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Climate Resilient Agriculture in Nepal: Challenges, Innovations, and the Path Toward Sustainable Food System

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Abstract: Climate change has seriously threatened agriculture in Nepal due to the vulnerable topography and a significant proportion of the population being dependent on agriculture. This review examines the impact of climate change on agriculture in Nepal, which has contributed to food insecurity and socioeconomic challenges. The increase in greenhouse gases leads to climatic variation, including erratic rainfall patterns, temperature fluctuations, and extreme events such as floods and landslides. Such alterations in climate conditions significantly affect agricultural productivity, thereby putting the livelihoods of millions of farmers, who rely on subsistence farming, at risk. The irregular pattern of weather has led to a decrease in yield, increased pest infestations, and soil degradation, all of which complicate food availability, accessibility, and affordability. Climate-resilient agriculture, an approach that mitigates the adverse effects of climate change, helps build resilience in farming through methods such as agroforestry, conservation agriculture, and stress-tolerant crop varieties, which enhance crop viability and help sustain production in a particular environment. CRA also focuses on the role of biotechnological innovations and technologies, such as GIS and ICT tools, in reducing climate risk and supporting sustainable farming practices. Nepal has adopted various climate change policies and adaptation plans to address specific vulnerabilities related to climate actions. However, their execution is obstructed due to various challenges coming from the socio-economic, policy, and institutional levels. High costs, low levels of awareness, and a weak institutional framework significantly restrict the implementation of resilience strategies. The integration of traditional knowledge, the enhancement of renewable energy sources, and the improvement of water management practices can be effective methods for managing climate risks and ensuring food security. Similarly, research on invasive species, biotechnological solutions, and policy development needs to be strengthened in the future to develop resilience to climate change.

Keywords: *Climate resilience, Emissions, Adaptations, Agroforestry, Crop diversification, Stress resistant*

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1. Introduction

An emerging issue of the world, climate change is the change in the climatic condition of the earth over time, mainly caused by anthropogenic activities, which resulted in an increase in GHGs and several harmful impacts on the earth (Tripathi & Pandey, 2022). As per the Intergovernmental Panel on Climate Change (IPCC), Climate change is defined as, any 'change in climate over some time, whether due to natural variability or as a result of human activity', however since the start of the Industrial Revolution, the rise of CO2 level is mainly caused due to human activity (Pound et al., 2018). Nepal is a landlocked country situated between China to the north and India to the east, west, and south in South Asia, with coordinates of 27 ° N and 84 ° E (Paudel, 2016). It is considered one of the five most vulnerable countries to climate change in the world (Dawadi et al., 2022). Between 2000 and 2019, Nepal was ranked as the 10th most vulnerable nation in

terms of the frequency of extreme weather events, with 0.82 fatalities per 100,000 people and 0.39% losses per unit of GDP (Joshi & Bhandari, 2023). Over the last 40 years, flooding, heat exposure, drought, and landslides have been the major climate change-related incidents that the country has experienced (World Bank, 2022).

The increase in anthropogenic activities since the 20th century, primarily due to industrial development, has caused significant warming of the Earth (Sapkota, 2016). Although climate change has been developing its roots since the Earth's origin, in recent years, the agricultural sector has been severely hampered by its risks (Rijal & Rijal, 2019). The widespread use of modern technologies and the green revolution has increased agricultural production in recent years; however, with increasing environmental and financial costs over the last few years, the agricultural sector is encountering losses (Adhikari et al., 2018). Climate change causes a shift in the growth cycle of major crops, which subsequently decreases productivity and impacts the socio-economic condition of more than 1 million farmers worldwide who rely entirely on farming (Eswaran & Anand, 2024). The degradation of soil health, enhancement of pest metabolism, and alteration of water resources are some indirect effects of climate change in agriculture (Eswaran & Anand, 2024). Developing nations, such as Nepal, are more severely affected by climate change than developed ones, as they often lack the proper infrastructure and financial resources to combat this issue (Tripathi & Pandey, 2022). Global warming, which exacerbates food security issues, is also found to threaten the Sustainable Development Goals, specifically SDG 1, SDG 3, SDG 6, SDG 11, and SDG 13 (Pound et al., 2018).

2. Materials and methods

To conduct the review, a systematic assessment of the literature and papers on Climate Change, Climate Resilience, and their impact on food security in Nepal was methodically evaluated. A more comprehensive search was conducted through academic databases, including Google Scholar, ResearchGate, and Institutional databases (FAO, World Bank, Ministry of Agriculture, etc.). The chosen sources, published between 2010 and 2024, were accessed for their relevance and credibility, with a focus on peer-reviewed articles and relevant reports from respected organisations. Outdated studies (pre-2010) and non-agricultural and climate studies were excluded. This review focuses on research in Climate Resilient Agriculture (CRA), the impacts of climate change on Nepalese agriculture, food security, laws and barriers to climate adaptation, and recommendations for the future. In the end, the results were combined to highlight patterns, gaps and suggestions for further studies on CRA, enhancing food security, and promoting resilient technologies in agriculture in Nepal.

3. Results and Discussion

3.1 Nepalese Agriculture and Food System

The agricultural sector is the main driver of food security and economic growth in Nepal, comprising 66% of the country's labour force (Joshi et al., 2021). With 21% of its land utilised for agricultural production, rice, wheat, and maize are the major crops grown in Nepal (Chapagain et al., 2023). Nepalese agriculture is characterised by low land productivity, with an average of USD 1804 per hectare (Joshi & Bhandari, 2023). With 80 million small and marginal farmers, the average landholding size is less than 1 hectare, or nearly equal to 0.1 hectares in some cases (World Bank, 2010). The traditional way of farming in Nepal is being threatened by climate change, so there is a need to adopt a sustainable agricultural system (Pandey, 2012). Low-value cereal crops and extreme subsistence farming, with less than 13% of output in the traded market, are characteristics of agriculture that shrink any kind of economic opportunity within the country (IFAD, 2012). 62% of the total labour workforce is dependent on agriculture, and the economy of the country is on the verge of several shocks due to climate change (World Bank, 2022). The increasing problem of population growth in the country has also exacerbated the effects of climate change, leading to unsustainable farming practices (Pandey, 2012).

The main concept of food security encompasses food availability, accessibility, and affordability for the people (Bista et al., 2013). Nepal has a huge potential to produce a wide variety of crops due to its variable climatic conditions, ranging from subalpine to alpine regions (Bista et al., 2013). However, in mountainous countries like Nepal, floods and droughts that arise due to irregular rainfall patterns cause approximately three-fourths of the economic loss, primarily due to crop damage in the field and storage conditions, resulting in food insecurity (Neupane et al., 2022). The decline in agrobiodiversity over the last three decades, due to floods, droughts, and landslides, has resulted in a decrease in nutritional and dietary diversity, which is responsible for food insecurity in the country (Thapa & Hussain, 2021). Nepal ranks 68th out of 127 countries, with a score of 14.7 on the Global Hunger Index, indicating a moderate level of hunger (GHI, 2024). Strengthening food and nutrition security and improving extension systems in agriculture are the interventions planned by the SDG (2016).

Out of the 77 districts of Nepal, 42 districts are food insecure, and 1.9 million people are more vulnerable to the impacts of climate change (MoFE, 2021). Production, access, utilisation, and stability are the primary aspects of food security that are being compromised by climate change and the increased threat of crop failure (Amoak et al., 2022). In Nepal, more than 40 million people are found to be food insecure, with 20% of households falling into the mildly food insecure category, 22% into the moderately food insecure category, and 10% into the severely food insecure category (Chemjong & KC, 2020). Similarly, high floods in Nepal's western region that year caused a more than 30% decrease in agricultural production (Neupane et al., 2022).

3.2 Climate Change Impacts on Nepalese Agriculture

Nepal is a landlocked country situated between China to the north and India to the east, west, and south in South Asia, with coordinates of 27 ° N and 80 ° E (Paudel, 2016). It is considered one of the five most vulnerable countries to climate change in the world (Dawadi et al., 2022). The impacts of climate change on agriculture are shown in Table 1.

1. Temperature Variability and Crop Production

Nepal's climate ranges from subtropical to arctic, all within approximately 180 kilometres, and there is a wide variety of microclimate conditions, which lead to an array of land uses and land practices, ranging from 60 meters to over 8,000 meters throughout the country (Paudel, 2016). The country has experienced a marked increase in average temperatures, with mountain regions warming at nearly twice the global rate (Dawadi et al., 2022). In the Terai plains, a rising temperature during the critical growth stage reduced wheat production by 15-20% (Lin, 2011) and also led to poor quality rice due to high nighttime temperatures.

2. Changing Precipitation Patterns

Because of the presence of a monsoon-dominated environment, Nepal is experiencing water stress, which ultimately means that the wet season has too much water and the dry season has too little water (Tikhatri & Bhattarai, 2023). These precipitation changes have led to prolonged dry spells, flooding in low-lying areas and shifting in the cropping calendar of many commercial crops. A 12.5% decrease in production occurred in the eastern region of the country in 2006 due to a lack of rainfall during the monsoon season, resulting in 10% of the land being left fallow (Neupane et al., 2022). Farmers are facing delays in harvesting major crops like potatoes, wheat, and maize, due to climatic irregularities (Tripathi & Pandey, 2022). Paddy, the major crop of Nepal, grown in the Terai and some parts of the hilly regions, is severely affected due to irregular or late monsoons and long-term drought (Neupane et al., 2022).

3. Biodiversity Loss and Pest Dynamics

Climate change has accelerated the loss of biodiversity in agriculture, with several indigenous crops in the verge of extinction. Approximately 1.7mm of topsoil is estimated to be lost each year due to both climatic and agricultural practices (Bhusal et al., 2022). The Karnali region of Nepal, once renowned for its diverse crops, including buckwheat and barley, now primarily produces only brown rice and millet (Thapa & Hussain, 2021). Concurrently, the high temperatures due to climate change have enabled:

- Expansion of invasive species like *Chromoleana odorata* (Banmara) in agricultural and water resources
- Increased pest lifecycles and their metabolic rates, making them resistant to pesticides
- Emergence of new crop disease reducing the productivity in agriculture (CBS, 2017)

Nepal is experiencing a temperature rise of around 0.04 °C per annum, which is higher than the world's average temperature increase (Tripathi & Pandey, 2022). According to the Asian Development Bank report, by 2050, climate change is expected to cause a 2.2% annual decrease in Nepal's Gross Domestic Product (GDP) (Kandel et al., 2023).

Table 1: Climate change impacts on agriculture (Eswaran & Anand, 2024)

Impact category	Description	Examples	Affected regions	Adaptation strategies
Temperature changes	Increased average temperatures and affecting crop growth and season length	Reduced crop yields in wheat, maize	Tropics and subtropics	Heat- tolerant crop varieties, shifting planting dates
Water availability	Altered precipitation patterns leading to droughts or excessive rainfall	Water scarcity in dry regions	Sub- Saharan Africa, Asia	Improves irrigation, water conservation
Soil degradation	Intensifies erosion and nutrient depletion from extreme weather	Loss of arable land	Coastal and semi- arid areas	Soil conservation techniques, agroforestry
Pest and disease spread	Expanded habitats for pests and pathogens due to warmer climates	Increased pest pressure in rice, coffee	Tropical and temperate climate	Integrated pest management (IPM), resistant varieties

Extreme weather events	More frequent and severe storms, floods, and heatwaves impacting crop productivity	Crop damage from floods, storms	Coastal and flood –prone areas	Disaster-resilient infrastructure, crop insurance
Crop and livestock health	Heat stress impacting livestock health and productivity	Lower milk yield in cattle	Arid and semi-arid zones	Shade structures, heat-resistant breeds

3.3 Principles of climate-resilient agriculture

At present, the world is stuck between two situations, which include ensuring the proper availability of food to the whole population along with protecting the agricultural sector from the harmful consequences of climate (Karri & Nalluri, 2024).

The ability of social, economic, and environmental systems to respond and reorganise in ways that preserve their fundamental identity, structure, and function in the face of a disruptive event, trend, or disturbance is known as resilience (Amoak et al., 2022). The approach to supporting agricultural practices that reduces hunger and poverty in the face of climate change, while preserving resources for future generations, is known as climate resilience (Karri & Nalluri, 2024). Climate Resilience Agriculture (CRA), a subset of Climate Smart Agriculture (CSA) focuses on sustainable agriculture, where farming is based on agricultural principles and does not cause any depletion of natural resources (Pound et al., 2018). CRA includes recognition of threats due to climate change and helps to respond to them effectively (Debangshi, 2021).

The three stages of climate resilience include (Karri & Nalluri, 2024) (Figure 1);

1. Recognition phase

The unpredictable hazards, such as rainstorms, droughts, cyclones, pests, and disease outbreaks, created by climate change are recognised by the CRA system.

2. Curing phase

The CRA system self-cures by mitigating the ill effects of climate change and adapting to it. It includes mechanisms such as carbon sequestration, precision farming, conservation agriculture, direct-seeded rice, and an integrated arming system, among others.

3. Sustaining phase

All adjustments made during the curing phase are maintained for a longer period, allowing the system to overcome any problems it encounters.

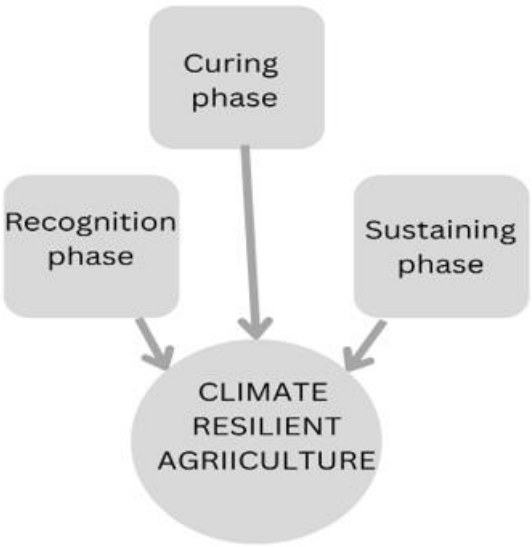

Figure 1: Three stages of climate resilience agriculture (Karri & Nalluri, 2024)

3.4 Climate-Resilient Agriculture (CRA) Strategies in Nepal

As outlined by SDG 13, Nepal is focused on promoting climate-smart agriculture and climate-smart villages, while also reducing emissions of various ozone-depleting substances and carbon dioxide from various sectors (Giri et al., 2023). Due to the rapid impact of climate on the agricultural sector of Nepal, farmers are shifting towards Climate Resilience Agriculture from the conventional approach (Rai et al., 2018).

Agroecological Approaches

Nepal has seen promising results from various agroecological practices:

- Agroforestry Systems: The integration of trees with crops has shown multiple benefits, mainly the reduction of soil erosion by 30-40%. Agroforestry systems also improved the condition of microclimates for sensitive crops and increased the additional income from fruits and nuts of trees (Paudel, 2015).

- Conservation Agriculture: Practices like the use of cover cropping, organic soil amendments and reduced

tillage are the major approaches for climate adaptation (Eswaran & Anand, 2024). These increase the organic matter content in soil by 15-20%, improve water retention during droughts and reduce the cost of production by 25% (Adhikari et al., 2018). The alteration of cropping patterns and irrigation intensities has resulted in the early maturation of crops, allowing farmers to include more crops in their cropping cycle (Neupane et al., 2022). Similarly, the use of living animals in Nepal for ploughing, bio pesticides, straw mulching, and local methods of seed selection for upcoming years, though being subsistence, contributes greatly to increasing crop productivity and developing resistance to climate change (Bhusal et al., 2022)

Technological Innovations

Several biotechnological and digital solutions are being implemented in Nepal:

• Stress- Tolerant Varieties: Considering rice is the primary agricultural crop of Nepal, submergence tolerance varieties such as Sworna Sub 1 and IR4 have been developed to withstand waterlogging for 17-20 days (Paudel, 2015).

• Digital Tools: GIS-based land suitability mapping and mobile apps are used for pest identification and weather forecasts.

Water Management Solutions

• Rainwater Harvesting: Surface rainwater harvesting and rooftop rainwater harvesting systems are adopted in many regions of hills and mountains in Nepal to reduce the risk of drying up and water scarcity. Adequate water usage helps to mitigate climate vulnerabilities in agriculture in these regions (Haque et al., 2020).

• Sloping Agriculture Land Technology (SALT): SALT is an ecologically suitable and technologically sound farming system adopted widely in hills and mountainous regions of Nepal. It integrates spatial patterns and landscape ecology to help ensure the proper functioning of the soil-water cycle of the land (Lamichhane, 2013).

3.5 Policies on Climate Change and Agriculture in Nepal

With the aim of building enough capacity to address food security threatened by climate change and creating livelihood opportunities, Nepal is focusing on the identification and implementation of Good Agriculture Practices (Chapagain et al., 2023). Below are some policies adopted by Nepal for promoting climate-resilience agricultural practices (HELVETAS, 2011; Chapagain et al., 2023).

1. National Climate Change Policy 2011

The key focuses of the National Climate Change Policy 2011 include the development of low-carbon economic strategies, integration of climate justice and sustainable development, focus on local skills and knowledge, promoting the use of resilient crop varieties, enhancing soil conservation and watershed management, and promoting renewable energy in irrigation. It was endorsed by the Government of Nepal under the chairmanship of the Prime Minister in 2009 (Sapkota, 2016).

2. National Adaptation Program of Action (NAPA)

Nepal's National Adaptation Program of Action(NAPA) was formulated in 2010 as a response to the country's climate change vulnerability (UNFCCC, 2023). Agriculture and food security are the core thematic areas, along with community-based adaptation to climate change, linking agricultural adaptation to livelihood improvement. Identification of adaptation needs of vulnerable communities, mobilisation of support and reducing poverty among marginalised communities are the major objectives of NAPA.

3. Local Adaptation Plan of Action (LAPA)

With the aim of integrating climate change adaptation into local farming development, the Local Adaptation Plant of Action (LAPA) was launched in 2011.The major focus areas of LAPA include addressing climate change-related vulnerabilities in agriculture, identifying resilient crop varieties, and localising assessments of farming methods, as well as ensuring farmers' participation and ownership in climate change-related programs.

4. Water Resources Act (1992)

The Water Resources Act 1992 aims to provide a legal framework for the conservation, utilisation, and management of the country's water resources. Ensuring water availability to farmers under variable climatic conditions by promoting sustainable irrigation conditions. The formation of Water User Associations (WUAs), the restriction of water misuse, and the implementation of various policies regarding irrigation, hydropower, and drinking water projects are under the control of this act.

5. Agriculture and Food Security Legislation

The legislation on agriculture and food security provided financial aid to farmers to access climate-resistant seeds and fertilisers. Key legislations include the Right to Food and Food Sovereignty Act 2018, the Seeds Act 1988, the Agriculture Development Strategy (ADS) and the Land Use Act 2019.

6. Rural Renewable Energy Grant 2007

The legislation was introduced by the Government of Nepal to promote clean, affordable, and sustainable energy in Nepal's remote and rural areas. This supports the use of renewable sources of energy, like solar energy, in irrigation and other agricultural works.

7. Reducing Emission from Deforestation and Forest Degradation (REED) Strategy,2016

REED is primarily aimed at enhancing the resilience of forest ecosystems to achieve increased environmental, social, and economic benefits through institutional policies and measures, while also reducing emissions.

8. Agriculture Development Strategy(ADS), 2015-2035

ADS is a long-term agricultural development vision and plan that integrates climate change adaptation and resilience development in the agricultural sector.

Likewise, Nepal is working under the UNFCCC (United Nations Framework Convention on Climate Change) to achieve improved livelihoods, mitigate risks, and adapt to research and technology, thereby increasing resilience to climate change (Giri et al., 2023). Nepal has implemented a twenty-year Agricultural Perspective Plan (APP) to mitigate the negative impacts of climate change, as well as signed the Kyoto Protocol to reduce the emission of greenhouse gases (Pandey, 2012).

3.6 Challenges and Barriers to Climate Resilience

Socio-economic barriers

The high cost of tools for precision agriculture and the affordability of proper irrigation management practices hinder farmers from adopting climate-resilient practices (Eswaran & Anand, 2024). Most farmers appear to be uninterested in adopting conservation tillage practices and indigenous crops (Eswaran & Anand, 2024).

Policies barrier

The shift in the government's interest from agriculture to other sectors has resulted in a reduced allocation of expenditure in this sector, leading to the formulation of very few policies aimed at enhancing the resilience of the agricultural sector (Bista et al., 2013). The interests of donors typically influence government actions, and they often lack clear insights into climate change (Regmi & Bhandari, 2013). The knowledge gap problem is widespread among many practitioners and policymakers of climate change (Regmi & Bhandari, 2013).

Institutional and technological barriers

The alteration caused by climate change to the moisture regime and growth duration of plants provides signals to various institutions to develop new technologies and policies tailored to the new environment (Chhetri et al., 2011). However, due to a weak institutional framework, climate-related policies are still in the development phase and require further strengthening to be effectively implemented (Dhungana et al., 2017). A proper understanding of the variety and complexity of social obstacles, with a focus on addressing the root causes of vulnerability and social exclusion, is essential for the successful adaptation of local-level and national-level policies on climate change (Dhungana et al., 2017). The lack of trust and blurred roles of different ministries responsible for addressing climate change in Nepal have led to improper coordination and communication between funding agencies, farmers, and the government (Regmi & Bhandari, 2013).

Prospects and Recommendations for Strengthening Resilience

- Intercropping, strip cropping, row cropping, mixed cropping, etc., include several types of crops grown in the same piece of land. A varietal mixture of crops in a single field provides more resistance to climate extremes (Bullock et al., 2017). The dependency on monoculture farming can be replaced by promoting local and underutilised crops (Thakur & Bajagain, 2020). The retention of crop residue in the soil helps maintain microclimate conditions, enhances soil microorganism diversity, recycles nutrients, and increases yield (Lal, 2015).
- The widespread use of infected germplasm has been found to increase the risks of disease, pests and is susceptible to every climate extremity, decreasing the resistance of farming to climate change. Proper research should be conducted on invasive and exotic species to reduce the importation of uncertified germplasm and control pest and disease infestations in the field (Bhatt, 2022).
- Pest suppression strategies in any agricultural system should include the creation of biotic barriers like shaded agroforestry systems, habitat management and alteration of plant age, along with promoting natural enemy abundance and promoting plant diversity (Lin, 2011).
- Likewise, there must be recognition and promotion of indigenous crops of different values that are adaptable to certain climates for the enhancement of the resilience of vulnerable places (Sherpa, 2023). Local people are the storehouse of valuable knowledge that they have been practising from generation to generation for the sake of enhancing crop production.
- The sustainability of ecological relationships and natural resources management is obtained by the digitalisation of local knowledge with ICTs to decrease the vulnerability of climate change on agricultural practices. The assessment of weather patterns, tools for disease identification, hand tools to detect nutrient deficiencies, and checking soil quality before planting crops can be effective in managing risks due to climate change in agriculture.
- A climate forecasting system is essential for farmers to predict the climate patterns and prepare against disasters. It helps to mitigate the ill effects of climate change (Pandey, 2012). Crop insurance, awareness campaigns, and training can be organised for farmers to prepare them for facing climate change. At the global scale, policies must be properly implemented in a coordinated manner to ensure adequate resilience in farmland to climate change (Bullock et al., 2017).
- There must be adequate coordination between donors, agencies, NGOs/ INGOs, and concerned ministries to work to limit the climate extremities (Dhungana et al., 2017). Adequate resources should be allocated to enhancing the economic status of farmers and developing technologies resilient to climate change.

By the adoption of the above techniques, the agricultural aspect of the country can be less prone to climate change, and the food security of the country can be ensured.

4. Conclusion

Climate change poses a significant threat to Nepal's agriculture, which is crucial to sustaining its economy and ensuring food security. This review highlights the diverse impacts of climate change, including irregular rainfall patterns, temperature fluctuations, biodiversity loss, and increased pest attacks, which collectively undermine crop yields and livelihoods. Climate-Resilient Agriculture (CRA) emerges as an essential response to the challenges posed, highlighting the importance of sustainable food systems. Practices such as agroforestry, conservation agriculture, stress-tolerant crops, and high-tech water management have great prospects for enhancing resilience. The implementation of these practices, however, is hampered by socio-economic conditions, institutionally weak frameworks, and gaps in policy implementation.

To overcome these challenges, all concerned stakeholders, including policymakers, scientists, and local people, must work collectively. Institutional support must be bolstered, investments mobilised, and local knowledge integrated with emerging technologies to significantly promote the success of CRA activities. In addition to these, policy measures such as the National Climate Change Policy (2011) and the Local Adaptation Plan of Action (LAPA) must be critically evaluated and enhanced to better meet the needs of vulnerable agricultural communities. Future efforts must emphasise research on invasive species, biotechnology, and scalable adaptation plans tailored to Nepal's diverse agro-climatic zones.

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References

Adhikari, P., Araya, H., Aruna, G., Balamatti, A., Banerjee, S., Baskaran, P., Barah, B. C., Behera, D., Berhe, T., Boruah, P., Dhar, S., Edwards, S., Fulford, M., Gujja, B., Ibrahim, H., Kabir, H., Kassam, A., Khadka, R. B., Koma, Y. S., … Verma, A. (2018). System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. *International Journal of Agricultural Sustainability, 16*(1), 1–28. https://doi.org/10.1080/14735903.2017.1402504

Amoak, D., Luginaah, I., & McBean, G. (2022). Climate Change, Food Security, and Health: Harnessing Agroecology to Build Climate-Resilient Communities. *Sustainability (Switzerland), 14*(21). https://doi.org/10.3390/su142113954

Bhusal, K., Udas, E., & Bhatta, L. D. (2022). Ecosystem-based adaptation for increased agricultural productivity by smallholder farmers in Nepal. *PLoS ONE, 17*(6 June), 1–16. https://doi.org/10.1371/journal.pone.0269586

Bista, D., Amgain, L., & Shrestha, S. (2013). Food security scenario, challenges, and agronomic research directions of Nepal. *Agronomy Journal of Nepal, 3*, 42–52. https://doi.org/10.3126/ajn.v3i0.8985

Bullock, J. M., Dhanjal-Adams, K. L., Milne, A., Oliver, T. H., Todman, L. C., Whitmore, A. P., & Pywell, R. F. (2017). Resilience and food security: rethinking an ecological concept. *Journal of Ecology, 105*(4), 880–884. https://doi.org/10.1111/1365-2745.12791

CBS. (2017). National Climate Change Impact Survey 2016: A Statistical Report. https://climate.mohp.gov.np/downloads/National_Climate_Change_Impact_Survey_Report_2016.pdf

Chapagain, T. R., Karki, T. B., Shah, P., Dutta, G., Kinzang, A., Robyul, G. M., & Hossain, I. M. B. (2023). Consortium for Scaling-up Climate-Smart Agriculture in South Asia (C-SUCSeS) Project Climate-Smart Agriculture Technologies and Practices in Nepal South Asian Association for Regional Cooperation (SAARC) (Issue January). https://doi.org/10.13140/RG.2.2.28000.25603

Chemjong, B., & KC, Y. (2020). Food Security in Nepal: A Review. *Rupantaran: A Multidisciplinary Journal, 4*(1), 31–43. https://doi.org/10.3126/rupantaran.v4i1.34015

Chhetri, N., Chaudhary, P., Raj, P., & Baran, R. (2011). Institutional and technological innovation : Understanding agricultural adaptation to climate change in Nepal. *Applied Geography*, 1–9. https://doi.org/10.1016/j.apgeog.2011.10.006

Dawadi, B., Shrestha, A., Acharya, R. H., Dhital, Y. P., & Devkota, R. (2022). Impact of climate change on agricultural production: A case of Rasuwa District, Nepal. *Regional Sustainability, 3*(2), 122–132. https://doi.org/10.1016/J.REGSUS.2022.07.002

Dhungana, N., Khadka, C., Bhatta, B., & Regmi, S. (2017). Barriers in local climate change adaptation planning in Nepal. *Journal of Law, Policy and Globalization, 62*, 20–24. https://www.iiste.org/Journals/index.php/JLPG/article/view/37535/45875

Eswaran, S., & Anand, A. (2024). Climate Change Impacts on Agricultural Systems Mitigation and Adaptation Strategies : A Review. *Journal of Experimental Agriculture International. 46*(11), 1–12.

GHI. (2019). Global hunger index. October.

Giri, S., Prabhakar, A., Malla, R. B., Oli, S., Poudel, S., & Khanal, A. (2023). Climate Change Mitigation and Adaptation in Nepal and South Asia: Challenges, Progress, and Recommendations. Review Article *Journal of Sustainability and Environmental Management, 2*(2), 133–140. https://doi.org/10.3126/josem.v2i2.55206

Haque, A. K. E., Mukhopadhyay, P., Nepal, M., & Shammin, M. R. (2021). Climate Change and Community Resilience: Insights from South Asia. *Springer Nature, 460*.

HELVETAS. (2011). Nepal's Climate Change Policies and Plans : Local Communities' Perspective Environment and climate series 2011 / 1.

IFAD. (2012). Independent Office of Evaluation Nepal Country Programme Evaluation. December.

Joshi, D. R., Clay, S. A., Ghimire, R., Kharel, T., & Mishra, U. (2021). Conservation agriculture for food security and climate resilience in Nepal. *Agronomy Journal, 113*, 4484–4493. https://doi.org/10.1002/agj2.20830

Joshi, G. R., & Bhandari, R. (2023). Determinants of Intensity of Adoption of Climate Change Adaptation Practices in the Agriculture Sector in Nepal. *International Journal of Environment and Climate Change, 13*(1), 30–41. https://doi.org/10.9734/ijecc/2023/v13i11602

Kandel, G. P., Bavorova, M., Ullah, A., Kaechele, H., & Pradhan, P. (2023). Building resilience to climate change: Examining the impact of agro-ecological zones and social groups on sustainable development. *Sustainable Development, 31*(5), 3796–3810. https://doi.org/10.1002/sd.2626

Karri, V., & Nalluri, N. (2024). Enhancing resilience to climate change through prospective strategies for climate-resilient agriculture to improve crop yield and food security. *Plant Science Today, 11*(1), 21–33. https://doi.org/10.14719/pst.2140

Lal, R. (2015). A system approach to conservation agriculture. *Journal of Soil and Water Conservation, 70*(4), 82A-88A. https://doi.org/10.2489/jswc.70.4.82A

Lamichhane, K. (2013). Effectiveness of sloping agricultural land technology on soil fertility status of mid-hills in Nepal. *Journal of Forestry Research, 24*(4), 767–775. https://doi.org/10.1007/s11676-013-0415-0

Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience, 61*(3), 183–193. https://doi.org/10.1525/bio.2011.61.3.4

MoFE. (2021). Nepal's Third National Communication To The United Nations Framework Convention On Climate Change (UNFCCC). In Government of Nepal Ministry of Forests and Environment. https://www.mofe.gov.np/resources/study-reports-3115

Neupane, N., Paudel, S., Sapkota, R., Joshi, Y. P., Rijal, Y., & Chalise, A. (2022). Enhancing the resilience of food production systems for food and nutritional security under climate change in Nepal. *Frontiers in Sustainable Food Systems, 6*. https://doi.org/10.3389/fsufs.2022.968998

Pandey, C. L. (2012). The impact of climate change on agriculture. *Agribusiness and Information Management, 4*(1), 13–23. https://doi.org/10.1007/BF00140510

Paudel, M. N. (2015). Global effect of climate change and food security with respect to Nepal. *Journal of Agriculture and Environment, 16*(June), 1–20. https://doi.org/10.3126/aej.v16i0.19836

Paudel, M. N. (2016). Prospects and Limitations of Agriculture Industrialization in Nepal. *Agronomy Journal of Nepal, 4*(August 2016), 38–63. https://doi.org/10.3126/ajn.v4i0.15515

Pound, B., Lamboll, R., Croxton, S., Gupta, N., & Bahadur, A. V. (2018). *Climate-Resilient Agriculture in South Asia: An analytical framework and insights from practice.* Action on Climate Today. June.

Prasad Bhatt, R. (2022). Consequences of Climate Change Impacts and Implications on Ecosystem and Biodiversity; Impacts of Developmental Projects and Mitigation Strategy in Nepal. *Climate Change in Asia and Africa - Examining the Biophysical and Social Consequences, and Society's Responses*, 1–27. https://doi.org/10.5772/intechopen.96455

Rai, R. K., Bhatta, L. D., Acharya, U., & Bhatta, A. P. (2018). Assessing climate-resilient agriculture for smallholders. *Environmental Development, 27*, 26–33. https://doi.org/10.1016/j.envdev.2018.06.002

Regmi, B. R., & Bhandari, D. (2013). Climate Change Adaptation in Nepal: Exploring Ways to Overcome the Barriers. *Journal of Forest and Livelihood, 11*(1), 43–61. https://doi.org/10.3126/jfl.v11i1.8612

Rijal, S., & Rijal, B. (2019). Climate Smart Agriculture Concept and Adaptation in Nepal: An Overview. *International Journal of Research and Review,6*(1),47–56.

Sapkota, R., & Rijal, K. (2016). Climate change and its impact in Nepal. *Tribhuvan University Journal*. 9 – 11.

SDG. (2016). Sustainable Development Goals. 2016–2030.

Sherpa, T. O. (2023). Indigenous people's perception of indigenous agricultural knowledge for climate change adaptation in Khumbu, Nepal. *Frontiers in Climate, 4*. https://doi.org/10.3389/fclim.2022.1067630

Thakur, S. B., & Bajagain, A. (2020). Moringa: Alternative for the Food Security, Climate Resilience and Livelihood Improvement in Nepal. *International Journal of Research -GRANTHAALAYAH, 8*(3), 190–200. https://doi.org/10.29121/granthaalayah.v8.i3.2020.142

Thapa, S., & Hussain, A. (2021). Climate change and high-altitude food security: a small-scale study from the Karnali region in Nepal. Climate and Development, 13(8), 713–724. https://doi.org/10.1080/17565529.2020.1855099

Tikhatri, D., & Bhattarai, S. S. (2023). Impact of Climate Change on water security and Endorsing importance of Rainwater Harvesting Technology in Nepal. American Journal of Environment and Climate, 2(3), 24–32. https://doi.org/10.54536/ajec.v2i3.1643

Tripathi, A., & Pandey, M. (2022). Climate Change: It's Causes, Inflicted Hazards, Adopted Strategies and

Opportunities in Agriculture of Nepal: A Detailed Review. *American Journal of Environmental Economics, 1*(1), 1–12. https://doi.org/10.54536/ajee.v1i1.358

Udit Debangshi. (2021). Climate Resilient Agriculture an Approach to Reduce the Ill-Effect of Climate Change. *International Journal of Recent Advances in Multidisciplinary Topics. 2*(7), 309–315.

World Bank. (2010). Source: Adapted from DFID-World Bank 2006. 1–6.

World Bank. (2022). Climate risks , exposure , vulnerability and resilience in Nepal 1 Abstract. 1–61.