community health workers to increase the provision of basic health interventions, specific programs focused on child and

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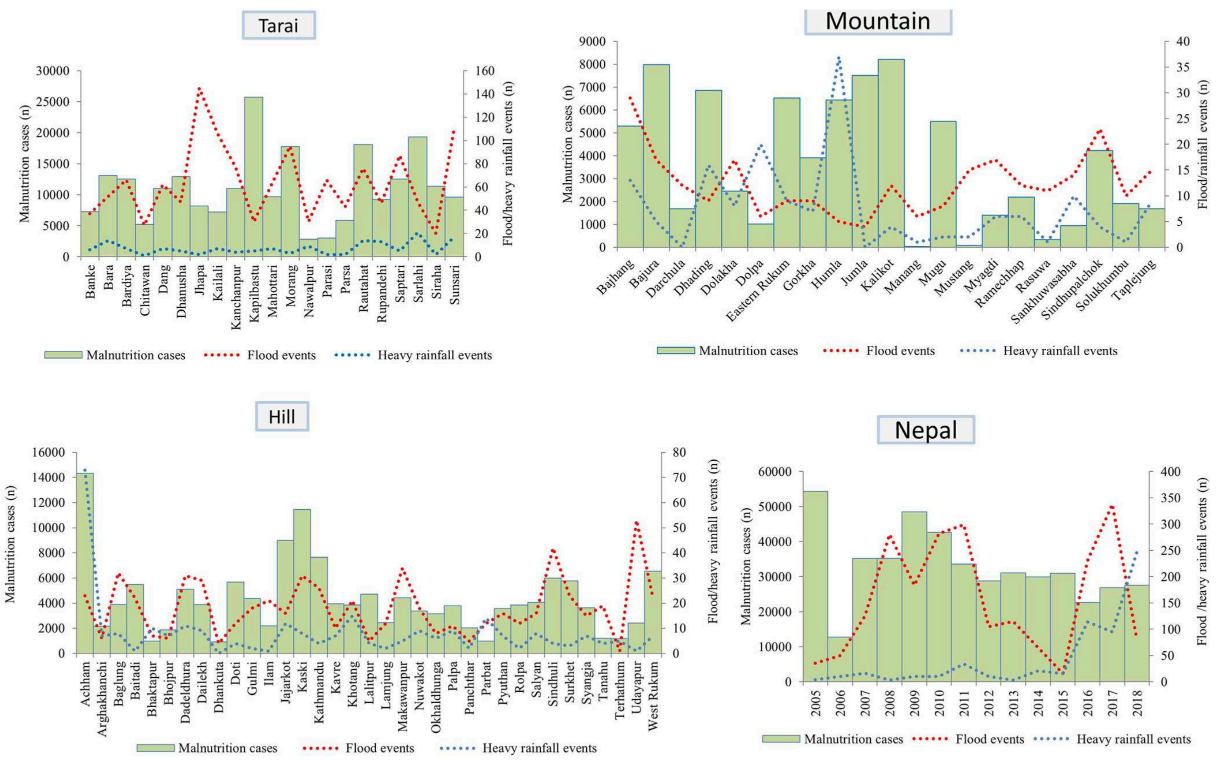

FIGURE 3
Ecological and district-wise distribution of malnutrition cases, flood, and rainfall events from 2005 to 2018 in Nepal.

maternal nutrition along with prioritized nutrition sensitive initiatives from different government and nongovernment agencies has been noted as a major driver to decline the number of malnutrition cases (Conway et al., 2020). Despite Nepal's progress in reducing malnutrition, it remains one of the major causes of child mortality (DoHS, 2021). The situation of malnutrition is alarming in the country, especially among infants, adolescent girls, and pregnant and lactating mothers (USAID, 2021). National food security has been getting high priority in each development plan in Nepal, but the situation has not improved as anticipated. Likewise, despite the country's focus on the production of adequate food supplies, food insecurity remains an alarming national problem.

Climate change has adversely affected Nepal's economy by affecting the livelihoods of those who rely heavily on agriculture. The majority of Nepalese people are subsistence farmers (MoPE, 2004). In 2006, farmers in the eastern part of the country experienced a low amount of rainfall during the monsoon season, which resulted in 10% of the land being left fallow, causing a 12.5% reduction in production. In the same year, high floods hit the western part of Nepal, reducing the production by more than 30% (Regmi and Adhikari, 2007). Nepalese communities are at high risk and prone to climate-induced disasters due to their higher exposure and poor capacity to adopt and/or respond to these climate stressors (DHM, 2017; Walker et al., 2019).

Crop production cycles have been disrupted due to climate change, which has especially impacted vulnerable groups, such as marginal farmers, indigenous groups, female-headed households (Hussain et al., 2016). From the FGD sessions, we found that the vulnerable groups are those with limited access and control over resources, which has impacted them more than the others. An increase in maladaptation, such as reduced meals, sale of assets, and girls dropping out of schools, has also been observed in Nepalese communities due to acute food insecurity (Khadka et al., 2014; Hussain et al., 2016). Similar consequences were also observed during our FGD sessions. We have observed that limited access to land and credit and lack of climate smart farming knowledge make the vulnerable farmer group less likely to change conventional farming and adopt climate-resilient farming practices to combat the impacts of climate change. Climate change has adversely affected the lifestyle, livelihoods, health status of the most vulnerable farmer groups, making them more sensitive to adapt to a changing climate (Khadka et al., 2014).

We found that frost is one of the main climate hazards for farming communities in Nepal. A number of villagers from higher altitudes noted that though there is a reduction in snowfall, there is an increased amount of frost, which severely affects vegetable production. During the time of our study, most of the potato farmers reported that they experience a reduction in their production by almost half (49%) in 2019 due to severe frosts.

Farmers also reported that all villagers have experienced an increase in their production costs as they are bound to buy expensive pesticides. Multiple diseases and pests that were normally found at lower altitudes and in warmer climatic conditions are now thriving at higher altitude, suggesting that climate change has resulted in enabling environmental conditions for such pests and diseases to thrive at higher altitudes. Farmers reported that the weeds, once managed with organic remedies and hand picking, are now almost incurable due to traditional measures that require the use of strong chemical pesticides.

The hailstone is not a new hazard in the mountainous areas of Nepal. Villagers are mostly prepared for some level of hailstones during March and May. However, we found that in the last 10 years, the intensity and frequency of hailstone have changed and go beyond the expectations and preparation of the villagers. Moreover, future scenarios analysis of extreme events shows that they are going to increase under different climate change projections i.e. Representative Concentration Pathways of 4.5 and 8.5 (MoFE, 2019). With the increase in numbers and intensity of extreme events, farmers shared their threat of significantly losing their wheat and potato production, thus impacting production and food security.

Considering the importance of land-based livelihoods in the agriculture sector of Nepal, the main impact of climate hazards is the reduction of water availability. This study shows that excess water due to extreme climatic conditions and too less water during the dry season are also affecting crop productivity. Moreover, in the future, climatic events such as extreme hot days are likely to increase by up to 55% by 2060 and up to 70% by 2090. Along with these heat waves, cold waves, heavy rainfall, and fire events are likely to increase (MoFE, 2019). Moreover with increased temperature, warm days and nights, and heat waves, it is likely that seasonal drought will also increase (Dahal et al., 2018). Currently, the majority of the hilly communities (85%) depend on rainfed agriculture (Kattel and Nepal, 2022). A similar case was observed in the districts selected for the FGDs. Irrigation systems are limited due to the hilly terrain and fragmented land holdings, on the other hand, running water sources are decreased by 30% by 2025 (Alexandratos and Bruinsma, 2012). Farmers acknowledged that many of the drinking water sources and small irrigation schemes of the hills have dried up. Therefore, extreme, unpredictable and unfavorable climatic conditions along with various anthropogenic factors are likely to have adverse impacts on agricultural production in Nepal.

In this study, villages in Dolakha district reported that in the early days, especially in the monsoon season, the rains used to stay throughout the monsoon, but recently there were several monsoon breaks. The pattern of too much and too little rainfall is increasing. There is often a shortage of winter rains, which has resulted in reduced productivity of wheat and other winter crops. Farmers from Chitwan and Makwanpur districts also mentioned that they have not noticed the occurrence of winter rainfall in the last 10 years. As a result, they have stopped cultivating wheat and mustard, which were previously major crops in their area. Most of the rice growers, particularly at the tail ends of Sindhupalchowk, Dolakha and Kavre, shared an occupational disturbance from recurrent floods and droughts.

Adaptation options enhancing a resilient food production system

Based on FGDs conducted among farmers, it was noted that local communities have developed their own local adaptation practices over time, several of which have been tested and validated over time while others are evolving. Adaptation practices adopted by local communities using their local knowledge and skills can be grouped into livestock management, migration, evacuation and resettlement, alternative crop cultivation, growing drought-tolerant crops and varieties, the change in cropping patterns, and riverbed farming. The important adaption options practiced are elaborated below.

Growing drought-tolerant varieties

The impact of climate change on land-based livelihoods is visible in Nepal. Farmers reported that they are experiencing reduced agricultural yields mainly due to drought. In response to droughts, some of the farmers in our study area have started alternative drought-tolerant crops. Many farmers in the Hill region have converted their paddy fields to maize and finger millet. Some others have started growing ginger and turmeric, which are relatively more drought tolerant than paddy, maize, and millet. These are some of the self-directed local adaptation practices.

Most of the farmers expressed their willingness to look for an alternative crop if traditional paddy cultivation is not possible to grow because of limited water availability. They were eager to try drought-tolerant varieties of paddy and other similar crops. Some of the farmers in our study areas reported starting alternative crops to replace traditional cereal crops on concentrated farmland. Tomato cultivation, tea gardening, cardamom plantation, and ginger cultivation can be taken as examples. Tomato cultivation has been practiced in those areas where there is a nearby market. Farmers also suggested that tea gardening looks good for utilizing fallow land with fewer human resources for long-term benefit. However, the market is very important to get the expected benefits from tea leaves and other crops.

Changes in the cropping system

In the FGDs carried out in Sindhupalchowk and Dolakha, farmers reported that their recent cropping cycle follows wheat—finger millet—potato/maize in a 2-year span. This is mostly because in high altitude areas farmers normally produce three crops in 2 years. As an impact of climate change, the increase in temperature has resulted in an early maturation of 1–2 months of these crops. This early maturity of crops has also been reported by other studies in eastern Nepal (Chaudhary and Aryal, 2009; Chaudhary and Bawa, 2011). In this case, farmers in these area comfortably estimate that they can add one more crop in the middle, but they are quite confused on what to add and when. Only a few innovative farmers have started some changes on a trial-and-error basis but over 95% farmers are following the same traditional cropping cycle.

Changes in the cropping cycle and irrigation facilities are also interrelated. If farmers want to add one more crop in the ongoing cycle, they need to arrange irrigation because the intensity and duration of the dry period also increase. Due to limited adaptive capacity, lots of running water sources are underutilized. Such poor adaptive capacity of farmers adds to vulnerability and weakens their climate resilience. Some of the off-farm options for livelihood are already practiced in the high hills. The paper industry, tourism industry, and the cultivation of medicinal plants can be taken as examples. Likewise, many people choose to plant other traditional varieties as they are found to be better suited for harsh environmental conditions. High hill communities have started to rely on non-timber forest products. Some of these communities are practicing an organized collection by forming cooperatives through leasehold forestry groups.

Riverbed farming

In the southern part of Nepal, where there is massive deposition of sand from rivers, cultivation on sandy riverbeds and river banks has been tried out by several farmers in the Tarai region. Some farmers are successful in producing watermelon, pointed gourd, ginger, and sweet potatoes on the sandy soil where there is recurrent soil deposition from river floods. For example, in the sand deposition created by the 2008 Koshi flood, farmers in that region are practicing riverbed farming such as watermelon, pumpkin, cucumber, and pointed gourd. The use of sand-cast lands for fruit cultivation can be a coping strategy for making the best use of unusable land. Vegetable farming is highly prone to disease and pest attacks, and to price volatility that is beyond the risk-bearing capacity of poor farmers. Similarly, the use of sand-cast lands for fruit cultivation has been taken as one of the coping strategies to make the best use of unusable lands. Unlike vegetable farming, it has been used by both small and large-scale farmers for different types of fruit depending on their risk-taking potential (Rai et al., 2019). There are several other riverbed farming initiatives undertaken by different institutions (Gurung et al., 2012; Maharjan, 2017, 2020).

Migration and resettlement

Because of climate change, many glacier lakes are at risk of erupting. The latest study carried out by ICIMOD, 2020 shows there are 47 such glacial lakes in Nepal (Bajracharya et al., 2020). The possibility of glacier lake outburst floods (GLOFs) has been increasing in the mountainous areas of Nepal. There are several river valleys in Nepal, which are very productive and densely populated, such as Tumlingtar of Sankhuwasabha district, Nepalthok of Kavre district, and Manthali of Ramechhap district. There are hundreds of such highly productive river valleys in the country. With rising temperatures, it has become apparent that rivers fed by glacier lakes can flood at any time of the year and bring about devastating effects. All of these scenarios indicate that human settlements on the bank of glacier-fed rivers are not safe.

Furthermore, the river banks used to be the attraction of poor people and indigenous communities for fishing. Fluvial flooding, flash flooding, glacier lake outburst risk coupled with the anthropogenic factors, such as hydro projects, excessive harvesting, and the use of unnecessary fertilizers, and electrical fishing, the riverbed ecosystem has been disrupted compelling people to depend on riverbeds for their livelihoods to seek alternatives economic sources or even to migrate to other places.

Mountain people have taken immigration as an opportunity to earn a good remittance from foreign employment, on the other hand, they have fewer number of human resources for their agriculture and livestock at home. The number of domestic animals, the amount of compost, and human resources are directly related to agricultural production. The lower the input, the lower the outputs of agricultural products. This trend has created an overload for women and the feminization of agriculture as women are also taking on more roles in farming (UNDP, 2009; Paudel et al., 2020). In Nepal, the women labor population in agriculture has increased from 36% in 1981 to 45% in 1991 and 48.1% in 2001 and 49.8% in 2011 (Jalsrot Vikas Sanstha (JVS)/GWP Nepal, 2015). Similarly, the lack of proper irrigation, and climate induced disasters also compelled people to think of changing their settlements.

Conclusion

Climate change and its induced disasters, such as floods, heavy rains, and droughts, have caused notable impacts on Nepalese agriculture leading to food insecurity, threating nutritional wellbeing, and loss of overall economic development. The annual national average production of major crops is adversely affected by fluctuating precipitation and seasonal variations. However, farmers are minimizing the impacts of climate change and variability by changing cropping patterns, switching crop varieties, riverbed farming, and improving technology and water management practices. These practices are autonomous and are unlikely to build long-term adaptation and resilient food production systems. Therefore, there is a need for planned adaptation practices. This study suggests short- and long-term pathways for planned adaptation. In a short run, the focus should be on growing drought-tolerant crops, making changes to the crop cultivation cycle and riverbed farming practices, developing contingency crop planning, changing planting dates, planting short-duration varieties, or long-term strategies such as population migration to safer locations, resettlement programs with transformative livelihood options with sustainable agricultural practices.

This study also suggests further research to quantify the disaggregated impact of climate change on food production systems and its consequences on food and nutritional security, along with a rigorous cost-benefit analysis of each potential adaptation option including the transformative adaptation option is essential. To achieve this, this study has paved a solid foundation and provided guidance for policymakers and implementers.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The data is acquired from the Ministry of Agriculture and Livestock Development, Government of Nepal for the research purpose which cannot be shared without permission from the Ministry. Requests to access these datasets should be directed to https://moald.gov.np/.

Ethics statement

The study uses freely available secondary data with permission. For the Focus Group Discussions approval was acquired from the respective Municipal office and informed consent was acquired from the participants.

Author contributions

NN and YPJ conceptualized the research and analyzed the data. NN conducted the FGD. NN, SP, RS, and YPJ analyzed the information and prepared the first draft. NN, SP, RS, YPJ, YR, and AC revised this manuscript. All authors reviewed the first draft, contributed to the improvement, reviewed the final draft, read, and agreed to the final version of this manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.968998/full#supplementary-material

SUPPLEMENTARY FIGURE 1
Annual average production (mt) of Barley from 1970/71-2014/15.

SUPPLEMENTARY FIGURE 2
Annual average production (mt) of Maize from 1970/71-2014/15.

SUPPLEMENTARY FIGURE 3
Annual average production (mt) of Millet from 1970/71-2014/15.

SUPPLEMENTARY FIGURE 4
Annual average production (mt) of Wheat from 1970/71-2014/15.

SUPPLEMENTARY FIGURE 5
Annual average production (mt) of Paddy from 1970/71-2014/15.

References

Alexandratos, N., and Bruinsma, J. (2012). *World Agriculture Towards 2030/2050: The 2012 Revision*. UN: FAO.

Atanga, R. A., and Tankpa, V. (2021). Climate Change, Flood Disaster Risk and Food Security Nexus in Northern Ghana. *Front. Sustain. Food Syst.* 5, 706721. doi: 10.3389/fsufs.2021.706721

Bajracharya, S. R., Shrestha, A. B., Shrestha, F., Wagle, N., Maharjan, S. B., Sherpa, T. C., et al. (2020). *Inventory of Glacial Lakes and Identification of Potentially Dangerous Glacial Lakes in the Koshi, Gandaki, and Karnali River Basins of Nepal, the Tibet Autonomous Region of China, and India*. Nepal: United Nations Development Programme (UNDP).

Bhatta, L. D., Shrestha, A., Neupane, N., Jodha, N. S., and Wu, N. (2019). Shifting dynamics of nature, society and agriculture in the Hindu Kush Himalayas: Perspectives for future mountain development. *J. Mountain Sci.* 16, 1133–49. doi: 10.1007/s11629-018-5146-4

Chaudhary, P., and Aryal, K. P. (2009). Global warming in Nepal: challenges and policy imperatives. *J. For. Livelihood* 8, 5–14.

Chaudhary, P., and Bawa, K. S. (2011). Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biol. Lett.* 7, 767–70. doi: 10.1098/rsbl.2011.0269

Chemjong, B., and KC, Y. (2020). Food security in Nepal: a review. *Rupantaran Multidiscip. J.* 4, 31–43. doi: 10.3126/rupantaran.v4i1.34015

Chinnakali, P., Upadhyay, R. P., Shokeen, D., Singh, K., Kaur, M., Singh, A. K., et al. (2014). Prevalence of household-level food insecurity and its determinants in an urban resettlement colony in north India. *J. Health Popul. Nutr.* 32, 227.

Conway, K., Akseer, N., Subedi, R. K., Brar, S., Bhattarai, B., Dhungana, R. R., et al. (2020). Drivers of stunting reduction in Nepal: a country case study. *Am. J. Clin. Nutr.* 112, 844S—59S. doi: 10.1093/ajcn/nqaa218

Dahal, N., Shrestha, U. B., Tuitui, A., and Ojha, H. R. (2018). Temporal changes in precipitation and temperature and their implications on the streamflow of Rosi River, Central Nepal. *Climate* 7, 3. doi: 10.3390/cli7010003

DHM (2017). Observed climate trend analysis in the districts and physiographic regions of Nepal (1971–2014). *Depart. Hydrol. Meteorol. Kathmandu* 1, 74.

DoHS (2021). *Annual report 2019/20, Department of Health Services, Ministry of Health and* Population. Nepal: Government of Nepal.

Eriksson, M., Xu, J., Shrestha, A. B., Vaidya, R. A., Santosh, N., Sandström, K., et al. (2009). *The Changing Himalayas: Impact of Climate Change on Water Resources and Livelihoods in the Greater Himalayas*. Patan, Nepal: International centre for integrated mountain development (ICIMOD).

FAO (2005). *Food Security Information for Action Practical Guide.* Rome: Food and Agriculture Organization (FAO).

FAO (2015). *Climate Change and Food Security Risks and Responses*. Rome: Food and Agriculture Organization (FAO). Available online at: https://www.fao.org/3/i5188e/I5188E.pdf (accessed June, 2022).

Gregory, P. J., Ingram, J. S., and Brklacich, M. (2005). Climate change and food security. *Philos. Transac. Royal Soc. London Ser. B, Biol. Sci.* 360, 2139–48. doi: 10.1098/rstb.2005.1745

Gurung, G. B., Koirala, P., Pande, D. P., Basnet, D. B., and Kafle, O. (2012). Promoting rural livelihoods through riverbed vegetable farming in the Tarai region of Nepal. *J. Int. Dev. Cooper.* 18, 113–21.

Hussain, A., Rasul, G., Mahapatra, B., and Tuladhar, S. (2016). Household food security in the face of climate change in the Hindu-Kush Himalayan region. *Food Secur.* 8, 921–37. doi: 10.1007/s12571-016-0607-5

Jalsrot Vikas Sanstha (JVS)/GWP Nepal (2015) *Stocktaking: Climate Vulnerability on Agricultural Sector for National Adaptation Plan Process.* Nepal: JVS/GWP.

Kattel, R. R., and Nepal, M. (2022). Rainwater harvesting and rural livelihoods in Nepal. *Clim. Change Commun. Resil.* 159–73. doi: 10.1007/978-981-16-0680-9_11

Khadka, M., Rasul, G., Bennett, L., Wahid, S., and Gerlitz, J-. Y. (2014). Gender and social equity in climate change adaptation in the Koshi basin: An analysis for action. *Handbook Clim. Change Adap.* 10, 978–3. doi: 10.1007/978-3-642-40455-9_78-1

Maharjan, S. K. (2017). Riverbed farming as source of income, family nutrition and food security for landless and poor farmers in Tarai region of Nepal. *Scientia Ricerca: Innov. Techniq. Agric.* 2, 316–9.

Maharjan, S. K. (2020). *Socio-Economic Determinants for Adoption of Riverbed Farming in Deukhuri Valley of Western Nepal.* Preprints. doi: 10.20944/preprints202004.0478.v1

Malla, G. (2008). Climate change and its impact on Nepalese agriculture. *J. Agric. Environ.* 9, 62–71. doi: 10.3126/aej.v9i0.2119

MoALD (2021). *Statistical Information on Neplease Agriculture 2076/77, Ministry of Agric. Livestock Development, Planning and Development Cooperation Coordination* Division, Nepal.

MoF (2021). *Economic Survey Report of 2020/21.* Kathmandu: Ministry of Finance (MoF), Government of Nepal.

MoFE (2019). *Climate Change Scenarios for Nepal, Ministry of Forest and Enviroment*. Kathmandu: Government of Nepal.

MoFE (2021a). *Vulnerability and Risk Assessment and Identifying Adaptation Options in the Agriculture and Food Security*. Kathmandu: Ministry of Forests and Environment (MoFE), Government of Nepal.

MoFE (2021b). *Vulnerability and Risk Assessment and Identifying of Adaptation Options in Disaster Risk Reduction and Management (DRRM).* Kathmandu: Ministry of Forests and Environment (MoFE), Government of Nepal.

MoHA (2022). *Nepal Disaster Risk Reduction Portal, Government of Nepal, Kathmandu*. Available online at: http://drrportal.gov.np/ (accessed July, 2022).

MoPE (2004). *Nepal Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate* Change. Kathmandu: Government of Nepal.

Nepal, A. K., and Neupane, N. (2022). Living in the flood plain: can financial inclusion, productive assets and coping mechanism help reduce food insecurity? *Environ. Challenges* 6, 100437. doi: 10.1016/j.envc.2021.100437

NPC (2021). *Nepal Multidimensional Poverty. Index Analysis Towards Action, National Planning Commission.* Nepal: Government of Nepal.

Pant, K. P. (2012). Climate change and food security in Nepal. *J. Agric. Environ.* 13, 9–19. doi: 10.3126/aej.v13i0.7582

Paudel, B., Wu, X., Zhang, Y., Rai, R., Liu, L., Zhang, B., et al. (2020). Farmland abandonment and its determinants in the different ecological villages of the Koshi river basin, central Himalayas: Synergy of high-resolution remote sensing and social surveys. *Environ. Res.* 188, 109711. doi: 10.1016/j.envres.2020.109711

Rai, M. K., Paudel, B., Zhang, Y., Khanal, N. R., Nepal, P., Koirala, H. L., et al. (2019). Vegetable Farming and Farmers' Livelihood: Insights from Kathmandu Valley, Nepal. *Sustainability* 11, 889. doi: 10.3390/su11030889

Rasul, G. (2021). Twin challenges of COVID-19 pandemic and climate change for Agric. food security in South Asia. *Environ. Challenges* 2, 100027. doi: 10.1016/j.envc.2021.100027

Rasul, G., Pasakhala, B., Mishra, A., and Pant, S. (2020). Adaptation to mountain cryosphere change: issues and challenges. *Clim. Dev.* 12, 297–309. doi: 10.1080/17565529.2019.1617099

Regmi, B. R., and Adhikari, A. (2007). Human development report 2007. Climate change and human development-risk and vulnerability in a warming world Country Case Study-Nepal. New York, NY: UNDP. Available online at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10,1.1.422.4595andrep=rep1andtype=pdf

Schnitter, R., and Berry, P. (2019). The climate change, food security and human health nexus in Canada: a framework to protect population health. *Int. J. Environ. Res. Public Health.* 16, 2531. doi: 10.3390/ijerph16142531

Shrestha, A., Eriksson, M., Mool, P., Ghimire, P., Mishra, B., Khanal, N., et al. (2010). Glacial lake outburst flood risk assessment of Sun Koshi basin, Nepal. *Geom. Nat. Haz. Risk* 1, 157–69. doi: 10.1080/19475701003668968

Shrestha, N., Raes, D., and Sah, S. K. (2013). Strategies to improve cereal production in the Terai region (Nepal) during dry season: simulations with aquacrop. *Proc. Environ. Sci.* 19, 767–75. doi: 10.1016/j.proenv.2013.06.085

Shrestha, U. B., Shrestha, A. M., Aryal, S., Shrestha, S., Gautam, M. S., Ojha, H., et al. (2019). Climate change in Nepal: a comprehensive analysis of instrumental data and people's perceptions. *Clim. Change.* 154, 315–34. doi: 10.1007/s10584-019-02418-5

Thakur, S. B. (2017). Climate change related policy environment in Agric. food security in Nepal. *J. Agric. Environ.* 18, 120–30. doi: 10.3126/aej.v18i0.19897

Thapa, S., and Hussain, A. (2021). Climate change and high-altitude food security: a small-scale study from the Karnali region in Nepal. *Clim. Dev.* 13, 713–24. doi: 10.1080/17565529.2020.1855099

UNDP (2009). *Resource Guide on Gender and Climate Change*. Geneva: United Nations Development Programme and Global Gender and Climate.

USAID (2021). *Nepal Nutrition Profile*. Available online at: https://www.usaid.gov/sites/ default/files/documents/Copy_of tagged_Nepal-Nutrition-Profile.pdf (accessed May, 2022).

Walker, T., Kawasoe, Y., and Shrestha, J. (2019). *Risk and Vulnerability in Nepal: Findings from the Household Risk and Vulnerability Survey*. Washington, DC: World Bank. Available online at: http://hdl.handle.net/10986/33365 doi: 10.1596/33365

World Bank (2021). *Climate Change Knowledge Portal: For Development Practitioners and Policy Makers*. Available online at: https://climateknowledgeportal.worldbank.org/country/nepal/climate-data-historical (accessed June, 2022).