Embracing Proactive Measures for Climate Change Adaptation: People's Understanding of Climate Change and Initiation of Adaptation Activities

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Dedicated to

my late father Sanaman Darjee and

late mother Manamaya Darjee

Declaration

I hereby declare, on oath, that I have written the present dissertation by my own and have not used other than the acknowledged resources and aids.

Hamburg, 25.08.2023

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Summary

Climate change is one of the crucial components in the interaction of physical, chemical, and biological processes of the Earth system. While climate change is unequivocally a global phenomenon, its impacts are local and disproportionate, mostly based on geographical fragility and temporal scales; and the vulnerability of individuals, groups, and communities. Rising temperature and changing precipitation patterns and their wide-ranging consequences have adversely impacted people's livelihoods around the globe. So, climate change adaptation has become an inescapable option in addressing climate change impacts in minimizing vulnerability to growing and potential climate risks. Geographical diversity coupled with socio-economic disparity results in inconsistent impacts of climate change and thereby actual adaptation is variable, both locally and globally. Geographically at-risk, poor, and developing countries face the need for a wide range of adaptation measures in terms of timing and scale. However, designing and implementing appropriate climate change adaptation strategies has proven to be very challenging due to limited local-specific climate data, financial resources, inadequate infrastructure, and insufficient access to information and technology. As a result, the impacts of climate change are often felt more acutely in these countries and communities. In this backdrop, this thesis investigates how local people perceive climate change and its impacts; and explore the list of locally tailored activities (menu for adaptation) practiced by local households and communities, suggesting that policymakers and climate scientists emphasize bottom-up adaptive strategies for effective and efficient implementation.

The climate change trends and variability using data from local meteorological records were analyzed and compared with local people's perception. The empirical data and evidences were collected from more than 500 households representing three ecological regions of Nepal to analyze how people perceive and anticipate climate risks and implement locally doable adaptation measures proactively; and to investigate the determining factors in choosing proactive adaptation options. In addition, the thesis examines policies coherence and contradictions in addressing local practices.

The study followed socio-cognitive processes for climate change risk appraisal and adaptation appraisal of individual to implement proactive adaptation measures against locally experienced impacts of climate change. Furthermore, the content analysis of major policies of Nepal including National Adaptation Program of Action, Local Adaptation Plan of Action, Community Level Adaptation Plan of Action, and Climate Policy 2019 have been performed to examine vertical coherence of policies and programs in addressing local people needs and their practical skillset to combat with climate change.

The quantitative and qualitative data acquired from local meteorological stations and household surveys were analyzed. We analyzed temperature and precipitation patterns, including the Rainfall Anomaly Index (RAI) and the Precipitation Concentration Index (PCI). Proactive measures were evaluated based on essential criteria extracted from published literature and insights gathered from consulting experts. We employed the ordered logistic regression model to explain the explanatory power of essential socio-economic and demographic factors in influencing the choice of proactive adaptations.

The results showed that, over the last three decades, temperature and precipitation trends and variability between regions varied, largely corroborating the local experiences. The temperature increased in Mountain, Mid–hills, and Low-land by 0.061^{o}C yr^{-1}, 0.063^{o}C yr^{-1}, and 0.017^{o}C yr^{-1}, respectively. In contrast, average annual rainfall decreased by -9.7 mm yr^{-1}, -3.6 mm yr^{-1}, and -0.04 mm yr^{-1} for the regions, respectively. Although the amount of rainfall decrease observed in the Mountain was the highest, its variability was found to be relatively low, and vice versa in Low-land. Approximately 88% of respondents perceived temperature rise, and 74% noticed rainfall decline. The local people linked these changes with their livelihood activities, as exemplified by, for example, crop's quality and quantity or birds' migration. The results indicate that local understandings complement the scarce observational data and provide a reliable and additional foundation to determine changes in climatic variables. The result also shows that small changes in climate variables have noticeable implications on human behavior change leading to implement local level adaptation measures.

The study confirms that local people in Nepal are not only aware of escalating climate risks but also engage their cognition and knowledge proactively to adapt locally. The results show that 84% of households adapted both proactive and reactive measures, while 10.5% applied solely reactive adaptation and 5.6% were exclusively focused on proactive adaptation measures. Over 50 different proactive adaptation measures were implemented by the households. The measures were significantly associated with agricultural diversification, cash crop cultivation, livestock raising, small-scale enterprise development, and disaster control. Socio-economic and spatial factors such as a household's wellbeing, land holding size, geographical location, livelihood options, and the number of adaptation measures implemented by the households were found to be decisive factors in choosing proactive adaptation. The results suggest that even small proactive initiatives by the households can offer multiple benefits against climate risks as an architect of individuals. However, the analysis of coherence and contradiction of different layers of policies and strategies show that this local knowledge and practices of community have been hardly acknowledged in the policy process due to some contradiction in focus and implementation mechanism.

The framework for Local Adaptation Plan of Action considers the local governments as implementing units, while National Adaptation Program of Action puts an emphasis on the local community groups. Emphasizing the role of local government in planning and program implementation suggests that the current framework for implementing the Local Adaptation Plan of Action breaches the provisions intended for community-level institutions, as conceived in the national framework. Through the Community Level Adaptation Plan of Action, local communities have planned and implemented adaptation measures envisioned in the thematic areas identified in the climate change policy of Nepal: agriculture and food security; forests and biodiversity; water resources and energy; climate-induced disasters; public health; and urban settlements and infrastructure. Nevertheless, the Community Level Adaptation Plan of Action is not institutionalized under government policies as a local level implementing unit. So, the consensus for a local implementing unit in the policies has remained a key issue. We suggest the identification of a suitable and acceptable unit for implementing climate change adaptation at the community level. Only if an appropriate implementing units and appropriate measures are identified the policies can be successful with a broader acceptance and desirable outcomes enshrined in the climate change policies.

Finally, local perceptions of climate change and the initiatives undertaken by the communities highlight the importance of incorporating local perspectives, knowledge, and expertise into broader policy frameworks for both climate change adaptation and mitigation. By acknowledging and integrating the insights gained from these grassroots' efforts, policymakers and planners can develop robust and contextually tailored strategies to tackle climate change in a transdisciplinary approach to contribute climate goal of Paris Agreement which has been a centerpiece of global efforts to tackle climate change.

Zusammenfassung

Der Klimawandel ist eine der entscheidenden Komponenten im Zusammenspiel physikalischer, chemischer und biologischer Prozesse des Erdsystems. Während der Klimawandel eindeutig ein globales Phänomen ist, sind seine Auswirkungen lokal und betreffen hauptsächlich die geografischen Fragilität und den zeitlichen Maßstab sowie die Verletzlichkeit von Einzelpersonen, Gruppen und Gemeinschaften. Steigende Temperaturen und veränderte Niederschlagsmuster sowie deren weitreichende Folgen haben negative Auswirkungen auf die Lebensgrundlagen der Menschen auf der ganzen Welt. Daher ist die Anpassung an den Klimawandel zu einer unumgänglichen Option geworden, um den Auswirkungen des Klimawandels zu begegnen und die Anfälligkeit für wachsende und potenzielle Klimarisiken zu minimieren. Geografische Vielfalt gepaart mit sozioökonomischer Ungleichheit führt zu uneinheitlichen

Auswirkungen des Klimawandels und daher ist die tatsächliche Anpassung sowohl lokal als auch global unterschiedlich. Geografisch fragile, arme Länder und Entwicklungsländer stehen vor der Notwendigkeit, aus einer breiten Palette von Anpassungsmaßnahmen in Bezug auf Zeitpunkt und Umfang auszuwählen. Begrenzte lokale, spezifische Klimadaten, unzureichender Infrastruktur, Technologie und Zugang zu Informationen sowie unzureichende finanzielle Ressourcen eine hierbei eine große Herausforderung für eine angemessene Gestaltung und Umsetzung der Anpassung an den Klimawandel dar. Daher sind die Auswirkungen des Klimawandels in diesen Ländern und Gemeinden oft stärker zu spüren. Vor diesem Hintergrund untersucht die vorliegende Arbeit, wie die lokale Bevölkerung den Klimawandel und seine Auswirkungen wahrnimmt, erkundet lokal maßgeschneiderten Aktivität, die von lokalen Haushalten und Gemeinden praktiziert werden, und erarbeitet für politischen Entscheidungsträgern und Klimawissenschaftlern Anregung zur Entwicklung von Bottom-up-Anpassungsstrategien für eine effektive und effiziente Umsetzung.

Die Trends und Variabilität des Klimawandels wurden anhand von Daten aus lokalen meteorologischen Aufzeichnungen analysiert und mit der Wahrnehmung der Menschen vor Ort verglichen. Die empirischen Daten und Belege wurden von mehr als 500 Haushalten aus drei ökologischen Regionen Nepals gesammelt, um zu analysieren, wie Menschen Klimarisiken wahrnehmen und antizipieren und lokal durchführbare Anpassungsmaßnahmen proaktiv umsetzen. Hierbei werden die bestimmenden Faktoren bei der Auswahl proaktiver Anpassungsoptionen untersucht. Darüber hinaus werden in dieser Arbeit die Kohärenz und die Widersprüche der Politik in Bezug auf lokale Praktiken untersucht.

Die Arbeit verfolgt sozio-kognitive Prozesse zur Risikobewertung des Klimawandels und zur Anpassungsbewertung einzelner Personen, um proaktive Anpassungsmaßnahmen gegenüber lokal erlebten Auswirkungen umzusetzen. Darüber hinaus wurde eine Inhaltsanalyse wichtiger Richtlinien und Strategien Nepals durchgeführt, darunter das nationale Aktionsprogramm zur Anpassung, der Aktionsplan zur lokalen Anpassung, der Aktionsplan zur Anpassung auf Gemeindeebene und die Klimapolitik 2019, um die vertikale Kohärenz von Richtlinien und Programmen bei der Bewältigung lokaler Probleme zu untersuchen, die auf die Bedürfnisse der Menschen vor Ort und ihre Fähigkeiten zur Bekämpfung des Klimawandels eingehen.

Die quantitativen und qualitativen Daten, die von lokalen Wetterstationen und Haushaltsbefragungen erfasst wurden, wurden mithilfe mehrerer Tools und Techniken analysiert. Wir haben Temperatur- und Niederschlagsmuster analysiert, einschließlich des Rainfall Anomaly Index (RAI) und des Precipitation Concentration Index (PCI). Proaktive Maßnahmen wurden anhand zentraler Kriterien bewertet. Wir verwendeten das geordnete logistische Regressionsmodell, um die Erklärungskraft wesentlicher sozioökonomischer und demografischer Faktoren bei der Beeinflussung der Wahl proaktiver Anpassungen zu erklären.

Die Ergebnisse zeigen, dass die Temperatur- und Niederschlagstrends sowie die Variabilität zwischen den Regionen in den letzten drei Jahrzehnten unterschiedlich waren, was die lokalen Erfahrungen weitgehend bestätigt. Die Temperatur stieg im Gebirge, im mittleren Hügelland und im Tiefland im jährlichen Durchschnitt um 0,061^{o}C, 0,063^{o}C und 0,017^{o}C. Im Gegensatz dazu verringerte sich der durchschnittliche jährliche Niederschlag für die Regionen um -9,7 mm, -3,6 mm und -0,04 mm. Obwohl der beobachtete Niederschlagsrückgang im Gebirge am höchsten war, wurde festgestellt, dass seine Variabilität relativ gering und umgekehrt im Tiefland relativ hoch war. Ungefähr 88 % der Befragten nahmen einen Temperaturanstieg wahr und 74 % bemerkten einen Rückgang der Niederschläge. Die Menschen vor Ort verknüpften diese Veränderungen mit ihren Lebensunterhaltsaktivitäten, wie beispielsweise die Qualität und Quantität der Ernte oder der Vogelzug. Die Ergebnisse zeigen, dass lokale Erkenntnisse die spärlichen klimatischen Beobachtungsdaten ergänzen und eine zuverlässige und zusätzliche Grundlage für die Bestimmung von Veränderungen klimatischer Variablen bieten. Das Ergebnis zeigt auch, dass kleine Änderungen der Klimavariablen spürbare Auswirkungen auf menschliche Verhaltensänderungen haben, die zur Umsetzung von Anpassungsmaßnahmen auf lokaler Ebene führen.

Die Studie bestätigt, dass sich die Menschen vor Ort in Nepal nicht nur der eskalierenden Klimarisiken bewusst sind, sondern ihre Erkenntnisse und ihr Wissen auch proaktiv einsetzen, um sich vor Ort anzupassen. Die Ergebnisse zeigen, dass 83,9 % der Haushalte sowohl proaktive als auch reaktive Maßnahmen anwendeten, während 10,5 % ausschließlich reaktive Anpassungen anwendeten und 5,6 % sich ausschließlich auf proaktive Anpassungsmaßnahmen konzentrierten. Über 50 verschiedene proaktive Anpassungsmaßnahmen wurden von den Haushalten umgesetzt. Die Maßnahmen waren in erheblichem Maße mit der Diversifizierung der Landwirtschaft, dem Anbau von Marktfrüchten, der Viehhaltung, der Entwicklung kleiner Unternehmen und dem Katastrophenschutz verbunden. Sozioökonomische und räumliche Faktoren wie das Wohlergehen eines Haushalts, die Größe des Landbesitzes, die geografische Lage, die Möglichkeiten des Lebensunterhalts und die Anzahl der von den Haushalten durchgeführten Anpassungsmaßnahmen erwiesen sich als entscheidende Faktoren für die Wahl einer proaktiven Anpassung. Die Ergebnisse legen nahe, dass selbst kleine proaktive Initiativen von Haushalten zahlreiche Vorteile gegen Klimarisiken bieten können. Die Analyse der Kohärenz und Widersprüche verschiedener Ebenen von nationalen Richtlinien und Strategien zeigt jedoch, dass dieses lokale Wissen und diese

Praktiken der Gemeinschaft im politischen Prozess aufgrund einiger Widersprüche in der Ausrichtung und den Umsetzungsmechanismen kaum berücksichtigt wurden. Der Rahmen für den lokalen Anpassungsaktionsplan betrachtet die lokale Regierung als Umsetzungseinheit, während der nationale Anpassungsaktionsplan den Schwerpunkt auf die lokalen Gemeindegruppen legt. Die Betonung der Rolle der Kommunalverwaltung bei der Planung und Programmumsetzung deutet darauf hin, dass der aktuelle Rahmen für die Umsetzung des lokalen Anpassungsplans gegen die Bestimmungen, die für Institutionen auf Gemeindeebene vorgesehen sind, verstößt. Im Rahmen des gemeinschaftlichen Anpassungsaktionsplans haben lokale Gemeinschaften Anpassungsmaßnahmen geplant und umgesetzt, die in den in der nepalesischen Klimawandelpolitik identifizierten Themenbereichen vorgesehen sind, notabene Landwirtschaft und Ernährungssicherheit; Wälder und Artenvielfalt; Wasserressourcen und Energie; klimabedingte Katastrophen; Gesundheitswesen; und städtische Siedlungen und Infrastruktur. Dennoch ist der Aktionsplan zur Anpassung auf Gemeinschaftsebene nicht in der Regierungspolitik als Umsetzungseinheit auf lokaler Ebene institutionalisiert. Daher ist der Konsens über eine lokale Umsetzungseinheit in den Richtlinien nach wie vor ein zentrales Thema. Wir schlagen vor, eine geeignete und akzeptable Einheit für die Umsetzung der Anpassung an den Klimawandel auf Gemeindeebene zu identifizieren. Nur wenn geeignete Umsetzungseinheiten und geeignete Maßnahmen identifiziert werden, können die Maßnahmen erfolgreich sein und eine breitere Akzeptanz sowie wünschenswerte Ergebnisse in der Klimaschutzpolitik erzielen.

Schließlich verdeutlichen die lokale Wahrnehmung des Klimawandels und die von diesen Gemeinschaften ergriffenen Initiativen, wie wichtig es ist, lokales Wissen, Fachwissen und Perspektiven in umfassendere politische Rahmenbedingungen sowohl für die Anpassung als auch für die Eindämmung des Klimawandels einzubeziehen. Durch die Anerkennung und Integration der aus diesen Basisbemühungen gewonnenen Erkenntnisse können politische Entscheidungsträger, Klimawissenschaftler und Planer robustere und kontextbezogenere Strategien zur Bewältigung des Klimawandels in einem transdisziplinären Ansatz entwickeln und so zum Klimaziel des Pariser Abkommens, das im Mittelpunkt der globalen Bemühungen zur Bewältigung des Klimawandels steht, beitragen.

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Table of contents

List of figures

Acronyms

AR	Assessment Report
CAPA	Community Level Adaptation Plan of Action
CBA	Community-based Adaptation
CCA	Climate Change Adaptation
CFUGs	Community Forestry Users Groups
COP	Conference of the Parties
FGDs	Focused Group Discussions
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
LAPA	Local Adaptation Plan of Action
LDCs	Least Developed Countries
MK	Mann–Kendall test
NAP	National Adaptation Plan
NAPA	National Adaptation Program of Action
NATCOM	The initial National Communication
NCSA	National Capacity and Self-Assessment
PCI	Precipitation Concentration Index
PMT	Protection Motivation Theory
RAI	Rainfall Anomaly Index
SDGs	Sustainable Development Goals
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Desertification
UNEP-GCF	United Nations Environment Programme- Green Climate Fund
UNFCCC	United Nations Framework Convention on Climate Change

Part I. Thematic context

1. Introduction

Climate change is a global phenomenon mainly characterized by rising temperatures and fluctuating precipitation pattern due to increasing greenhouse gas (GHG) emissions primarily caused by human activities (Eckstein et al., 2021; Lasco et al., 2004; Paeth et al., 2009; UNFCCC, 2007). This leads to changes in climate patterns and heightened vulnerability to the impacts of climate change, resulting in various unsurmountable hazards and disasters with huge loss and damages worldwide. Ample scientific evidence provides a clear warning, indicating that both natural and human-induced climate changes pose significant threats to numerous aspects of human lives, ecosystems, and economies. The climate variations bring about uncertain risks, especially concerning extreme weather events such as flash floods, landslides, storms, destructive forest fires, heatwaves, cold waves, and droughts worldwide (Archer et al., 2021; Cassardo et al., 2018; Chao and Feng, 2018; Haile et al., 2020; IPCC, 2023; Jolly et al., 2015; Makondo and Thomas, 2020; Thomas and López, 2015; Weerasekara et al., 2021). The distribution of climate change impacts is uneven (Berrang-Ford et al., 2021), with lower income countries being more vulnerable (McGranahan et al., 2007; Stern et al., 2006; Tol, 2009). The Intergovernmental Panel on Climate Change (IPCC) reports consistently highlight the destructive impacts of climate change, particularly on remote and vulnerable communities in poor and developing countries (IPCC, 2021; IPCC, 2022; IPCC, 2023) like Nepal. Nepal is highly exposed to climate change impacts such as glacial lake outbursts, droughts, floods, and landslides because of its geographical fragility and altitudinal variations from low-land to high mountain (Gentle et al., 2014; GoN, 2021; MoE, 2010; Pandey and Bardsley, 2015). The combination of Nepal's geology, fragile ecosystem, impoverished socioeconomic conditions, reliance on natural resources-based livelihoods, and limited adaptive capacity due to higher incidence of poverty has rendered it one of the most vulnerable countries to the impacts of climate change (Alam and Regmi, 2004; Chaudhary and Aryal, 2009; Eckstein et al., 2021). This intricate phenomenon shaped by the interplay of economic, social, cultural, and political dynamics is likely to expedite vulnerability (Sapkota et al., 2016).

In response to climate change, various climate change policies and strategies are in place, drawing upon the United Nations Framework Convention on Climate Change 1992 (UNFCCC) (UNFCCC, 1992), which serves as a global policy framework to climate offset through mitigation and adaptation approach. Climate change adaptation has been an inescapable option to address climate change impacts and received immense importance to minimize vulnerability to growing climate risks (Aryal et al., 2020;

Conway and Schipper, 2011) as mitigation strategy is no longer adequate to avoid loss and damage (IPCC, 2018). It is an ongoing and dynamic process, thereby, societies across space and time have adjusted to climatic stresses (Butzer, 2012; Jodha, 1978). Geographical diversity, coupled with socio-economic disparities, results in differential impacts of climate change, leading to variable levels of adaptation both locally and globally (Berrang-Ford et al., 2021).

The climate change adaptation shows the range of attributes of adaptation strategies and actions to cope with multiple dimensions of vulnerability and impacts. Commonly used attributes are distinguished by their purpose, timing, temporal scale, and spatial scale (Bryant et al., 2000; Carter et al., 1994; IPCC, 2022; Smithers and Smit, 1997; UNEP, 1998).

While adaptation actions are categorized into several types based on key attributes, there is growing recognition among climate scientists, policy makers and planners about timing of climate change adaptation distinguishing proactive measures, implemented in advance to enhance resilience, or reactive, responding to issues as they arise (Bardsley and Sweeney, 2010; de Bruin et al., 2011; Grant et al., 2017). Local people use their adaptation measures proactively against locally experienced climate change impacts based on their individual perception of climate change (Ayanlade et al., 2017; Li et al., 2013) gained from consistent and persistent engagement with surrounding environment including daily weather patterns (Darjee et al., 2022). The local communities rely on themselves, sustaining their way of life through locally available resources and traditional knowledge passed down through generations (Race et al., 2023), which are mostly determined by socio-economic differences and geographical disparities (Adger et al., 2009; IPCC, 2022; Smit and Pilifosova, 2003).

Given these facts, rhetorical policy approaches that apply broadly to all circumstances may overlook the specific situations of local realities. The recent tendency shows that national and regional climate records are often used to formulate those adaptation strategies, neglecting local environmental consequences and locally implemented measures. Inadequate or limited climate data (Adhikari et al., 2019; Karki et al., 2017), reliance on scientific information or local perceptions alone, and failure to consider regional and topographical differences (Darjee et al., 2022) hinder fully informed conclusions about the relationship between climate change and local conditions. So, this thesis aims at examining the correspondence between biophysical changes of climate; local perceptions; the execution of proactive adaptation measures taken by local communities against locally perceived impacts and threats; and the recognition of local proactive actions in climate change policies and strategies taking a case of Nepal. In doing so, this thesis particularly addresses the following key research questions:

1. Do the local people’s perceptions of climate change and its impacts correspond to biophysical alternation of climate change?
2. Do the local people proactively execute adaptation measures on their own against locally existed and perceived potential climatic impacts?
3. Do the climate change policies and strategies recognize local proactive actions implemented by vulnerable communities?

The purpose of this thesis is to gain a comprehensive understanding of how diverse communities in Nepal perceive and respond to climate affliction. To achieve this, climatic data spanning from 1988 to 2018 were obtained from meteorological stations within the study areas and analyzed to assess the trends and variability of temperature and precipitation. In addition, the study involved interviews with over 500 households and conducted 29 focused group discussions (FGDs). Through these approaches, the study seeks to obtain a comprehensive understanding of how diverse communities in Nepal perceive and respond to the challenges posed by climate change. Moreover, this research quests to examine the recognition of local responses in the policy process. By examining these, findings aim to bridge the gap between community perceptions and policy formulation that align with the needs and perspectives of diverse communities.

1.1. Climate change and climate change impacts

The average Earth surface temperature is a key indicator of climate change (Rohde et al., 2013). Since the pre-industrial era (between 1850 and 1900), there has been a sustained increase in global surface temperature. According to the latest assessment by the IPCC (IPCC, 2023), the average temperature is estimated to be 1.1°C above pre-industrial levels in the period of 2011-2020. Over the 20th century, the Earth's surface temperature has increased by approximately 0.6 ± 0.2°C, with greater increases observed over land (1.59°C) compared to the ocean (0.88°C) (IPCC, 2001b). This phenomenon is primarily caused by human activities, especially the burning of fossil fuels, which leads to higher levels of heat-trapping greenhouse gases in the atmosphere (Houghton, 2005), and land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (IPCC, 2001b; IPCC, 2023). These changes manifest in multiple ways, such as alterations in temperature patterns, shifts in precipitation levels, disruptions in seasonal cycles, and modifications in the distribution and behavior of plant and animal species. These have led to changes in climate patterns and intensified vulnerability to the impacts of climate change, resulting in a wide range of devastating hazards and disasters that cause significant worldwide losses and damages (IPCC, 2023; Melvin et al., 2017; Sesana et al., 2021). These encompass a wide range of detrimental phenomena such as sudden shifts in the natural physical environment (e.g., storm surges, floods, landslides, and wildfires), rising sea levels, permafrost thawing, desertification, and changes in oceanic properties (Haile et al., 2020; Tabari, 2020; Thomas and López, 2015), which increasingly threatens human wellbeing (Devine-Wright and Quinn, 2020) and food security (Wheeler and Von Braun, 2013). Recognizing and addressing these impacts are crucial for developing effective strategies to mitigate further damage, protect vulnerable ecosystems, and ensure the sustainability of our planet.

1.2. Navigating climate change impacts: Dual global strategies of mitigation and adaptation

The primary goal of both climate change mitigation and adaptation is to minimize the adverse effects of climate change. However, historical circumstances have led to the separate treatment of these two aspects in both scientific research and policy process. The IPCC reinforces the separation defining mitigation as '*anthropogenic intervention to reduce the sources or enhance the sinks of GHGs and adaptation as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*' (IPCC, 2001a).

In the latter half of the 20th century, environmental concerns gained global attention, leading to the emergence of climate change as a global issue by the early 1990s (Anker, 2011; Yearley et al., 2012). In 1988, the IPCC was established, and in 1990, it produced its first scientific report. Two years later, in 1992, the United Nations Convention on Environment and Development (UNCED) was held, resulting in the Rio Declaration on Environment and Development, Agenda 21, and Forest Principles (Gupta, 2014). The summit established three Rio conventions, i.e., the United Nations Convention to Combat Desertification (UNCCD), the United Nations Convention on Biological Diversity (UNCBD), and the UNFCCC. The UNFCCC (UNFCCC, 1992) is a global policy framework that addresses both climate change mitigation and adaptation, recognizing governments as key actors at the national level (Schipper and Pelling, 2006). At the 1997 Conference of the Parties (COP) to the UNFCCC, the first international agreement (the Kyoto Protocol) on reducing GHG emissions was established. It specified that developed nations would target a reduction of 5.2% in their emissions compared to 1990 levels by 2008-2012 (Gupta, 2014). During the earlier negotiations within the UNFCCC, there was a clear distinction between discussions on mitigation and adaptation.

Reducing GHG emissions to mitigate climate change continues to be a key political concern worldwide. The UNFCCC acknowledges that mitigation is a top priority for developed nations (Huq et al., 2004). However, even with stringent emission controls in place, GHG concentrations are projected to increase, leading to further global warming (Metz et al., 2001). Consequently, adaptation measures are crucial in addressing climate change impacts (Smith et al., 2003). The UNFCCC recognizes the importance of adaptation as the primary concern for developing nations, particularly those classified as Least Developed Countries (Watkiss et al., 2015). Despite continuous efforts in adaptation, significant challenges persist in fully comprehending and effectively implementing practical adaptation strategies to reduce vulnerability to climate change in developing countries. These challenges arise from a variety of factors including insufficient availability of financial resources and technology for developing nations; capacity-building; institutional and governance hurdles; social and cultural factors; and availability and quality of data and information related to climate change and vulnerability.

At the 20th session of the IPCC in Paris in 2003, the interrelations between the three Working Groups of the IPCC were examined, specifically focusing on the integration of mitigation and adaptation as one of the "crucial cross-cutting themes", in preparation for the scoping of the Fourth Assessment Report (AR4) (Huq and Grubb, 2003). The significance of enhanced efforts towards adaptation is prominently highlighted in the Bali Action Plan of UNFCCC COP 15 held in Bali in 2007 (UNFCCC, 2007). In 2009, during COP15 in Copenhagen, the endorsement to continue the Kyoto Protocol emphasized the urgent requirement for enhanced action and international cooperation in adaptation to reduce vulnerability and strengthen resilience in developing and vulnerable countries. Several decisions made by the COP15 have aimed to acknowledge the scientific consensus that limiting the rise in global temperature to below 2°C is imperative. These decisions have also sought to foster long-term collaborative efforts in tackling climate change. The Paris Agreement enabled the IPCC to publish the influential 1.5°C global warming report in 2018, which underscored the substantial differences in impact between a 1.5°C and 2.0°C world. The report served as a critical wake-up call to the international community, emphasizing the urgency of limiting global temperature rise to 1.5°C above pre-industrial levels to avoid severe and irreversible consequences. The report accentuated the necessity of achieving net zero carbon emissions by 2050 and removing carbon from the atmosphere for the remainder of the century to achieve 1.5°C world. In order to attain this climate goal, the Paris Agreement establishes binding commitments by all member countries to prepare, communicate and maintain a nationally determined contribution, which are crucial for realizing its long-term temperature goals. These contributions signify the actions taken by each nation to mitigate their domestic emissions and effectively cope with the consequences of climate change. The Agreement has mandated governments to adhere to key commitments, which include limiting global temperature rise to below 2°C, with additional efforts made to restrict it to 1.5°C. Moreover, governments are required to implement adaptation measures aimed at reducing the vulnerability of individuals and ecosystems to the adverse impacts of climate change (IPCC, 2018).

Mitigation and adaptation, inherently interconnected, share the aim of reducing the risks and impacts of climate change by addressing the causes (mitigation) and coping with the consequences (adaptation) (Laukkonen et al., 2009; Watkiss et al., 2015). Laukkonen et al. (2009) put it in plain terms as "mitigation aims to avoid the unmanageable and adaptation aims to manage the unavoidable." While GHG emissions have a global impact (Swart and Raes, 2007) and mitigation success entails preventing emissions and enhancing carbon sequestration, with progress measured by changes in GHG fluxes (Morecroft et al., 2019), the consequences of GHG fluxes (climate change) disproportionately affect specific regions and vulnerable populations (Eckstein et al., 2021; IPCC, 2023; Satterthwaite, 2007; Stern et al., 2006). So, the implementation of adaptation happened at the local level where the specific realities of climate change occur. The severity of impact and adaptation depend on a variety of factors including climatic and geographic differences, governance systems, housing realities, public infrastructure, resource accessibility, as well as the incorporation of traditional local knowledge in decision-making (Beniston, 2006; Dasgupta, 2007; Eckstein et al., 2019; Gum et al., 2009; Satterthwaite, 2007). Consequently assessing the success of adaptations poses a greater conceptual challenges (Berrang-Ford et al., 2019; Dilling et al., 2019). The Paris Agreement and the Katowice Climate Package provide a clear directive for all parties to actively pursue and report on their progress in adaptation (UNFCCC, 2015; Waskow et al., 2018). However, persistent obstacles, stemming from various factors such as geographical, political, socio-economic, and cultural dimensions, have impeded significant progress in the monitoring and evaluation of adaptation actions and their outcomes (Berrang-Ford et al., 2019).

1.3. Climate change adaptation, mitigation, and sustainable development

In 2015, the United Nations (UN) established the 2030 Agenda for Sustainable Development, providing a comprehensive roadmap to foster peace and prosperity for humanity and the environment, both in the present and in the long term. This ambitious agenda is driven by the pursuit of the 17 Sustainable Development Goals (SDGs), which stand as a compelling and inclusive call to action for all nations, irrespective of their development status, to unite in a global collaboration (UN, 2015). SDG 13 explicitly calls for taking urgent action to combat climate change and its far-reaching impacts. Additionally, various other SDGs also directly and indirectly focus on climatic concerns and potential remedies. For instance, SDG 2 aims to achieve food security and promote sustainable agriculture, while SDG 6 emphasizes the sustainable management of water resources. SDGs 9 and 11 prioritize the development of safe and resilient infrastructure for inclusive human settlements, and SDG 15 is dedicated to protecting, restoring, and sustainably using resources to combat land degradation and biodiversity loss. This diverse range of SDGs indicates the interconnectedness of global challenges and the importance of a holistic approach in creating a sustainable future for all.

Several researchers have explored the interconnections, interdependencies, and incorporation of climate change adaptation and mitigation efforts within the framework of sustainable development (Klein et al., 2005; Wilbanks, 2005; Wilbanks et al., 2003), highlighting the advantages and opportunities of mainstreaming adaptation and mitigation into development policies (Denton et al., 2014; IPCC, 2014; Suckall et al., 2014; Swart and Raes, 2007). The IPCC's AR4 examined the interdependence of adaptation and mitigation (IPCC, 2007), and the Fifth Assessment Report (AR5) further explored climate-resilient approaches integrating adaptation, mitigation, and sustainable development (IPCC, 2014). Integrating adaptation and mitigation measures within climate-resilient pathways, which involve an ongoing process of effectively managing climate-related changes and other driving forces impacting development, is crucial to achieving sustainable development by combining flexibility, innovation, participative problem-solving, and effective strategies for mitigating and adapting to climate change (Denton et al., 2014). Mitigation plays a crucial role in reducing the rate and severity of climate change, thereby alleviating climate-related pressures on sustainable development, including the impacts of extreme weather events (IPCC, 2012; Lenton, 2011; Washington et al., 2009). On the other hand, adaptation encompasses the capacity of communities and individuals to respond to climate change through various resources and factors such as human capital, technology, infrastructure, social and political capital, financial resources, and institutions, which often overlap with indicators of sustainable development (IPCC, 2012; Lenton, 2011; Washington et al., 2009).

1.4. Climate change adaptation initiative in Nepal: Policy and practice

In 2002, Nepal initiated the National Capacity and Self-Assessment (NCSA) (Karki et al., 2021) to develop a national action plan in line with international conventions, specifically the UNFCCC and the UNFCBD. The initial National Communication (NATCOM-1) Report, submitted to the UNFCCC in 2004, offered an overview of Nepal's national circumstances, assessing its capacity to address the issue and discussing the causes, consequences, vulnerability, and adaptation concerns (MoPE, 2004). The NCSA report, published in 2008, unveiled Nepal's obstacles, technologies, and strategies related to adaptation activities in the country (MoEST, 2008).

As a least developed nation, Nepal followed to the generic universal guidelines and developed a National Adaptation Program of Action (NAPA) in 2010 as its domestic strategy for climate change adaptation (CCA) (Ojha et al., 2016). The NAPA outlines nine key areas of focus for adaptation, with the foremost being the advancement of community-based adaptation (CBA) through the integrated management of agriculture, water, forest, and biodiversity sectors (MoE, 2010). In order to advance this primary area of focus, the Government of Nepal developed the National Framework on Local Adaptation Plans for Action (LAPA) (MoE, 2011b) and the Climate Change Policy 2011 (MoE, 2011a). The LAPA framework serves as a comprehensive guideline that outlines the necessary procedures for formulating local adaptation plans, while the Climate Change Policy 2011 functions as a national-level policy aimed at achieving environmental-friendly physical, social, and economic development by effectively mitigating and adapting to the effects of climate change. The implementation of the LAPA and Climate Change Policy has increased awareness of climate change issues and helped to build capacity through cross-sectoral and multi-stakeholder coordination.

Drawing upon the insights acquired from implementing the NAPA and the Climate Change Policy of 2011, the Government of Nepal began the process of developing a National Adaptation Plan (NAP) in 2015. As a result, the newly developed NAP for the period of 2021 to 2050 serves as a framework to foster comprehensive climate change adaptation setting out short-term priority actions until 2025, a medium-term program until 2030, and a long-term strategic goal for adaptation until 2050 (GoN, 2021). The NAP also serves as a national instrument for communicating national adaptation efforts, fulfilling the requirements of the Paris Agreement. So, it is to reinforce the goals of the Paris Agreement. Through the NAP process, countries can assess climate risks and vulnerabilities, and develop CCA plans at medium-term and long-term scales. Following Nepal's declaration as a federal republic, the country revised the Climate Change Policy in 2019 (GoN, 2019), which included a provision for provincial governments to develop their respective Provincial Adaptation Program of Action (PAPA).

Recognizing the importance of integrating CCA strategies into various policies, programs, practices, and development processes, considerable efforts have been made in Nepal to incorporate CCA into existing and new policies, programs, and development processes. In 2020, United Nations Environment

Programme- Green Climate Fund (UNEP-GCF) and NAP-Nepal focused on consolidating CCA interventions and evaluating their impact on vulnerability reduction and resilience enhancement. Over the past two decades, significant progress has been achieved in integrating CCA into planning and implementing projects aimed at reducing vulnerability. However, there is still a need to enhance the mainstreaming of adaptation into development planning and address challenges such as limited information and accessibility to resources.

1.5. Structure of the comprehensive summary

The comprehensive summary provides a concise overview of rural communities' proactive initiatives against climate change impacts. It encompasses the perceptions of rural communities regarding climate change in the local context, the responses of affected communities, and the significance of local actions in the policy process and implementation. The thesis examines the implementation of adaptation actions by Community Forestry Users Groups (CFUGs) across three ecological regions of Nepal: Mountain, Mid-hills, and the Low-land (*Terai*). It firstly addresses the challenges faced by climate change policy and strategy due to limited reliable meteorological data and diverse impacts, leading to an exploration of local people's perceptions and impacts of climate change. Secondly, the thesis analyzes the proactive adaptations of local communities in response to climate change, contributing valuable insights for policymakers in designing appropriate adaptation options. Thirdly, it assesses the coherence and contradictions within policies in addressing local knowledge and adaptation practices, considering concerns regarding disproportionate and differentiated climate impacts, emphasizing the need for context-specific adaptation approaches.

In the initial part of this comprehensive summary, an overview of the thematic context is provided, highlighting the introduction, research questions, and methodological approach. In the second part of this comprehensive summary, the journal articles published in the field are succinctly summarized and discussed within the framework of the study's context. The published articles are:

> Darjee, K.B., Neupane, P.R. and Köhl, M., 2022. Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries. Weather, Climate, and Society, 14(1): 205-222. https://doi.org/10.1175/WCAS-D-21-0081.1

> Darjee, K.B., Neupane, P.R. and Köhl, M., 2023. Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts. Sustainability, 15(14): 10952. https://doi.org/10.3390/su151410952

Darjee, K.B., Sunam, R.K., Köhl, M. and Neupane, P.R., 2021. Do National Policies Translate into Local Actions? Analyzing Coherence between Climate Change Adaptation Policies and Implications for Local Adaptation in Nepal. Sustainability, 13(23): 13115. https://doi:10.3390/su132313115

Finally, the third part presents conclusions of the cumulative dissertation, followed by an outlook for future considerations.

2. Framework for examining proactive adaptation

2.1. Defining adaptation

While multiple definitions of adaptation exist, there is a widely accepted understanding that adaptation involves making enduring adjustments within a system in order to effectively manage external stressors over the long term (e.g., Adger et al., 2005; Smit and Wandel, 2006). Examples include changing planting times, or diversifying livelihoods (Stringer et al., 2009). Climate change adaptation is a "process of adjustment to actual or expected climate and its effects" (IPCC, 2022, p. 5). It enables to anticipate the changes and adjust the response to have as smallest negative effects as possible (Cinner et al., 2018). Therefore, climate change adaptation has been an incessant and dynamic process, leading societies across different locations and time periods to adapt to the challenges imposed by climatic stresses (Butzer, 2012; Jodha, 1978). Adaptation greatly depends on adaptative capacity or adaptability of an affected system, regions, or community to cope with impacts and risks of climate change. The adaptive capacity, which provides practical means to deal with climate-related changes, uncertainties, including climate variations and extremes, is determined by the socio-economic attributes of communities or individuals (Smith et al., 2003). According to the IPCC, adaptive capacity is determined by factors such as wealth, access to technology, the presence of stable and effective institutions, mechanisms for information dissemination, equitable power distribution (Smit and Pilifosova, 2001), and the well-functionality of social systems (Adger, 1999).

2.2. Proactive adaptation *vs* reactive adaptation

Pittock and Jones (2000) introduced two distinct forms of adaptation to consider: autonomous adaptation and planned adaptation. Autonomous adaptation refers to the spontaneous response of unmanaged ecosystems or unaware human systems, relying on their experience of recent and ongoing conditions, which may be subject to change. On the other hand, planned adaptation involves conscious human intervention in a system, driven by an understanding of projected climate change, aiming to safeguard or enhance its desirable characteristics. Planned adaptation, which involves proactive measures, and autonomous adaptation, which occurs reactively, are widely recognized as two types of adaptation strategies (Smit and Pilifosova, 2003) that are commonly observed and implemented. Rasmussen and Suedung (2000) used the term 'proactive' as preplanned control approach for risk management. de Bruin et al. (2011) illustrated proactive (anticipatory) measures are implemented prior to the occurrence of climate change, often on a larger scale and with irreversible implications, whereas reactive adaptation measures are taken in response to climate change after it has already happened, where the costs and benefits are perceived simultaneously. So, proactive management endeavors aim to mitigate risks and minimize the costs of management more effectively compared to reactive efforts that are implemented only after the issues have already emerged (Palmer et al., 2008).

2.3. Concept and analytical framework for proactive adaptation measures

Persuaded by the concept, context, and the escalating urgency of understanding ongoing and dynamic process of adaptation to cope with changing environments, this thesis is motivated by the concepts and principles of the protection motivation theory (PMT) (Rogers, 1975; Rogers, 1983; Rosenstock, 1974) which has been extensively employed to explain adaptative behaviors and the effects of fear on health hazards on individuals' attitudes and actions. This theoretical framework explicitly addresses both risk and adaptation. It has widely been extended to natural environmental risk and hazards including droughts (Truelove et al., 2015) and flood risks (Babcicky and Seebauer, 2019; Le Dang et al., 2014) as well as climate change adaptation and mitigation (Fischer, 2019; Ghanian et al., 2020; Grothmann and Patt, 2005). A PMT socio-cognitive model postulates two cognitive processes - risk appraisal of climate change and adaptation appraisal (Grothmann and Patt, 2005). This model has been considered suitable to perceive climate change, discern impacts of climate change predicting proactive adaptation to climate change risks using indicators of climate change impacts and adaptive capacity. The risk appraisal concentrates on the evaluation of source of climate threat and factors that increase or decrease the possibility of likelihood severity. The risk appraisal apprehends the individual perception on the expectancy of being exposed to the risks (perceived probability) and the perception on how severe the consequences of the risks would be (perceived severity) thereby, assuming the probability of engaging in protective responses. Adaptation appraisal refers to individuals' cognitive processes when evaluating their ability to avoid or reduce particular risk. Within the adaptation appraisal, three distinct components are interpreted to evaluate individual response measures: perceived adaptation efficacy, perceived self-efficacy, and perceived adaptation costs. While individuals often have adaptation intentions, in some cases, they find themselves unable to carry them out in actual behavior due to a lack of objective adaptive capacity (e.g., lack of resources, time, money, power, knowledge or social support) (see Figure 1) including policy constraints.

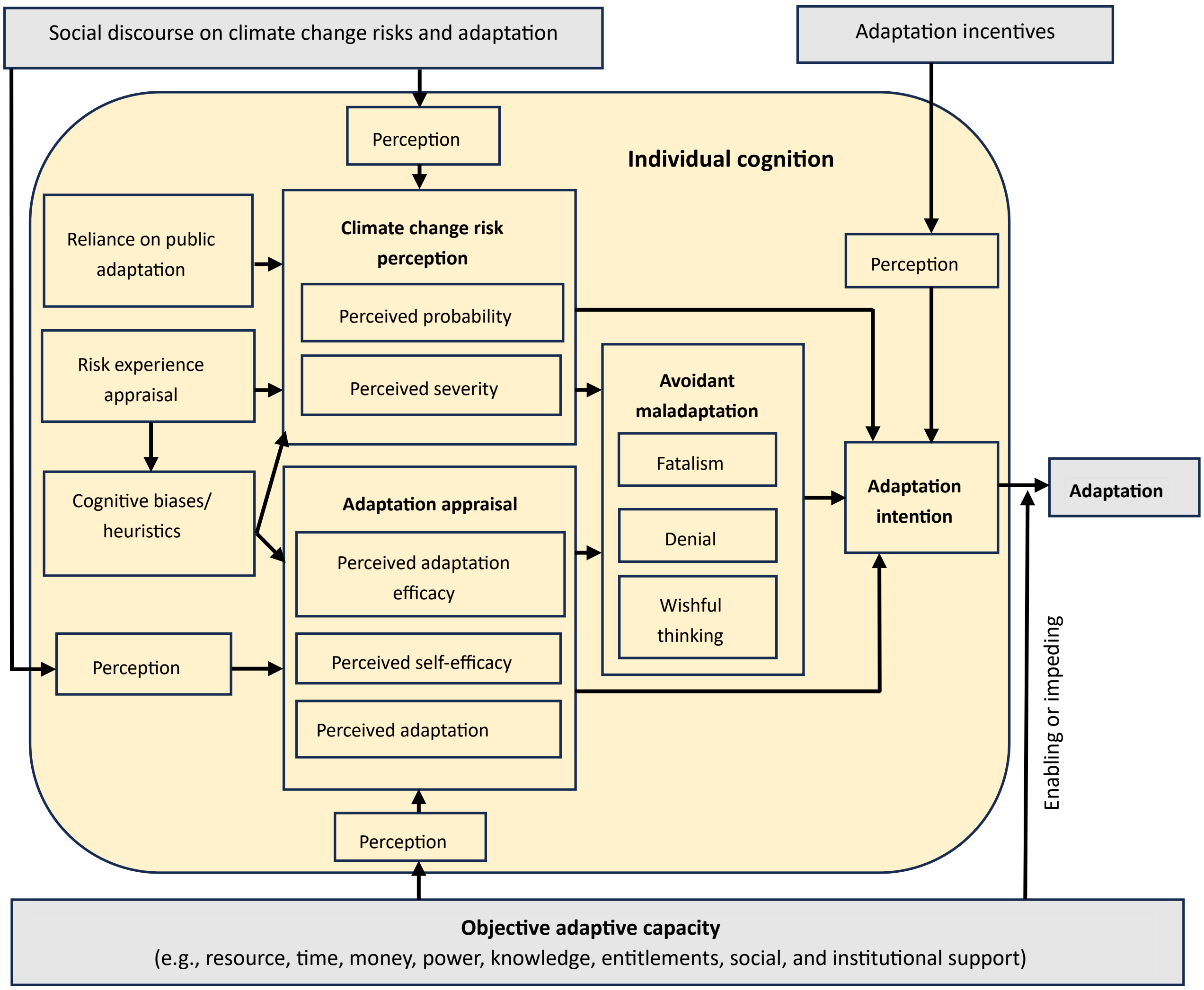

Figure 1 Socio-cognitive model of proactive private adaptation to climate change impacts developed by Grothmann and Patt (2005)

Following this framework, the thesis investigates the interplay between three major questions: How individuals perceive climate change and evaluate potential threats (risk appraisal)? How individual proactively engage in adaptation (adaptation appraisal and adaptation)? And what are the factors that influence the local adaptation measures (objective adaptive capacity)? In doing so, the current thesis splits into three separates but highly correlated thematic issue following the publication of journal articles. The first article investigates the local people's perception and threat comparing with analysis of local meteorological climate data. The second article explores the proactive adaptation of local communities against experienced impacts and potential risks. The third article analyses the local policies coherence and contradiction to promote and internalize local community practices.

Part II. Integration of the articles into the thematic context

Part I of the thesis provides a comprehensive overview of the physical changes of climate, the consequences of these changes, the need for adaptation, and the policy considerations involved in addressing climatic issues. Climate change is a global phenomenon primarily driven by human activities. The destructive impacts of climate change are unevenly distributed, with remote and vulnerable communities in impoverished and developing nations being disproportionately affected. In order to tackle these impacts and reduce potential risks, adaptation to climate change has become imperative.

However, a significant challenge in addressing climate change lies in the development of adaptation policies and strategies that are tailored to specific contexts and locations. Since climate change impacts are experienced locally, and adaptation efforts are undertaken by local communities, generic approach to adaptation policies has been a major obstacle. Therefore, it is crucial to acknowledge the knowledge and practices of local communities regarding climate change and adaptation in the policy-making process.

In this section, the core research papers are summarized, followed by a comprehensive examination of each paper within the framework of the thesis. The methods employed and the results obtained are described in detail in articles.

1. Darjee et al. (2022): Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries

This article[1] was written by Kumar Bahadur Darjee, Prem Raj Neupane and Michael Köhl. The article has been published in the peer-revied journal "Weather, Climate, and Society" on 08 January 2022.

1.1. Summary of the paper (Darjee et al., 2022)

Given the limited availability of location-specific trends and variabilities, as well as the diverse nature of climate change impacts, this paper aims to address the existing knowledge gap by exploring the perceptions of local communities towards climate change. The study involves 327 household interviews

[1] **Author Contributions:** Conceptualization, Methodology, Investigation/Data collection, Formal analysis, Writing—original draft preparation, Writing—review and editing: Kumar Bahadur Darjee (K.B.D.). Contribution to Conceptualization, Methodology, Formal analysis, Writing—review and editing: Prem Raj Neupane (P.R.N.) and Michael Köhl (M.K.). All authors have read and agreed to the published version of the manuscript.

and 16 FGDs with residents from six CFUGs representing three ecological regions in Nepal: The Mountain, Mid-hills, and Low-land. We compared the people's perception with the analysis of trends and variabilities of observed temperature and rainfall patterns obtained from meteorological stations in the regions from 1988 to 2018. By emphasizing the insights derived from the local population, the research aimed to address the gaps created by the insufficient availability of comprehensive climate data. The objective was to gain a deeper understanding of how climate change is perceived and experienced at the local level, thereby providing a more comprehensive perspective on the issue. The results showed that, over the past three decades, temperatures increased in the Mountain, Mid-hills, and Low-land regions at rates of $0.061^{o}C\ yr^{-1}$, $0.063^{o}C\ yr^{-1}$, and $0.017^{o}C\ yr^{-1}$, respectively. Conversely, rainfall decreased by $-9.7\ mm\ yr^{-1}$, $-3.6\ mm\ yr^{-1}$, and $-0.04\ mm\ yr^{-1}$ in these regions, respectively. While the Mountain region witnessed the highest decline in rainfall, its variability was relatively low compared to the Low-land region. The findings revealed significant variations in temperature and precipitation trends and variability between regions, which aligned with the local people's experiences. These changes were linked by residents to their livelihood activities, such as crop quality and quantity, as well as vertically upward bird migration. The results indicate that local understanding complements scantiness of observational climate data, providing a reliable foundation to assess climate change. Furthermore, the study suggests that even slight changes in climate trends and variabilities can have noticeable implications on human behavior change against locally experienced climate change impacts. Therefore, incorporating local knowledge alongside active participation from communities is indispensable for developing effective climate change policies and strategies at both the local and national levels.

1.2. Discussion of the paper in the thematic context

The first article presents a comprehensive analysis of the spatial and temporal shifts in climate data, specifically temperature and precipitation, across three ecological regions in Nepal. Additionally, it compares these findings with the perceptions of climate change by local people. The article offers detailed answers to the following questions:

a) What are the differences in the trends and variabilities of temperature and precipitation records over the past three decades within the Mountain, Mid-hills, and Low-land regions of Nepal?
b) How do these climate changes align with the perceptions of local inhabitants?

Over the past three decades, there have been varying spatial and temporal changes in temperature trends and variability patterns across the Mountain, Mid-hills, and Low-land regions. However, there have been no significant variations in rainfall patterns, although there are differences in rainfall amounts and variability. The Mountain region faced the most substantial reduction in rainfall, leading to water resource depletion due to retreating glaciers. The Mid-hills also experienced a noticeable decline in rainfall, contributing to water resource depletion. In contrast, the Low-land region had a relatively smaller decrease in annual precipitation but exhibited higher annual variability, monthly concentration, and intensity. These factors increased the risks of hazards such as floods, inundation, and heavy rainfall in the Low-land region.

Some earlier studies also highlight the regional disparities in temperature changes within Nepal, with higher altitude areas experiencing more warming compared to lower altitude regions. Middle Mountains and Himalayas have shown pronounced warming rates, however, the *Terai* region exhibited lower warming rates (Shrestha and Aryal, 2011; Tiwari et al., 2010). Shrestha et al. (2019) reported an increase in annual mean temperature ranging from 0.01 to 0.09 °C per year during the period of 1979 to 2016. This increase varies depending on the elevation, with higher altitudes experiencing greater temperature rises. The Department of Hydrology and Meteorology of Nepal (DoHM) analyzed that the maximum temperature in Nepal has been warming at a rate of 0.056 °C per year, while the minimum temperature has been increasing at a rate of 0.002 °C per year (DoHM, 2017). Shrestha et al. (1999) suggested the rate of annual temperature rise to be 0.06^{o}C for the Trans-Himalayan, Himalayan regions, and Middle Mountains; and lower than 0.03^{o}C for Low-land region. The national maximum temperature rate is approximately close to our results of Mid-hills and the Mountain. It suggests that the high-altitude regions are getting warmer intensifying the national mean.

The national annual trend of precipitation in Nepal is not clear (MoFE, 2019). The study by Shrestha et al. (2020) in Mustang district (Nepal) which lies in high mountainous shows an annual declining trend over the last 30 years. Most of the stations of central and eastern regions of Nepal showed a declining rainfall during monsoon season (Karki et al., 2017). Studies of Baidya et al. (2008), Shrestha et al. (2017b), and Shrestha et al. (2019) have shown some increasing trends in precipitation, but these trends were mostly not statistically significant. Our findings align with these studies, showing small and non-significant results. The using of diverse datasets from different time periods and the inclusion of different geographical regions may have contributed to the inconsistent findings (Shrestha et al., 2017a). Since our study focused on a specific local context and relied on time series climate records, the results strongly reflect the local atmosphere. This suggests that the local climate may deviate significantly from the national average scenarios. The results of this study demonstrate an increase in irregularities characterized by high internal variability and concentration.

The findings are consistent with the experiences and observations of local inhabitants. The local perceptions of temperature changes align with the meteorological observations. Local inhabitants, particularly those older than age 40 have noticed changes in temperature and provided evidence of the impacts, such as the disappearance of Himalyan Bulbul (*Pycnonotus leucogenys*) and House Sparrow (*Passer domesticus*) in the Mid-hills and increased them invading agricultural crops in the Mountain region. The locals claimed that the changes in habitat and migration of the bird species to the higher altitudes is caused by the temperature rise in the regions. As suggested by Pearson and Dawson (2003), continuous warming 'bioclimate envelopes' towards higher altitudes affecting fauna's preferred vegetation community and shifting their range poleward latitudinally and upward altitudinally. Long-term changing of climate inevitably shifts geographical range of many taxa, predominantly on birds, mammals and butterflies (Beever et al., 2003; Hill et al., 1998; Hill et al., 1999).

Local communities have reported the observed reduction in snow cover and the retreat of glaciers, which are attributed to rising temperatures. The perception of climate change among locals is also influenced by historical climatic events and their impacts on livelihood activities. Locally, there have been observations of shifts in growing seasons, such as the early ripening of crops like rice, wheat, maize, lentils, and mustard, which can be attributed to temperature increases. Furthermore, locals have perceived changes in rainfall patterns, including early onset and early cessation of the monsoon, significant alterations in rainfall distribution with reduced drizzling and increased instances of intense rainfall, as well as increased uncertainty in precipitation. Similar phenomena have also been documented in other studies (e.g. Ayanlade et al., 2017; Jalota et al., 2012; Kolawole et al., 2016; Malla, 2009; Pandey, 2012; Shrestha et al., 2017b; Tiwari et al., 2010). They have also noted a reduction in water sources, including mountain spring water, wells, ponds, groundwater tables, and lakes. Additionally, locals have observed a decrease in the number of rainy days and an increase in prolonged dry episodes. These impacts are indicative of fluctuations in precipitation concentration and patterns. These local observations align with studies conducted in various regions worldwide, highlighting the widespread impacts caused by changing precipitation patterns (e.g., Abram, 2019; Asfaw et al., 2018; Ayanlade et al., 2017; Banerjee, 2015; Chaudhary and Bawa, 2011; Hu et al., 2020; Legesse et al., 2013; Mertz et al., 2012; Michaelsen et al., 2020; Rao et al., 2011; Roco et al., 2014; Silvestri et al., 2012; Suberi et al., 2018; Tambo and Abdoulaye, 2013).(Hu et al., 2020; Michaelsen et al., 2020).

The article provides four main findings. Firstly, regions at higher altitudes experience a greater rate of temperature rise and highest amount of rainfall decrease, while lower regions encounter more pronounced variabilities and concentration of rainfall. Secondly, the local population's perception of temperature closely corresponds with the analysis of historical meteorological data, however, there are discernible disparities in rainfall patterns. Thirdly, the local people evaluate climate change parameters based on how directly they impact their livelihoods and the seasons when their livelihood activities are predominantly carried out. Even minor changes that may not be statistically significant are perceived by the local population due to their noticeable implications for human behavior change. Finally, the observed changes in temperature and precipitation patterns have had significant ramifications on multiple facets of rural communities' livelihoods, encompassing agriculture, livestock, and business activities. In response to these climate changes, the affected population has initiated local-level measure to address existential impacts and proactive measures to mitigate anticipated risks. Understanding how local communities adapt and cope with is a crucial aspect investigated in the subsequent paper of this thesis.

2. Darjee et al. (2023): Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts

This article[2] was written by Kumar Bahadur Darjee, Prem Raj Neupane and Michael Köhl. The article has been published in the peer-revied journal "Sustainability," the Special Issue Farmers' Adaptation to Climate Change and Sustainable Development on 12 July 2023.

2.1. Summary of the paper (Darjee et al., 2023)

While climate change policies and adaptation strategies often lack appropriate practical adaptation measures tailored to specific local contexts, this paper explores the self-driven proactive adaptation measures implemented by rural households to address locally experienced climate change impacts and mitigate potential threats. The study involved 124 household surveys and 9 FGDs from three CFUGs representing three ecological regions of Nepal- the Mountain, Mid-hills, and Low-land. The study employed eight criteria to recognize proactive adaptation, applying both qualitative and quantitative methods. Data analysis involved the Chi-Square (χ2) test to assess proactive measures' association with livelihood options, and an ordered logistic regression model to identify factors influencing the choice of proactive adaptations. Results revealed that 83.9% of households implemented both proactive and

[2] **Author Contributions:** Conceptualization: Kumar Bahadur Darjee (K.B.D.) and Prem Raj Neupane (P.R.N.); Formal analysis: K.B.D. and P.R.N.; Investigation: K.B.D.; Writing—original draft preparation: K.B.D.; Writing—review and editing: K.B.D., P.R.N. and Michael Köhl (M.K.). Supervision: P.R.N. and M.K. All authors have read and agreed to the published version of the manuscript.

reactive measures, while 10.5% relied solely on reactive adaptation and 5.6% chose exclusively on proactive measures. Households implemented over 50 different proactive adaptation activities, significantly linked to agricultural diversification, cash crop cultivation, livestock raising, small-scale enterprise development, and disaster control. Socio-economic and spatial factors such as household well-being, landholding size, geographical location, livelihood options, and the number of implemented adaptation activities were crucial in determining proactive adaptation choices. The study concludes that rural people in Nepal are aware of the escalating climate risks and actively utilize their knowledge to adapt. Even small proactive initiatives by households can yield multiple benefits in mitigating climate risks. Consequently, it is essential to adopt a transdisciplinary approach and foster local proactive actions that connect environmental, political, and societal aspects to ensure successful implementation of climate change policies and strategies. Besides, the findings offer valuable insights for policy and strategy planning to address the unintended consequences of climate change and emphasize the significance of considering the perspectives of local communities. This contributes to both the mitigation and adaptation goals of the Paris Agreement, which has been the centerpiece of global efforts to tackle climate change. Because the proactive actions the individuals and society take today are to address changing climate benefiting to achieve climate goals.

2.2. Discussion of the paper in the thematic context

This article refers to thematic context of this thesis concentrating to the proactive adaptation of local communities against climatic challenges. This article presents comprehensive empirical evidence of how the proactive measures of climate change adaptation markedly implemented at local surroundings by rural households of Nepal. The formulation of this research issue was strongly influenced the research gap raised by Darjee et al. (2022) as a first article in the same locations. Building upon their findings, this article aims to address the following questions in a comprehensive manner:

a) How are local people proactively engaged in adapting with locally experienced climate change impacts and unexpected climatic risks?
b) What are the determining factors associated with proactive adaptation measures initiated by local households?

The findings of this study aligns with protection motivation theory (Rogers, 1975; Rosenstock, 1974) and the process model of private proactive adaptation to climate change (Grothmann and Patt, 2005), suggesting that individuals engage in a process of proactive adaptation by perceiving climate threats, assessing their ability to adapt, making decisions to take adaptation actions, and implementing those actions. The findings indicate that households actively assess the severity of climate conditions and make adaptation choices based on their evaluation. A large proportion of households (77.42%) are motivated to take proactive steps to reduce potential risks associated with climate change. This motivation is driven by their precautionary cognition about the future impact of worsening climate conditions. These approaches are largely developed from empirical and analogical analyses of how individuals adjust to changed environments over time (Bryant et al., 2000; Burnham and Ma, 2017; Engler et al., 2021; Glantz, 1996; Regasa and Akirso, 2019; Robert et al., 2016; Smit et al., 1999; Tol et al., 1998; Villamor et al., 2023; Yohe and Dowlatabadi, 1999; Zobeidi et al., 2022), suggesting that perceived severity of climatic threats, self-efficacy, and adaptation efficacy significantly influence individuals' motivation to actively engage in climate change adaptation.

The analysis reveals that five out of the six clusters of adaptation activities, namely agricultural crop diversification, cash crop cultivation, livestock raising, small-scale enterprise improvement, and disaster control, were identified as proactive adaptation measures which includes 50 different activities. These activities aligned with one to four criteria of multiple forms of adaptive behavior observed in the studied households. These criteria involved taking actions prior to potential climate change impacts, investing for future benefits, scaling up adaptation options at the farm level, and perceptual risk assessments of future climate change impacts. The examples of proactive adaptation include plantation in risky zones, controlling grazing on riverbanks, raised foundation of houses/sheds, storing potato seeds underground, and promoting mud and wood-coated houses, diversifying agriculture involves switching to resilient crops, cultivating off-season crops and vegetables, and experimenting with different crop varieties. Proactive adaptation is widely recognized as an essential strategy for not only mitigating the cumulative effects of climate change but also reducing adaptation costs. A study by Melvin et al. (2017) on Alaska's public infrastructure shows that without adaptation, climate damage expenses would reach US$ 5.5 billion (RCP 8.5) and US$ 4.2 billion (RCP 4.5). However, with proactive adaptation, costs were reduced to US$ 2.9 billion (RCP 8.5) and US$ 2.3 billion (RCP 4.5).

Our findings align with research conducted in Chile (Engler et al., 2021) and Bangladesh's coastal region (Ashrafuzzaman, 2023). These studies highlight weather unpredictability, heat stress, water scarcity, and pest invasions as significant risks to agriculture. Farmers in these areas employ proactive measures such as diversifying crops, adjusting farming practices, and utilizing improved seeds. Similar proactive practices were observed in a study by Roche (2016) on livestock promotion. Various studies have illustrated analogous activities (e.g., Ashalatha et al., 2012; Ayanlade et al., 2017; Bui and Do, 2021; Charmakar, 2010; Darjee et al., 2022; Darjee et al., 2021; Devkota et al., 2017; Lebel et al., 2020; Paudel et al., 2020; Rai et al., 2022; Sujakhu et al., 2016; Tambo and Abdoulaye, 2013; Tesfaye and Nayak, 2022; Tiwari et al., 2010) when examining locally implemented adaptation activities. However, in certain cases, abandoning agricultural activities can have immediate consequences for locally intertwined self-employment (Agarwal and Agrawal, 2017; Engler et al., 2021; Zhan et al., 2012). In Mid-hills, a blacksmith is on the verge of leaving his traditional occupation due to reduced demand for agricultural equipment caused by decreased agricultural practices. The situation is also observed in the Low-land region. It suggests that developing and implementing context-specific adaptation strategies is essential to ensure the long-term sustainability of these systems.

Our study highlights that various socio-economic factors influence the adaptive capacity for the selection of proactive adaptation measures. Factors such as household well-being, available livelihood options, agricultural land size, geographical variations, and the number of implemented adaptation activities play a significant role in determining proactive adaptation choices. The determinants of adaptation analyzed in the earlier studies , for example, the studies of Kabir et al. (2021) in Bangladesh, Tun Oo et al. (2017) in Myanmar and Tambo and Abdoulaye (2013) in Nigeria also support our findings. Wealthier and households possessing larger agricultural landholdings are more likely to engage in proactive measures also tended to engage in a greater number of adaptation activities (Bui and Do, 2021; Darjee et al., 2022; Nhemachena and Hassan, 2007; Ojo and Baiyegunhi, 2020) by partitioning their farming land for multiple purposes. Altitudinal variation also influences adaptation strategies. Mid-hills displayed a greater inclination towards proactive adaptation. Numerous studies support the facts that higher altitudinal regions experience greater climate severity (e.g., Adler et al., 2019; Beniston, 2003; DoHM, 2017; Gerlitz et al., 2015; GoN, 2021; IPCC, 2018; Rangwala and Miller, 2012; Schild, 2008), thereby increasing the likelihood of households adopting proactive measures (Grothmann and Patt, 2005). Age and length of major occupation have no significant influence on proactive adaptation actions. Contrary to previous studies (e.g., Nhemachena and Hassan, 2007), our findings suggest that older age and farming experience do not necessarily drive the selection of proactive adaptation measures. Younger farmers with better education may be more open to adopting novel ideas (Ojo and Baiyegunhi, 2020; Tesema, 2006), while older and experienced farmers may be more hesitant to embrace new technologies (Acquah, 2011).

The major challenge for innovative farmers is market access and availability for their products. Limited markets dominated by outsiders and middlemen result in farmers struggling to obtain fair prices and facing price fluctuations for their perishable goods. The combination of climate change impacts and market constraints discourages farmers from continuing with their proactively adopted measures. Market constraints have been identified as a significant issue in various studies (e.g., Below et al., 2012; Deressa et al., 2011; Piya et al., 2013).

Local proactive actions not only address adaptation but also contribute to climate change mitigation. Examples include tree planting in high-risk areas, promoting windbreak trees, utilizing trees for seed protection, using solar energy, engaging in vegetable farming, and shifting to off-farm businesses. These measures effectively reduce GHG emissions while addressing climate change impacts. So, the study highlights the importance of a transdisciplinary approach that involves collaboration between disciplines and engages stakeholders in addressing climate change challenges. The findings emphasize the need for policymakers and climate scientists to embrace this approach in developing adaptation and mitigation strategies concurrently. Transdisciplinarity involves restructuring disciplinary knowledge through collaboration to address real-world issues (Mobjörk, 2010; Naveh, 2005). It adopts a systemic approach that engages with local concerns, incorporating scientists, non-academic participants, and the public (Attwater et al., 2005; Tress et al., 2006; Walter et al., 2007). By combining interdisciplinarity and participation, it fosters a collaborative and inclusive process (Tress et al., 2006) to enhance climate sustainability.

3. Darjee et al. (2021): Do National Policies Translate into Local Actions? Analyzing Coherence between Climate Change Adaptation Policies and Implications for Local Adaptation in Nepal

This article[3] was written by Kumar Bahadur Darjee, Ramesh Kumar Sunam, Michael Köhl and Prem Raj Neupane. The article has been published in the peer-reviewed journal "Sustainability" on 26 November 2021.

3.1. Summary of the paper (Darjee et al., 2021)

In light of the increasing concerns surrounding climate change and the need for effective policies and implementation strategies, this study aims to provide an advanced analysis of how climate change policies

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are reflected into the local context to address locally experienced climate change impacts and threats. The study examines key climate change policy documents in Nepal including Climate Change Policy 2019, NAPA, PAPA, and LAPA through a content review. Additionally, a field study was conducted in the Rajdevi CFUG, located in the Mid-hills of Nepal, which has developed and implemented a Community Level Adaptation Plan of Action (CAPA). The field study involved household interviews, FGDs, key informant interviews, expert interviews, and an in-depth analysis of CAPA implementation. The findings reveal that while the policies in Nepal are coherent in targeting highly affected areas and communities, there is a lack of clarity in identifying an appropriate planning and implementation unit. LAPA designates the local government as the implementing unit, whereas the NAPA emphasizes the role of local community groups. This discrepancy signifies a breach in the implementation provisions envisioned in the central framework, as the existing LAPA implementation does not align with intended community-level institutions. The CAPA developed by local communities successfully plans and implements adaptation measures related to thematic areas identified in the policy, such as agriculture and food security, forests and biodiversity, water resources and energy, climate-induced disasters, public health, and urban settlements and infrastructure. Despite the limited attention given to promoting food security in climate change policy, the community implemented various measures to increase food sufficiency through the CAPA implementation. However, the CAPA lacks institutionalization within government policies and the broader institutional framework as a local-level implementing unit. It highlights the ongoing challenge of establishing a consensus on the appropriate implementing unit in climate change policies. The findings recommend the identification of a suitable and widely accepted implementing unit for local/community-level climate change adaptation. The CAPA has been an example of assessing local climate change impacts, identifying locally suitable adaptation and mitigation measures, and implementing them based on local knowledge. Only by establishing an appropriate implementing unit can the policies gain broader acceptance and achieve the desirable outcomes outlined in the climate change policy and plan.

3.2. Discussion of the paper in the thematic context

This article is to discuss to thematic context of climate change policies and strategies and their implementation. Particularly exploring to coherence and contradictions between national, provincial, and local climate change policies of Nepal and their impact on the implementation of adaptation measures at local level focusing on major three following questions:

a) How coherent are the climate change policies: Climate Change Policy 2019, NAPA, PAPA, and LAPA?
b) To what extent are policy's provisions/prioritization reflected in the local adaptation plan, and how community's practices complement the climate change policies and strategies?
c) What are critical gaps between policies and the local adaptation actions enshrined in CAPA?

Climate Change Policy 2019 (GoN, 2019), NAPA (MoE, 2010), PAPA (MoITFE, 2019) and LAPA framework (MoE, 2011b) are the major policy instruments dealing with climate change adaptation issues in Nepal. These policies share the common goal of enhancing socio-economic prosperity and building a climate-resilient society at national, provincial, and local levels.

The implementation of climate change policies at the local level is exemplified by the case of CAPA implementation by Rajdevi CFUG located in the Mid-hills of Nepal. Participatory vulnerability assessment identified response options and implemented selected measures that aligned with the thematic areas of NAPA. The CFUG implemented adaptation measures related to water scarcity and climate-induced disasters, focusing on water-related issues and responses to disasters like landslides.

The CFUG also addressed social justice and equity through practices such as fair distribution of forest resources, interest-free loans to poor climate-vulnerable people, and leasing forest areas to the poor and vulnerable population. These practices were found to be already established and implemented as regular scheduled tasks under the CFUG forest operational plan before the development of CAPA. These practices are aligned with the goals of climate change policies and contribute to enhancing social equity and justice. While previous studies (e.g. Nightingale, 2014; Silwal et al., 2019) found that LAPA failed to address the social equity and justice issues of sustainability, the case of CFUG with CAPA implementation contradicts this reflection. The practices of the local community under CAPA align with the goals of climate change policies and contribute to enhancing social equity and justice. The effective implementation of CAPA by the local community emphasizes the significance of local groups and institutions in climate change impacts assessment, adaptation planning and implementation. These are regarded as an integral part of sustainable adaptation strategies (Eriksen and Brown, 2011). These findings are consistent with the practices observed in the local community of CFUG in rural Nepal (Paudel et al., 2013) and indigenous groups in the Philippines (Matias, 2015), where they have been shown to be effective in implementing adaptation activities.

A successful climate change policy necessitates the active involvement of the most affected local groups (Bunce et al., 2010; Darjee, 2008; Khadka et al., 2014). This is because the impacts of climate change are inherently context-specific and require interventions at the local level (Agrawal et al., 2009; Darjee and Ankomah, 2017; Darjee et al., 2023). Policy success, as highlighted by Gurung et al. (2008), relies on more than just physical participation; it requires aligning the perspectives of government officials with community views and needs, rather than contradicting them. Achieving successful implementation hinges on maintaining policy consistency and harmony across different levels of governing measures (Neupane et al., 2019; Neupane, 2015; Sunam et al., 2015).

While there is a growing recognition of the need and importance of involving local people, groups, and institutions in planning and implementing adaptation activities at the local level (Agrawal and Perrin, 2009; Agrawal et al., 2009; Amaru and Chhetri, 2013; Darjee et al., 2022; Rodima-Taylor et al., 2012), it is worth noting that local institutions have received limited attention concerning adaptation issues, policies, and strategies (Agrawal and Perrin, 2009). Our findings highlight considerable gaps in policy coherence and the localization of national policies. These gaps stem from an unclear institutional framework for implementation and coordination, as well as a limited information, knowledge, and capacity concerning climate change impacts and adaptation measures necessary for effective policy implementation. There is an ambiguous institutional framework for implementation and coordination, with no clear responsibility assigned to local level institutions and organizations for implementing adaptation interventions. While PAPA and LAPA emphasize local government institutions, NAPA focuses on existing community-level organization, however, it fails to integrate community-based adaptation plans and organizations into the local government's planning process. Ojha et al. (2016) also highlight the similar issues.

Insufficient information and knowledge on climate change impacts and adaptation hinder policy implementation. The NAPA's vulnerability assessment relied on expert judgment due to the absence of reliable location-specific meteorological data, making it challenging for policymakers to identify appropriate local adaptation measures and leading to subjective decision-making. Numerous studies (e.g., Adger et al., 2003; Ayers and Huq, 2009; Darjee et al., 2022; Gentle et al., 2014; Jamarkattel et al., 2019; Ribot, 2013; Smit et al., 2000) highlight the importance of considering local contexts in climate change impacts. Policy and strategy formation should prioritize location-specific climate impacts and local adaptation measures as the primary consideration. The role of climate science, analyzing climate change impacts and intervention of technologies for location specific adaptation measures have been key issues in the planning process (Silwal et al., 2019). There is a knowledge gap among different stakeholders, resulting in poor linkages between national plans and local needs. The shortage of qualified staff and the lack of expertise in addressing climate change as a cross-cutting issue (Bird, 2011; Wiggins, 2011). Dongol and Heinen (2012) further contribute to implementation challenges. Khatri et al. (2013) also showed that the local government in Nepal lacks capacity to make the best use of available climate change information and knowledge. McLaughlin (1987) identified capacity and will as key factors.

Lack of coordination between relevant institutions, especially at the province level, leads to duplication of activities and complicates implementation. Poor coordination at the district level between state and non-state organizations hinders program development for local communities.

Addressing these gaps requires clear and explicit institutional frameworks, improved coordination mechanisms, enhanced capacity building, and better utilization of available local knowledge and experiences.

Part III. Conclusions of the cumulative dissertation

1. Climate change insights from daily interactions and livelihood activities of locals complement scarce data on changing climate, providing nuanced local condition

Policy-makers and planners often prioritize the development of adaptation strategies without fully incorporating the options and measures based on ground-level experiences (IPCC, 2019). This is primarily due to a lack of understanding of and adequate information on local-level climate change, its specific impacts, and the perceptions of local communities. So, the findings from the first article of this thesis provide valuable insights into the knowledge held by local communities.

The local communities have noticeably observed and experienced climate change and it impacts in rural Nepal. These observations are closely tied to the impacts on their daily lives and sources of income. Notable changes include shifts in floral growing seasons, changes in faunal distribution, and impacts on crop yields and agricultural activities. A high majority of the local respondents attributed these phenomena to rising temperatures and changing precipitation patterns. The reduction in snow cover and glacier retreat are perceived by the locals as consequences of temperature rise. Additionally, changes in rainfall patterns, such as early onset and early cessation of the monsoon, altered concentration, and increased instances of intense rainfall, have led to a reduction in water sources affecting local livelihoods seriously, particularly needed in agriculture sector. These local perceptions align with meteorological analysis, which indicate significant temperature increase and precipitation decrease with escalating trends and variability differences across Mountain, Mid-hills, and Low-land regions. The local population keenly observed that even subtle alterations in climate variables leading to noticeable implications for human behavioral change by initiating some local-level actions against existential climate change as well as some proactive actions for expected change in the future. In conclusion, the local people and communities develop a profound awareness and comprehension of climate change scenarios, thereby influencing their responses to the repercussions of climate change. This valuable insight serves as a reliable input for the development of policies and strategies at the local level, as well as for regions that share similar geographical characteristics but lack comprehensive climatic measurements.

2. Proactive climate change adaptation by the local communities not only addresses the climatic issues at the local level but also contributes to achieving climate change adaptation goals at the national and international levels

The rural communities have implemented a range of adaptation measures to combat the impacts of climate change in their localities. Adaptations were observed to be associated with daily livelihood priorities, suggesting that adaptation is the most demanding priority. The proactive actions are in line with the criteria of proactive behavior, which involve taking preemptive steps to address potential climate change impacts, making investments for future benefits, scaling up adaptation options at the farm level, and assessing the risks of potential future climate change. It suggests that local people are not only reactive against changed scenarios but also sensible about future risks of climate change.

We discovered that household well-being, available livelihood options, agricultural land size, geographical variations, and the number of implemented adaptation activities by the households play a crucial role in choosing proactive measures. This implies that policymakers should focus on these decisive factors. Moreover, the results indicated that the identified adaptation activities not only contribute to climate change adaptation but also offer opportunities for livelihoods and serve as mitigation measures. This dual contribution of climate change adaptation measures suggests the need for transdisciplinary approaches to address climate-related challenges.

While the Paris Agreement emphasizes the importance of strengthening societal choices and socio-economic development to address climate issues (Rogelj et al., 2017), understanding the perceived climate risks and analyzing the effectiveness and compatibility of applied adaptation measures with local priorities are crucial for both the adaptation process and local development. This suggests that proactive actions taken by local communities can contribute to addressing the impacts, risks, and threats of potential climate change onslaughts, thereby benefiting the achievement of climate change adaptation goals.

3. Strengthening policy coherence to recognize local climate adaptation initiatives and localization of national policies enhance the effectiveness of climate change adaptations

The Climate Change Policy 2019, National Adaptation Program of Action, Provincial Adaptation Program of Action, and the framework for Local Adaptation Plan of Action serve as the major policy instruments that address climate change adaptation issues in the country. These policies are commonly aimed at both enhancing socio-economic prosperity and constructing a climate-resilient society across national, provincial, and local levels. The NAPA document specifically emphasizes the importance of integrating local adaptation priorities for the most vulnerable communities through community-based adaptation. It recognizes the significance of local community groups in implementation. Community Forest User Groups have already begun implementing adaptation-related actions through the regular implementation of the community forestry operational plan, benefiting from their prominent institutional setup for planning and implementation. As an example, CFUG already started practice of subsidies, free forest products, offer low-interest or interest-free loans during emergencies, and allocate forest land to economically disadvantaged groups for income-generating activities through developing equitable community rule and regulation.

Although Nepal's policies and practices show a commitment to involving local communities and groups in climate change adaptation, there are significant gaps in policy coherence and the localization of national policies. While the effective implementation of community-based adaptation plans by local communities highlights the importance of local groups and institutions in assessing climate change impacts and implementing adaptation strategies, there is still ambiguity in incorporating them into the local planning process. This lack of integration hinders the effective coordination and collaboration between community-level initiatives and local government efforts. Nevertheless, societies possess inherent capacities to adapt to the impacts of climate change and to mitigate anticipated climatic threats, even without explicit policy guidance.

4. Outlook

The Twenty-Fourth Conference of the Parties to the UNFCCC held in Katowice in 2018 emphasized the importance of a participatory approach in adaptation planning and implementation (UNFCCC-COP, 2018). This approach aims to leverage input from various stakeholders, including the private sector, civil society, indigenous peoples, local communities, migrants, children and youth, persons with disabilities, and those in vulnerable situations. By incorporating diverse perspectives and involving multiple stakeholders, the COP sought to foster effective political discourse and negotiations to address climate change challenges. In light of the COP's call for a participatory approach, this thesis emphasizes the significance of actions taken by local communities in the context of climate change adaptation and mitigation. It encourages the development of a comprehensive transdisciplinary approach to effectively address both climate change adaptation and mitigation. Through adopting such an approach, decision-makers and practitioners can enhance their capacity to tackle the complex challenges posed by climate change and strive towards a sustainable and resilient future.

Indigenous knowledge plays a crucial role in disaster preparedness and the implementation of disaster-related policies and plans (Hiwasaki et al., 2014). However, this thesis does not address this aspect, highlighting the need for further research. It is important to note that indigenous knowledge has been shown to surpass contemporary science and technology in specific situations due to its inherent local relevance (Zhang and Nakagawa, 2018).

In this thesis, the primary framework employed was the socio-cognitive model of proactive private adaptation to address the impacts of climate change (Grothmann and Patt, 2005). The focus was on exploring proactive adaptation measures adopted by local households. However, an important aspect that was not addressed in this thesis is the concept of "maladaptation," which encompasses both avoidance of beneficial adaptation measures and unintended adaptations that inadvertently exacerbate climate change damage. Therefore, further research is recommended to investigate this aspect in detail.

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Annex I: Scientific articles and personal contribution

1. Darjee, K.B., Neupane, P.R. and Köhl, M., 2022. Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries. Weather, Climate, and Society, 14(1): 205-222. https://doi.org/10.1175/WCAS-D-21-0081.1
2. Darjee, K.B., Neupane, P.R. and Köhl, M., 2023. Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts. Sustainability, 15(14): 10952. https://doi.org/10.3390/su151410952
3. Darjee, K.B., Sunam, R.K., Köhl, M. and Neupane, P.R., 2021. Do National Policies Translate into Local Actions? Analyzing Coherence between Climate Change Adaptation Policies and Implications for Local Adaptation in Nepal. Sustainability, 13(23): 13115. https://doi:10.3390/su132313115

Personal contribution:

The published scientific papers, along with the comprehensive summary, form a significant part of my cumulative dissertation, reflecting a substantial portion of my scientific research. These papers were carefully selected based on my high personal contribution, as evident from my lead-authorship for all the presented articles. This includes developing methodologies and statistical frameworks, writing, submitting, and overseeing the review process for each article. However, it is essential to acknowledge the valuable contributions of the co-authors of these articles, which shall not be questioned.

None of the scientific articles presented here have been or are currently part of another cumulative dissertation.

Annex II: Letter of contribution to the peer-reviewed articles in the cumulative dissertation

1. Darjee, K.B., Neupane, P.R. and Köhl, M., 2022. Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries. Weather, Climate, and Society, 14(1): 205-222. https://doi.org/10.1175/WCAS-D-21-0081.1

   The contributions of the authors to the first peer-reviewed article in the cumulative dissertation were as follows:

   Conceptualization, Methodology, Investigation/Data collection, Formal analysis, Writing—original draft preparation, Writing—review and editing: Kumar Bahadur Darjee (K.B.D.). Contribution to Conceptualization, Methodology, Formal analysis, Writing—review and editing: Prem Raj Neupane (P.R.N.) and Michael Köhl (M.K.). All authors have read and agreed to the published version of the manuscript.

2. Darjee, K.B., Neupane, P.R. and Köhl, M., 2023. Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts. Sustainability, 15(14): 10952. https://doi.org/10.3390/su151410952

   The contributions of the authors to the second peer-reviewed article in the cumulative dissertation were as follows:

   Conceptualization: Kumar Bahadur Darjee (K.B.D.) and Prem Raj Neupane (P.R.N.); Formal analysis: K.B.D. and P.R.N.; Investigation: K.B.D.; Writing—original draft preparation: K.B.D.; Writing—review and editing: K.B.D., P.R.N. and Michael Köhl (M.K.). Supervision: P.R.N. and M.K. All authors have read and agreed to the published version of the manuscript.

3. Darjee, K.B., Sunam, R.K., Köhl, M. and Neupane, P.R., 2021. Do National Policies Translate into Local Actions? Analyzing Coherence between Climate Change Adaptation Policies and Implications for Local Adaptation in Nepal. Sustainability, 13(23): 13115. https://doi:10.3390/su132313115

   The contributions of the authors to the third peer-reviewed article in the cumulative dissertation were as follows:

   Conceptualization: Kumar Bahadur Darjee (K.B.D.) and Prem Raj Neupane (P.R.N.); Formal analysis: K.B.D., P.R.N. and Ramesh Kumar Sunam (R.K.S.); Investigation: K.B.D.; Writing—original draft preparation: K.B.D.; Writing—review and editing: K.B.D., P.R.N., R.K.S. and Michael Köhl (M.K.). Supervision: P.R.N., and M.K. All authors have read and agreed to the published version of the manuscript.

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Supervisor: Prof. Dr. Michael Köhl

Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries

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ABSTRACT: This study explored people's perceptions of climate change by conducting interviews and focus-group discussions with local residents of three ecological regions of Nepal, i.e., mountain, midhills, and lowland. Climatic measurements from meteorological stations of the regions were acquired for the period from 1988 to 2018. We compared the people's perception with trends and variabilities of observed temperature and rainfall patterns. The results showed that, over the last three decades, temperature and precipitation trends and variability between regions varied, largely corroborating the local experiences. The temperature increased in mountain, midhills, and lowland by 0.061°, 0.063°, and 0.017°C yr^{-1}, respectively. In contrast, rainfall decreased by −9.7, −3.6, and −0.04 mm yr^{-1} for the regions, respectively. Although the amount of rainfall decrease observed in the mountain was highest, its variability was found to be relatively low, and vice versa in lowland. Approximately 88% of interviewees perceived temperature rise, and 74% noticed rainfall decline. Local residents linked these changes with their livelihood activities, as exemplified by, for example, crop's quality and quantity and birds' migration. The results indicate that local understandings complement the scarce observational data and provide a reliable and additional foundation to determine changes in climatic variables. Moreover, the result infers that small changes in climate variables have noticeable implications on human behavior change. Therefore, besides active participation of local communities, integrating local understanding is crucial in developing climate change–related policies and strategies at local and national levels.

KEYWORDS: Climate change; Climate variability; Temperature; Precipitation; Trends

1. Introduction

Climate is one of the crucial components in the interaction of physical, chemical, and biological processes of the Earth system. Climate change refers to changes in climatological conditions of the Earth system over decadal and longer periods (IPCC 2021; Travis et al. 2018). It includes attributes such as temperature, precipitation, humidity, and atmospheric pressure, which are described in terms of means and variability over a period ranging from months to thousands or millions of years (IPCC 2021). The impacts of climate change are widespread and are becoming alarming. In many parts of the world, wide-ranging impacts of climate change have already been experienced, particularly extreme weather events such as flash flooding, landslides, devastating forest fires, and droughts (Chao and Feng 2018; Jolly et al. 2015). As suggested by Stern et al. (2006), climate change has large consequences in environmental and socioeconomic activity threatening the basic elements of people's lives around the world including access to water, food production, health, and use of land.

IPCC's atmosphere–ocean general circulation models conclude that by the end of this century climate change drives both increase in the mean temperature and changes in precipitation, and it is anticipated to occur erratically in space and time (Collins et al. 2013). This change mostly affects some specific and critical regions (Beniston 2006). For example, the mountain and adjacent areas are expected to experience a relatively larger temperature increase and precipitation fluctuations (Giorgi and Lionello 2008). The impacts of extreme climate events hit the poorest countries hardest as their scale of exposing to uncertain loss and damage is high with limited coping capacity (Eckstein et al. 2019). Nepal is one of the countries that will be mostly affected by climate change. The risk of flash flooding, erosion, and landslides with an increasing intensity in monsoon will be increased exacerbating the vulnerability of Nepal (Piya et al. 2012). The global climate risk index 2020 has identified Nepal as one of the most affected countries, ranking within the top 10 (Eckstein et al. 2021). Nepal's geology and ecological fragility, coupled with poor socioeconomic condition, predominantly natural resource–based livelihoods, and low level of adaptive capacity due to higher incidence of poverty have made it one of the most vulnerable countries to climate change (Alam and Regmi 2004; Chaudhary and Aryal 2009; Gum et al. 2009). This complex phenomenon shaped by interactions between economic, social, cultural, and political dynamics will tend to accelerate vulnerability (Sapkota et al. 2016).

An increasing number of hazards and their exacerbating dynamics have been found by climate scientists and experts as

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they develop climate change models and assess impacts of climate change (Michel 2017). The models could offer mounting information for the future scenarios of climate change and possible impacts but are limited in providing conclusive information for improving climate risk management at the local level (Manandhar et al. 2015). Every hazardous event tends to have a unique attribute (Barring and Persson 2006) caused by change in climatic attributes (e.g., temperature and precipitation), and local people have rich experiences in this regard. The understanding and knowledge of local people provide not only multiple solutions to minimize environmental risk in favor of nature and society (Blaikie and Muldavin 2004; Ives and Messerli 2003) but also could be advantageous to develop community-friendly adaptation and mitigation strategies and measures against climate change impacts (Paudel et al. 2020; Pröbstl-Haider et al. 2016). As suggested by Alexander et al. (2011), where there is lack of climate records or limited meteorological climate data, local understandings provide a strong foundation to determine changes in climate variables and trends.

Some studies do not allow one to draw comprehensive conclusions about the interactions between climate change and local perceptions because they are limited by, for example, relatively short records of climate attributes (e.g., Adhikari et al. 2019; Karki et al. 2017; Shrestha and Aryal 2011), by analyzing either scientific data or documenting local perceptions, or by failing to compare and connect the effect of regional and topographical differences in observational data with the perception of local communities. At the same time, active participation of affected communities has been crucial in developing climate change policies and strategies at national or international levels. Besides, participation of the local community in implementing policies are thought to be indispensable as they struggle with climate issues in many ways ever since they started experiencing climate-induced problems. Studies have shown that local people use their adaptation measures against climate change impacts based on their individual perception of climate change (Abid et al. 2015; Ayanlade et al. 2017; Li et al. 2013). Hu et al. (2020) suggest that the links between the meteorological observations and local knowledge need to be explored more deeply. The combination of perception of local communities and meteorological observations provide a new way to study climate and ecological changes (Hu et al. 2020). Such studies are crucial but are absent in Nepal. Differentiated climatic risk as with varied geographical locations pose anomalous risk and threats to local populations (Walther et al. 2002), particularly for those who have been entangled with rainfed agriculture and natural resource-based subsistence (Ashalatha et al. 2012; Ghimire et al. 2010; Merrey et al. 2018; Vermeulen et al. 2012). People are not only good natural observers, but they also perceive local environmental changes critically and respond (Becken et al. 2013; Salick et al. 2009). It suggests that individuals who have been living in the rural areas all of their lives might have strong experience on changes in climatic pattern. However, this knowledge has been barely articulated in policy development in the country.

Since 2015, Nepal is in the process of the developing the National Adaptation Plan (NAP) building on the lessons from implementation of the National Adaptation Program of Action (NAPA). For the NAP, Nepal's scenarios project that annual precipitation is likely to increase by 2%–6% for a medium-term scenario and by 8%–12% for a long-term scenario, and average annual mean temperature could increase by 0.9°–1.1°C and 1.3°–1.8°C, respectively [Ministry of Forests and Environment (MoFE); MoFE 2019]. The projections are based on the models for future scenarios. It needs the consideration of diverse ecological features of Nepal coupled with local people's perception as Nepal consists of varied ecological zones—mountain, midhills, and lowland (flat terrain—*Terai*)—with differentiated climate change impacts.

Geography-specific climate change indicators, and the complexity of socioeconomic and cultural factors coupled with local environmental circumstances determine the adaptive capacity of vulnerable people for unpredictable climate (Adger et al. 2013; Onta and Resurreccion 2011; Piya et al. 2019). Therefore, the overarching rhetorical policy and blanket approach will likely overlook local realities. Eriksen et al. (2015) revealed that local communities, particularly climate-vulnerable communities, have been presented as "recipients of adaptation" rather than being considered as an "active and vibrant agent" in climate change impact analysis and planning for adaptation and mitigation. The recent tendency shows that policy-makers and climate researchers are increasingly concentrating toward formulating adaptation strategies without concretizing options/measures associated with ground-level experiences (IPCC 2019). There is knowledge deficit of examining local-level climate change data, their corresponding impacts, and local people's perception on it. Local people often live close to the nature having an intuitive understanding of the atmosphere over long periods of time (Laidler 2006) ever since they started to feel and distinguish environmental changes. They develop their perceptions on climate change from consistent and persistent interactions with surroundings including daily weather conditions. Therefore, communicating the analytical results of the meteorological historic climate data and systematic interpretation of local understandings adequately informs policy-makers and program developers to design pertinent proactive intervention against climate threats and risks. This paper, therefore, aims to (i) understand local resident's perceptions of changing temperature and precipitation and (ii) compare the perceptions with the local meteorological records.

2. Materials and methods

a. Study areas

We conducted this study in Taplejung, Gorkha, and Kailali districts of Nepal located in high-mountain, midhills, and lowland (Terai) ecoregions, respectively (Fig. 1). The study acquired the time series historical temperature and precipitation data measured in three meteorological stations located in the districts. From each district, two community forestry user groups (CFUGs) located in the vicinity to the meteorological

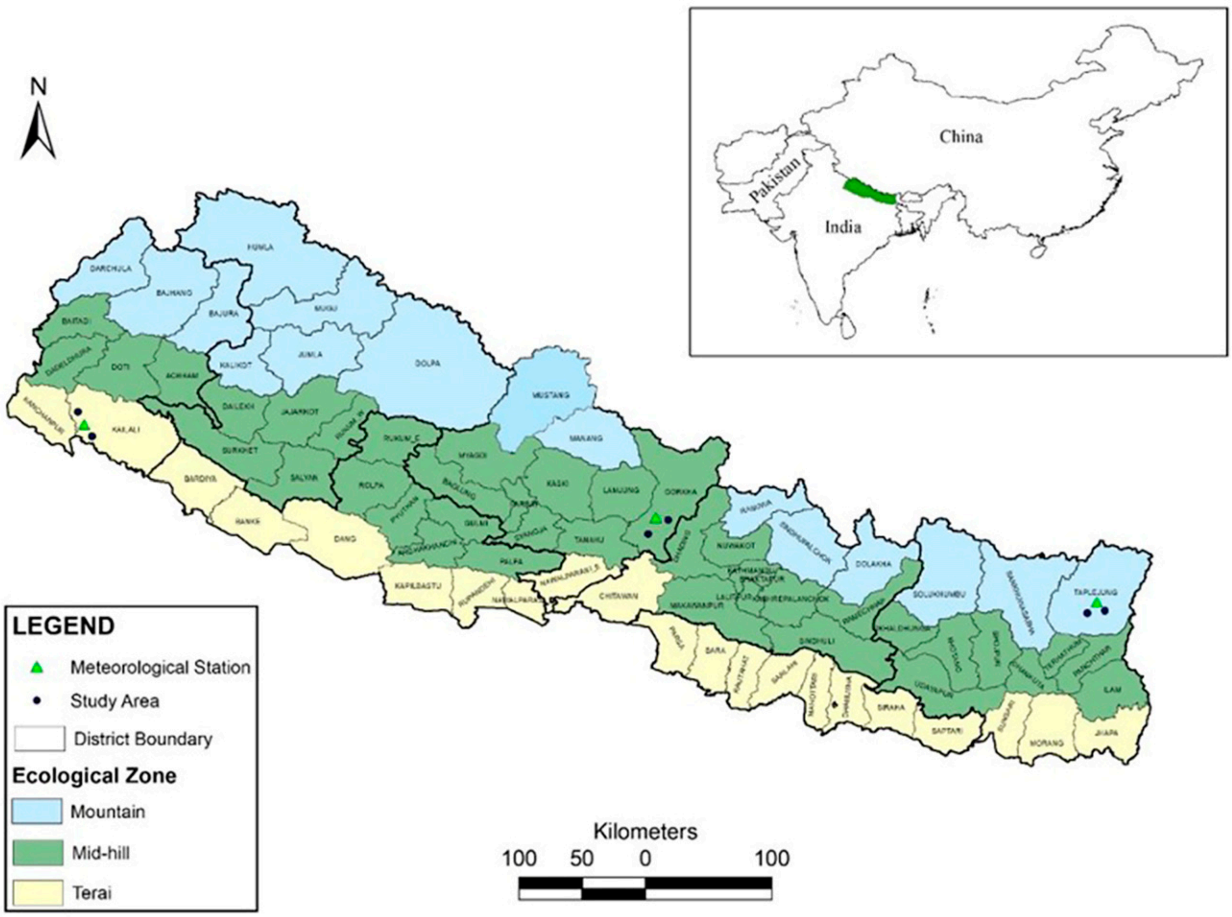


FIG. 1. Map of Nepal showing three ecological zones and the study sites of Nepal. Taplejung district is located in the northeast of Nepal in the high-mountain zone, Gorkha district is located in central Nepal in the middle-mountain zone, and Kailali district is located in the southwestern part of the lowland Terai zone.

stations were studied to understand the local perceptions toward climate change.

Nepal's remoteness, difficult terrain, fragile and young mountain geology, and highly diverse landscape poses different levels of locations and context specific climate change impacts. Such a considerable physiographic heterogeneity caused variations in demography including population density. People experience distinct climatic stimuli in different ecological zones with differing geography. Lowland is densely populated region, which includes southern plains and the foothills of the Siwalik (a mountain range of the outer Himalayas), with a tropical to subtropical climate. In the region, climate risk and disaster are mainly associated with flooding and inundation, hot waves in summer, and cold waves in winter. Midhills have warm to cool temperate monsoons. In this region people suffer higher risk of landslides and erosions due to coupled effects of erratic and intensive rainfall and young mountain geology. Prolonged droughts are also common in the region. The mountain possesses a cool temperate, alpine, and tundra type of climate. The people living in this zone face permafrost thaw, glaciers, and threats of bursting of glacial lakes that are associated with climate change.

b. *Data, data source, and data collection*

Observational data (1988–2018) of the three meteorological stations were obtained from the Department of Hydrology and Meteorology (DoHM), Nepal. Data included daily minimum (min) and maximum (max) temperature and daily average rainfall. Data missing for a couple of years were estimated by using multiple imputation by chained equations (MICE) (Royston and White 2011).

The study conducted social surveys from December 2019 to March 2020 to understand perceptions and experiences of local communities concerning physical and temporal changes in climatic variables, that is, temperature and rainfall in the study areas. Six CFUGs, two from each ecological region, of mixed populations with varied socioeconomic wellbeing were selected. From the CFUGs, 327 households (Table 1) were interviewed using semistructured questionnaires. In addition,

TABLE 1. Community forestry user groups (CFUGs), total CFUG member households, and number of interviewed households.

Name of CFUG	District	CAPA	Total households (HH)	No. of interviewed HH
Kalipokhari–Sidingba 7	Taplejung	Yes	99	51
Sinkechu–Pathibhara Yangbarak 2	Taplejung	No	53	35
Birenchok–Gorkha Municipality 9	Gorkha	Yes	200	67
Dhandswara Kapre–Barpak Sulikot 7	Gorkha	No	114	55
Chetana Mahila–Attariya Municipality 1	Kailali	Yes	73	42
Taranagar–Dhangadi Submetropolitan City 5	Kailali	No	338	77
Total			877	327

16 focus-group discussions (FGDs) (4 women groups, 3 indigenous peoples' groups, 3 poor and vulnerable peoples' groups, and 6 mixed groups) were conducted using FGD checklists related to perception of temperature and precipitation change and their experiential impacts.

The study used Yamane's equation (Yamane 1967) to determine the number of households for an interview. This equation calculates the total number of samples to be interviewed with error of tolerance. The interviewed households were chosen randomly and the respondents ≥40 years of age were interviewed to ensure reliable and comparative understanding of climate change over the past three decades. However, few informants below age of 40 years were also considered to triangulate the information about present scenarios.

Three native forestry experts conducted the interviews. The respondents were asked whether they have observed changes in the temperature and rainfall over the last 30 years and were requested to provide comments and insights how they perceive the changes and relate the changes with their livelihood activities. FGDs were conducted to triangulate the information obtained from the interviews. Diverse groups (women, indigenous communities, and poor and climate-vulnerable people) were considered so as to represent local understandings of the different sectors of the society.

c. *Data analysis*

Rainfall and temperature generally are subject to trend and variability analysis. Data distributions were tested by using Shapiro–Wilks test for normality (Öztuna et al. 2006). Since most of the data were not found normally distributed, trend detection and analysis were performed through nonparametric test. The Mann–Kendall (MK) test was used to detect monotonic (upward or downward) trends in the time series climate data and the statistical significance. This test has been widely used in many different similar studies (e.g., Asfaw et al. 2018; Dahal et al. 2019; Mohsin and Lone 2020; Panda and Sahu 2019; Seleshi and Zanke 2004; Tabari et al. 2015). The MK test does not compulsorily require normal distribution of data and is less sensitive to outliers when compared with another nonparametric tests (Dahal et al. 2019; Yue et al. 2002). The MK test statistic "S" is computed as explained by Mann (1945), Kendall (1948), and Yue et al. (2002). The MK trend test verifies whether the data series show any significance trend at a given significance level, but it cannot determine the magnitude of trends. Therefore, we used Sen's slope estimator (Sen 1968; Theil 1950) for computing the linear rate of change.

The coefficient of variation (CV) was used in evaluating the variability of rainfall. The CV classifies the degree of variability based on rainfall events as less variability ($CV < 20$), moderate variability ($20 < CV < 30$) and high variability ($CV > 30$) (Hare 2003).

Rainfall anomaly index (RAI) analysis was used for the analyses of annual and monthly rainfall variability (e.g., Costa and Rodrigues 2017; Raziei 2021; Sadiq et al. 2020). RAI is the actual rainfall for growing season and months developed by van Rooy (1965) from daily rainfall data. It has both positive and negative magnitudes of precipitation anomalies that can be used to analyze frequencies and intensity of the dry and rainy periods. It is calculated using the following equations:

$$\mathrm{RAI} = 3\left(\frac{\mathrm{Rc} - \mathrm{Rm}}{\mathrm{Mh10} - \mathrm{Rm}}\right) \text{ for positive anomalies} \quad (1)$$

and

$$\mathrm{RAI} = -3\left(\frac{\mathrm{Rc} - \mathrm{Rm}}{\mathrm{Ml10} - \mathrm{Rm}}\right) \text{ for negative anomalies,} \quad (2)$$

where RAI is rainfall anomaly index, Rc is the rainfall for the current year, Rm is the average actual rainfall for the total of the period, Mh10 is the average of the 10 highest values of rainfall of the period, and Ml10 is the average of the 10 lowest values of rainfall of the period.

The precipitation concentration index (PCI) identifies the temporal precipitation distribution annually and seasonally. PCI is calculated as

$$\mathrm{PCIannual} = \frac{\sum_{i=1}^{12} \mathrm{Pi}^2}{\left(\sum_{i=1}^{12} \mathrm{Pi}\right)^2} \times 100 \,. \quad (3)$$

In the equation, Pi indicates the rainfall amount of the *i*th month. PCI value tells about the precipitation concentration. According to Oliver (1980), $\mathrm{PCI} \le 10$ indicates uniform precipitation distribution (low precipitation concentration), $10 < \mathrm{PCI} \le 15$ indicates moderate precipitation distribution, $15 < \mathrm{PCI} \le 20$ indicates high precipitation distribution, and $\mathrm{PCI} > 20$ indicates very high precipitation distribution.

The qualitative categorical data collected from the household interviews and FGDs on local people's perceptions of climate change were analyzed using chi-square test and descriptive statistics. The local understanding of climate

TABLE 2. Key characteristics of household's interviewees.

Region	Total households	Household for interview	Proportion of total households	Sex		Education status				Age category (yr)		
				Male	Female	University level	School level	Literate	Illiterate	>50	40–49	<40
Mountain	152	86	0.57	53	33	9	39	15	23	50	26	10
Midhills	314	122	0.39	85	37	7	51	25	39	78	42	2
Lowland	411	119	0.29	73	46	15	51	40	13	32	55	32
Total	877	327	0.37	211	116	31	141	80	75	160	123	44

change was analyzed using chi-square goodness of fit test and summarized by using mean, frequencies and percentage. The local perceptions were compared with results of MK test and Sen's slope estimates for temperature and rainfall analysis, RAI with 5-yr moving average, CV, and PCI. The data were analyzed using RStudio (R, version 3.6.1) and Microsoft Excel.

3. Results

a. Key characteristics of household's interviewees

We interviewed 327 households, representing 37% of households in studied communities across three ecological regions of Nepal (Table 2). The table describes major demography of interviewed households, highlighting sex, educational status, and age category. These aspects add important value in the representation of qualitative information about perceptions of climate change impacts in our study sites. All of the households interviewed were involved in agriculture for their livelihoods directly and indirectly. In some of the cases women are actively and compellingly engaged, for example, fetching drinking water and collecting forest products from the forests comes under the responsibility of women in the context of rural Nepal. So, of the 327 households, we selected 116 women instead of men for households' interviews.

The study covers educated, literate (can read and write, having little or no formal school education but may have nonformal education; e.g., adult literacy classes), and illiterate (cannot read and write) respondents. The inclusion of interviewees with a wide range of educational background helped to acquire a comparatively explicit explanation of perception of climate change impacts from educated people (university and school level) and indicative understanding from literate and illiterate respondents linking to experienced issues or events through which they have gone. A majority of the respondents were from a group of school-level education, followed by a literate group. Substantial numbers of the household's respondents were from the age group of more than 50 years, followed by a group between 40 to 50 years of age. The responses of those groups were considered to be closer to actual perceptions of climate change impacts between now and 30 years ago. Forty-four individuals were from the age group below 40, and their responses concentrated particularly to recent changes of climate and its impacts. The diverse inclusion of household respondents in terms of sex, education level, and age suggest that the qualitative responses are representative, ensuring a higher level of confidence.

b. Variability and time series trend analysis of observed temperature

The analysis of 31 years of annual, seasonal, and monthly data from the meteorological stations provides evidence of changes in climatic variables in the study areas. The Shapiro–Wilks normality test showed that the change of temperature patterns for all of the studied sites is within the normal distribution range at a significance level of 5%. The mean average

TABLE 3. Analysis of changes in temperature-related attributes for different geographic regions.

Indicator	Mountain (Taplejung)	Midhills (Gorkha)	Lowland (Kailali)
Avg annual mean temperature	16.67°C	21.66°C	24.12°C
Avg annual min temperature	12°C	16.24°C	18.61°C
Avg annual max temperature	21.34°C	27.07°C	30.77°C
The hottest year and temperature	2016 (18.08°C)	2016 (23.15°C)	2002 (24.83°C)
The coldest year and temperature	1997 (15.46°C)	2004 (18.99°C)	1997 (23.21°C)

temperatures, the hottest year, and the coldest year are depicted in Table 3.

The analysis of annual, seasonal, and monthly mean temperature for the period from 1988–2018 showed an increasing trend for all of the three study areas. However, the magnitude of the trends across the study areas differs (Table S1 in the online supplemental material). Linear regression analysis shows that the average rate of warming is 0.061°C yr^{-1} ($p \leq 0.0001$) for Taplejung, 0.063°C yr^{-1} ($p \leq 0.0001$) for Grokha, and 0.017°C yr^{-1} ($p \leq 0.0173$) for Kailali (Fig. 2). This shows that the mountain and the midhills of Nepal warmed up at an almost equal rate.

The monthly changes are significantly positive for all months in Taplejung. In Gorkha, two-thirds of the months show significant positive changes. In the case of Kailali, however, only one-fourth of the months depict significant positive trends. It suggests that the mountain region (Taplejung) experienced significant temperature increase throughout the year followed by midhills (Gorkha). In lowland (Kailali), the situation is more likely to reverse where three-quarters of months showed no temperature increase. The seasonal temperature changes shows that the highest rate of temperature increase in winter season in mountain region, in summer season in midhills, and in spring season in lowland (Table 4).

c. *Variability and time series trend analysis of observed precipitation*

For the same period, the average annual precipitation varies considerably across the three ecological regions. Mean annual rainfall was found to be highest in Gorkha with 3289.5 ± 719.5 mm. For Taplejung and Kailali districts, it was 1971.3 ± 291.6 mm and 1878.7 ± 422 mm, respectively. Although all of the study sites witnessed no outrightly significant trend, some noticeable changes explain a rainfall decline as highest in Taplejung (−9.7 mm yr^{-1}) followed by Gorkha (−3.6 mm yr^{-1}) and Kailali (−0.04 mm yr^{-1}). However, variability remains different between regions. Taplejung faced lower annual rainfall variability (CV 14.79%) relative to Gorkha and Kailali where rainfall patterns looked moderately variable (CV 21.87% and 22.47%, respectively). Almost all of the months were found to have CV values more than 30 for Gorkha and Kailali, which showed high rainfall variability. Kailali exhibited CV with more than 100% for majority of the months, and thus can be categorized as a district having highest irregular rainfall pattern between the study sites. There are no significant monthly trends observed except January and February in Taplejung and December in Gorkha. The seasonal analysis shows that the winter season suffered significant rainfall decrease in Taplejung. The details are provided in Table S2 in the online supplemental material.

The summer is the main rainy season of all of the districts. This season contributed 56.57% of rainfall for Taplejung, 60.81% for Gorkha, and 69.57% for Kailali. Although the seasonal rainfall changes do not show significant trends, the absolute numbers of fluctuating rainfall amounts differ between regions. Summer season shows a decline of 4.64 mm per summer per year in Taplejung, 2.71 mm per summer per year in Kailali, and 1.14 mm per summer per year in Gorkha. Other seasons also demonstrate variations between them (Table 5).

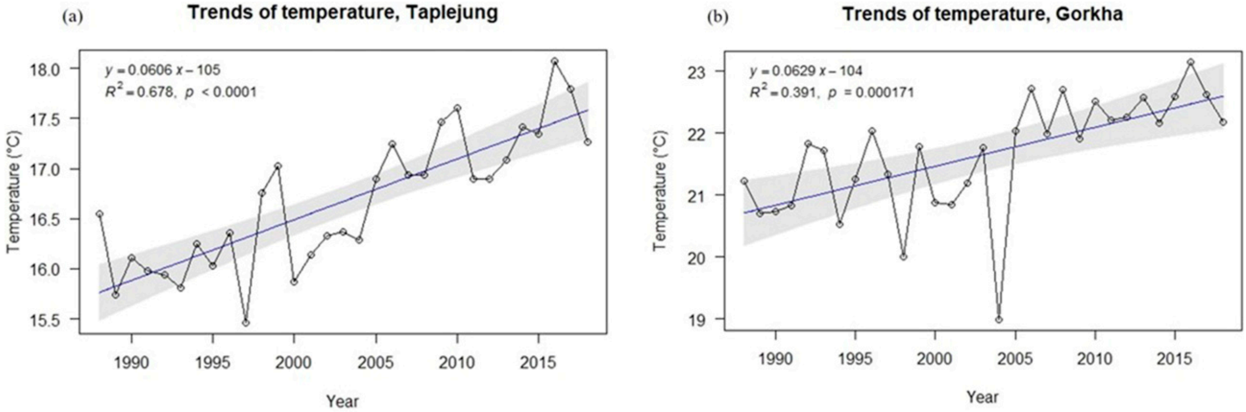
Analysis obtained from the PCI test revealed a diverse concentration of monthly distribution of rainfall amount throughout the years (Table 6). In Kailali, most of the years (29 years of the total 31 years) showed a very high monthly precipitation concentration ($PCI > 20$) and 2 years exhibited high monthly precipitation distribution ($15 < PCI \leq 20$). In the case of Gorkha, 10 different years exhibited very high ($PCI > 20$) and majority of the years (21) hold high monthly precipitation concentration. In Taplejung none of the year showed very high concentration but most of the years (26 years of the total 31 years) showed high precipitation concentration and moderate monthly precipitation distribution for 5 different years.

The RAI with 5-yr moving average (Fig. 3) trends was inconsistent throughout the study periods for all the sites. This result indicates a high incessant variability of annual rainfall for the period. All of the study sites revealed annual rainfall below normal just more than half of the years. RAI outcome explained that Kailali experienced the pronounced downfall of annual rainfall below normal for 20 different years, whereas Taplejung and Gorkha experienced the downfall for 14 different years of the total period of 1988–2018.

The variability and concentrations observed between the regions are dissimilar (Fig. 4). The lowland experiences more irregularity showing high internal variability and concentration. Midhills reveals less, and it is least in the mountain region.

d. *Local perception of climate change*

Local residents who participated in the interviews and FGDs observed noticeable changes in the climate over the period. They were found to be sensitive to changes in temperature associated weather events. Table 7 presents the summary of the perception and experiences of the local residents. The chi-square goodness of fit test showed that the local understanding on temperature fluctuation demonstrate a strong association between people's responses and geographical locations ($\chi^2 = 20.891$,



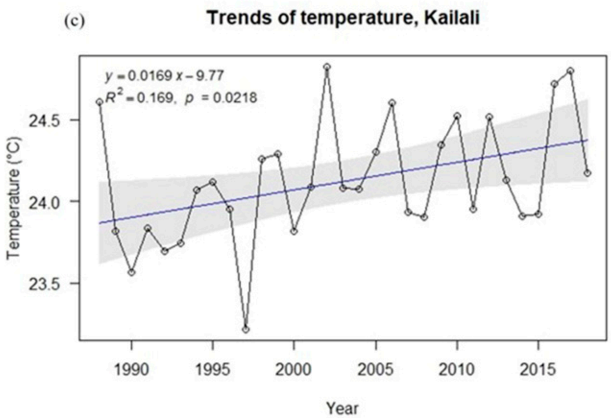


FIG. 2. Annual temperature patterns of the study sites (1988–2018): (a) Taplejung (northeastern part of the high-mountain zone), (b) Gorkha (central part of the middle-mountain zone), and (c) Kailali (southwestern part of the lowland Terai zone).

degrees of freedom df = 6, and p = 0.0019). On average, approximately 88% of interviewees have perceived that the temperature has increased during recent years. More than 90% of the locals experienced upward temperature rise in Taplejung and Gorkha. It was observed by 81% of locals in Kailali. Ten percent of residents of Kailali responded that they have no idea about temperature fluctuations. This portion is more than double when compared with the other two study sites (Fig. 5).

The residents of Taplejung observed that the rate of snow melting is increasing. They suggested that most of the mountain peaks used to be covered in snow in the winter season in the past decades. In recent years, they witnessed that most of the peaks in the vicinity of their communities lost their entire snow cover and were hardly covered in snow even in the winter season. For the past couple of years, the residents felt unusually warmer in December and January than usual. They expressed that the winter snowmelt is associated with the increasing temperature.

Local residents noticed that increasing temperature has been impacting the distribution of wild animals and birds in the study areas. Locals of the mountain region (Taplejung) observed that the population of two birds, namely, Himalayan bulbul (*Pycnonotus leucogenys*) and house sparrow (*Passer domesticus*), has increased in recent years and showed massive invasion to agriculture crops such as barley (*Hordium vulgare*), mustard (*Brassica juncea*), and wheat (*Triticum aestivum*). Because of the severe crop damage resulting from the population explosion of the birds, many farmers abandoned cultivating these crops. In contrast, residents of midhills (Gorkha) noticed that the population of these birds has declined during the past 5–7 years in their vicinities. Many of the locals from both regions claimed that the migration of the birds toward the higher altitude is due the rising temperature in the regions.

People have experienced shifting in the crop maturity time and reduction in crop yield associated with both decrease and increase of temperature. A majority of the interviewees pointed out that the temperature has decreased in the winter season with intense cold waves that resulted in degrading potato quantity and quality. Furthermore, the local residents observed an early shifting of ripening time for a few crops. The most noticeable effect is found in rice (*Oryza sativa*). In recent years, it gets ready for harvesting in around the last week of September instead of early November in the past. Wheat (*Triticum aestivum*) is harvested between the last week of March and first week of April, that is, approximately 3 weeks earlier than in the past. Similarly, in recent years, maize (*Zea mays*) ripens early in July that used to harvest in August in the past 25–30 years. The local people claimed that the shifting of such a crop maturity time is due to temperature increase in the regions.

TABLE 4. Seasonal variations in temperature in the study areas. The table presents Mann–Kendall (MK) and Sen's slope test results of the temperature. Boldface values indicate statistical significance at the 5% level.

		Temperature max			Temperature min			Temperature mean		
Season	Mean	MK *Z* value	*P* value	Slope	MK *Z* value	*P* value	Slope	MK *Z* value	*P* value	Slope
Taplejung										
Spring	17.20	4.011	**0.0001**	0.073	2.312	**0.0208**	0.027	3.841	**0.0001**	0.042
Summer	21.51	5.677	**0.0000**	0.073	3.603	**0.0003**	0.033	5.201	**0.0000**	0.052
Autumn	17.40	4.997	**0.0000**	0.078	3.093	**0.0020**	0.037	4.351	**0.0000**	0.055
Winter	10.57	4.895	**0.0000**	0.115	2.889	**0.0039**	0.050	4.487	**0.0000**	0.077
Gorkha										
Spring	23.01	3.671	**0.0002**	0.144	2.006	**0.0449**	0.039	3.501	**0.0005**	0.087
Summer	26.17	4.249	**0.0000**	0.076	4.045	**0.0001**	0.103	4.385	**0.0000**	0.088
Autumn	22.08	3.331	**0.0009**	0.082	2.482	**0.0131**	0.040	2.958	**0.0031**	0.065
Winter	15.35	2.787	**0.0053**	0.072	−1.53	0.1261	−0.037	0.646	0.5184	0.018
Kailali										
Spring	26.35	1.122	0.2620	0.021	3.025	**0.0025**	0.047	2.380	**0.0173**	0.034
Summer	29.69	0.442	0.6586	0.008	−1.734	0.0830	−0.019	−0.340	0.7339	−0.004
Autumn	24.69	1.836	0.0664	0.023	1.326	0.1849	0.017	2.006	**0.0449**	0.019
Winter	15.74	0.68	0.4966	0.018	2.244	**0.0249**	0.038	2.142	**0.0322**	0.026

The interviewees experienced that the occurrence of rainfall has become very unpredictable. People observed both increasing and decreasing patterns, particularly annually and seasonally. An analysis of local understanding showed a decreasing rainfall quantity over the recent years for all of the three sites; however, the proportion of respondents' responses are varied. On average, 74% of those locals experienced decreasing trend of rainfall, relatively higher (87%) in Taplejung and lower in Kailali (63%); however, 27% of the local residents observed increase of rainfall in Kailali and in Gorkha. Less than 10% of the residents experienced increased rainfall in Taplejung (Fig. 6). However, a few residents experienced stable rainfall pattern and some of them expressed that they have no idea about changes in the pattern.

The variations of local perceptions on rainfall pattern between study sites exhibited a strong relationship with locations ($\chi^2 = 40.552$, df = 6, and $p \leq 0001$). This suggests that variation of proportion of understanding has been affected by the geographical locations.

Mountain dwellers noticed that amount of rainfall has drastically reduced during spring and summer seasons and decrease in the number of rainy days. They pointed out that water sources are being depleted rapidly. Local people experienced that monsoon starts during July and August in the recent years are delayed by almost 2–2.5 months relative to the past decades. They noted that the number of rainy days has decreased considerably and that the number of dry days increased. This phenomenon has caused the introduction of unexpected threats such as excessive short rain, drought, and hailfall increase, along with a snowfall decrease during the winter period over the last few years.

In the midhills (Gorkha), residents reported that most of the water sources for drinking and irrigation have dried up during the last couple of years. The number of rainy days is decreased. Both excessive rainfall with higher intensity of hailfall and prolonged drought posed serious threats to rain fed agriculture. For example, the majority of the local farmers have abandoned cultivating local varieties of rice due to low and highly erratic monsoon rainfall, and deficit of water for irrigation.

In the lowland (Kailali), a highly erratic rainfall pattern has been observed by the local people in recent years. Locals experienced that the rainfall intensity (scale and severity) has remarkably increased, which exacerbated floods and inundation along with escalated and devastating river flow. They noticed that rainfall is showing heavy erratic nature throughout the year and excessive reduction in amount of rainfall in summer seasons. These caused the changes in the time of

TABLE 5. Seasonal MK and Sen's slope test results of rainfall (1988–2018). Boldface values indicate statistical significance at the 5% level.

	Rainfall, Taplejung				Rainfall, Gorkha				Rainfall, Kailali			
Season	Mean	MK *Z* value	*P* value	Slope	Mean	MK *Z* value	*P* value	Slope	Mean	MK *Z* value	*P* value	Slope
Spring	427.36	−0.238	0.8119	−0.241	842.25	−0.510	0.6101	−2.888	135.36	0.8838	0.377	1.493
Summer	1115.24	−1.122	0.2620	−4.644	2000.35	−0.034	0.9729	−1.140	1306.94	−0.6119	0.541	−2.707
Autumn	352.85	−0.233	0.8119	−0.532	287.79	0.442	0.6586	1.633	349.29	0.6799	0.497	2.405
Winter	60.45	−2.346	**0.0190**	−1.883	162.09	−1.496	0.1347	−2.639	88.82	−0.6119	0.541	−2.707

TABLE 6. Precipitation concentration index (PCI) of the study areas for the period 1988–2018.

Year	Taplejung	Gorkha	Kailali
1988	15.79	16.57	7.14
1989	14.64	15.23	23.97
1990	15.01	17.22	22.65
1991	16.41	18.85	21.88
1992	16.84	23.84	23.76
1993	15.39	17.40	23.30
1994	17.17	22.98	27.77
1995	15.27	23.49	33.35
1996	15.75	22.79	22.79
1997	15.17	18.12	20.87
1998	14.81	28.24	27.08
1999	16.05	20.16	21.87
2000	18.65	18.03	21.51
2001	14.96	19.52	25.55
2002	17.93	17.02	25.91
2003	15.29	20.01	23.33
2004	14.56	17.84	20.88
2005	16.87	14.87	24.36
2006	19.03	17.98	24.33
2007	15.10	17.98	21.48
2008	17.05	15.11	18.80
2009	16.30	21.64	22.18
2010	15.70	17.86	27.54
2011	17.23	19.32	24.00
2012	16.19	19.09	31.51
2013	15.40	15.99	17.87
2014	16.65	16.70	20.87
2015	16.35	17.42	21.83
2016	14.31	20.97	27.49
2017	18.69	18.21	34.48
2018	18.23	20.04	24.29

seed sowing, planting, and harvesting of the crops markedly. Local people claimed that groundwater table has been drastically reduced because of the decreasing quantity of rainfall for more than two decades. More than 60% of the local residents said that "up to 150 feet-deep dug water well is needed for drinking water available for all seasons in recent years, while it was possible to get the drinking water from the wells with the depth of 40 to 60 feet in the past" (1 ft = 30.5 cm). Local people assumed that amount of groundwater diminished by about 25%–35% in recent years. People observed persistent reduction in number of rainy days and prolonged dry episodes, consisting of consecutive dry days in recent years. Sixty-two percent of the interviewees indicated that the maize yield has reduced. Fifty-five percent of them indicated the degradation of potato quality due to excessive rain. Similarly, local people faced early onset and early cessation of rainfall. Eighty-one percent of local farmers reported that they cultivate local rice in May these days while it was done in June in the past. Some farmers have abandoned local rice cultivation due to unpredictable rainfall patterns.

4. Discussion

a. Changes in temperature varied in magnitude across three ecological regions over the period of 1988–2018

Over the last three decades, the spatial and temporal changes in temperature trend and variability pattern across mountain, midhills, and lowland regions varied. The regions suffer significant temperature changes but found no significant variation in rainfall pattern; however, the variability and concentration of rainfall amounts are marked different. The observed changes were largely substantiated with wide-ranging experiences of local inhabitants. Our analysis showed positive magnitude in the overall trend of the temperature witnessing a pronounced rate in higher altitude. Previous studies have prevailed the similar results with warming rate having pronounced in the higher altitude such as the middle-mountain and Himalaya regions, while significantly lower warming rate in the Terai and Siwalik (a mountain range of the outer Himalayas) regions of Nepal (Shrestha and Aryal 2011; Tiwari et al. 2010). For the entire country, the temperature for the period of 1979 to 2016 showed an increase of annual mean ranging from 0.01° to 0.09°C yr^{-1} depending on altitudinal variations (Shrestha et al. 2019). The Department of Hydrology and Meteorology of Nepal analyzed the warming of maximum and minimum temperature at the rate of 0.056° and 0.002°C, respectively (DoHM 2017). The results from our study are consistent with the previous studies. The national maximum temperature rate is approximately close to the annual temperature increase rate of the midhills (Gorkha)

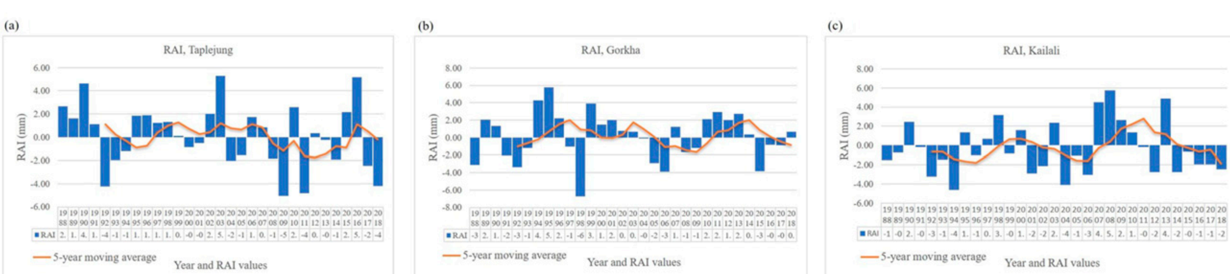


FIG. 3. Rainfall anomaly index (RAI; 1988–2018) and its 5-yr moving average for (a) Taplejung, (b) Gorkha, and (c) Kailali.

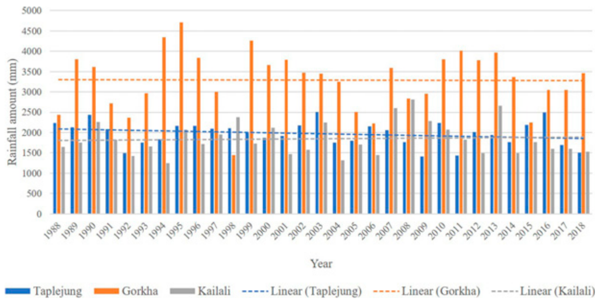


FIG. 4. Annual rainfall trends (1988–2918) in the study sites: Taplejung (mountain), Gorkha (midhills), and Kailali (lowland).

and the mountain (Taplejung). It suggests that the high-altitude regions are getting warmer intensifying the national mean. For the period of 1977–94, Shrestha et al. (1999) suggested the rate of annual temperature rise to be 0.06°C for the trans-Himalayan and Himalayan regions and the middle mountains. For the lowland (Terai) region, they found the rate to be lower than 0.03°C or even decreasing trend for the same period. As compared with that finding, our study found that the rate of maximum temperature increase for midhills and mountain was more pronounced. Both studies agreed that temperature has been gradually increasing in the higher altitudes. In the case of lowland, our findings differ from Shrestha et al. (1999). According to their findings, the temperature in Terai was increased by 0.041°C annually for the period of 1977–94, and we analyzed the average annual warming rate for the region is 0.017°C for the period of 1988–2018. It indicates that the lowland in Nepal is getting slightly cooler. However, note that Shrestha et al. (1999) and this study compare two different time periods, but with partially overlapping years. Our study showed that the warming rate of most of the months in the lowland (Kailali) were insignificant showing cooling in winter (particularly in January) and in summer contrasting to the mountain region where the temperature is getting relatively warmer. The mountain region (Taplejung) has been going through warming climate significantly for the entire year—for all months and seasons. In midhills (Gorkha), most of the months as well as spring, summer, and autumn seasons were warmed up by significant temperature rise. Thus, the reduction of snow in the regions might have contributed constant temperature rise, which is strongly claimed by the local residents during the interviews and FGDs. The shrinking of snow cover and retreating glaciers were marked in local understanding of trans-Himalayan communities, noted to have reduced to negligible presence from 2–2.5-ft thickness (Tiwari et al. 2010). Many empirical and model studies suggest that melting of snow and reducing glacier coverage contribute to the changes in surface albedo that in turn warm up the surface temperature (e.g., Cassardo et al. 2018; Fujita et al. 1997; Kadota and Ageta 1992; Meehl 1994). Qinghai–Tibet Plateau had shown a decreasing trend of snow cover during 1970–2010 (Bo et al. 2014) and the permafrost temperature increased at the rate of 0.02°C yr^{-1} from 2006 to 2010 (Wu et al. 2012). The northeastern mountain region under this study is adjacent to Tibet.

The results of this study confirmed that the local perceptions of the changes in temperature are consistent with meteorological observations in the regions. To compare the changes observed in meteorological variables with the local perception, all of the interview participants were asked, "Have you experienced changes in temperature?" Their obvious answer was "Yes, it is increasing." Most of the local people, particularly those above 40 years old, tended to explain about the changes taking some evidence of impacts of temperature fluctuations. For example, the answer of most of the interviewees from midhills was "Some faunas are vanishing" but it appeared the opposite in the answers of interviewees from mountain region, who said, "Some bird populations have increased invading agriculture crops." The responses to the question indicate that local people have regularly experienced the indication of climate change and its physical manifestations, i.e., changes in temperature and precipitations. However, people could not quantify the magnitude of the changes. The local residents have wisely linked climate change to the historical climatic events occurring within their communities and in their vicinities. They noticed that the temperature has increased, which in turn impacted their livelihoods. However, their perceptions could not exclusively discriminate to what extent the temperature fluctuated between regions. The analysis of time series observational data clearly quantifies the change and explained that mountain region (Taplejung) experienced the highest rate of temperature rise and the lowland (Kailali) experienced the least. People explained changes linking with events occurred in particular time period and place. As seen in interviewee's responses, the local observation of marked decline of the Himalayan bulbul (*Pycnonotus leucogenys*) and house sparrow (*Passer domesticus*) population in midhills, and outright increase its density in mountain regions introducing their widespread invasion to several agriculture crops sets the example of temperature effects in those regions. The locals claimed that the changes in habitat and migration of the bird species to the higher altitudes is caused by the temperature rise in the regions. Local people affirmed the shift of growing seasons of local crops triggered by the temperature rise. The timing of the annual cycles of flora and fauna is extremely sensitive to climate change such as flowering plants and animal migration to preferred locations due to changes in weather. As suggested by Pearson and Dawson (2003), continuous warming "bioclimate envelopes" toward higher altitudes affect fauna's preferred vegetation community and shift their range poleward latitudinally and upward altitudinally. Long-term changing of climate inevitably shifts geographical range of many taxa, predominantly on birds, mammals, and butterflies (Beever et al. 2003; Hill et al. 1998; Hill et al. 1999). The local perception on the impacts of temperature in Madre de Dios, Peru, explicitly found to have diminished water sources and loss of crops and animals (Michaelsen et al. 2020). Our finding of temperature increase in the mountain regions is consistent with the study done by Hu et al. (2020) in eastern Tibetan Plateau. They found that most of the local perceived consistently upward trends in temperature. While there are local differences between three sites representing different ecological regions—particularly in climate variability—the overall local perceptions concur with common findings of the general trends recorded and documented in various parts of the world suggesting that temperature is increasing and precipitation is decreasing (e.g., Abram 2019; Asfaw et al. 2018; Ayanlade et al. 2017; Banerjee 2015; Chaudhary and Bawa 2011; Legesse et al. 2013; Mertz et al. 2012; Rao et al. 2011; Roco et al. 2014; Silvestri et al. 2012; Suberi et al. 2018; Tambo and Abdoulaye 2013).

b. Changes in rainfall varied in magnitude across three ecological regions over the period of 1988–2018

There was a spatial variation in annual and seasonal changes of precipitation between the three ecological regions of Nepal. Although the changes in rainfall trends are not underpinned by significant trend, results showed that mountain regions not only severely suffered with the highest amount of rainfall loss among the regions but also have considerable effects on water resources depletion as glaciers are retreating due to the influences triggered by rising temperature. In addition to the temperature rise, the midhill region has also faced noticeable rainfall decline causing depletion of the water resources. The annual precipitation reduction in lowland was found to be lower relative to the higher altitudes; however, internal variability and rainfall concentration was found to be high as depicted from the analysis of CV, PCI, and RAI. The calculated values of these three parameters are higher for lowland. It suggests that annual variability, monthly and seasonal rainfall concentration, and variation in rainfall below normal were highest in the lowland (Kailali) and lowest in the mountain region (Taplejung). The higher degree of variability, concentration, and intensity cause high risks of hazards primarily for human as well as farming activities. The insurgency of these events has pronouncedly occurred in the recent years in lowland regions in the form of floods, heavy rainfall, dry spell, wet spells, and so on.

The study by Shrestha et al. (2020) in the Mustang district (Nepal), which is a mountainous and rain-shadow area located beyond the Himalaya and adjacent to Tibet, shows an annual declining trend over the last 30 years. However, there is not a clear national annual trend of precipitation in Nepal (MoFE 2019). A few studies showed an increasing but mostly not significant trend (e.g., Baidya et al. 2008; A. B. Shrestha et al. 2017; Shrestha et al. 2019). Reaching to small, nonsignificant results, our findings corroborate to these former studies showing negative changes in rainfall over the same period. Using varieties of datasets from different time periods focusing on and consisting of different geographical regions might have caused discordant findings about precipitation trend of Nepal (A. B. Shrestha et al. 2017). As this study was concentrated in the specific local context based on time series climate records, findings strongly represent local atmosphere suggesting that local climate may largely deviates from national average scenarios. Nepal is endowed with a vast ecological and geographical variations experiencing contrasting weather patterns even within small localities. There is an incredible dissimilarity in the quantity and pattern of rainfall within a distance of a few kilometers (Shrestha et al. 2019). Examining the global pattern, South Asia, as most disaster-prone region [United Nations Environment Programme (UNEP); UNEP 2003] has witnessed an overall increase in precipitation extremes (Sheikh et al. 2015); however, the patterns were varied in nature. The precipitation extremes recorded a falling trend over southwestern Pakistan but rise in northeast Pakistan (Hussain and Lee 2013). The eastern Gangetic plains and some parts of Uttaranchal of India also showed a falling trend, but in central India it was recorded rising (Goswami et al. 2006; Rajeevan et al. 2008; Sen Roy and Balling 2004).

The seasonal rainfall analysis showed a positive change for spring and autumn in the lowlands (Kailali) and for autumn in the midhills (Gorkha). The seasonal changes are consistent with Karki et al. (2017), who depicted that premonsoon (spring) and postmonsoon (autumn) precipitation increased, and monsoon (summer) precipitation decreased in western lowland, and monsoon (summer) experienced downward trend in the central midhills. The direction of rainfall changes for winter season of all three areas find agreement with the previous studies (e.g., Karki et al. 2017; Khatiwada et al. 2016; Wang et al. 2013). The findings from the mountain region (Taplejung) partially agreed with current climate change scenario of Nepal (MoFE 2019) for the postmonsoon (autumn—October, November) precipitation that presented a decreasing trend all across Nepal. The findings of our study for rainfall decline during spring and summer seasons have close congruence with Karki et al. (2017). They found that most of the stations of central and eastern regions of Nepal showed a declining rainfall during monsoon season.

Unpredictable rainfall patterns were experienced by almost all interviewees of all sites, primarily raising the probability of the lack of adequate rainfall during crop cultivation and the growing season and more intense rainstorms when rainfall is actually not needed. In the regions, local interviewees were asked the major question of "How do you perceive rainfall change?" The common responses we found are "early starts and early ends of monsoon" and "the pattern of rainfall has remarkably changed, we hardly see 'drizzling' which used to be in the past, but uncertain 'pouring' in recent years." Mountain dwellers noticed that rainfall amount has drastically reduced during spring and summer seasons, with decreasing trend of number of rainy days, and drying out water resources. The local meteorological records showed the declining of rainfall amount over these periods. Local people of lowland experienced decreasing rainfall amount with extreme erratic nature; sometimes, intense rainstorm caused degradation and loss of crops and livestock. Local people affirmed that the late downpour onset and early cessations exerted the strong influence on decreasing groundwater availability, deteriorating rain-fed agriculture and livestock. Small-scale mixed farming system with livestock is the major livelihood strategy for the rural people of Nepal. Delays and uncertain rainfall affect the production negatively. Our findings on early starts monsoon and its impacts to the changing of timing for sowing seeds and harvesting crop yields were also featured in previous studies (e.g., Ayanlade et al. 2017; Jalota et al. 2012; Kolawole et al. 2016; Malla 2009; Pandey 2012; R. P. Shrestha et al. 2017;

TABLE 7. Local people's perception on climate change.

Taplejung (mountain); observation/ intensity (n = 86)	Gorkha (midhills); observation/intensity (n = 122)	Kailali (lowland); observation/intensity (n = 119)
	Temperature	
High majority of local people experienced that the temperature increased during last few years (94% HH)	Local people observed that the temperature has increased during last few years (90% HH)	Temperature has increased in the recent decades (81% HH)
We do not feel so much cold in January and December like we used to realize in the earlier decades	Mosquitos are seen in recent years due to an increase in temperature	Majority of the interviewees claimed that temperature has increased slightly and that cold seasons, however, remain unchanged despite the increase in temperature
Amount of snow is reduced; most of the mountain peaks used to be covered by snow in the earlier decades, but most of the nearby peaks do not show snow anymore these days (66% HH)	Poultry have been affected and chicken death rate is increased (33% HH) due to an increase in cold days in winter season	Most of the locals observed that rice (*Oryza sativa*) has been matured (ripening) earlier and that the early ripening is associated with the increased temperature; they suggested that the rice, in general, gets ready for harvesting around the last week of September in recent years, whereas it used to be harvested during early November in the past years
In the lower belt of the hills, we hardly see snow these days, because of temperature rise (100% HH)	The population of house sparrows has decreased due to an increase in temperature, and the birds are migrating to the higher altitudes	Similarly, the growth period of wheat (*Triticum aestivum*) has been shortened and the ripening period has shifted to approximately 2 weeks earlier
Mustard (*Brassica juncea*) and barley (*Hordium vulgare*) were badly damaged and destroyed by Himalayan bulbul (*Pycnonotus leucogenys*), which was not the case before; people believed that this bird came from somewhere seeking a favorable environment as temperature incrementally changed	"We have experienced that the temperature has increased mostly during summer; even in winter we do not feel so much cold in the last few years as we felt before 20/25 years"	Wheat used to be harvested between the second and third week of April, and in the recent years it has been getting ready for the harvest between the last week of March and the first week of April
The house sparrow (*Passer domesticus*) has been increasing in the higher altitudes (upper belt) while disappearing in the lower belt		A considerable shift of maturity time was also noticed in maize (*Zea mays*); it is being harvested in June in recent years instead of August as a couple of years ago
Maize gets ripe early in July (shifted early from August		In recent years, lentil (*Lens culinaris*) is harvested in February; the harvesting period is shifted earlier from March, and a similar trend can be noticed in mustard
		Mustard gets ripe during the last week of January in recent years instead of the second week of February as in the past decades
	Rainfall—rainy season/early and late growing season	
Almost all locals claimed that rainfall onset and cessation are very uncertain, as compared with the events in the past decades	Irregularity of onset and cessation for rainfall has posed a serious threat to locals by introducing high uncertainties in determining the period of cropping, and seeding in particular	Uncertainty is escalating for rainfall onset and cessation
In recent years early rainfall has been considerably reduced during April, May, June, and July	In recent years the frequency of rainfall has been considerably reduced during early rainy seasons—particularly,	Throughout the year, the rainfall pattern is changing toward high intensity and is highly erratic, particularly in the

TABLE 7. (*Continued*)

Taplejung (mountain); observation/intensity (n = 86)	Gorkha (midhills); observation/intensity (n = 122)	Kailali (lowland); observation/intensity (n = 119)
	March, April, and May	summer season; the changing pattern has been affecting crop cultivation (seeding; planting) and crop maturity time, including harvesting
Water sources (mountain spring water, wells, ponds, and lakes) are getting dried up because of low recharge potential (79% HH)	Water sources are getting dried up because of low recharge potential, and the acute scarcity of drinking water and irrigation water is forcing people to migrate (77% HH)	Groundwater table is reduced significantly; one of the pieces of evidence for the reduced water table is the depth of wells in the Terai region; in the past, a 60-ft-deep well is enough for water harvesting for all of the seasons, but in recent years, up to 150-ft-deep digging is needed to harvest the water all year-round (61% HH)
Observed reduction in water quantity and rainy days (87% HH)	Water quantity and the number of rainy days has been decreased (71% HH)	Decrease in the number of rainy days and increasing prolonged dry episodes, consisting of consecutive dry days have become more common (44% HH)
A majority of the locals experienced that intensity of hailfall increased along with a decrease in snow falling	Potato yield and quality have been reduced because of excessive water for certain time periods	In the recent years, rice is cultivated in May, instead in June (early onset of rain) in the past decades (81% HH)
In recent years, the monsoon starts during July and August; the onset of the monsoon is delayed by almost 2 months in comparison with the past decades; in the past, it used to commence during May and June	Because of water deficiency, people started upland rice (locally called *Ghaiya*), but their interest is falling because of more labor-intensive cultivation (56% HH)	People abandoned local rice cultivation because of uncertainty in the time of raining [internal variability high (67% HH)]
	Intensity of hailfall increased, damaging local crops and fruits enormously	Potato quality and quantity degraded because of excess water (55% HH)
	Intensively local farming faces prolonged drought days in agriculture	Because of heavy rainfall, maize production is reduced (62% HH)
		A majority of locals experienced that the rainfall pattern has reduced but intensity has remarkably increased, which exacerbated the floods and inundation along with devastatingly increased river flow

Tiwari et al. 2010). This unsolicited change has caused reduction in quantity and quality of agriculture products, decreased crop yields per unit area, and degradation in quality and quantity due to increasing pest and pathogens attacks. RAI with 5-yr average line showed the onset rainfall and early cessation for all studied sites that profoundly accord with local observation. Although the locals are adjusting their cropping practices with shifting seasonal calendar, extremely uncertain precipitation such as intense and flash rain, hailfall, frost, and fog have prominently influenced the farmers' cognition making them reluctant at selection and prioritization of planting crops.

The perception of changes in the amount of rainfall and meteorological data correspond to the results that have been reported in many parts of the world. A study of the Melamchi valley in central Nepal noted that local people perceived an increase in temperature and a decrease in precipitation over the last two decades (Sujakhu et al. 2016). Devkota et al. (2017) also found similar results in the western mountain region of Nepal. Paudel et al. (2020) pointed out a strong association between local farmers' perceptions of climate change and its adverse impact on staple crops, livestock, vegetation, and human health. The recent study done in the Bundelkhand region of India showed an analogous pattern of local perception on climate change as of declining rainfall and increasing temperature over the past decade that provided significant biophysical determinants in identification of adaptation strategies (Singh 2020). Roco et al. (2015) suggest that local farmers have clear understanding of local environment that enabled them to detect climatic issues in local context. The local understanding of the falling pattern of precipitation in Damzhung County in the Tibet Autonomous Region (Hopping et al. 2016), a large-scale survey on aquaculture farmers' perception in South and Southeast Asian regions in Cambodia, Laos, Myanmar, Thailand, and Vietnam (Lebel et al. 2020) and a farmer's-level study in Bangladesh (Uddin

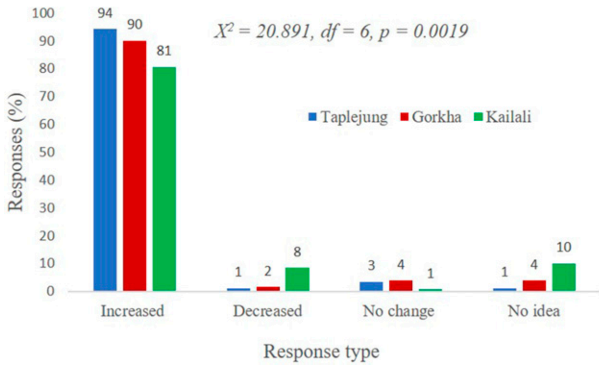


FIG. 5. Local understanding of temperature fluctuation between the three studied sites.

et al. 2017) have documented the local perception that people have perceived decreasing trend of rainfall amount with higher degree of inconsistency causing high intensity and frequencies of associated impacts including droughts, floods, cyclone, and salinity. Our findings, however, contradict Shrestha et al. (2019), where they found no connections between farming and perceived accuracy of climate change.

Although there are scientific findings for both positive and negative effects of climate change on diverse components of environment and society (Behringer et al. 2000; Neupane 2015), there is only limited evidence of local collective strategies to adapt to the perceived and predicted impacts (Schermer et al. 2018). Given the current state of climate change impacts, not only has the environmental dynamics caused but also diverse aspect of human interaction is responsible for climate change. It deduces a necessity of integrated perspective of transdisciplinary approach to deal with the issues through concise, up-to-date communication of climate change knowledge and appropriate measures for both climate change adaptation and mitigation in a society as a whole—environmental and socioeconomic dimension including agriculture, forestry, land use, extension education, business, and industries. While there are existential impacts and predictions of its severity in future scenarios, even small (nonsignificant) changes in temperature and precipitation are perceived by local populations, thereby changing their behavioral actions. As suggested by Grothmann and Patt (2005), people develop their capacity in "threat appraisal" and "coping appraisal." Based on it, an individual evaluates his/her capacity (perceived self-efficacy) to cope with threats and perceived impacts responding by changing behavior.

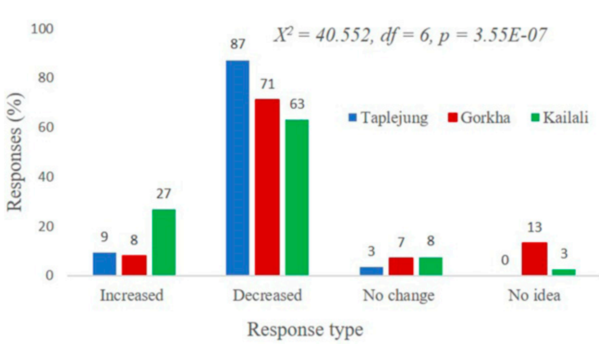


FIG. 6. Local understanding of rainfall fluctuation between the three studied sites.

5. Conclusions

The spatial–temporal changes in temperature and precipitation trend and variability between the three ecological regions of Nepal over the last three decades varied. The variations largely corroborate with the wide-ranging local experiences. Results showed an increasing trend of temperature, with a pronounced rate in higher altitudes composed of elevated geography, and a decreasing amount of rainfall, with the minimal rate in lower altitudes composed of flat land. However, the lower region suffers relatively pronounced rainfall variability and concentration. Our study found that local perceptions of temperature and precipitation changes are highly consistent with the time series of meteorological climatic measurements, with some apparent discrepancies for rainfall patterns. Nearly all of the local residents agreed that monsoon has been affected by "starting late and early ending rainy season phenomenal change" making weather atrocious for agriculture crops and livestock but unveiled partial conflicting experiences with decreasing trend of meteorological records. The findings of this study would contribute to the field of climate change adaptation in two ways. First, local understanding on changes in climatic variables and climate change provides a reliable input in formulating policies and strategies at the local level and for those regions that are similar geographically but lack observational climatic measurements. The study highlights the importance of recognizing the local perceptions and responses in the changes in climatic attributes in the context of prevailing high uncertainties in climate change and associated parameters. Second, as explained by Bruen and Gebre (2001), the local vulnerable community who observe climate change correctly are more likely to be prepared for warnings with appropriate prevention measures, hence, would help in designing the operational strategy for adaptation and mitigation in the local context of transdisciplinary approach.

The study shows that local people are very sensitive to climate change. In this study, locals judge climate change parameters in a way that how closely the parameters have entangled with their livelihoods and on which seasons those livelihood activities have mostly undertaken. Nearly all of the local residents agreed that rainfall duration and timing have changed but their consensus in pattern is markedly doubtful. More in-depth research is, therefore, necessary to identify local livelihoods activities undertaken throughout the year and to document those activities explicitly influenced by changing trend and variation in climatic attributes.

Local population perceives even minor changes (i.e., not significant in statistical terms) of temperature and rainfall. The population affected from climate change has started some local-level actions against existential change as well as some proactive actions for expected change in the future and associated uncertainties. This could have profound implications for limiting the expected temperature increases to be below the 1.5°C goal of the Paris Agreement. The goal of 1.5°C is far larger than the observed changes in temperature, so the actions society takes today are to address climate change to benefit reaching the climate goal.

This study gives a precognition how climate change will affect local communities in vulnerable areas. Dealing with climate change is an environmental and societal imperative. The intricate relationship between environment and people, therefore, needs transdisciplinary research to address the impacts of climate change on local communities. The measurements of changes in climatic parameters, their impacts and individual perceptions are prerequisite to assess the full range of consequences, proactive adaptation and mitigation measures employed at local areas. This would inform the science, policymakers, and the planners for effective adaptation actions and stringent mitigation efforts.

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Article

Proactive Adaptation Responses by Vulnerable Communities to Climate Change Impacts

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Abstract: We explored the proactive responses of local communities against locally experienced climate change impacts and anticipated threats. This study interviewed 124 rural households from three community forestry user groups representing three ecological regions of Nepal using a semi-structured questionnaire. The study used eight criteria to distinguish the proactive nature of adaptation. Both qualitative and quantitative methods were used to analyze data, including the use of a chi-square (χ^2) test to determine the proactive measures and their association with livelihood options and the ordered logistic regression model to explain determining factors of choosing proactive adaptations. The results indicate that 83.9% of households adapted both proactive and reactive measures, while 10.5% applied solely reactive adaptation and 5.6% were earmarked only for proactive adaptation measures. Over 50 different proactive adaptation measures were implemented by the households. The measures were significantly associated with agricultural diversification, cash crop cultivation, livestock raising, small-scale enterprise development, and disaster control. Socio-economic and spatial factors such as a household's wellbeing, land holding size, geographical location, livelihood options, and the number of adaptation measures implemented by households were found to be decisive factors in choosing proactive adaptation. The study concludes that local people in Nepal are not only aware of escalating climate risks but also engage their cognition and knowledge proactively to adapt locally. The results suggest that even small proactive initiatives by households can offer multiple benefits against climate risks as an architect of individuals. Therefore, adopting a trans-disciplinary approach and nurturing local proactive actions in strategic connectivity between environmental, political, and societal functions is pivotal, which primarily takes a step to drive expediently successful climate change policy and strategy implementation. The findings of this study offer valuable insights into policy and strategy planning for the unsolicited consequences of climate change and highlight the importance of understanding the perspective of local communities in adaptation planning and implementation.

Keywords: climate change; climate change adaptation; adaptation strategy; proactive adaptation; climate change policy; Nepal

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1. Introduction

Climate change is unequivocally a global phenomenon; however, the impacts are local and differential [1–4], mostly based on geographical remoteness and temporal scales [5–8] and the vulnerability of individuals, groups, and communities [4,9,10]. Rising temperature and shifting precipitation patterns [11] and their wide-ranging consequences, particularly extreme weather events such as flash flooding, landslides, devastating forest fires, heat waves, and drought, have adversely impacted people's lives and several dimensions of livelihoods around the globe [12–17]. The subsequent Intergovernmental Panel on Climate Change (IPCC) assessment reports [6,18,19] confirm that the destructive impacts of climate change are being felt with increasing frequency and the intensity of severe weather events is profoundly causing changes in the livelihoods of remote and vulnerable communities. The amplification of these events has intensified the vulnerability of people in developing nations, particularly those who are predominantly entangled with natural resource-based climate-sensitive livelihoods [20,21] and subsistence farming. Climate change adaptation (CCA) has become an inescapable option in addressing climate change impacts. As mitigation strategies are no longer adequate to avoid loss and damage [22], CCA has immense importance in minimizing vulnerability to growing climate risks [20,23]. Climate change adaptation is a "process of adjustment to actual or expected climate and its effects" [18] (p. 5). It enables individuals and groups to foresee changes and adapt the response to minimize negative effects [24]. Thus, climate change adaptation has been an ongoing and dynamic process, thereby prompting societies across space and time to adjust to climatic stresses [25,26].

The adaptation is influenced by various spatial and socio-economic factors. Geographically fragile, poor, and developing countries face the need for a wide range of adaptation measures in terms of timing and scale. However, implementing these measures is challenging due to limited financial resources, inadequate infrastructure, and insufficient access to information and technology. So, the effects of climate change are often felt more acutely in these countries and communities.

Considering the nature, severity, and location of the impacts, CCA involves a range of attributes of adaptation strategies and actions aimed at helping communities, organizations, or countries to cope with multiple dimensions of vulnerability and impacts. A large body of literature on CCA has been devoted to explaining the characteristics of the six principal strategic responses of adaptation: timing relative to stimulus (proactive, concurrent, reactive, planned), intent (personal, collective), drivers (private, public), spatial scope (local, regional, national), form (technological, behavioral, financial), and degree of response (incremental, transformational) (e.g., [27–34]). While adaptation actions are categorized into several types based on their key attributes, there is growing recognition among climate scientists, policymakers, and planners about the timing of climate change adaptation, distinguishing proactive and reactive strategies to respond to highly erratic and uncertain future climatic threats and existential impacts (e.g., [35–37]), particularly in the local context. Differentiated impacts revealed from continuously changing climatic parameters force local affected communities or individuals to cope with self-initiated proactive and reactive adaptation measures or a combination of both through local means and knowledge acquired and shared over generations. Because local communities and/or individuals often have close connections to nature, this builds an intuitive understanding of the changing climate over long periods of time [38]. They have long been attuned to environmental changes, allowing them to discern and respond to these shifts [39]. As a result, they have employed adaptations that are intricately tailored to their unique contexts.

This emphasizes the crucial role of local communities as the initial and foremost responders, as they possess the potential to act to the best of their abilities, given that the impacts of climate change are intensely localized [4,9,40] despite it being a global burden [41,42].

There are several scholarly suggestions that the persistent knowledge of local people offers multiple solutions in abating environmental risk in favor of both nature and society (e.g., [43–48]). Applied adaptation measures in the view of society's efficacy and compatibility with local priorities are of paramount importance in the adaptation process and local development. Consistent interactions of individuals with daily weather conditions thereby change their adaptive behavior, which not only offers cognizant measures to cope with locally experienced climate change impacts [39] but also enhances the practical application of climate change policies and strategies. However, as concluded by Darjee, Neupane and Köhl [39], and Darjee, et al. [49], these practices and associated local knowledge have been hardly acknowledged in climate change policies and strategies. This might have been underpinned by the lack of grounded findings from such studies related to self-initiated proactive and reactive actions as the survival mechanism employed by climate-affected communities. This paper intends to identify such efforts and make them visible to decision makers.

Most studies predominantly focus on climate change trend and vulnerability analysis, policy process, policy coherence, local people perceptions, impacts on peoples' livelihoods, community adaptations, and participation (e.g., [14,39,44,48–63]). There is alarming scientific evidence pointing to the inevitability of constant modification of existing adaptation measures and identifying possible interventions building on local knowledge, local resources, and indigenous practices in consideration of dire and extremely unpredictable climatic change (e.g., [49,64–68]). Smit, Burton, Klein, and Wandel [27] suggest that adaptation to climate change and variability is a complex subject that requires thorough investigation. It is crucial to distinguish between different types and attributes of adaptation to effectively implement specific measures. This process involves understanding the intertwined nature of adaptation measures with both natural and socio-economic systems.

In this backdrop, this study aims at exploring the proactive responses of local communities in Nepal against locally experienced impacts and existential threats. As a mountainous country, Nepal has experienced an extremely unpredictable onset of monsoon seasons, increasing temperatures, and uncertain rainfall which has intensified vulnerability to glacial lake outburst, droughts, floods, and landslides [69]. Since 1971, the temperature has been exhibiting a positive trend, accumulating at an average annual rate of 0.06 °C with a higher rate of warming in the higher altitudinal range [39,70,71]. Geological and ecological fragility coupled with predominantly natural resource-based livelihoods and a low level of adaptive capacity due to poor socio-economic conditions and higher incidence of poverty have made Nepal one of the most vulnerable countries to climate change [62,72,73]. Compared to the long-term climate risk index (CRI) considering the period from 2000 to 2019, the 2021 global climate risk index has ranked Nepal as one of the ten most affected countries [42].

Exploring and distinguishing between the proactive and reactive measures of local communities has not been investigated and documented, although communities' responses have been a significant part of ongoing climatic challenges. Historically, most of the adaptation activities employed have been reactive [74,75]. As proactive choices rely on predictions about future events or challenges that are subject to uncertainty [76], these responses to future climate change have not been sufficiently interpreted into strategic or anticipatory planning, due to shorter-term priorities [77]. However, a changing climate suggests that there is an opportunity of proactive adaptation to tackle the anticipation of climate adversity predicted by scientists [78] to reduce losses and damages as well as costs of adaptation [79,80]. An unprecedented level of funding including a World Bank investment of more than USD 30 billion in 2022 has been allocated to support countries to address climate change and build resilience [81]. The Green Carbon Fund (https://www.greenclimate.fund/ (accessed on 28 April 2023) is in its second phase, building on its initial USD 10 billion to empower "climate action" in developing countries and to help vulnerable societies impacted by climate change. But the synthesis report of IPCC from the sixth reporting period in March 2023 draws global attention on the critical need to make strategic investments to accelerate the effectiveness of such funding and actions to address climate change [19]. While the need for a wise and equitable distribution of efforts and funding for remote communities to adapt and build resilience to climate change has been extensively discussed [82], it is important to address the scarcity of suitable practical adaptation measures that are tailored to the local context [49]. Furthermore, the recognition of the significance of enhancing overall societal choices and developments in terms of lifestyles and socio-economic factors in tackling climate issues has been realized [83,84]. In the backdrop of all, this study analyzes local climate-friendly proactive adaptation measures implemented by households against local impacts supporting their livelihoods. Findings from this study provide locally tailored solutions to increase the local ownership of ongoing responsibility for sustainable climate action.

2. Proactive and Reactive Adaptation: Concept and Analytical Framework

Climate change adaptation and its types have been classified based on several attributes. Commonly used attributes are distinguished with purpose, timing, temporal scale, and spatial scale [18,85–88]. Planned adaptation, which involves proactive measures and autonomous adaptation, which occurs reactively, are widely recognized [89] and are commonly observed and implemented. Proactive adaptation is recognized in the United Nations Framework Convention on Climate Change (UNFCC) (Article 3.3) urging its member counties to take precautionary measures without postponement in order to anticipate, avoid, or abate the causes of climate change and minimize its adverse effects to ensure global benefits at the lowest possible cost [90].

The definitions and use of the terminologies proactive and reactive are context-specific. It is used in multiple fields of studies, for example, population and health, e.g., [91–93], business and education, e.g., [94,95], organizational management, e.g., [96,97], psychological studies, e.g., [98,99], policy and institution, e.g., [76,80], climate and management, e.g., [100–102], and so on. Here, we accentuate these terminologies in the field of climate change adaptation to describe people's adaptive behaviors. This includes examining how individuals adjust their actions in response to changes in climatic conditions caused by multiple impacts. Tinch, et al. [103] defined "adaptive capacity" for proactive adaptation and "coping capacity" for reactive adaptation. Smit, Burton, Klein, and Wandel [27] explain that adaptation could be proactive or reactive considering timing—autonomous or planned based on degree of spontaneity—as well as economic, legal, institutional, and technical form. Autonomous or spontaneous adaptations are considered to be reactive responses. Planned adaptations can be both proactive or reactive [89]. While proactive measures are taken well in advance or now to maintain or increase resilience, reactive measures involve responding to issues as they have been immersed by repairing impairment and mitigating ongoing impacts [97]. Plummer [104] explained that resilience maintains stability with the absorption of coping capacity in the face of shocks and stresses; adaptability shows flexibility in modifying systems to cope with changes in their environment, and transformation tends to radically change or replace the current system with a new one. On these grounds, it suggests that proactive behavior concerns future circumstances or predicaments, preparing for unforeseen circumstances to avoid negative outcomes to favor of positive results, driving towards transformation and resilience, and reactive behavior often addresses an immediate response against uncontrollable circumstances or issues.

Carman and Zint [28] proposed a comprehensive definition of personal and household adaptation behavior consisting of "purpose (i.e., preventing harm or gaining benefits), timing (i.e., proactive or reactive), time scale (i.e., short-term or long-term), as well as who acts (i.e., the individual alone or with others), and who is affected by those actions (i.e., the individual, other people, or the environment)." Purposefulness and timing are the most commonly used distinctions [89]. Reinforcing timing, scientists, policymakers, and planners have raised attention about distinguishing proactive and reactive strategies, e.g., [35–37]. Robert, Thomas, and Bergez [75] classified adaptation using timing, temporal, and spatial scopes. The timing and scope include reactive response (after the shock) and proactive response (preventive) adaptation. The temporal scope encompasses strategic adjustments (long-term) and tactical adjustments (short-term), and spatial scope involves both localized (e.g., single crop) and widespread (e.g., farm system) adaptation. Rasmussen and Suedung [105] used the term "proactive" as a preplanned control approach for risk management. de Bruin, Weikard, and Dellink [37] illustrated that proactive (anticipatory) measures are taken before climate change happens and are often on a larger scale and irreversible, whereas reactive adaptation measures are considered a reaction after climate change has occurred wherein both costs and benefits are concurrently perceived. As suggested by Palmer, Reidy Liermann, Nilsson, Flörke, Alcamo, Lake, and Bond [79], the efforts of proactive management will abate risks and reduce the costs of management more than the reactive efforts taken only after the issues have arisen. Given the wide range of concepts and contexts, proactive adaptation seeks ways to decrease the risk of anticipated climate change impacts occurring in the future and reactive adaptation alleviates the undesirable impacts accompanying existential climate change.

Persuaded by the concept, context, and the escalating urgency of understanding ongoing and dynamic process of adaptation to cope with changing environments, this article aims at exploring the expedient climate change adaptation actions proactively adapted by affected households. In doing so, this research is motivated by the concepts and principles of the protection motivation theory (PMT) [106–108] which has been extensively employed to explain adaptation behaviors and the effects of fear on health hazards affecting individuals' attitudes and behaviors. PMT is a theoretical framework which explicitly addresses both risk and adaptation. It has widely been extended to natural environmental risk and hazards including droughts [109] and flood risks [110,111] as well as climate change adaptation and mitigation [102,112–117]. A PMT socio-cognitive model has been considered suitable for predicting proactive adaptation to climate change risk using impact indicators, e.g., flooding and drought effects and socioeconomic parameters [102] as it considers an individual's motivation to protect themselves from any risks and threats. A PMT socio-cognitive model postulates two cognitive processes—risk appraisal of climate change and adaptation appraisal (Figure 1).

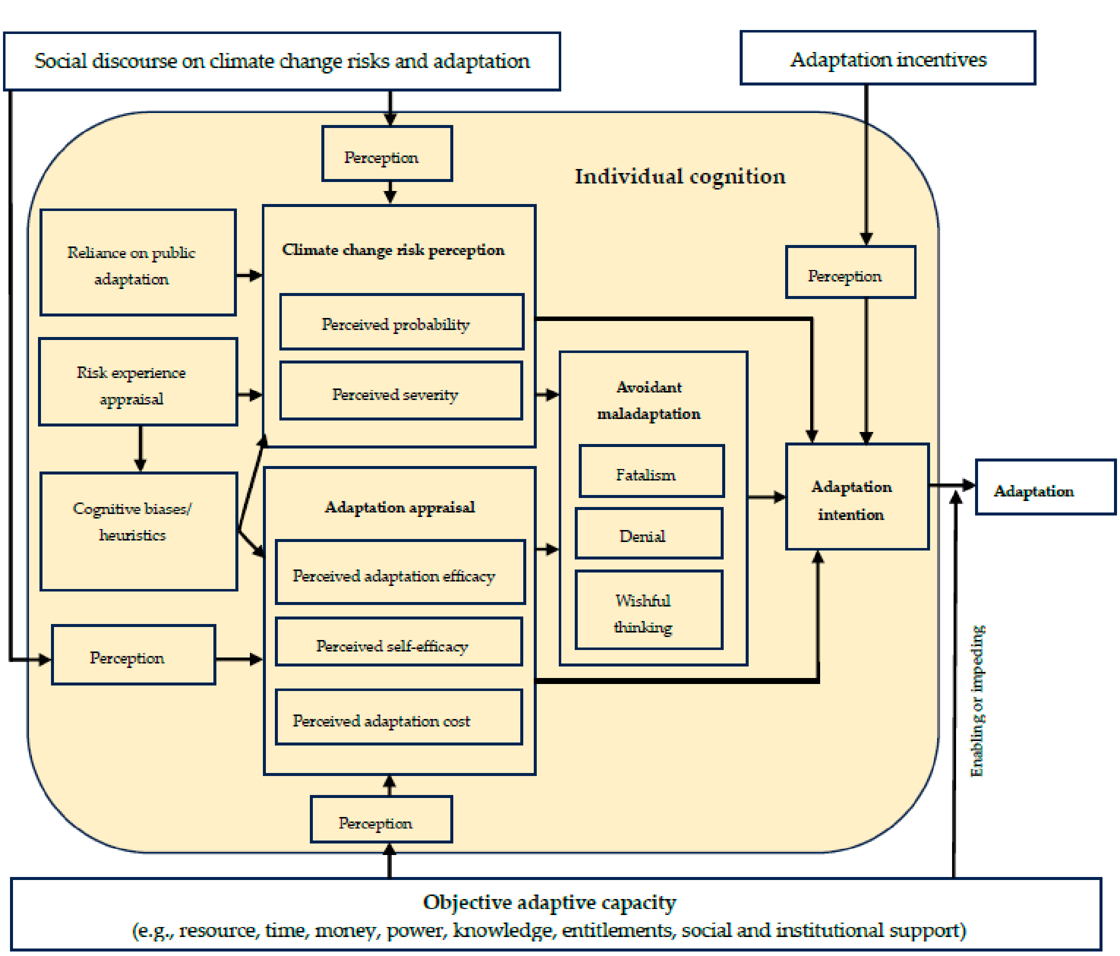

Figure 1. Socio-cognitive model of proactive private adaptation to climate change impacts developed by Grothmann and Patt (2005) [102].

Risk appraisal concentrates on the evaluation of sources of climate threats and factors that increase or decrease the possibility of likelihood severity. Risk appraisal apprehends the individual perception on the expectancy of being exposed to risks (perceived probability) and the perception on how severe the consequences of the risks would be (perceived severity), thereby assuming the probability of engaging in protective responses.

Adaptation appraisal refers to individuals' cognitive processes when evaluating their ability to avoid or reduce particular risks. Within the adaptation appraisal, three distinct components are interpreted to evaluate individual response measures: perceived adaptation efficacy, perceived self-efficacy, and perceived adaptation costs. Perceived adaptation efficacy evaluates believing in adaptive responses to be effective in preventing harm from perceived threats; perceived self-efficacy focusses on the person's perceived capability essentially to accomplish the adaptive responses; and perceived adaptation costs assess the costs of undertaking the adaptive responses. Individuals often have adaptation intentions; however, in some cases, they find themselves unable to carry them out in actual behavior due to a lack of objective adaptive capacity (e.g., lack of resources, time, money, power, knowledge or social support), see [102].

In the wake of this comprehensive and extensive theory and associated model, this article is framed for the subjective assessment of proactive measures, distinguishing perceived adaptation efficacy and self-efficacy and determining factors to choose these measures. Several studies have explored diverse adaptation options against the most noticeable forms of climate change impacts and indicators including extreme temperature, drought, ground water table reduction, decrease in the number of rainy days, increase in prolonged dry episodes, erratic rainfall, early starts and early ends of monsoon, cold wave, permafrost thaw, fire, intrusion/expansion of pest and pathogens, and multiple issues of human and livestock heath, e.g., [3,6,12,14,39,49,62,69,118–128]. Our analysis considered these impacts and indicators while exploring proactive measures.

To distinguish between different proactive measures, we used eight major criteria (Table 1) and analyzed their association with diversification of livelihood options which were locally practiced. The proactive measures were modeled with selective independent variables associated with socio-economic and demographic variations, i.e., diversity of household's livelihood options, wellbeing category, agricultural land owned, sex, number of adaptation activities employed, length of experiences in major occupation, and geographical variation of the dwellings to identify major determining factors. The independent variables were chosen by reviewing a wider range of pertinent literature, e.g., [73,103,109,115–117,129–134], and consultation with local experts and community members while keeping in mind the local circumstances. In the context of Nepal, these variables hold great importance in addressing adaptation issues. Nepal's diverse ecological and geographical features result in contrasting weather patterns, even within short distances of a few kilometers [135] and in small localities [39]. Additionally, the country exhibits significant socio-economic and cultural variations influenced by factors such as land ownership, wellbeing, location, gender roles, occupational engagement, and the diversification of livelihood options.

Building on the reviews of the concepts, theories, framework, and pertinent literature, our study mostly accentuates the empirical evidence of proactive measures of climate change adaptation markedly implemented in local surroundings. In doing so, we principally focus on two major leading questions: (1) how are local people proactively engaged in adapting uncontrolled and unexpected climatic risk? and (2) what are the determining factors associated with proactive adaptation of the households?

The findings from the results are discussed in relation to the expedient advancement of proactive measures and its vitality in achieving successful implementation of climate change policy and strategy. The discussion is predominantly framed under the socio-cognitive process model of proactive adaptation to climate change elaborated by Grothmann and Patt [102]. Finally, we argue that the responses of local people to climate change should be seen as widening opportunities of adaptation in maintaining and/or enhancing the functionality of the system considering the unavoidable uncertainty of climate and associated compounding risks.

Table 1. Criteria and indicators used for distinguishing proactive and reactive climate change adaptation measures.

Proactive Adaptation		Reactive Adaptation		
Indicators	**Explanation**	**Indicators**	**Explanation**	**Referenced Consulted**
Actions before possible shock	Solve a future problem, Activities implemented in advance, Type of activities implemented	After/during shock	Solve matters as they come up by repairing impairments and mitigating ongoing impacts, Types of activities implemented in advance, See record and verbal note	[75,97]
Investment for future benefits	Amount of funding invested for future benefits of climate change, Property insurance	Costs and benefits are felt simultaneously	Cost–benefit trade-off, Costs invested in climate change impact-related activities during last year, Benefits from invested costs for last year	[37]
Large scale (e.g., farm level)	Crop diversification in entire farm, Irrigation system development, Displacement of farm activities, Land use change	Small scale (e.g., crop level)	Measures for single crops, Measures for seasonal calendar for a year	[37,75]
Planned for long-term climatic shocks (at least for ten years)	Minimum ten-year periodic plan against expected climate change impacts, e.g., drought, flood, crop pest, hailstorm, Multi-year strategic plan, Conservation of water sources	Planned for short-term climatic shocks (e.g., yearly)	Short plan for experienced impacts, e.g., crop and livestock yield, price fluctuations, market fluctuations in food and input prices, Annual plan/short plan for existing stimuli, Seasonal plan in the year	[117,136,137]
Risk assessment of future climate change impacts	Use of information for plan to curb harm, Use of climate data to increase beneficial opportunities in the future	Instant implementation of measures	Based on available skills, resources, and opportunities for actions to contemporary/changed climatic condition	[138,139]
Aimed to reduce exposure to future risks	Investment/initiations at reducing anticipated risk and cost	Informed by direct experiences	Resources are targeted to already-known risks	[140]
Use of historical pattern for long- term plan	Considering the climate/weather trend of at least 10 years before while making plan	Individual experiences	No consideration	Based on local people, circumstances, and experts
Arrangement of emergency supports	Establishment of emergency support system within individuals/groups	Fund/trained person for disasters and risk	Not yet concern	Based on local people, circumstances, and experts

3. Materials and Methods

3.1. Study Area

We conducted this study in Nepal which is endowed with diverse ecological and geophysical variations from lowlands to high mountains. The physiographical heterogeneity caused not only demographical variations but also differentiated climate change impacts. This study represents three ecological regions of Nepal—high mountains, mid-hills, and lowlands (*Terai*) concentrated in Taplejung, Gorkha, and Kailali districts of the regions, respectively (Figure 2). The districts in Nepal serve as administrative divisions used to assess the climate vulnerability of different regions. According to a recent vulnerability report by the Government of Nepal, Taplejung has been categorized as having a very high vulnerability and Gorkha as having a high vulnerability to landslide disasters. Similarly, Kailali has been classified as having a very high vulnerability to floods [141].

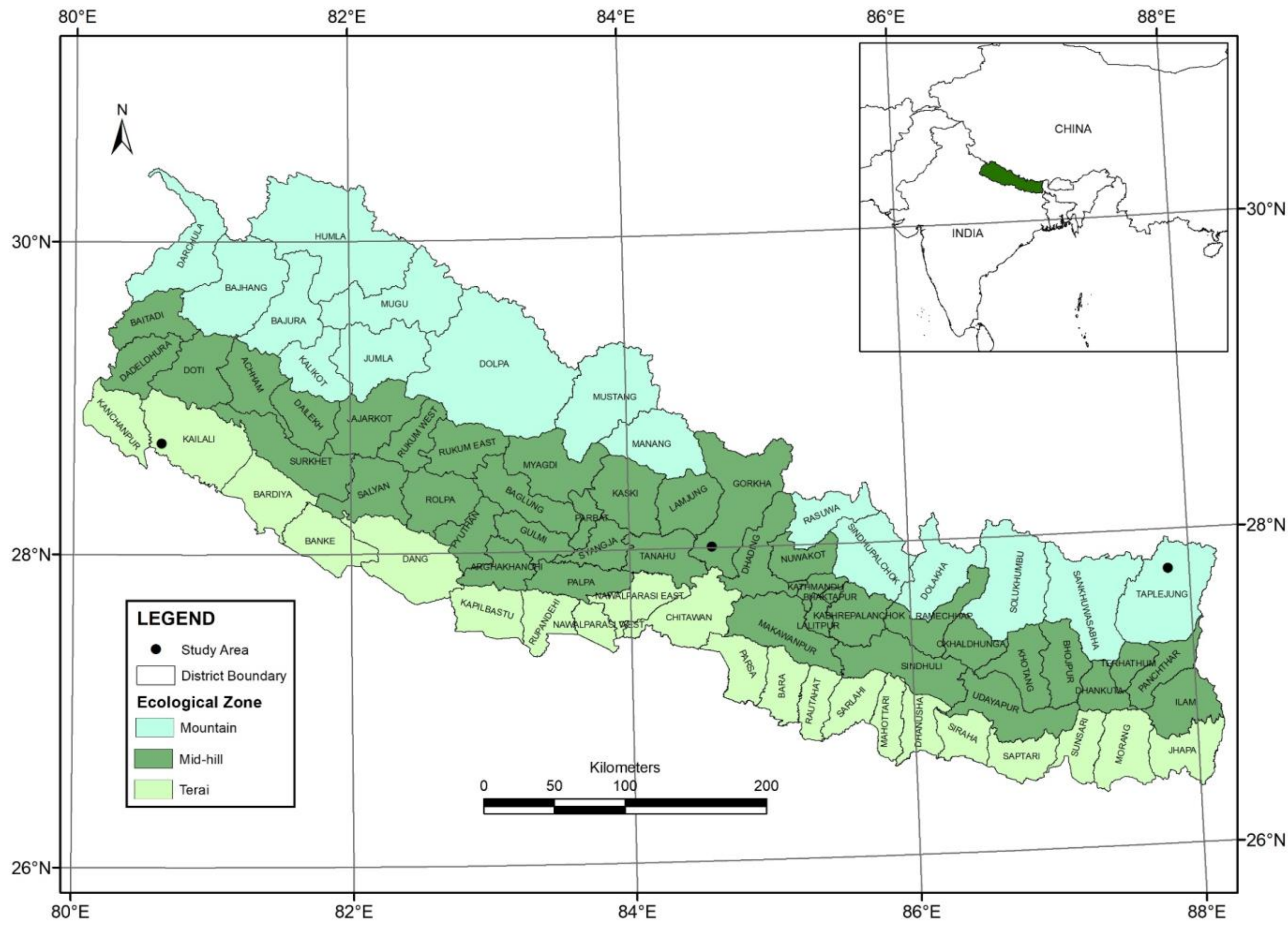

Figure 2. Map of Nepal showing three ecological zones and the study sites, which are indicated with black filled circles. Taplejung district is in the northeast in the high-mountains region, Gorkha district is in center in the mid-hills region, and Kailali district is situated in the southwestern part of the lowland *Terai* region.

Three community forestry user groups (CFUGs) with varied socio-economic backgrounds were chosen for the study, each representing a different ecological region (Table 2).

Table 2. Studied Community Forest User Groups (CFUGs) and number of interviewed households.

Name of CFUG and Location	Geographical Regions	Total Number of Households (HH) in the CFUG	Sampled HH (No)
Sinkechu CFUG—Pathibhara Yangbarak 2, Taplejung	Mountain	53	21
Dhandswara Kapre CFUG—Barpak Sulikot 7, Gorkha	Mid-hills	114	35
Taranagar CFUG—Dhangadi Sub-metropolitan City 5, Kailali	Lowland	338	68
Total		505	124

There are several reasons behind choosing the CFUGs. First, meteorological data of temperature and precipitation for the last 30 years (1988–2018) observed by meteorological stations located in the vicinity of the CFUGs have been analyzed by recent study. While the annual temperature increased in Taplejung, Gorkha, and Kailali districts at rates of 0.061 °C, 0.063 °C, and 0.0178 °C, the corresponding rainfall decreased by −9.7 mm, −3.6 mm, and −0.04 mm per year for the districts, respectively [39]. Although the trend of rainfall patterns was decreasing, the internal variability and concentration of rainfall distribution were observed to be becoming erratic, most noticeably in Kailali (ibid). This analysis provides an important relationship with the local impacts generated from climate change. Second, the climate and the attributes of climate change impacts vary between ecological regions. Darjee, Neupane, and Köhl [39] also discuss that mountain regions possess a cool temperate, alpine, and tundra type of climate and suffers from permafrost thaw, glaciers, and risks of bursting of glacial lakes incurred by climate change. The people from the mountain region of Taplejung experienced multiple impacts and indicators including shrinking snow layer, drying water source, and shifting seasonal calendar. The mid-hills contain warm-to-cool temperate climates and suffer a higher risk of landslides and erosion due to erratic rainfall. In the mid-hills region of Gorkha, prolonged droughts, dried-up water sources, and increasing rainfall intensity were commonly experienced by local people. The *Terai* comprises a tropical-to-subtropical climate having southern plains and the foothills of the Siwalik. The people living in Kailali district of the *Terai* region have been severely affected by flooding, inundation, and hot and cold waves. Given these facts and features, the selected sites are appropriately representative in studying climate change impacts and local people's responses.

3.2. Sampling Frame and Data Collection

This study employed a mixed methods research (MMR) approach which combined and integrated both qualitative and quantitative data collection and analysis. Several research methods were used, including household surveys, focused group discussions (FGDs), expert interviews (EIs), and interviews with key informants (KIs). Primary data were collected using social survey methods during the period from May to August 2022. The household survey conducted in this study exclusively focused on proactive responses of local communities to climate change impacts experienced at the local level, as well as determining factors influencing the implementation of these adaptations. A total of 124 households participated in the survey (Table 3). The sample size for household interviews was determined using Yamane's equation [142], which calculates the number of households to be interviewed based on a specified level of precision, as illustrated in the following formula.

$$n = \frac{N}{\left(1 + Ne^2\right)}$$

where n is the sample size, N is the population size, and e is the level of precision.

Table 3. Types of data collection methods and descriptions of the participants.

S.N.	Data Collection Tools	Number of Events	Number of Total Participants	Men	Women
1	Household survey (semi-structured interviews)	124	124 (25%) *	93	31
2	Focus group discussions	9	85	47	38
3	Key informant interviews	18	18	14	4
4	Expert interviews	20	20	15	5

* indicates "out of total households".

Semi-structured interviews were conducted with the households. These interviews involved a combination of predetermined and open-ended questions, focusing on households' observations of climate change impacts and their response strategies. The primary emphasis of the semi-structured interviews was to explore local proactive adaptation measures implemented by households following their experiences with climate change impacts. Given the study's focus on local adaptation practices among vulnerable groups, respondent diversity was ensured by including women, indigenous peoples, poor households, and those considered climate-vulnerable. To enhance the reliability of the interview responses, data triangulation was conducted through nine FGDs with three FGDs conducted in each district, comprising 8–10 participants per FGD.

Expert interviews were carried out to obtain insights into the consideration of locally practiced adaptation in policy. A total of twenty experts from various organizations, including the Ministry of Forest and Environment (MoFE), Department of Forest and Soil Conservation (DoFSC), REDD Implementation Centre, International Non-governmental Organizations (INGOs), and National Non-governmental Organizations (NGOs) were consulted. Additionally, 18 key informants from the Federation of Community Forestry Users Nepal (FECOFUN), the ex-chairperson of the studied CFUG, local health technicians, and local entrepreneurs provided valuable information. Furthermore, the study incorporated additional information and knowledge obtained from case studies and direct observation notes. For the FGDs, EIs, and KIs, a predetermined checklist was used to keep participants focused on the primary objective of the discussions.

The study employed a stratified random sampling method for the household survey and purposive sampling for the FGDs, considering different community categories identified in the CFUG's operational plan. Snowball sampling was used for expert interviews and key informant interviews.

3.3. Statistical Analysis

We used descriptive statistics to summarize and present the data. A chi-square (X^2) test of independence was used to determine the degree of association between indicators of varieties of proactive adaptation and the range of measures employed by local households. We tested the relations between eight distinct criteria of proactive adaptation (Table 1, Column 1) and the adaptation activities adapted to the six different categories, i.e., "Agriculture crop", "Cash crop", "Livestock", "Business", "Disaster", and "Other". All of the responses were dichotomous (1 for "yes" and 0 for "otherwise"). We employed the ordered logistic regression model to explain explanatory power of some essential socio-economic and demographic variables on the level of choosing proactive adaptations. We used the log likelihood ratio chi-square test to measure the goodness of fit of the model. This test has been widely used in many different similar studies, e.g., [102,129,130,132].

We used STATA 17 to analyze the data, mostly using the quantitative method. A detailed explanation of the variables is presented in Table 4.

Table 4. Summary statistics of explanatory variables for ordered logistic regression and chi-square test for categorical variables.

Variable	Explanation	Mean	S. D.
Livelihood option	Diversification of livelihood options of the households (HH) (1 = only one option, 2 = two options, 3 = three or more options)	-	-
Wellbeing category	Wellbeing rank of the HH (1 = poor, 2 = medium, 3 = rich)	-	-
Land area	Cultivated land areas owned by the HH (m sq.)	6.909	0.668
Sex	Sex of household head interviewed (0 = female, 1 = male)	-	-
Geographical variation	Geographical location of the household respondents (1 = *Terai*, 2 = mid—hill, 3 = mountain)	-	-
Number of adaptation activities	Number of climate change adaptation activities employed by the individual HH (1 = 1–2, 2 = 3–4, 3 = more than 4)	-	-
Average experience of major occupation	Duration of major occupation of respondents (years)	25.911	0.869
Adaptation measure before possible shock	1 = ″yes″ and 0 = "otherwise"	-	-
Investment for future benefits	1 = ″yes″ and 0 = "otherwise"	-	-
Large scale (e.g., farm level)	1 = ″yes″ and 0 = "otherwise"	-	-
Planned for long-term climatic shocks (at least for 10 years)	1 = ″yes″ and 0 = "otherwise"	-	-
Risk assessment of future climate change impacts	1 = ″yes″ and 0 = "otherwise"	-	-
Acquired skill trainings for future possible shock	1 = ″yes″ and 0 = "otherwise"	-	-
Use of historical pattern for long-term plan	1 = ″yes″ and 0 = "otherwise"	-	-
Arrangement of emergency support/funds for uncertain shocks	1 = ″yes″ and 0 = "otherwise"	-	-

4. Results

4.1. Key Characteristics of Household Interviewees

Table 5 displays the key descriptive characteristics of the households including sex, age, education, wellbeing, and land areas owned by households. The diverse inclusion of household respondents suggest that the qualitative responses are representative, ensuring not only a higher level of confidence, but also increasing the reliability and validity of information obtained from heterogeneous communities. We interviewed 124 households out of 505, representing 25% of the households of the studied communities. All of the households in the communities were directly and indirectly involved in subsistence agriculture for their livelihoods. In the rural communities of Nepal, a large proportion of women are vigorously active in agricultural works and day-to-day household chores, hence deemed to be more affected by climate change in the farming community. So, a quarter of the total number of women respondents in sampled households were chosen for the interview.

Household surveys included respondents with ages ranging from 28 to 87 years. Nearly two-thirds of the respondents were older than 50 years followed by the group with ages between 40 to 50 years. These groups have been considered being able to compare the past events at least 30 years prior with current experiential climatic events and execute appropriate proactive adaptations in every way possible and as much as they can. Nearly 17% of household respondents were from the age group below 40, and they were expected to be concentrated predominantly on recent changes of climate and its impacts and thereby apply adaptation measures. The study covers educated, literate, and illiterate respondents. Educated respondents included individuals with university- and school-level education. Literate individuals were those who could read and write, possessing little or no formal education but might have nonformal education, such as adult literacy classes. Illiterate individuals were considered to be those who could not read and write. The wellbeing categories of households were mentioned in the constitution of the studied CFUGs. More than 80% of respondents were from the "medium" category. The wellbeing categories are essential in determining the choice of adaptation options in rural communities. The mean agriculture land size of interviewed households was 0.34 ha, ranging from 0.006 ha to 2.7 ha. In Nepal, the majority of the farmers are small farmers operating on less than 0.5 ha [143]. The size of land for cultivation is considered a robust indicator for determining the wellbeing of rural dwellers. Thus, it influences the implementation of proactive and reactive adaptation measures related to agriculture and livelihood-based climate change adaptation.

Table 5. Basic socioeconomic attributes of studied households.

Characteristics	Sub-Characteristics	Total No. (*n*)	Percentage (%)
Sex	Male	93	75.0
	Female	31	25.0
Age (years)	>50	65	52.4
	40 to 50	38	30.6
	<40	21	16.9
Education	University level	11	8.9
	School level	54	43.5
	Literate	32	25.8
	Illiterate	27	21.8
Wellbeing category	Rich	7	5.6
	Medium	100	80.6
	Poor	17	13.7
Land description	Minimum	0.006 ha	
	Maximum	2.7 ha	
	Mean	0.34 ha	

4.2. Proactive Climate Change Adaptation Implemented by the Households

Residents in the communities who participated in the interviews and FGDs implemented several proactive and reactive adaptation activities to tackle the perceived severity of future and current existential climate change impacts. Given the experience of local people regarding the trends of climate change and its consequences over the last three decades, analysis shows that 22.6% of interviewed households assumed the present climate change scenario will continue in the future, while 77.4% of them predicted that the impacts of climate change will become even more perilous, and were initiating local level adaptations proactively.

Building on the eight criteria for proactive and reactive adaptation, 84% of the households adapted to climate change by implementing both proactive and reactive measures simultaneously, 10.5% households applied only reactive adaptation measures, and 5.6% were earmarked for climate change issues with the implementation of proactive adaptation measures only. To adjust with the changing climate, the households shifted livelihoods options in multiple ways through the implementation of more than 50 diverse adaptations activities proactively (details in Table S1 in the supplementary materials). Table 6 provides an overview of the six major categories of those adaptation measures related to rural livelihoods. The analysis revealed that a significant proportion of the adaptation measures undertaken by the households were focused on climate hazards and agriculture. Around one-third of the proactive measures were aimed at reducing the impacts of natural disasters (30%), followed by agricultural crop diversification (26%). Additionally, 18% of the measures included promoting and adjusting livestock practices to climate conditions. The promotion of small enterprises (16%) and the cultivation of cash crops were also identified as viable livelihood options. Other activities such as livestock insurance, promotion of solar energy, migration, and wage labor were also observed.

Table 6. Thematic areas of the climate change adaptation and climate change adaptation measures implemented by the local households.

Thematic Areas of Adaptation	Activities Implemented by Households	Proportion
Disaster/hazards control	• Plantation in flood- and landslide-risk zones (e.g., canal site bamboo plantation) to control landslide/flood, protect water source • Establishment of wind break • Control grazing on riverbank to make riverine erosion feeble and to avoid further expansion • Goat shed built 2–3 feet above ground level with aluminum roof that prevents the shed from heavy rain and hail • Wrapped livestock shed with wooden planks for warmth during winter • Storing of potato seeds wrapped with rice straw below the ground/hole inside the house • Hanging crop seeds on tree branches to protect from floods and inundation, used same tree for timber, fruits, shade, soil protection, and so on • Raised foundation of house for avoiding risk of intense flood and inundation • Promoted houses coated with mud and wood to prevent from extreme cold and heat, drainage/cabin box construction, and so on	30%
Agriculture crop diversification	• Switching to more adversity-resistant crops • Promotion of off-season crops and vegetable cultivation (e.g., cauliflower, lentils (*Lens culinaris*) instead of rice) • Testing of different varieties of crop cultivars (e.g., red potato, white potato, baby potato, locally known as Tharu Aalu, and other hybrids of potatoes; mango; rice varieties locally known as Ramdhan, Sabitri, Chainpur, and Radha-4; and upland rice (*Oryza sativa* L.), locally called Ghaiya being replaced by millet • Promotion of local crop variety	26%
Livestock raising	• Shifting to livestock (e.g., goat farming, chicken farming, fish farming, pig rearing) • Local livestock promotion • Local chicken promotion	18%
Small enterprise development	• Business in lieu of agriculture crops (e.g., local sugar juice production, electric shop, hardware shop, small retail shop, cycle repairing stall, stool-making business) • Local business enlargement	16%
Cash crop cultivation	• Promotion of cash crop variety (e.g., ginger, turmeric, Colocasia fruit/Yam)	6%
Other option	• Livestock insurance, promotion of solar energy, migration, labor	4%

4.3. Proactive Climate Change Adaptations and Their Association with Local Livelihoods Options

Table 7 presents eight indicators for proactive climate change adaptations (PCCA) and explains them in relation to six major aspects of local livelihood options that have been affected by climate change. Chi-square test statistics of the relationship between indicators of PCCA measures and local livelihood options depict noticeable associations. Out of the eight indicators of PCCA, five were significantly connected to PCCA activities, namely actions before possible shock, investment for future benefits, large scale, risk assessment of future climate change impacts, and use of historical patterns for long-term plan.

As adaptive measures, agricultural crop diversification was found to be strongly associated with prior actions of adaptation ($p \leq 0.003$), investment for future benefits ($p \leq 0.007$), expanding in larger farm scale ($p \leq 0.007$) at the significance level of 1%, and risk assessment of future climate change impacts ($p \leq 0.073$) at the significance level of 10%. The local people have a tendency towards cash crop cultivation which is significantly correlated with investment for future benefits ($p \leq 0.071$, significance at 10%) and use of historical patterns of weather and climate change for introducing crops to farmland ($p \leq 0.025$, significance at 5%). The adaptation actions related to livestock raising showed connection with investment for future benefits ($p \leq 0.002$, significance at 1%) and actions before possible shock ($p \leq 0.075$, significance at 10%). Shifting towards small enterprise development for adaptation displayed signs of significant relationship with larger scale coverage of farmland ($p \leq 0.026$) at the significance of 5%. Disaster control-related activities implemented by households were found to hold significant association with their own way of perceptual risk assessment of future climate change impacts ($p \leq 0.086$) at the significance level of 10 %. Other options, for example, livestock insurance, promotion of solar energy, and migration, showed no significant relations with any of the PCCA criteria; however, these activities' components are considered essential in adaptation to climate adversity. The results clearly informed that most of the rural adaptation activities are connected to the scope of proactive initiations against climate change impacts and risk. This indicates that individual households possess valuable knowledge about the local climate and have acquired it through their own traditional practices of assessing climate impacts and analyzing threats. This knowledge is closely intertwined with their livelihood strategies, leading them to implement local adaptation measures.

Table 7. Chi-square test statistics of the associations between the selected criteria of proactive climate change adaptation measures and major areas of adaptation of rural farm households.

Criteria of Proactive Adaptation Against Climate Change Impacts	Agriculture Crop Diversification X^2 (*p*-Value)	Cash Crop Cultivation X^2 (*p*-Value)	Livestock Raising X^2 (*p*-Value)	Small Enterprise Development X^2 (*p*-Value)	Disaster Control X^2 (*p*-Value)	Other options X^2 (*p*-Value)
Actions before possible shock	8.8837 (0.003 ***)	0.0194 (0.889)	3.1654 (0.075 *)	0.0013 (0.971)	0.4657 (0.495)	1.2783 (0.258)
Investment for future benefits	7.2650 (0.007 ***)	3.2570 (0.071 *)	9.7006 (0.002 ***)	1.4097 (0.235)	0.2996 (0.584)	1.6977 (0.193)
Large scale (e.g., farm level)	7.2188 (0.007 ***)	0.2657 (0.606)	1.9429 (0.163)	4.9887 (0.026 **)	0.4958 (0.481)	2.0239 (0.155)
Planned for long-term climatic shocks (at least for ten years)	1.1819 (0.277)	0.0024 (0.961)	0.4211 (0.516)	0.4211 (0.516)	0.0487 (0.825)	0.1352 (0.713)
Risk assessment of future climate change impacts	(3.2220 (0.073 *)	(0.9544 (0.329)	(0.6163 (0.432)	(0.6163 (0.432)	(2.9509 (0.086 *)	0.6235 (0.430)
Acquired skill training for future possible shock	0.6888 (0.407)	0.3119 (0.577)	0.0815 (0.775)	1.9429 (0.163)	1.7190 (0.190)	1.0472 (0.306)
Use of historical patterns for long-term plan	0.9518 (0.329)	4.9932 (0.025 **)	0.3391 (0.560)	0.3391 (0.560)	1.1719 (0.279)	0.1360 (0.712)
Arrangement of emergency support/funds for uncertain shocks	0.0130 (0.909)	0.4831 (0.487)	0.1661 (0.684)	0.1661 (0.684)	0.0386 (0.844)	0.3631 (0.547)

*** Significance at 1% level, ** 5% level, * 10% level.

4.4. Factors Affecting Households' Choice of Proactive Adaptation Measures

The results of an ordered logistic regression model of factors associating choices of proactive adaptation strategies are presented in Table 6. The likelihood ratio test showed that the model was significant with a chi-square value of 26.69 ($p \leq 0.0034$) and had a pseudo R^2 of 0.26. Our results showed that five out of eleven socio-economic explanatory variables were statistically significant with proactive adaptation measures taken by climate-affected households. Significant factors include the number of livelihood options, wellbeing of households, land area owned, geographical variations, and the number of adaptation activities (Table 8). In comparison to households relying on a single livelihood option, households with two livelihood options demonstrated a significant tendency towards proactive adaptation ($p \leq 0.047$) at a 5% level of significance. However, the proactive adaptation of households with three or more livelihood options was not statistically significant, although the coefficient value was positive. The findings suggest that there is a positive relationship between the number of livelihood options available to the households and their likelihood of taking proactive actions.

The analysis found that households with poor wellbeing had significantly negative impacts ($p \leq 0.009$) at a 1% level of significance compared to those households with a medium level of wellbeing. However, the comparison between the households with medium and high levels of wellbeing did not yield significant results, although the coefficient was positive. This suggests that the likelihood of taking proactive measures decreases significantly with increasing poverty and vice versa.

The analysis of proactive actions in relation to land ownership reveals a negative association. Households with smaller land areas for cultivation were significantly less likely ($p \leq 0.027$ at a 5% level of significance) to adopt proactive climate change adaptation measures. When examining the population across three ecological regions, it was observed that households residing in the mid-hills demonstrated a significant tendency ($p \leq 0.017$ at a 5% level of significance) to engage in proactive adaptation compared to those residing in the lowland region. This suggests that the variation in altitude influences the selection of adaptation strategies. One possible explanation for this observation is that higher-altitude areas are more susceptible to climate-induced hazards, leading to greater impacts on the populations living there. As a result, these populations are more likely to proactively engage in adaptation measures to mitigate the effects of such hazards.

The number of adaptation activities implemented by individual households emerged as a decisive factor. Households implementing more than three distinct adaptation activities were significantly more likely ($p \leq 0.068$ at a 10% level of significance) to include proactive adaptation measures, compared to the households implementing up to two activities. However, there was no significant association observed between proactive adaptation and factors such as sex or the length of major occupation experience. Nevertheless, the negative coefficient between sex and proactive adaptation indicated that women appeared less likely to implement proactive adaptation measures. The same trend was observed with occupational experience, suggesting that a shorter duration of experience reduced the likelihood of including proactive adaptation in overall adaptation measures.

Table 8. Ordered logit estimation explaining major socio-economic factors for proactive adaptation measures.

Variables Number of Proactive Measures with Reactive	Coefficient	S.E.	*Z*-Value	*p*-Value
No. of livelihoods options adapted by the households				
• Only one option adopted (Base)				
• Two options adopted	1.525	0.766	1.990	0.047 **
• Three or more options adopted	1.780	1.318	1.350	0.177
Wellbeing category of the households				
• Rich household	20.065	1394.114	0.010	0.989
• Medium household (Base)				
• Poor household	−2.617	0.999	−2.620	0.009 ***
Land area owned by the households	−0.185	0.083	−2.210	0.027 **
Sex of the respondent interviewed (Base Male)	−0.500	0.748	−0.670	0.504
Regional residential differences				
• Mountain-region residents (Base)				
• *Terai* residents (Lowland)	0.813	0.892	0.910	0.362
• Mid-hills residents	2.554	1.068	2.390	0.017 **
Number of adaptation measures implemented				
• One to two adaptation measures implemented (Base)				
• Three to four adaptation measures implemented	0.581	0.887	0.660	0.512
• More than four adaptation measures implemented	2.237	1.228	1.820	0.068 *
Experience of major occupation (years)	−0.031	0.045	−0.690	0.490

LR $chi^2(11)$ (*p*-value) = 26.69 (0.0034), Pseudo R^2 = 0.2648, Log likelihood = −36.435095; *** Significance at 1% level, ** 5% level, * 10% level.

5. Discussion

5.1. Proactive Climate Change Adaptation through the Lens of Local Communities Affected by Climate Changes

Based on the eight criteria for assessing the proactive nature of adaptation, the diverse range of local-level adaptation measures implemented by the households indicate proactive responses to the recurring impacts and escalating severity of climate events. Rural households have demonstrated a self-driven proactive approach by implementing diverse adaptation measures at the local level. The proactive measures implemented by the local households not only reflect the local community's efforts to address immediate challenges posed by climate change but also demonstrate their awareness of future environmental risks and their proactive measures to mitigate them.

The analysis of the responses indicates that the proactive adaptation process undertaken by households aligns with the motivation theory [106,108] and the process model of private proactive adaptation to climate change proposed by Grothmann and Patt [102]. Knowledge and the processes of adaptation, by which individuals or communities effectively adjust to changed environments over time, largely stem from empirical and analogical analyses [88,144–147]. The significant findings regarding the association between the cognitive evaluation of households in assessing the risks of future climate change impacts and their choice of livelihood options indicate that individuals actively assess the severity of climate conditions in their surroundings (risk appraisal) and make decisions based on this evaluation. The majority (77.42%) of the households interviewed expressed the anticipation that climate change will become more menacing in comparison to the current scenario, leading to more rapid and erratic fluctuations in temperature and precipitation. Conversely, the remaining respondents believed that the current trend and variability of climate change would persist without significant change (risk appraisal). These findings align with a previous study conducted in the same area, which examined the significance of meteorological records and local peoples' perceptions [39]. Subsequently, they anticipate a higher likelihood of being further exposed to the worsening of climate-related disasters, such as floods, inundation, landslides, extreme temperatures, heatwaves, cold waves, wind-throw, and wind damage (perceived probability). Based on these anticipations, the households predicted severe impacts, including property loss (such as houses, land, and livestock), reduced land productivity, crop quality loss, and the invasion of pests and pathogens (perceived severity). Consequently, they engaged in preparatory measures to avoid or minimize potential worst-case scenarios (adaptation appraisal). As suggested by Schwartzer [148], individuals contemplate the possibility of beneficial adaptation options and reflect on their suitability. Considering the predicted threats and the severity of impacts, local households have developed beliefs about certain adaptation measures that could reduce vulnerability (perceived adaptation efficacy). For instance, in this case, local people have recognized that diversifying crops and adopting more resilient and climate-adapted varieties can provide better protection against losses and damages caused by drought, heatwaves, cold waves, extreme weather events, and disease outbreaks. After careful consideration, the local households made decisions to pursue over 50 different proactive adaptation activities (perceived self-adaptation efficacy) based on their own knowledge, available resources, and perceived costs associated with adaptation (perceived adaptation cost). Subsequently, they implemented these chosen measures (adaptation).

Based on our findings, it is evident that the perceived severity of climatic threats, self-efficacy, and adaptation efficacy significantly influence an individual's motivation to actively engage in practical climate change adaptation measures. These results align with previous studies that have also demonstrated the predictive role of these factors in motivating individuals to take action towards climate change adaptation, e.g., [116,149–151]. Regarding the adaptation behavior of forest growers, our findings largely support the study conducted by Villamor, Wakelin, Dunningham, and Clinton [117] on risk appraisal. They found that local forest owners perceive climate risks such as heavy rain, floods, debris flow, landslides, wind damage, pests, diseases, forest fires, and market disruptions. However Bostrom, Hayes, and Crosman [114] argued that the perception and judgment of self-efficacy and response efficacy may differ between individual actions and those taken by the government or collective entities. They highlighted that these perceptions are context-specific and can be challenging to perceive precisely.

As indicated in the results, five out of the six clusters of adaptation activities aligned with one to four criteria of multiple forms of adaptive behavior observed in the studied households. These criteria included taking actions prior to potential climate change impacts, investing for future benefits, scaling up adaptation options at the farm level, and perceptual risk assessments of future climate change impacts. An illustrative example of proactive adaptation practiced by local people is the plantation of trees in risk-prone zones, which has been shown to save lives and properties. In Kailali district (*Terai*), for instance, a severe storm occurred in June 2019, causing significant damage to the Najaria and Dogara hamlets. While 20 to 25 out of 70 houses were destroyed in Najaria, 4 houses were affected in Dogara. According to the respondents, the presence of a large number of trees surrounding the houses in Dogara reduced the impact of the storm. Moreover, these trees served the additional purpose of hanging crop seeds, a traditional practice used to store seeds and protect them from floods. This example demonstrates how local people took proactive measures in anticipation of potential risks, indicating long-term planning, future risk speculation, and control as indicators of proactive adaptation. Other typical examples of proactive adaptation measures include building goat sheds raised 2–3 feet above ground level and constructing houses with raised foundations coated with mud and wood. These measures serve as protective actions against climate adversities such as floods, inundation, extreme heat, and extreme cold. They are precautionary measures aimed at mitigating future climate-related challenges. Several proactive actions serve multiple purposes, and one such example is the planting of trees by the households. Households receive multiple benefits from this, including mitigating the risks of soil erosion and wind damage, protecting agricultural lands from inundation, preserving seeds during floods, producing timber and fruit, and providing shade during extreme temperatures. It suggests that households' adaptation measures not only help them adjust to the changing climate but also serve as viable means of sustenance in rural areas.

These findings provide strong empirical evidence that households impacted by climate change tend to proactively engage in climate change adaptation. Proactive adaptation is widely recognized as an essential strategy for mitigating the cumulative effects of climate change and reducing adaptation costs. A study conducted by Melvin, et al. [152] on the economic impacts of climate change on Alaska's public infrastructure under high and low climate forcing scenarios (Representative Concentration Pathways RCP 8.5 and RCP 4.5) supports this concept. The study estimated that, without adaptation measures, the cumulative expenses for climate damage to infrastructure from 2015 to 2099 would amount to USD 5.5 billion for RCP 8.5 and USD 4.2 billion for RCP 4.5. However, with proactive adaptation measures in place, the total projected cumulative expenditures were reduced to USD 2.9 billion for RCP 8.5 and USD 2.3 billion for RCP 4.5. This projection highlights that proactive adaptation not only mitigates the severity of climate change impacts but also alleviates the economic burden on stakeholders involved in the adaptation system.

As described by Smit and Pilifosova [89], proactive (planned, anticipatory) adaptation has the potential to reduce vulnerability and capitalize on beneficial opportunities. In our study, shifting from subsistence agriculture to new livelihood options, such as small enterprise development, livestock raising, and cash crop cultivation, exemplifies the opportunities created by climate change. Many households recognized the increased sensitivity and riskiness of annual cereal crops to climate change variability as well as the higher incidence rates of pests and pathogens. Consequently, they made decisions to shift towards livestock production and vegetable farming, which are considered relatively less sensitive to climate change compared to cereal crop production. This demonstrates the local community's ability to consciously assess future climate risks based on historical patterns of impacts. Most farmers were expected to transition from cereal crop production to livestock and vegetable production, on a larger scale than before, for a period of 5 to 10 years. These hands-on processes and actions align with multiple criteria of proactive adaptation. A compelling case from a young farmer in Gorkha district supports the case. After facing multiple climate-related challenges and failures with cereal and cash crop cultivation (such as rice, black cardamom, and potato), he decided to venture into cow farming, pig rearing, and a local poultry farm. Despite the initial difficulties, he expressed contentment with his new endeavors, stating, "*I used to do agriculture for subsistence in the past, but now I am pleased with my business as I earn more than expected. This allows me to afford a good education for my children, sufficient food for my family, and even some savings in the bank for emergencies*". This illustrates that individual households not only proactively seek to diversify their usual choices but also perceive them as opportunities for improved livelihoods.

Our findings are consistent with the research conducted on farmers in Chile [151] and the coastal region of Bangladesh [153]. These studies also identified unpredictable weather, heat stress, water scarcity, and pest and pathogen invasions as significant risks impacting agricultural productivity and livelihoods. In response to these challenges, farmers employed proactive adaptation measures such as diversifying species, switching to more resilient crops, altering farming practices, and utilizing improved seeds or varieties for annual crops. Similar proactive practices were also observed in the study by Roche [154], which focused on livestock promotion, including strategies like grass banking, stocking conservation, and incorporating yearling cattle and other livestock types to increase flexibility. Smit and Pilifosova [89] documented the implementation of artificial systems to improve water utilization, prevent soil erosion, and adopt different crop varieties. Our findings are in accordance with numerous previous studies, e.g., [39,49,67,68,125,132,155–162], that have examined locally implemented adaptation activities. However, it is important to note that in some cases, such as in agriculture, abandoning existing occupational activities or ceasing farming options [151,163,164] can have immediate consequences for locally intertwined self-employment. In Gorkha (mid-hills), for example, a blacksmith (one interviewee) who had been engaged in manufacturing agricultural equipment was on the verge of abandonment of his traditional occupation because of reduced demand for agricultural equipment, resulting from decreased agricultural practices in his village. This situation is not unique to Gorkha but is also observed in the *Terai* region. The economically marginalized and small-land holders (interviewees) used to work agricultural wage labor in the region. Several wealthier farmers are now downsizing their farming size. This has significantly reduced the seasonal and local employment in the agriculture sector. These examples signify that climate change is having significant and ongoing impacts on the interlinked systems of people's livelihood choices and the drivers of the local socio-economic system. Furthermore, it suggests that developing and implementing context-specific adaptation measures is essential in ensuring the long-term sustainability of these systems.

5.2. Factors Affecting Households' Choices of Proactive Adaptation

The effectiveness of adaptations relies on the adaptive capacity of the human system, as various types of adaptations are expected to take place [89]. Within this system, several socio-economic factors influence the selection of adaptation measures. In our study, household wellbeing, the number of available livelihood options, the size of agricultural land for cultivation, geographical variations, and the number of implemented adaptation activities were identified as key factors determining the choice of proactive adaptation measures. Households with multiple livelihood options, a greater number of adaptation activities, and larger agricultural land size are more likely to opt for and adopt proactive adaptation measures, alongside other climate change adaptation strategies and livelihood approaches. These factors also play a significant role in determining an individual's economic status, whether they are well-off or living in poverty.

The negative coefficient observed for the wellbeing category indicates that poorer households are less likely to engage in proactive adaptation actions. This suggests that wealthier farmers have a greater capacity to explore and utilize multiple alternative adaptation options. The determinants of adaptation analyzed in the earlier studies, for example, the studies of Kabir, et al. [165] in Bangladesh, Tun Oo, et al. [166] in Myanmar and Tambo and Abdoulaye [125] in Nigeria, also support the case. Households possessing more agricultural land also tended to engage in a greater number of adaptation activities [39,132,167,168] by partitioning their farming land for multiple purposes, for example, cultivating various crops, growing vegetables, and raising livestock simultaneously. Households with larger landholdings have greater flexibility in utilizing their land which reduces risks and enhances their ability to afford losses from crop failures. This suggests that land plays a crucial role in increasing the implementation of proactive measures to address climate change challenges.

Altitudinal variation significantly influences the selection of proactive adaptation strategies, as different regions exhibit varying levels of exposure and vulnerability to climate risks. Our findings indicate that households residing in the mid-hills display a greater inclination towards proactive adaptation compared to those in lowland areas. The choice of adaptation strategies is influenced by various factors, including exposure, vulnerability, local culture, society, economy, and geography. High-altitude communities often bear the brunt of more climatic hazards, leading to increased adoption of adaptation measures. Mountainous regions in Nepal face a heightened degree of climate threats [169,170]. Perception of higher climate risk severity and extreme threats in mountain regions drive proactive adaptation. Numerous studies support the facts that higher-altitude regions experience greater climate severity, e.g., [22,171–175], thereby increasing the likelihood of households adopting proactive measures [102]. Individuals employ adaptation measures against climate change impacts based on their personal perceptions and observations of climate change [156,176,177].

Age and length of major occupation did not significantly influence proactive adaptation actions. Previous studies have highlighted age and farming experience as important factors in climate change adaptation. However, our findings align with the observation of Bui and Do [132] that age does not impact adaptation choices. While Nhemachena and Hassan [168] suggest that highly experienced farmers are more likely to possess knowledge and take adaptation actions, our results show an ambiguous and insignificantly negative correlation. This suggests that long experience and older age do not necessarily drive the selection of proactive adaptation measures. One possible explanation is that younger farmers often have better education and are more open to adopting novel ideas [167,178], while older and experienced farmers may be more reluctant to embrace new technologies [179].

We observed that the biggest challenge faced by innovative farmers was the market and market access for cash crops, vegetables, and livestock products (e.g., milk, meat, and eggs). Limited available markets are often dominated by outsiders and middlemen. This situation has two negative effects. Firstly, farmers struggle to obtain fair prices for their perishable local products, which are prone to price fluctuations. Secondly, the combination of climate change impacts and market inaccessibility discourages farmers from continuing with their adopted measures. The issue of market constraints has been raised in various studies, e.g., [180–182].

The adaptive capacity of local households is shaped by a variety of factors, which influence their decision making regarding the utilization of limited resources. Common factors that come into play include economic wealth, infrastructure, technology, information and skills, institutions, and equity [18,89,183,184]. The decision-making process for adaptation varies across different scales, including adaptation by private individuals, local communities or institutions, national governments, and international organizations [89]. In our study, we specifically focused on private individual adaptation through direct interaction with individual households, which allowed us to draw conclusions about entire studied communities. Since the selected communities in our study have not received any external support for adaptation, external interventions were not applicable and were not considered in our analysis.

5.3. Proactive Local Actions: Embracing Transdisciplinary Approaches Bridging Adaptation and Climate Change Mitigation

Proactive actions implemented at the local level not only pertain to adaptive measures but also make valuable contributions to climate change mitigation. Illustrative examples of proactive measures against climatic issues at the local level include planting trees in high-risk areas prone to floods, inundation, and erosion; promoting windbreak trees to protect homes and properties; utilizing trees to safeguard crop seeds from floods; encouraging the use of solar energy; engaging in vegetable farming; and shifting to small off-farm businesses. These measures are equally effective in adopting a mitigation approach. Climate change, driven by greenhouse gas emissions resulting from human activities, has led to approximately 1.0°C of global warming above pre-industrial levels [22,185]. Local proactive measures demonstrate how individual actions effectively contribute to reducing and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere (mitigation), while also addressing existing and anticipated climate change impacts (adaptation). The findings of our study suggest that the proactive actions implemented by rural communities in Nepal serve as triumphant examples of a transdisciplinary approach encompassing both adaptation and mitigation.

Transdisciplinarity is a holistic perspective that involves restructuring and reorganizing disciplinary knowledge to address real-world issues through collaborative efforts [186,187]. In this approach, no single discipline holds intellectual precedence [188]. It adopts a systemic approach that actively engages with local and regional concerns [189], incorporating not only scientists and academic disciplines but also non-academic participants such as land managers, user groups, and the general public [190,191]. By combining interdisciplinarity with participatory approaches, it fosters a collaborative and inclusive process [191].

Our research findings demonstrate that the implemented proactive measures reflect a concerted effort to address climate change mitigation and adaptation. These measures encompass various domains, including agriculture, livestock, business/enterprise, and disaster management. They embody a synergistic approach, inviting policymakers, decision makers, scientific institutions, and planning agencies to embrace a transdisciplinary perspective when dealing with adaptation and mitigation challenges.

6. Conclusions and Recommendations

In this paper, we attempted to identify proactive adaptation actions implemented by rural households that are specifically linked to the subsistence livelihoods of rural communities. Livelihood options such as agricultural diversification, cash crop cultivation, livestock raising, small-scale enterprise development, and disaster control have emerged as proactive actions taken by local communities. These actions are driven by the intention to address potential climate change impacts in advance, invest for future benefits, scale up suitable adaptation options at the farm level, and assess perceived risks of future climate change impacts. We found that the factors such as household wellbeing, available livelihood options, agricultural land size, geographical variations, and the number of implemented adaptation activities have a significant influence on the selection of proactive adaptation strategies. Based on the results of the implemented proactive adaptation measures, we can conclude that the proactive actions taken by households reflect an incremental approach to decision making in climate change adaptation. Instead of attempting to tackle complex decisions all at once, households are effectively reducing potential risks and coping with existential impacts by making smaller, gradual changes. While there is growing emphasis on the direct responsibility of governments and collective entities in proactive adaptation as public policy initiative increases, the findings of this research provide valuable insights into practical adaptation initiatives. These initiatives can be utilized by government actors, policymakers, and a wide range of official and non-official organizations and associations. The significance of these initiatives is particularly evident for developing nations, where there is a growing need to encourage farmers and local communities to actively participate in adaptation practices. By implementing the strategies identified in this research, governments can empower these communities and facilitate their engagement in effective adaptation measures.

Given these findings, this study has made valuable contributions to the field of climate change adaptation in four key ways:

1. Enhanced Understanding of Local Practices:

Our results strongly support the cognitive process of individuals' perception of self-efficacy in shaping their intention to adapt. Local communities have chosen adaptation measures based on their economic calculations and subjective assessments, with the aim of coping with current impacts and proactively addressing anticipated climate hazards. Understanding the impact of cognitive constructs on adaptive behaviors helps policymakers improve people's understanding and recognize and value the proactive responses and skill set of local communities during the process of appropriate policy formation;

2. Emphasis on Societal Efficacy and Compatibility in Policy Process:

Viewing the management of climate risks as a strategic interplay between environmental, political, and societal imperatives, effectively communicating the findings of locally appropriate proactive measures becomes a vital step in informing policymakers, scientists, and program designers. It is essential to recognize that local communities are not merely passive recipients of adaptation efforts but are the primary architects of addressing local issues through a combination of traditional, indigenous, and contemporary practices developed through sustained interactions with their local environment. This communication better informs policymakers, scientists, and program designers to consider proactive measures as a primary requirement in decision-making processes, in order to develop relevant interventions against climate risks for both immediate and long-term goals. Therefore, we recommend policymakers gain a better understanding of and prioritize climate change adaptation choices and strategies at the local level to ensure successful implementation of policy initiatives;

3. Contribution to Achieving Climate Goals:

Understanding perceived climate risks and analyzing applied adaptation measures in terms of their efficacy and compatibility with local priorities are crucial in the adaptation process and local development. Some of our findings indicate that the adaptation activities identified in this research not only contribute to climate change adaptation but also serve as mitigation measures and options for livelihoods. The activities, e.g., planting in high-risk areas, promoting windbreak trees, utilizing trees for seed protection, using solar energy, engaging in vegetable farming, and shifting to off-farm businesses, have been shown to be effective in reducing greenhouse gas emissions while simultaneously addressing the impacts of climate change along with benefitting livelihoods. This suggests that the proactive adaptation of the local community can contribute to limiting the anticipated temperature increase below the 1.5 °C goal of the Paris Agreement. The proactive actions individuals and society take today address the changing climate, contributing to the achievement of climate goals;

4. Need for Transdisciplinary Approaches:

This study highlights the important role of local households and communities in possessing skills, experiences, and practical knowledge that enable them to choose and implement appropriate options that enhance resilience. The findings underscore the necessity of incorporating transdisciplinary aspects in the development of both mitigation and adaptation measures. This approach facilitates the engagement of local communities and stakeholders in designing effective and sustainable adaptation strategies to address the complex and interconnected challenges of climate change at the local level.

Finally, we strongly recommend conducting further research to understand the possibility of maladaptation occurring within the local context when addressing climate change issues. Similarly, there is an urgent need for comprehensive research to delve into indigenous knowledge systems and their potential to counteract threats and adapt to climate change, aiming to minimize the likelihood of maladaptation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151410952/s1, Table S1: List of major proactive adaptation measures adapted by households.

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Do National Policies Translate into Local Actions? Analyzing Coherence between Climate Change Adaptation Policies and Implications for Local Adaptation in Nepal

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Abstract: National climate change policy and strategies set out a framework for planning and undertaking climate change adaptation as well as mitigation activities at the national and local levels. In this article, we examine the coherence and contradictions between national policies and plans, and its impacts on the implementation of adaptation measures at the local level. We undertook a content review of key climate change policy documents (n = 4) of Nepal. In addition, we conducted a field study in the Rajdevi Community Forest User Group (CFUG) located in the mid-hills of Nepal, which has developed and implemented a community level adaptation plan of action (CAPA). The field study involved household interviews, focus group discussions, and an in-depth analysis of CAPA implementation. The paper found that while policies are coherent for targeting highly affected areas and communities, they deviate from discerning an appropriate planning and implanting unit. The local adaptation plan of action (LAPA) considers the local government as an implementing unit, while the national adaptation program of action (NAPA) puts an emphasis on the local community groups. It suggests that the existing LAPA implementation breaches the provision of community-level institutions for the implementation conceived in the central framework. Despite little attention to promoting food security in climate change policy, through the CAPA, local communities have planned and implemented adaptation measures envisioned in the thematic areas identified in the climate change policy of Nepal: agriculture and food security; forests and biodiversity; water resources and energy; climate-induced disasters; public health; and urban settlements and infrastructure. Nevertheless, the CAPA is not institutionalized under government policies and the institutional framework as a local level implementing unit. So, the consensus for a local implementing unit in the policies has remained a key issue. We suggest identifying a suitable and acceptable unit for implementing climate change adaptation at the community level. Only if an appropriate implementing unit is identified can the policies be successful with a broader acceptance and desirable outcomes enshrined in the climate change policy.

Keywords: climate change policy; adaptation; local adaptation; institutional framework; Nepal

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1. Introduction

Climate change effects are widespread and alarming, and many of them are already generating negative impacts on human well-being [1]. Poverty, lack of access to health facilities and education opportunities, and deficiency of social safety nets exacerbate people's vulnerability to climate change [2,3] in the least developed countries, including Nepal. Nepal's geology and ecological fragility, coupled with poor socio-economic condition, have made it one of the most vulnerable countries to climate change [4]. *Dalit* (a socially excluded community), indigenous peoples and local communities (DIPLCs) residing in geographically fragile mountainous areas are particularly vulnerable to climate change impacts in Nepal. Erratic rainfall, floods, prolonged droughts, landslide, and air and water-borne disease outbreaks have been the major climate-related disasters faced by the DIPLCs. The DIPLCs represent the economically and socially disadvantaged and are mostly thriving on marginal land for their livelihoods. They are being hit the hardest and disproportionately by the extreme events induced by climate change.

In Nepal, as in other countries, various climate change policies and strategies are in place to address climate change issue. They are informed by the United Nations Framework Convention on Climate Change 1992 (UNFCCC) [5], which is a global policy framework for climate change mitigation as well as adaptation, which sees governments as a principal actor at the national level [6]. Nepal's key climate change-related policies are the National Adaptation Program of Action (NAPA), Climate Change Policy 2019, the framework for Local Adaptation Plan of Action (LAPA), and Nationally Determined Contribution 2020 (NDC). The Government of Nepal (GoN) has prepared the NAPA, which was endorsed in 2010. The NAPA is a strategic tool to assess climate vulnerability and to address national adaptation priorities in a systematic manner. Climate Change Policy 2019 has provided multiple avenues for addressing the adverse impacts of climate change. The LAPA has been prepared to implement the NAPA and the Climate Change Policy, and to facilitate the climate change adaptation program at a local level.

Nepal was declared a federal republic in 2008 and is divided into seven provinces. As provisioned in Climate Change Policy 2019, the provincial government also started formulating the Provincial Adaptation Program of Action (PAPA) from 2019. As of 2021, more than 700 LAPAs have been developed and implemented across the country [7]. To implement LAPAs, the ward (the smallest unit of municipality or rural municipality of administrative divisions in Nepal), municipality, and rural municipality have been identified as operational entities. The LAPA preparation program is still ongoing in the remaining districts. In addition to LAPA, the concept and approach of the Community Level Adaptation Plan of Action (CAPA) has also been brought forward to develop and implement an adaptation plan at the community level [8]. Up to date, more than 2500 CAPAs have been prepared and implemented in Nepal [7]. Most CAPAs in the hilly regions of the country are prepared at the levels of Community Forest User Groups (CFUGs) and Farmer Groups. The CFUGs are considered relatively resourceful and successful grassroots institutions in the forestry sector and effective ways to reach climate vulnerable communities in Nepal [9].

The Government of Nepal has started the process of National Adaptation Plan (NAP) development since 2015 as a way to facilitate medium-to-long-term climate adaptation planning, building on the country's rich learnings from the implementation of NAPA and the previous Climate Change Policy of 2011. Nepal has formulated the Climate Change Policy 2019 [10] aiming at integrating climate change issues into policies and programs at all three tiers of government: federal, provincial, and local.

The successful implementation of policies to achieve desired objectives essentially expects policy coherence between different layers of the policies [11,12]. The policy coherence has received increased attention in recent days [13,14]. The concept of policy coherence in climate change and sustainable development has been a global concern. The formulation of national sustainable development strategies globally and the impact assessment procedure in the European Union [15] set an example of policy coherence. The coherent actions through mutually supportive policies are fundamental to the Sustainable Development Goals (SDGs) [16,17], and SDG 13 in particular highlights it for climatic issue. The UNFCCC, including the NDCs, should provide assurance of policy coherence across different sectors for effectively and efficiently addressing climate change challenges in line with the Paris Agreement [16,18]. The Framework for Disaster Risk Reduction 2015–2030 has also prioritized policy coherence [19]. Policy coherence deals with consistency and compatibility across different governance layers throughout the complete policy cycle, from policy objectives to impacts in order to promote synergies [15]. Policy coherence increases policy stability and decreases the chances of policy failure [20]. The poor policy coherence primarily causes coordination and implementation difficulties, leading toward an inefficient use of available resources [21,22]. So, policy coherence is required for a logical consistency throughout all dimensions of policy development and implementation process. The Organization for Economic Co-operation and Development (OECD) highlights that policy coherence is essential for the transformation of systems that undermine people well-being, structural inequalities, and enduring vulnerabilities [23]. It can help build resilience and bring necessary changes in the ways of economic use of resources (natural, economic, human, and social), leading to harnessing synergies and trade-offs while avoiding or reducing negative impacts of policies [23].

It can be inferred that when national policies are not translated into local actions, the desired outcomes cannot be achieved, making climate vulnerable people likely to face exacerbating impacts. A number of barriers hinder policies and plans to be translated into local actions. The major obstacles include inadequate national capacities to implement policies, a bunch of plans without securing necessary resources, lack of piloting, confusion due to lack of policy coordination and overlapping mandates, conflicting interests of stakeholders, political interference, and fragmentation and undermining of country-led processes due to incautious donor initiatives [24].

Given the number of climate change policies and adaptation strategies that have been developed and adopted for more than a decade at national, provincial, and local levels in Nepal, the question arises to what extent these policies are coherent and contradictory between themselves. Given the proliferation of policies, their implementation and impacts need to be analyzed from a coherent perspective. There have been very few studies in this direction in Nepal. In this backdrop, this paper investigates the implications of climate change policy's coherence and gaps between them to understand the translation of policy provisions into local level implementation.

Existing research on climate change adaptation and policy has predominantly focused on policy formulation process, climate vulnerability, impacts on peoples' livelihoods and community adaptation; few examine policy coherence. Ranabhat et al. [25] analyzed sectoral policy coherence between climate change policy and forest policy. Gentle and Maraseni [26] examined weather patterns and challenges associated with different aspects of the peoples' livelihoods including resource degradation, food scarcity, and increasing social inequalities. Dulal et al. [27] explored the ability of poor communities to adapt to climate change impacts, highlighting a knowledge gap to implement the policies, insufficient literacy, continuation of natural resource depletion, land and livestock ownership, and inadequate access to financial services. Jones and Boyd [28] explained the social barriers for adaptation action and adaptive capacity. They analyzed cognitive behavior, normative behavior, and institutional structure and governance, which play a vital role in allowing and/or avoiding successful and rational adaptation. Sapkota et al. [29] analyzed the importance of overcoming the socio-cultural drivers of marginalization in the spectrum of socio-economic heterogeneity at a wider societal level to work effectively for the marginalized groups. They highlighted the need for social inclusion by addressing intra-community distribution of vulnerability. Maharjan et al. [30] studied the indigenous skill and adaptation of *Tharu*, an indigenous community living in *Terai*, a low-land region of Nepal. They found that the indigenous community faced climatic stresses every year and used their traditional skills and experiences for building their adaptive capacity. Regmi and Bhandari [31] showed that the climate change policy of Nepal lacks clarity and policy visioning for the advancement of climate change adaptation. They analyzed barriers in designing and implementing climate change policy focusing on institution, technology, and information. Eriksen et al. [32] argued that adaptation needs to be reframed as a socio-political process interacting between authority, knowledge, and subjectivities across scales by multiple actors. Ojha et al. [33] explored the politics for climate policy development in Nepal examining the context of an international aid and demand for inclusive public processes. They depicted how a technocratic framing of climate change vulnerability and adaptation reinforced the design of the NAPA and other climate policies. Silwal et al. [34] analyzed the adaptation planning process in forest-based communities in Nepal. Paudel et al. [35] highlighted the advantage of marginalized communities in planning and implementation of adaptation actions. Aryal et al. [36] found that environmental policy making in Nepal is government monolithic and expert-based. While these existing studies have focused on diverse aspects of climate change, there remains little research on policy coherence, which we attempt to consider in this paper.

2. Policy Coherence: Definitions and Analytical Frameworks

While there is no universally agreed definition of policy coherence, it is widely conceived to contribute to policy stability and reduce policy failure [20]. Policy coherence is synonymous with various ideas and terms including coherent policy making, policy co-ordination, policy integration, holistic government, and joined-up government coherence [37]. For example, policies are integrated when their objectives, goals, actors, procedures, and instruments (organizations and administrative procedures) are explicitly adjoined [14]. Challis et al. [38] broadly classify policy co-ordination as "a pursuit of coherence, consistency, comprehensiveness and of harmonious compatible outcomes". The Organization of Economic Cooperation and Development, Development Assistance Committee (OECD-DAC) defines policy coherence as "the systematic promotion of mutually reinforcing policies across government departments and agencies creating synergies towards achieving the defined objective" [39]. The OECD's consideration of policy coherence gives emphasis on the policy-making process and identification of criteria including stakeholder involvement, knowledge management, and commitment and leadership [40]. The North–South Institute (NSI) in Canada defines policy coherence as "ensuring policies are coordinated and complementary or at least not contradictory" [41]. It is "an attribute of policy that systematically reduces conflicts and promotes synergies between and within different policy areas to achieve the outcomes associated with jointly agreed policy objectives" [15] (p. 396). May et al. [42] define that "policy coherence is a relative term that relates to the degree of integration of relevant components (of a policy)". The coherence explains policies that fit together for both an outcome and a process [43], referring to relationships between different tiers of policies [15]. Primarily policy coherence focuses on policy output including objectives, design, and instruments to implement at various levels [44,45]. Policy coherence is largely expected to minimize conflicts and disagreements promoting synergies between and within distinct policies [46]. It fosters better efficiency by reducing competition for the same available resources [47]. Whilst there is a mounting importance of policy coherence, identifying the presence and degree of policy incoherence is equally important to figure out the presence of problems. Hoebink [48] suggested that policy incoherence is not only guided by political, administrative, and institutional reasons but also by cognitive reasons. This indicates the fact that insufficient knowledge pertaining to the effects of policy decisions and disagreeing legitimate interests lead to policy incoherence [49]. In the context of climate change policies and strategies of Nepal, it can be argued that those policies are struggling to achieve stated goals. There is a paucity of research on whether there is informed decision-making practice and actions/activities representing legitimate interests of the local communities. Similarly, there is still little effort being made to find coherence between climate change policies. So, this study on these issues of Nepal is expected to be helpful in enhancing institutional synergy in the implementation of adaptation measures at a local level.

Different conceptual frameworks have been developed to measure the degree of policy coherence such as policy integration, policy interaction, or policy consistency [13]. Briassoulis [50] suggested that policy integration can be assessed vertically (across organizational levels) and/or horizontally (along the same levels).Vertical policy coherence refers to "coherence between different levels of government" [37], while horizontal policy coherence refers to "coherence between policy areas at one level" [15]. Duraiappah and Bhardwaj [14] explained that horizontal coherence involves coherence among policies at each level (international, national, and local) before the implementation of actions and vertical coherence integrates coherence between instruments, institutions and organizations. Meuleman [51] considers that the horizontal coherence requires overcoming silo thinking. He identifies that the vertical coherence is fundamental to anchor alignment, collaboration, and development that includes civil society, the private sector, and development institutions in order to provide input in policy development, facilitation, support, finance, and implementation. Policy coherence analysis tends to focus on both procedural aspects of the policy-making process [40,52] and output assessment of the policy [13,15,53,54], which can be carried out at three levels: policy objectives, policy instruments, and implementation practices [15]. Duraiappah and Bhardwaj [14] suggest that policy coherence can be analyzed in terms of goals (overall themes), instruments and decisions (ways to achieve the goals), and actors (institutions responsible) to achieve. A similar analytical framework has also been proposed by Nilsson et al. [15] that entails policy objectives, policy instruments, and policy implementation. Our study mostly follows the latter two policy-analytical approaches for policy coherence analysis. As suggested by Browne [55], the coherence of a policy aspects depends on how issues and their interests relate each other.

Building on these definitions and analytical frameworks, the study focuses on vertical coherence of climate change adaptation policies in regard to three policy dimensions: policy goals, provisions, and implementing actors at a local level. In doing so, we analyze the coherent characters of central, provincial, and local polices/plans, and major gaps between them, highlighting the consequences to the local-level implementation of adaptation measures. The policy analysis includes the analysis of major climate change adaptation policies, i.e., Climate Change Policy 2019 and NAPA; the provincial policy covers the PAPA and local policies consider the LAPA. The implementation of adaptation measures is drawn from the case study of the CAPA developed and implemented by the CFUG in the mid-hills of Nepal linking to the thematic areas of climate change policies and adaptation framework of Nepal. As mentioned in NSI's definition, the complementary of the policies as the assurance of coherence [41], this study also highlights the CFUG's practices that are congruent to the objectives of climate change policies. Fiske [56] also explains complementarity as the respective actions of the participants cooperating with each other and benefitting mutually by shared coordination devices and understanding.

This study comprises three research questions. (i) How coherent are the climate change policies: Climate Change Policy 2019, NAPA, PAPA, and LAPA? (ii) To what extent are the policy's provisions/prioritization reflected in the local adaptation plan, and how do the community's practices complement the climate change policies and strategies? (iii) What are critical gaps between policies and local adaptation actions enshrined in CAPAs?

Policy coherence considers policy focus (goal/objectives), instruments (institutional decision, provision), and actors for planning and implementation. The reflection of policy provisions at the local level explains the communal as well as individual adaptation activities of CAPA linking to the thematic areas of Climate Change Policy 2019. The complementary measures explain the community's practices that have been already initiated at the local level and are corresponding to the Climate Change Policy's aspirations. Finally, analyzing critical gaps highlights institutional involvement; the capacity building of stakeholders who are being closely worked with; and the local level implementing unit.

As adaptation programs emphasize the need for addressing local requirements and these essentially need to be implemented and managed locally [57,58], this study considers the CFUG having the CAPA as an implementing unit of local adaptation actions. Khatri et al. [59] outlined the major six types of local groups engaged in natural resource management and community development in Nepal: CFUGs, Water User Groups, Agriculture Groups, Livestock-Based Group, Saving and Credit Cooperatives, and Women Groups, emphasizing the CFUG having a prominent institutional setup for adaptation planning. The findings from analyzing the content and contention between climate change policies, strategies, and local practices could be utilized by policy makers, service delivery agents, implementers, and those engaged in climate change adaptation to inform their works for better policies and strategies.

3. Materials and Methods

3.1. Study Area

Fieldwork for collecting empirical data was conducted in Rajdevi CFUG of the Gorkha district, which is located in the mid-hill region of Nepal (Figure 1). Based on the IPCC vulnerability index (i.e., very highly vulnerable, highly vulnerable, medium vulnerable, and low vulnerable) [60], the Gorkha district falls under the highly vulnerable category [61].

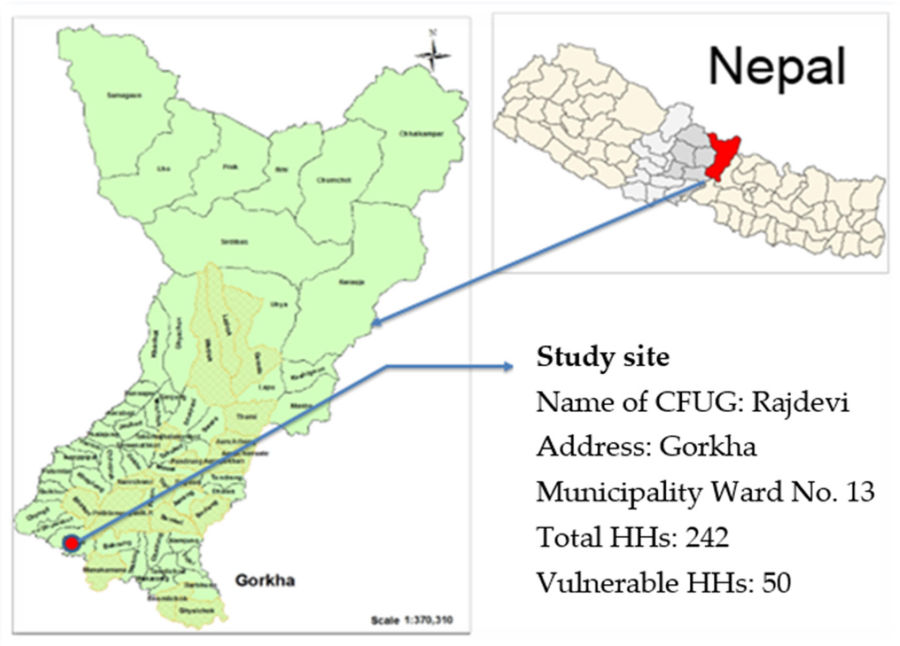

Figure 1. Map of Nepal showing study area Gorkha district, located in the central Nepal in the Middle-Mountain zone.

The Rajdevi CFUG was selected for several reasons. First, the NAPA 2010 and the first Climate Change Policy 2011 provisioned local communities as implementing units for climate change adaptation program. Under this provision, the CFUG has prepared a CAPA that has been implemented for over five years. Second, the CFUG lies in a vulnerable geographical area experiencing extreme climate vulnerability, facing climate-induced hazards such as landslides, droughts, and water deficiency. The heterogeneity of CFUGs in relation to caste, ethnicity, and well-being of users was also one of the main reasons for the selection of this CFUG. The CFUG is comprised of a total of 242 households representing diverse caste, ethnicity, and economic status. Out of the total households, 50 households fall under the vulnerable category (very highly vulnerable 20, and highly vulnerable 30), 123 are moderately vulnerable, and 69 are in the group of low vulnerability. Out of the 50 vulnerable households, 37 households belong to indigenous peoples.

3.2. Data Collection Tools and Analysis

This study used a mixed methods research approach. Both qualitative and quantitative data were collected using a range of research methods namely household (HH) surveys, focused group discussions (FGDs), expert interviews, and interviews with key informants (KI). For policy analysis, a rigorous document review was conducted. Table 1 below presents methods used for data collection and details of the respondents.

Table 1. Types of respondent and data collection tools used.

S.N.	Data Collection Tools	Events (No)	Participants (No)	Men (No)	Women (No)
1	Household survey (semi-structured interviews)	61	61 (25%) *	38	23
2	Focus group discussions	4	109 (45%) *	58	51
3	Key informant interviews	11	11	7	4
4	Expert interviews	17	17	15	2

* Percent of total households in the CFUG.

A semi-structured questionnaire was used for household surveys. Few predetermined and open-ended questions were asked focusing on whether households have observed impacts of climate change and how they have grappled them. Particularly, the semi-structured interviews were emphasized to explore local adaptation measures after the community developed and implemented the CAPA. To triangulate the responses obtained from the interviews, FGDs and KIs were conducted. The KIs were consulted about policy coherence, too. The respondent's diversity was maintained by involving women, indigenous peoples, poor households, and climate-vulnerable people to represent the experiences of local impacts and adaptation measures.

Semi-structured interviews with HHs covered 25% of the total households within the CFUG: 61 out of 242 households. Since the study was focused at local adaptation practices to understand and explore the impacts of climate change adaptation interventions to the vulnerable group, most of the houses were interviewed from "very highly" and "highly" vulnerable communities (46 out of 50) (Table 2). This study followed a stratified random sampling for HH survey and purposive sampling for FGDs considering different vulnerability status of community. For expert interviews and KIs, the snowball method was used.

Table 2. Types of household respondents (n = 61) according to the IPCC vulnerability index.

S.N.	Vulnerability	No of HHs		Total
		Men	Women	
1	Very high	9	11	20
2	High	22	4	26
3	Moderate	3	4	7
4	Low	4	4	8
Total		38 (62%)	23 (38%)	61

This study carried out four FGDs with the participation of 109 individuals (one moderate and low vulnerable group; one women group; one CFUG executive members; and one very highly vulnerable group). Discussions were open; however, the checklists have been used to lead the participants toward the main focus of the study. More than half of the total participants were women. In the FGDs, school teachers and local political leaders also participated and expressed their views. FGDs were very helpful to understand the views of the respondents belonging to different sections of the society, and representing different interest groups and well-being categories.

Altogether, 17 experts and eleven key informants (KIs) were interviewed with individuals with different designations and responsibilities in various levels from policy makers to implementers at the ground level (Table 3).

Six experts from the Ministry of Forest and Environment (MoFE), Department of Forest and Soil Conservation (DoFSC), andREDD Implementation Centre were consulted to gain insights about the policy process, coherence, strengths, and gaps. Similarly, eleven experts were interviewed from the climate change adaptation projects, international non-governmental organizations (INGOs), and national non-governmental organizations (NGOs) to acquire information about contribution of the climate change adaptation interventions to enhance local adaptive capacity. Furthermore, eleven KI from the Federation of Community Forestry Users Nepal (FECOFUN), ex-chairperson of CFUG, local climate change facilitators, health technicians, and local entrepreneurs were also the source of information.

Table 3. Number of experts and key informants and their organizations affiliated.

SN	Organizations	Number	Remarks
1	Ministry of Forest and Environment (MoFE) (Then)	3	Experts
2	Department of Forest and Soil Conservation (DoFSC)	2	Experts
3	REDD Implementation Centre	1	Experts
4	Climate change adaptation projects, international non-governmental organizations (INGOs) and national non-governmental organizations (NGOs)	11	Experts
5	Federation of Community Forestry Users Nepal (FECOFUN), ex-chairperson of CFUG	4	Key informants
6	Local climate change facilitators	2	Key informants
7	Health technicians	2	Key informants
8	Local entrepreneurs	3	Key informants

The contents and plans of CAPA were reviewed, and its implementation status was analyzed. We reviewed major policy documents including Climate Change Policy 2019 (central level policy), NAPA (central-level framework), PAPA (provincial-level framework), and LAPA (local-level framework). The data collected from the HH survey were analyzed using the Statistical Package for Social Science (SPSS) software and Microsoft excel. The HH surveys and FGDs at the community level were accomplished in 2017 just after the CFUG completed the five-year of CAPA implementation. Experts and KIs were interviewed in 2020. Climate change related policies published until 2019 were analyzed.

4. Results

4.1. Content and Coherence of Climate Change Policies and Strategies of Nepal

The Government of Nepal (GoN) started addressing climate change issues in 2010 with the formulation and implementation of NAPA 2010 followed by the Climate Change Policy 2011 and the Framework on Local Adaptation Plans for Action (LAPA framework 2011) of Nepal. Nepal was declared a federal republic in 2008 and is divided into seven provinces. From 2019, the Provincial Government also started the formulation of PAPA. CAPA was initiated informally in 2009 with the help of some development organizations (based on experts involved since the beginning of CAPA development and implementation) before formal policy instruments came into force. Although these policy strategies have contained their own objectives, institutional arrangement, and operational modality, they exhibit coherent attributes (see Table 4).

Table 4. Holistic analyses of climate change policy's focus, provision, and implementing actors.

Policy Documents	Focus of Goal/Objectives	Policy Provisions and Instruments	Implementing Actors (Institutional Responsibility)	Policy Coherence
Climate Change Policy, 2019	• Contribute to socio-economic prosperity of the nation by building a climate-resilient society • Enhance climate change adaptation capacity of persons, families, groups, and communities vulnerable to, and at risk of, climate change	• Identified priority sectors (themes) • At least 80% fund allocation for ground-level climate change activities • Building capacity and technology development, transfer, and utilization • Conducting climate change-related research	• Policy focus on local government for local implementation and is not clear about local level community/groups for implementation • Implementation by integrating in the plan and program of concerned line ministries at the national, province, and local level • Functional coordination by Ministry of Forest and Environment	• Climate Change Policy 2019, NAPA, PAPA and LAPA—all of them focus on urgent and immediate adaptation actions • All policy's output/outcomes are expected to reach the entire ward and vulnerable communities • All policies envision integration of climate change adaptation into local development • Ministry of Forest and Environment (MoFE) act as coordination body • NAPA highly emphasizes local groups for implementation
National Adaptation Program of Action, 2010	• Enable Nepal to respond strategically to the challenge and opportunities posed by climate change • Priorities vulnerability and identify adaptation measures • Develop multistakeholder framework	• More than 80% of fund allocation for ground-level climate change activities • Theme and sector-wise prioritized adaptation measures as mentioned in climate change policy • Vulnerability assessment	• Local-level implementation by existing community-level organizations such as CFUGs, farmer groups, irrigation groups, and other interest groups	
Provincial Adaptation Program of Action, 2019	• Develop consolidated and comprehensive province-level climate change adaptation plan for the province • Identify the climate-induced risk areas • Prepare the climate change adaptation programs	• Mainstream climate change adaptation into development process • Prepare the policies and plans • Consider and emphasis on sectoral themes as mentioned in climate change policy and NAPA	• Local groups/community/municipality/ metropolitan city/municipalities/ rural municipalities • The Ministry of Industry, Tourism, Forest, and Environment (MoITFE) is responsible for overall co-ordination • Forest Directorate coordinates and helps district-level organizations to implement the PAPA	
Framework for Local Adaptation Plan of Action, 2019	• Translate NAPA into action, identification of local adaptation actions with people's participation as prescribed in NAPA • Development and implementation of action plans, to provide the effective delivery of adaptation services to the most climate vulnerable areas and people	• Integrate climate adaptation and resilience aspects in local and national plans • Bottom–up, inclusive, responsive, and flexible• Formulation of local adaptation plan at ward, municipality, and rural municipality level • Ward and the municipality have been considered the most appropriate unit for integrating into local and national development planning processes • Raising awareness to household, community, ward, municipality, DCC and national level	• Ward and municipality/rural municipality • Ward, municipalities, and rural municipality are responsible for planning, coordination, monitoring, and evaluation • District Coordination Committee (DCC) is responsible for overall coordination	

4.1.1. Focus of Climate Policies and Strategies

As pointed out in Table 4, the Climate Change Policy 2019 aims at improving livelihoods by mitigating and adapting to the adverse impacts of climate change, and by adopting a low-carbon emissions socio-economic development path [62]. Strengthening the institutional and financial systems of climate-affected people to make climate change responses more effective and efficient is also a major thrust of the climate change policy. The policy focuses on the socio-economic prosperity of the nation by building a climate-resilient society and enhancing the adaptive capacities of individuals, major groups, and communities. This policy has set clear goals and targets to address climate change risk and vulnerability. The policy emphasizes the constitutional commitment of Nepal, assuring the fundamental right of every citizen to live in a clean and healthy environment. It considers an integrated climate change management concept in the backdrop of the federal system at all three levels—federal, provincial, and local government, thereby contributing to the vision of "Prosperous Nepal, Happy Nepali" adopted by the Government of Nepal [10] (p. 5). The policy also bolsters Nepal's commitment to national and international agreements related and relevant to climate change.

The NAPA was developed for urgent and immediate adaptation actions by identifying priority activities for climate change adaptation (see Table 4). The major focus of the NAPA is to enable Nepal to respond strategically to the challenge and opportunities posed by climate change by developing a multistakeholder framework for assessing vulnerability and identifying adaptation measures. As per the provision of climate change policy, the provincial governments have started a PAPA preparation. The Gandaki Province has come up with a final draft of this document which was formulated following the content and process of NAPA. The major focus of the PAPA is to develop a consolidated and comprehensive climate change adaptation plan for the province. Identifications of the climate-induced risk areas and preparing adaptation program accordingly has been descried in the PAPA.

The LAPA framework was first developed in 2011 to facilitate the implementation of climate adaptation programs at the local level. The Village Development Committee (previous structure of local government, the lowest administration unit of Nepal), municipality, and rural municipality-level LAPA preparation started and was implemented. Recently, the LAPA framework has been revised as Nepal transformed into federal and provincial administrative systems. This framework committed to translating the policy's priorities of climate adaptation into action, identifying local adaptation actions with people's participation as prescribed in NAPA, and providing the effective delivery of adaptation services to the most climate-vulnerable areas and people. As provisioned in the Climate Change Policy and NAPA, CAPAs have also been developed and implemented at various community levels, including CFUGs.

4.1.2. Provisions and Instruments in the Policies

A major climate change policy provision includes the decentralization of financial resources for climate change and the channeling of over 80% of the total climate budget directly to the grassroots level for implementing climate change adaptation activities. This provision has been re-emphasized in the NAPA, too. Conducting climate change research, technology development and transfer, and building the capacity of stakeholders are also included in the policy. The Climate Change Policy 2019 has prioritized seven different thematic and five inter-thematic areas. Thematic areas include agriculture and food security; forest, biodiversity, and watershed conservation; water resources and energy; rural and urban habitats; industry, transport and physical infrastructure; tourism and natural and cultural heritage; health, drinking water, and sanitation; and disaster risk reduction and management. Inter-thematic areas involve gender equality and social inclusion; livelihoods and good governance; awareness raising and capacity development; research, technology development, and expansion; and climate finance management. The NAPA 2010 clustered priority activities into six thematic areas: agriculture and food security; forests and biodiversity; water resources and energy; climate-induced disasters; public health; and urban settlements and infrastructure. PAPA has aligned in a way of mainstreaming climate change adaptation into the development process and preparing provincial-level policies and plans for climate change adaptation. PAPA has also emphasized sectoral themes as mentioned in the Climate Change Policy and NAPA.

The LAPA framework defines the process of formulating a local adaptation plan at ward, municipality, and rural municipality levels and considered the most appropriate unit for integrating them into local and national development planning processes. Raising awareness at household, community, ward, municipality, DCC, and national-level stakeholders has also been provisioned in the LAPA framework.

4.1.3. Institutional Structure for Policy Implementation

Central Level Institutions

The Government of Nepal has established the Climate Change Council (CCC) chaired by the Prime Minister for high-level political support. A Multi-Stakeholder Climate Change Initiatives Coordination Committee (MCCICC) was formed in 2009. In 2010, the GoN established the Climate Change Management Division (CCMD) under the then-Ministry of Population and Environment (then MoPE) and the REDD Forest and Climate Change Cell (now REDD Implementation Centre) under the Ministry of Forest and Environment (then MoFSC). While in the transformation of the unitary to federal system, two ministries—namely, the Ministry of Environment and the Ministry of Forests and Soil conservation—were merged into one and named as the Ministry of Forests and Environment (MoFE). CCMD under the MoFE is dedicated to climate change management. Furthermore, climate change management has been streamlined through the establishment of MoITFE in all of the seven provinces of the country. The CCMD coordinates with the provincial MoITFE. All of the coordination and leading tasks of the previous Ministry of Environment have been shifted to CCMD under MoFE. NAPA implementation is also coordinated by this division. This institutional framework has been considered effective for the planning and implementation of a climate change adaptation program to reduce the climate risk vulnerability of the local communities [63–65].

Provincial-Level Institutions

The Gandaki Province has finalized a PAPA. The MoITFE of the province is responsible for the overall co-ordination between line ministries and other respective bodies [66]. The MoITFE prepares policies and plans with the help of other implementing bodies and stakeholders. The Forest Directorate (FD) takes a responsibility as a connecting body between MoITFE and district-level organizations for the PAPA implementation. The FD is a provincial office to coordinate and monitor the Division Forest Offices (DFOs) and Soil and Watershed Management Offices (SWMOs), thereby helping the district-level organizations to implement the PAPA.

District Level/Local-Level Institutions

The LAPA framework facilitates a formulation of a local adaptation plan at the local level: ward, rural municipality, and municipality. At the district level, DCC plays a key role in coordinating climate change initiatives. As the LAPA framework considers the ward, municipality, and rural municipality as the most appropriate local implementing units [67], LAPA is prepared based on the prioritized need of local communities and forwarded to DCC for approval. For sectoral plans, district line agencies plan and implement adaptation activities. At a community level, various projects and government institutions have implemented adaptation interventions at different levels to capacitate the local communities and institutions to cope with climate change impacts. Development partners are using different local/community organizations as per their convenience since the government has not recommended an appropriate institution at a local level as an entry point for climate change interventions. Table 5 shows various local groups involved in climate change adaptation programs.

Table 5. Principal institutions mobilized at a different level by various projects/organizations.

Principal Institutional Mechanisms	Level	Project/Organization
Village Forest Coordination Committee (VFCC), Agriculture Forest and Environment Coordination Committee (AEFCC)	LAPA	Livelihoods & Forestry Program/ Department for International Development (LFP/DFID) and Interim Forestry Project/Multi-stakeholder Forestry Program (FP/MSFP): from 2011 to 2016
CFUGs and public land management groups	CAPA	
Village Energy Environment and Climate Change Coordination Committee (VEECCCC)	LAPA	Nepal Climate Change Support Program/Government of Nepal (NCCSP/GON-European Union/Department for International Development (EU/DFID)
CFUGs	CAPA	Hariyo Ban Program/ United States Agency for International Development (USAID) Nepal
Village Climate Change Coordination Committee (VC4)	LAPA	Initiative for Climate Change Adaptation/(ICCA/USAID)
VFCC	LAPA	
CFUG and Farmers Group (FG)	CAPA	
VC4	LAPA	Creating Community Climate Change Capacity (5C/Adventist Development and Relief Agency-ADRA-Australia and Rupantaran Nepal)
Cooperatives	CAPA	
CFUGs and groups of poor and vulnerable communities	CAPA	CARE Nepal

Source: [68,69]

Field research showed that in order to coordinate household and community-level climate change adaptation activities, CFUGs are mobilized as grassroots-level community groups. It shows that CFUGs play a complementary role to implement polices at the local level. The Village Coordination Committees were formed at the local level as per the demand and convenience by funding organizations; these were chaired by the VDC (previous structure, now it is called a ward) secretary including delegates from all the CFUGs in the ward, political parties, government service providers, and existing local NGOs. This indicates that diverse community institutions have played an important role in the local-level implementation of the climate change adaptation program, thereby ensuring the participation, coordination, and cooperation of local-level institutions, organizations, private sectors, academics, and development partners, in a way suggested by Duraiappah and Bhardwaj [14], and Meuleman [51] in the framework of vertical coherence analysis.

4.1.4. Coherence between Climate Change Policy, NAPA, PAPA, and LAPA

Our review of Climate Change Policy, NAPA, PAPA, and LAPA shows that the major coherence between them is to target immediate and urgent adaptation measures and reach the local vulnerable communities. An integration of climate issues into the local development process is enshrined in all the policy instruments. The NAPA 2010 emphasizes local groups for implementation, and the Climate Change Policy considers the importance of indigenous knowledge, skills, and technologies by identifying climate change-affected households, communities, and risk zones. The overall coordination is mostly dominated by MoFE. The consistency of these policies instruments to their objectives focusing on the same targeted vulnerable populations and locations sets an example of policy coherence, and this is one of the essential components of vertical coherence analysis defined by Duraiappah and Bhardwaj [14] and Nilsson et al. [15].

4.2. Reflection of Climate Change Policies' Provisions in Local Adaptation Actions and Complimentary Community Practices

As depicted in Table 5, there are various institutions and implementing units of the climate change adaptation program in Nepal. Primarily, the adaptation program has been implemented at ward, rural municipality/rural municipality, and community levels. We assessed the community level adaptation plan and program, a CAPA linking to Climate Change Policy priorities and provisions. We highlight major climate change impacts experienced by community people and adaptation activities carried out by a CFUG.

4.2.1. Assessing Climate Vulnerability and Local Impacts

Interviews with local residents along with FGDs as well as in-depth analysis of CAPA showed that CAPA has been prepared following rigorous processes recommended by the LAPA framework. The process includes awareness creation, capacity building, vulnerability assessment and mapping, and adaptation plan preparation and implementation. The local people in Rajdevi CFUG experienced an increase in temperature. They have been experiencing erratic rainfall during crop cultivating and growing seasons. Local people perceived that the changes in these two major climatic parameters resulted in diverse consequences on their livelihoods. They identified different levels of climate change impacts in agriculture, land degradation including landslides/erosion, water deficiency, and fodder scarcity for cattle (see Table 6).

Table 6. Impacts and the scale faced by different categories of vulnerable people (percentage in parenthesis indicates the percentage of total interviewees). The vulnerable categories are defined in IPCC (2014): very high, high, medium, and low.

Impacts	Agriculture Crops Loss	Landslide/Erosion	Water Deficiency	Fodder Scarcity
Very high	9 (15%)	5 (8%)	47 (77%)	0 (0%)
High	39 (64%)	8 (13%)	11 (18%)	3 (5%)
Medium	12 (20%)	34 (55%)	3 (5%)	12 (20%)
Low	1 (2%)	14 (23%)	0(0%)	46 (75%)

The community has been facing diverse impacts of climate change such as crop failure, declining crop productivity due to drought, pest, and diseases, declining health, and the depletion of water resources. The local people expressed water deficiency as the topmost impact (very high impacts) posed by climate change in the area. Seventy-seven percent of the interviewees responded that they faced a drinking water deficit as a prime problem followed by agriculture crop lost (high impact) due to uncertain rainfall patterns and increased drought intensity (64%). Meanwhile, 55% of interviewees were impacted from landslide and erosion (medium impact) due to heavy rainfall that has caused the destruction of agricultural land and river-triggered erosion caused by swollen stream. A large segment of the respondents (75%) raised the issue of increasing fodder scarcity because of a reduced trend of agriculture practice, degrading the quality and quantity of fodder species; however, this was considered low impact.

4.2.2. Responding to Locally Identified Impacts

Rajdevi CFUG adopted diverse adaptation measures even before the Climate Change Policy 2011 and NAPA came out (before 2011). After having the Climate Change Policy 2011 executed, the CFUG developed a CAPA identifying local impacts and necessary measures. The majority of the local adaptation measures were applied for landslides and water scarcity management (Table 7). The community built 45 check dams/gabion boxes benefiting more than 65 households and improved two walking trails in the village. The vulnerable community from the village retained better access to drinking water through the establishment of two water reservoir tanks in the two vulnerable villages within the CFUG; the protection of two water sources; water taps built for 72 vulnerable households; establishing 17 plastic ponds; a structure for rainwater harvesting at 200 households; and two sets of pumping water from the river for small irrigation. More than 130 improved cooking stoves helped to promote the economic use of fuel wood reducing pressure on the forest, which in turn helped preserve the water source in forests and improved people's health compared with using smokey ovens.

Table 7. Adaptation activities by Rajdevi Community Forestry User Group while implementing a community-level adaptation plan of action.

SN	Infrastructures (Unit)	Before 2011	After 2011 till 2017	Total	HHs Benefited
1	Earthen road (km)	2	0	2	180
2	Walking trails (km)	2	1.5	3.5	200
3	Water reservoirs tank (no.)	1	2	3	190
4	Water source protection (no.)	0	2	2	202
5	Water tap (no.)	0	72	72	72
6	Water pond (no.)	2	17	19	19
7	Rainwater harvest (no. of household)	20	200	220	220
8	Pumping water from river (no.)	0	2	2	20
9	Improved cooking stoves (no.)	20	130	130	150
10	Check dam/Gabion box (no.)	0	45	45	65
11	Fire lines (meter)	2	3	5	242
12	Nursery (no.)	1	0	1	180

As an implication of the adaptation program, Rajdevi CFUG found some subtle changes within the community in the areas of enhancing adaptive capacity. The constructions of erosion control measures created a safe environment for them; the pumped water from river supporting fish farming and irrigation, improving health and sanitation through enhanced access to drinking water due to water protection intervention. The protection of water sources, establishment of water reservoir tanks, and installation of water taps in individual households have contributed to improving the social and health condition of the community. In the past, people used to spend 3 to 6 h a day fetching drinking water from a very limited number of water sources. As a result of the water source management in the village, particularly with the installation of a water tap in each household, they do not have to spend a long time collecting drinking water. People, particularly women, saved time, which they now use to prepare food for getting their children ready for school in time. Children often used to go to school late. Similarly, people now have used this saved time for income-generation activities such as the brewing of local alcohol, an important source of rural income, and vegetable farming in the home garden.

The CFUG responded to climate change impacts by implementing several adaptation activities. Locally adapted measures showed that people are more concerned about water scarcity and the occurrence of landslides (Figure 2). People hardly responded to a loss of agricultural crops. Rather than taking any measures, nearly half of the households (30 out of 61 interviewed) left land fallow for about 10 years primarily due to insufficient rainfall and frequent drought. Five households managed to irrigate agricultural crops to deal with water scarcity. About one-fourth of total households still depended on rain-fed farming. To control landslides and erosion in the study area, the majority of the households (26) planted trees and were benefited from the constructions of check dams. Among the interviewed, 47 HHs benefitted from water reservoir tanks built to store water. Community people also have protected water sources by fencing it with barbed wire and by constructing cemented structures.

The CFUG has allocated some forest lands to a group of poor people as a leasehold forest allowing them to cultivate grass and fodder species that helped poor people raise livestock. The lease provision benefitted 52 poor households.

An analysis of data with SPSS from a household survey shows that the food-insufficiency months have increased significantly from 2011 to 2016 (df = 60, p = 0.005, α = 0.05). The average food scarcity months from their agriculture was 7.26 months in 2011, which increased to an average of 8.48 months in 2016 due to sharp declines in the production of rice (*Oryza sativa*), maize (*Zea mays*), mustard (*Brassica juncea*), millet (*Echinochloa frumentacea*), lentils (*Lens culinaris* subsp. *Culinaris*), and black gram (*Vigna mungo*) because of the increasing draught and outburst of pest and insects such as caterpillars, slugs, and snails. As a coping strategy, some households have started to cultivate Ghaiya rice (Upland rice, which is a drought-resistant variety compared to Oryza sativa), but producing this crop is labor intensive.

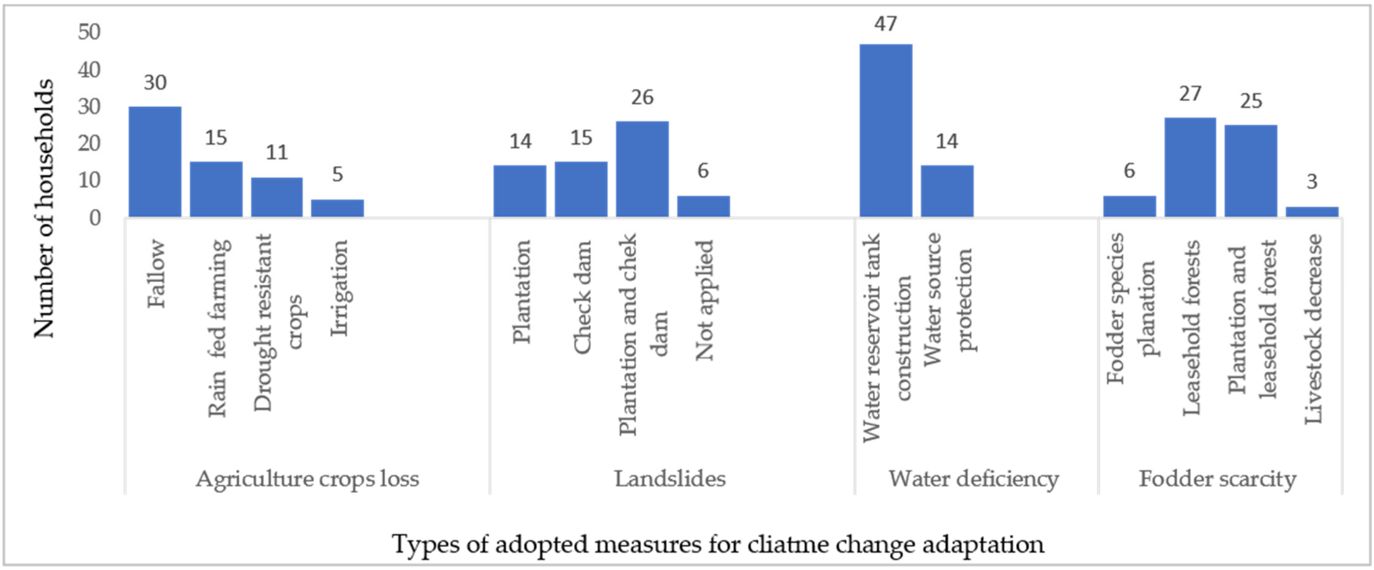

Figure 2. Climate change adaptation measures planned and implemented by households (according to CAPA implemented by Rajdevi CFUG for 2011–2016).

Community people experienced extreme impacts from the climate-induced hazards such as loss of agriculture crops and natural resources (e.g., land, forest tree species, reduced availability of water), damage to the physical properties (i.e., houses, livestock) as well as impacts on the human health (e.g., increasing mosquitos and related disease). People have not felt so much difference in terms of the severity of impacts between 2011 and 2016. However, the local community felt the need for the improvement in their coping strategies with technological advancement for drought and agriculture to deal with the climate-induced hazards and risks of agriculture.

4.2.3. Shifting Local Priority toward Climate Issues

Similar to other CFUGs in Nepal, Rajdevi CFUG conducts its activities based on its periodic forest management plan. Comparing the annual expenditure of the CFUG between 2011 and 2016 (Figure 3), nearly two-thirds of the budget has been spent on climate change adaptation activities in 2016, but it was hardly spent on such activities in 2011. However, the increased expenditure in 2016 is also due to the availability of additional funding coming from development partners for implementing such activities.

Comparing the annual budget for two years from the CFUG records shows that a total budget has increased nearly seven-fold from USD 1040 in 2011 to USD 7220 in 2016. The increased funding was from the project support for climate change adaptation. CARE Nepal (Hariyo Ban project/USAID) has supported this CFUG to develop and implement the CAPA. Given the substantial amount of funding coming from the external sources, it raises a question of the financial sustainability of the adaptation program in the community. However, the pattern of expenditure has been upward in climate change adaptation. Before the implementation of the climate change project, community development was the first priority of the CFUG, on which they spent 56% of their fund followed by the pro-poor program and forest management. In 2016, the distribution of expenditure differed considerably compared with the expenditure made in 2011. The climate change adaptation activities were the first priority with the expenditure of 63% on which no fund was allocated in 2011. The second important area of the expenditure was the pro-poor program with 27% of total expenses. It shows that the local community has prioritized climate change adaptation as a serious and urgent action. However, the consequences of the shift of focus from the pro-poor program to climate change adaptation activities remains to be assessed.

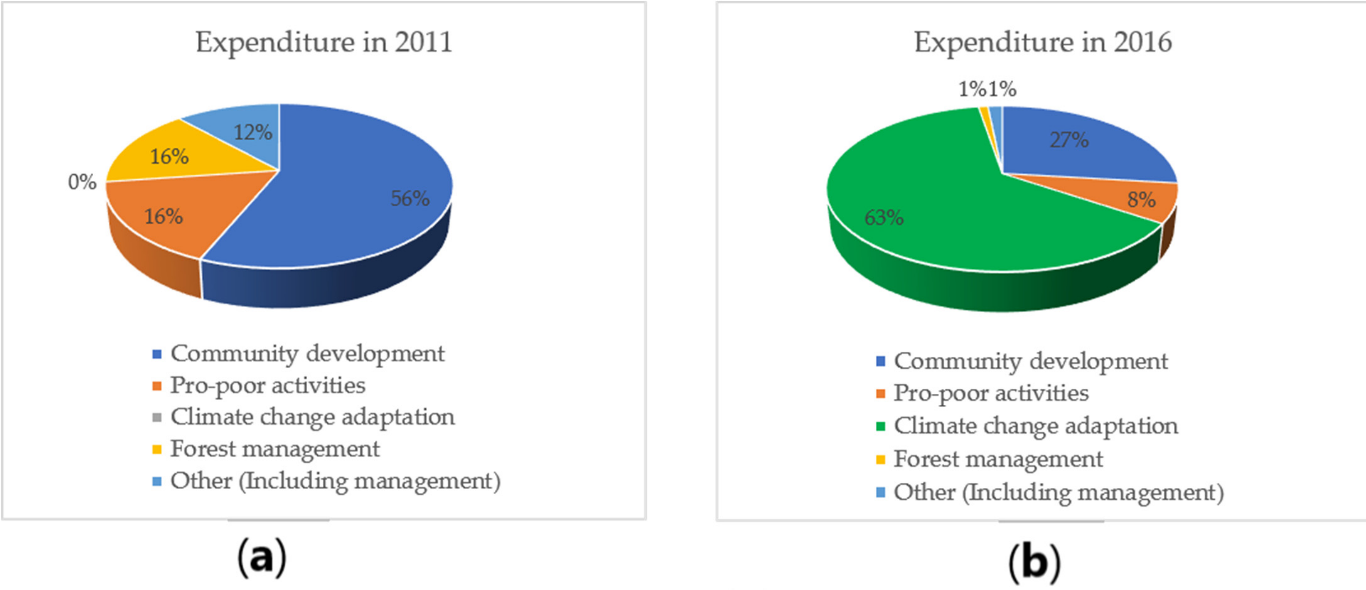

Figure 3. Comparing the CFUG expenditure in different activities between 2011 and 2016; (**a**) CFUG expenditure in 2011; (**b**) CFUG expenditure in 2016.

Analyzing the CAPA made by the community for 2012–2016, the total budget planned for this entire adaptation plan period was USD 24,068, of which nearly one-quarter of the budget (USD 5706) was borne by the community itself, and the rest was supported from the climate change project. The majority of the budget has been earmarked for the activities for water scarcity management (Figure 4). However, the budget for the upfront preparation of potential risk and hazards was nominal.

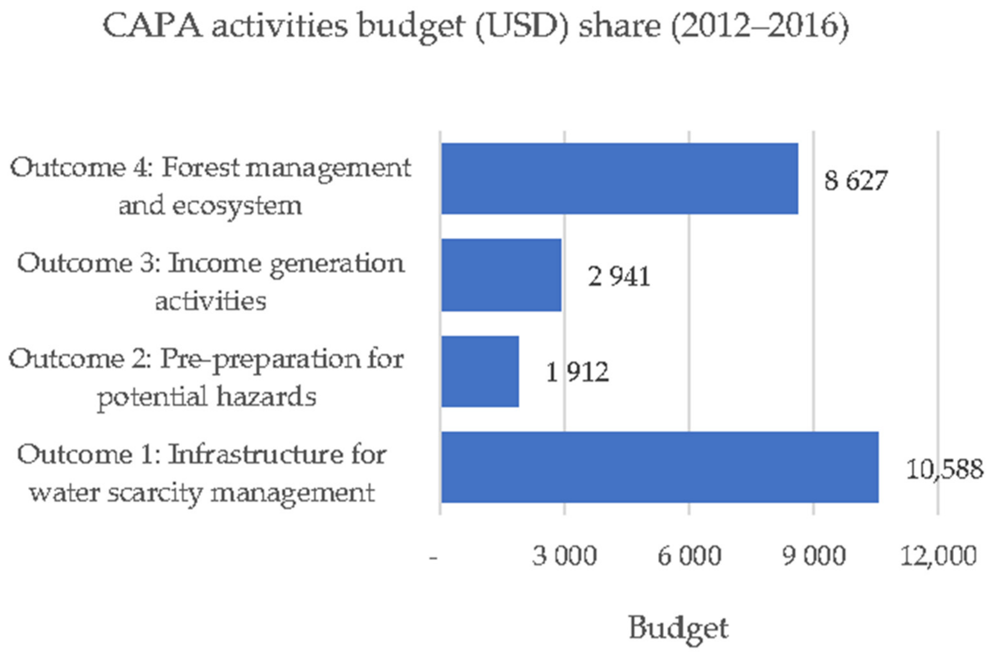

Figure 4. Budget share for different outcomes.

4.2.4. Overall CAPA Activities Linking to Policy Priority

Through the development of CAPA, the CFUG has implemented adaptation activities that corresponded to the six thematic areas of NAPA. Local measures are adopted at the community (group) level and household level as per the needs identified by the community itself while preparing the CAPA. A wide range of climate change adaptation activities implemented by the community have reflected the aspirations of the policies (see Table 8). For example, the introduction of drought-resistant crops and kitchen gardens has supported agricultural production and food security. Forest nurseries, forest plantation, fire line construction, and the use of improved cooking stoves for the economic use of fuelwood have been contributing to forest and biodiversity conservation. Building water reservoir tanks for drinking water, water ponds to catch rainwater, pumping water from river, and harvesting of rainwater for irrigation provided the evidence of a strong desire of the community coping with water scarcity. Protection measures from landslides or erosion by constructing check dams, walking trail improvement, and roadside plantations are examples of climate-induced disaster management employed by the local community. Introducing improved cooking stoves, practicing kitchen gardens particularly for fresh vegetables, and installing individual water taps in the house connecting to water reservoir tanks have indicated that local people are becoming aware of health issues generated from climate change. Village road and walking trail widening provide an example of urban settlements and infrastructure development that the local community has initiated. In addition, leasing patches of forest to the economically poor HHs, the practice of providing interest-free loans to those poor households, and curtailing of timber quantity against as usual demand for regulating emergency use during climatic hazards were some strong examples of justice and equity which is a wider issue in both climate change adaptation and mitigation; in addition, it has been prioritized as an inter-thematic area in the new Climate Change Policy 2019 of Nepal. Comprising such practices developed and implemented by the local community, CAPA reflects the policy provisions into actions at the very bottom level: both community/groups and household levels.

Table 8. Major climate change response of Rajdevi CFUG in relation to NAPA.

Climate Change Policy and NAPA's Thematic Priority	Locally Implemented Measures (CAPA)	Implementation Level
1. Agriculture and Food security	Drought resistant crop e.g., Ghaiya Kitchen garden	Household (HH) HH
2. Forests and Biodiversity	Plantation Fire line in the forest Improve cooking stove Nursey promotion	Community/Group Community/Group HH HH
3. Water resources and Energy	Water reservoir tank Water pond Pumping water from river Rain water harvest	Community/Group Community/Group Community/Group, HH HH
4. Climate-induced disasters	Check dam for landslide/erosion control Trail improvement Forest plantation	Community/Group, HH Community/Group, HH Community/Group
5. Public health	Water taps at households Improve cooking stove Kitchen garden-for vegetable	HH HH
6. Urban settlements and Infrastructure	Earthen road improvement Walking trail improvement	Community/Group Community/Group/HH
Justice and Equity	Allocate patch of forest Supply of timber quantity reduced from 30 cubic feet/HH per annum to 22 cubic feet/HH per annum interest free loan	HH (poorest of the poor HH) Promote forest/support vulnerable Poor

4.2.5. CFUG's Practices as Complementary to Climate Change Policy 2019

In addition to CAPA implementation, Rajdevi CFUG has implemented a number of activities as a regular program following the Community Forest Operational Plan (CFOP) which are directly and indirectly contributing to the goal and objectives of climate change policies and strategies as complementary measures (Table 9).

Table 9. CFUG's practices and activities complimentary to the overall climate change policies adopted in Nepal.

CFUG's Activities Implemented while Executing the Forest Management Operational Plan	Complementing Areas of Climate Change Policies (Complementary to the Policy)
Well-being ranking	Vulnerability assessment (Climate Change Policy 2019, NAPA, PAPA, LAPA)
Pro-poor forest product distribution	Priority to poor and climate vulnerable people, distributional equity
Allocation of forest land to small groups of the poorest of the poor CFUG members	Contribute to reducing vulnerability of poor people, distributional equity
Interest-free loan for income generation activities	Access to finance or loan particularly for vulnerable and poor people
Establishment of local saving and credit cooperatives	Emergency use for all

In Nepal, it is mandatory for every CFUG to prepare a CFOP and a CFUG constitution. The CFUG is an autonomous entity; however, the CFOP and the CFUG constitution should be approved by the DFO, which is a competent authority for monitoring the CFUG activities. In accordance with the Forest Regulation 1995, Forest Act 2019, or CFUG Formation Guideline 2014, the Rajdevi CFUG has prepared the CFOP and CFUG constitution. The CFUG formation guidelines have specified the guidelines to prepare the CFOP and CFUG constitution. Ensuring the active and meaningful participation of each CFUG member (household) is a must while preparing the CFOP and constitution. After the climate change adaptation project has been implemented, the Rajdevi CFUG has amended some rules and regulation according to the needs of CFUG members to address local issues related to impacts of climate change. First, the CFUG changed the rule about timber distribution to control its unfair consumption. Before the introduction of the climate change adaptation project, each of the CFUG members was entitled to receive timber up to 30 cubic feet (cft) per household per year without any charge. The quantity is reduced to 22 cft after the implementation of the project. The analysis of the data from the household survey showed that the quantity of timber used from the community forest reduced drastically from 24.1 cft per HH in 2011 to 1.98 cft per HH (df = 60, $p = 0$, $\alpha = 0.05$) in 2016. Similarly, the amount of fuel wood use has decreased from 102.36 *Bhari* (1 *Bhari* = approximately 35 kg) in 2011 to 69.75 Bhari (df = 60, $p = 0.001$ $\alpha = 0.05$) in 2016 due to the introduction of improved cooking stoves for the economic use of fuel wood in the household.

The results from the FGDs and expert interviews also complemented that the use of LP gas has also contributed to reducing the fuelwood consumptions. It infers that decreasing amounts of using forest products by the CFUG can contribute to increasing the growing stock in the forest, which would be available to climate-affected individuals when they need (as suggested in group discussions). The increased biomass stock in forests may enhance the climate change mitigation benefits from the forest. In addition, the CFUG changed a rule for the entry of a new member to the CFUG (for example, immigrants to the village). In the past, the newcomers were restricted to use timber from the forest for 5 years. They were only allowed to use fuelwood and fodder. However, considering the risk and vulnerability from climate change, the CFUG uplifts the restrictions of the five years for the new CFUG members. Such changes in the rules show that community people are more pragmatic to promote justice in tackling climate change impacts in a due consideration of allowable amounts prescribed in the CFOP. Furthermore, the CFUG modified the timber-harvesting rule. In the past, the users who demanded timber, after approval by the committee, were allowed to enter the community forest and cut those trees to the size and the quality they desired. However, now, committee members themselves are involved in selecting and cutting the trees with the technical assistance of a competent forest officer who is responsible for monitoring CFOP activities. This rule helps to reduce damages in the forest during harvesting, thereby contributing to reducing the harvesting damage to the residual forest stands.

On top of that, the CFUG promoted leasehold forestry within community forests to support economically-deprived households. The poorest of the poor members, based on the well-being ranking, are eligible for the leasehold forestry groups. The CFUG supported two leasehold forestry groups. Each group comprises of 28 households. They are provided with forest land in which they could manage forests as they need. The CFUG constitution and CFOP allow them to cultivate cash crops in the leased forestland; for example, they have planted broom grass (*Thysanolaena maxima*). They can establish forest plantations of the species of their need and preferences, e.g., preferred fodder species. In practice, they have further divided the leased forestland among themselves, and each household possesses about 0.25 hectares of it. Each group has been provided with NR 50,000 (USD 500 approximately) as a revolving fund for income generation activities: for example, bee keeping, pig rearing, goat keeping, and broom grass cultivation. From this fund, poor people use up to NRs 10,000 (USD 100 approximately) for two years as an interest-free loan for income-generating activities. A member received seedlings from the nursery established by the CFUG.

4.3. National Policies and Local Implementation: Gaps between Climate Change Policy 2019, NAPA, and LAPA

Although a handful of examples of coherence between the policies were identified, there were also some contradictions between them. Based on the review of the policy documents, expert consultations, and field observation, major gaps and contradictions are presented in Table 10.

As depicted in Table 10, there are policy breaches for the implementation of climate change adaptation programs at the local level. Some of the major gaps includes unclear implementing units, a lack of proper fund channeling, capacity development of local government authority, and program for food security and technology development for agriculture promotion at the local level.

NAPA assumes that the individual line ministries will take responsibility to mainstream climate change adaptation into their sectoral plans instead of developing a separate adaptation plan. However, the LAPA framework has been developed for preparing a local-level climate change adaptation plan and implementation. It seems there is a conceptual gap between these two frameworks. A lack of outright direction about how local-level adaptation plans could be mainstreamed in the regular development process might be a consequence of this confusion.

At a local group or community scale, CAPAs have been formulated following the steps of the LAPA framework and implemented by community-based groups including CFUGs [61] as proposed in the NAPA. As explained in the results, CAPA and the associated CFUG have demonstrated that they are capable of translating policy provisions into local actions. The Guidelines for the Community Forestry Development Program 2014 has also provisioned CAPA and been approved on the 22nd of July 2014 [70] (p. 15). According to this guideline, a CFUG can develop a local-level climate change adaptation plan based on the local context. However, these plans are rarely recognized and approved by the DFO for a couple of reasons, as suggested by expert interviews including government officials. First, the knowledge gap: most of the government staff members working locally have limited knowledge about climate change issues, how it happens, and what can be done to tackle them. Although the Climate Change Policy 2019, NAPA, and LAPA have been formulated to address climate change impacts, the local government officials seem unaware about the content of the policies and plan. In addition, the government does not have sufficient funding and a sound mechanism for building staff capacities. Second, the participation of government staff in the CAPA preparation process was not encouraged. In most cases in the CAPA preparation process in Rajdevi CFUG, responsible government officials did not participate (based on group discussion). Project and community sought the participation of the government staff only to get their signature (any of DFO's staff) in any one of the meetings. And thirdly, insufficient resources: in terms of human resource, DFO has a very limited number of local staff to work. According to a local government staffer from DFO, they have to handle many other important tasks covering large geographical working areas, besides climate change. Financially, the Government of Nepal is not in a position to allocate sufficient financial resource for staff as Daily Subsistence Allowance (DSA), and the adaptation project also does not offer sufficient DSA to get them involved in the entire process of CAPA preparation. Some experts argue that CAPA does not need an approval from the DFO. This is an overall adaptation plan of a particular community developed through the process of household level planning (e.g., household level livelihoods improvement plan) that seeks to cope with urgent climate risk and vulnerability and build resilience against spontaneous and anticipated climate change impacts. According to the experts, the community needs a DFO approval only for those activities which are planned to be carried out inside the forests and are likely to damage the forest. It suggests that CAPA and their effectiveness, and involvement in local adaptations are not addressed in national policies and strategies, thereby overlooking the overall development process.

Table 10. Gaps between climate change polices and local level implementation of climate change adaptation program.

Policy Provision	Gaps and Contradictions in Implementation	Consequences
NAPA does not spell out any separate plan for adaptation; rather, it presumes that sectoral ministries would mainstream the climate change adaptation into their sectoral plans.	Although LAPA emphasized integrating climate change adaptation into local development planning, it has focused on the development of separate climate change adaptation plans.	Created confusion of providing a proper institutional framework for integrating an adaptation program of line ministries into locally developed climate change adaptation plans.
The Climate Change Policy 2019 does not explicitly determine the implementing unit; however, it emphasized that the local adaptation plan was intended to households and the community. *"Adaptation measures will be adopted in line with local and indigenous knowledge, skills and technologies by identifying climate change affected households, communities and risk zones (Climate Change Policy 2019)"*. However, NAPA is clear about implementing units that local level groups can implement as adaptation programs. *"Program/project implementation through existing community level organization/s like CFUG, different farmers groups, irrigation groups and other interest group (NAPA 2010)"*.	LAPA emphasizes that local governments ought to prepare and implement adaptation programs. *"Local government will prepare climate friendly adaptation plan and implement (LAPA 2019)"*. LAPA suggests to select and prioritize adaption measures at the ward, municipality, and rural municipality level.	Role of community-level institutions has been overlooked/negated, because LAPA does not recognize CAPAs.
80% of climate budget should reach the local community. *"Mobilization of at least 80 percent of amount will be ensured for implementation of programs at the local level (Climate Change Policy 2019)"*.	No clear mechanism for expenditure and authority.	Vulnerable people lack access to available funding. More expense in district level meeting, workshop, etc.
Food security and technology development for agriculture promotion. *"Food security, nutrition and livelihoods will be improved by adopting [a] climate-friendly agriculture system (Climate Change Policy 2019)"*.	Lack of concrete program at the local level for food production and security (in LAPA framework).	Duration of food insufficiency has been increased at a local level. Kept lands fallow due to the high insurgency of drought period (lack of introducing drought-tolerant crops).
FUG's CAPA translated most of the policy prioritized actions mentioned in Climate Change Policy 2019 and NAPA.	However, CAPA are not legitimized as an implementing unit in the LAPA framework. DFO does not take the responsibility to approve it. Progress of the CAPA is not reflected in any of the government official reports.	Lack of funding for CAPA implementation Majority of the CAPA became functionless due to lack of funding after accomplishing the first duration (dormant). Struggling for legitimacy.
Capacity development of local government authorities including DFOs. *"Capacity of relevant governmental, non-governmental and academic institutions and community associations/organizations of all three levels will be enhanced to mainstream climate resilience into development programs (Climate Change Policy 2019)"*.	No clear mechanism and program for capacity development of local government authorities.	Communities rely on temporary project's staff. Lack of coordination with government authority. Paucity of local government authority's participation in the CAPA process.

5. Discussions

5.1. How Are Climate Change Policies Coherent? Contents and Provisions of Climate Change Policy 2019, NAPA, and LAPA

The Climate Change Policy 2019 [10], NAPA [61], PAPA [66], and LAPA framework [67] are the major policy instruments dealing with climate change adaptation issues in Nepal. As highlighted in the results (Table 4), enhancing the socio-economic prosperity of the nation by building climate resilient society, the adoptive capacity of individuals, groups, and communities through developing a suitable institution and organizational framework at all levels—national, provincial, and local levels are the common aspirations enshrined in these policies. The NAPA recognizes the importance of linking local adaptation with national-level policies and plans through the implementation of LAPA and the management of available local assets, including natural resources. The NAPA document is very specific in mainstreaming Community-Based Adaptation (CBA) because it emphasizes the need for integrating the local adaptation priorities of the most vulnerable communities [71,72]. NAPA as a national framework for climate change adaptation has made a provision of mobilizing existing community-level organizations such as CFUG, the Farmers' Group, Irrigation Groups, and other groups for adaptation planning and implementation. The Climate Change Policy 2019 provisioned the National Adaptation Plan (NAP), which is in the process of development. However, PAPA and LAPA are less explicit on mobilizing local groups in planning and implementation. The Climate Change Policy 2011, developed in line with NAPA, prioritized local community/groups for implementing climate change adaptation plans at a local level. However, the Climate Change Policy 2019 has given an emphasis on considering indigenous knowledge, skills, and technologies of households and communities in adaptation planning, but it is silent on the mobilization of those groups in adaptation program implementation. It has led us to argue that there is not only policy breach to ensure active participation of local people in climate change adaptation, but also the question of "will or attitude "of decision makers for policy reform toward mobilizing local groups. The Climate Change Policy 2019 is not explicit in entrusting implementation responsibilities to local groups. McLaughlin [73] argued that the success of polices fundamentally depends on the attitude and motivation of decision makers and implementers. The Environment Protection Act 2019 [74] has also addressed the provision of local community or groups for planning and implementation; nevertheless, it is poorly linked to the existing institutional framework.

LAPA, as a major framework for planning and implementation, has focused on the local government for the planning and implementation of climate change adaptation. The District Coordination Committee (DCC) and municipality/rural municipality have been entrusted with a lead role for planning and implementation at the local level. This has aligned with the Local Government Operation Act 2017 that provided the local development framework with specific roles of local governmental institutions including municipalities/rural municipalities [75]. Designating the DCC and municipality/rural municipality as a key agency for adaptation planning and implementation at local level, to some extent, has resolved the issues between the Local Government Operation Act 2017 and Forest Act 2019. The Forest Act 2019 entrusted DFO with the overall authority of forest management in the district [76]. As explained by Tiwari et al. [77], the LAPA development process offers opportunities for local communities and households to assess location-specific climate vulnerabilities, identify adaptation alternatives, and implement urgent and immediate climate adaptation actions. It intends to implement the priority programs and project of NAPA more effectively through public and local participation and integrating adaptation into the sectoral plans and policies. LAPA links local adaptation practices with national policies as it connects community-level adaptation planning into the overall development planning process at the ward and municipality level [78]. Given the scenario, it suggests that the policies are all coherent to acknowledge the objective of reaching out to the vulnerable communities, groups, and individuals but are seemingly fragmented for mobilizing those communities for implementation. They also commonly show an integrative nuance of integration of adaptation plans into the planning process. This sets an example that policies are coherent. However, they exhibited an incoherent nature when it comes to institutional units for implementation, inferring local government by LAPA and local community by NAPA. England et al. [79] found similar results in climate change adaptation policy analysis across southern Africa, indicating the need for improvement in vertical coherence between national policy and district-level climate change management plans as well as sectoral coherence. The different environmental policy coherence analysis of the European Union (EU) showed that the policies were coherent at the level of objectives but contradictory at the level of implementation [15]. The recent study between climate change policies and forest policies of Nepal showed similar findings that policies are more consistent on the level of motivation and adaptation measures, but on the level of implementation, they are less coherent [25]. Fernández-Blanco et al. [80] also highlighted the contradicting aspects among institutional elements of sustainable forest management regime. They found strong conflicts between the goals of explicitly strengthening the roles of indigenous peoples as civic actors and those explicitly supporting national governmental actors.

5.2. How Climate Change Policy Provisions Are Translated into Local Actions? A Case of CAPA Implementation by CFUG

A successful climate change policy needs to involve most affected local groups [81] as the impacts of climate change are intrinsically local context-specific, thus needing interventions at the local level [82,83]. Reflecting the implementation of the climate change adaptation plan at the local level, the Rajdevi CFUG from the central mid-hills of Nepal has shown noticeable results of planning and implementation, translating the national policy priority into local actions. To develop CAPA, the CFUG undertook a participatory vulnerability and impacts assessment; identification of response options; and implementation of selected measures considering essential social and equity issues in the community, setting an example of the implementation of climate change policy at the local level. As depicted in the results (Table 8), the implemented activities of CAPA mostly represented the thematic areas of NAPA. Previous studies reported many CFUGs already supporting health service, irrigation, drinking water, education and rural transportation service for their community members [84], which seem complementary to the goal of Climate Change Policy. The regularly implemented activities of CFOP of Rajdevi CFUG (Table 8) showed that the CFUG has already implemented some measures related to climate change adaptations complementary to Climate Change Policy provisions. Noticeable practices of the CFUG include the fact that 35% of CFUG's income [70] has to be allocated for poor and marginalized communities, which partially resembles the 80% of climate fund mentioned in the Climate Change Policy to reach the local community. Such provisions are aligned with the essence of distributional equity. The CFUGs implement it on the basis of categorization of users through the well-being ranking, which is remarkably complementary to the aspiration of vulnerability assessment of national Climate Change Policies as well as the IPCC guideline of climate change vulnerability assessment.

The CFUG has implemented a number of adaptation measures. The community assessed water scarcity and climate-induced disasters (landslide and erosion) as major climate change issues experienced at the local level, thereby focusing more on water-related issues followed by responses to climatic disaster. This finding of vulnerability assessment corroborated the findings of a national climate change impact survey report of Nepal 2016. The report showed that drought as a climate-induced disaster, erratic rainfall, and an increased incidence of landslides over the last 25 years affected many rural households and economies [85]. In terms of the sensitivity and severity of climate change, landslide and erosion were dire because they tended to massively destroy people's lives and livelihood assets. The Nepal Disaster Report 2015 showed that 487 persons were killed, 473 were injured, 39812 families were affected, 5282 animals were killed, and there was an equivalent economic loss in disaster of 16,753.7 million rupees, particularly from floods and landslides in 2014 [86].

The community has become very sensitive toward social justice and equity. While the previous studies [34,87] found that the LAPA failed to address the social equity and justice issues of sustainability, the CAPA has made some contribution to enhancing social equity and justice through community actions. Formulating rules to address an unfair distribution of forest resources, interest-free loans to climate vulnerable people, and the leasing productive patches of forest areas to the poor and vulnerable groups are key examples of community-led activities associated with social justice and equity. These practices are highly compatible with the spirit of the Climate Change Policy. Such practices may be regarded as an integral part of the sustainable adaptation strategies suggested by Eriksen and Brown [88].

The local measures discussed here are directly and indirectly linked to the six thematic areas identified in the NAPA. It implies that CAPA implementation by the community or local groups is relatively effective for the preparation and implementation of a local climate change adaptation plan. This finding resonated with Paudel, Ojha, Karki, and Gurung [35], who argue that local organizations such as CFUGs and agriculture groups have been proved effective in implementing adaptation activities. Matias [89] has also revealed similar results that a group of indigenous Palaw'ans in the Philippines exhibit a significant capacity for collective action in the maintenance of the water system as part of an adaptive response to climate change. The Palaw'an community has formed a local water users' association called *Danum na Buwal et Mundugen*, which agreed on the terms and actions on the maintenance of the water system. They planted fruit-bearing trees monthly along the water pipes and also cleaned the water tanks. As suggested by Laidler [90], local people have robust instinctual understanding of local atmosphere from their close interaction with nature all along ever since they started to sense environmental changes. They struggle against climate-induced problems; thus, their participation in climate change policies and program implementation are indispensable. Therefore, there is mounting realization of the need and the importance of local groups and institutions in the planning and implementation of adaptation activities at a local level [82,91–93]; nevertheless, local institutions have barely received any attention for adaptation issues, policy, and strategies [91].

5.3. Gaps Hindering the Policy Coherence and the Localization of National Policies

5.3.1. Ambiguous Institutional Framework for Implementation and Coordination

Nepal's Climate Change Policy 2019 covers diverse issues linked to climate change and highlights the need for engaging a wide range of stakeholders at the national and local levels. The policy is silent in terms of entrusting responsibility to the local level institutions and organizations to implement adaptation interventions. However, the NAPA focuses on planning climate change adaptation through existing local community-based organizations. The LAPA framework concentrates on the ward/municipality/rural municipality (local government's structure) for planning and implementation. The LAPA framework talks about an identification of local knowledge and experiences practiced by households, groups, and communities; it even allows them to prepare community-based adaptation plans. However, it has failed to integrate them into the local government's planning process, remaining silent on such plans and community-level organizations. Therefore, there is a huge policy ambiguity about the role of community organizations for planning and implementing adaptation activities at the local level. Although the LAPA emerged as a pioneering planning means to allow the adaptation process at the local level and trade-off between the top–down and the bottom–up approaches [94], the technocratic, top–down, and aid-driven adaptation policy is inadequate to address the vulnerability of people on the ground. Such an approach and policy overlook locally needed specific and contested realities of social dynamics and biophysical change [33]. As explained by Neupane et al. [95], climate change-related (or any environmental/biodiversity) frameworks should build upon already existing and well-functioning institutions. Therefore, a major gap between policy and implementation is likely to persist until the spontaneous as well as proactive activities of small community groups or households are articulated in the policies and strategies with clear and explicit local institutional setting and practical guidelines for implementation.

A coordination mechanism exists between line ministries; however, there is a lack of coordination between relevant institutions, particularly at the province level. Although the Forest Directorate (FD) has been given a responsibility to connect the MoITFE with district-level organizations, there is no direct coordination mechanism between FD, other directorates in the province, and DCC in the districts; therein lies a big gap in implementing adaptation programs in the districts. Therefore, such a working in silo approach would not only complicate the process of implementation but also have the probability of squandering resources by repetition of the same activities unnecessarily for the same target populations. Even at the district level, this issue has existed.

At the district level, the coordination mechanism is poor between relevant state and non-state organizations such as the District Agriculture Development Office, the District Livestock Service Office, the District Drinking Water Supply Office, and the District Soil and Watershed Management Offices when it comes to developing programs for local communities. None of the climate change policies offer a straightforward and coherent institutional operational framework for the implementation of climate change activities at the local level. The Climate Change Policy 2019, NAPA 2010, PAPA 2019, and LAPA 2019 deviate from each other for the local-level implementing unit.

The PAPA and LAPA are very clear about an implementing unit at the local level. They emphasize the local government's institutions (ward, municipality, rural municipality). NAPA is outright for local-level community institutions as a planning and implementing unit. It states as *"Program/project implementation through existing community level organization/s like CFUG, different farmers' groups, irrigation groups and other interest group (NAPA 2010)"*. The Climate Change Policy 2019 is unclear about recommending an implementing unit compared to the previous Climate Change Policy 2011. The Climate Change Policy 2011 states: *"Emphasizing the participation of government, semi-government, NGOs and user groups in formulation and implementation of programs related to climate adaptation, GHG mitigation, capacity building, technology development and extension (Climate Change Policy 2011)"*. The Climate Change Policy 2019, acknowledging the existing adaptation practices, states: *"Local Adaptation Plan has been introduced at various vulnerable areas as per LAPA framework. Similarly, Community Based Adaptation Plan is being implemented at community level with the support of various community organizations, civil society, private sector and other institutions (Climate Change Policy 2019).* Concerning the implementation, it states *"Adaptation measures will be adopted in line with local and indigenous knowledge, skills and technologies by identifying climate change affected households, communities and risk zones (Climate Change Policy 2019)"*. This statement hardly talks about the identification of implementing. It suggests that this policy might have a nuanced understating of local governments as implementing units.

The Climate Change Policy 2019 shows a promising strength in terms of differentiated impacts and vulnerability of climate change: *"Concerns of women, Dalit, indigenous people, Madheshi, Tharu, Muslim, oppressed groups, backward class, minorities, marginalized, farmers, laborer, youths, children, senior citizens, persons with all forms of disability, pregnant women, incapacitated and disadvantaged persons or groups will be addressed in matters related to climate change"*. As explained by various studies [2,3,96–98], climate change impacts are differentiated considering different dimensions, for instance, the level/context of vulnerability of individuals, groups, communities, gender, poor, marginalized, minorities, disability, elderly and children. The Climate Change Policy 2019 has rightly considered those differentiated impacts, which are common in developing countries ([99]. As stated in the results, NAPA looks committed to internalize adaptation programs into sectoral plans of the individual line ministries and to mobilize local communities and groups for implementation. However, concentrating programs in the political boundary of local government poses critical questions of reaching the diverse target populations mentioned in the policy. Climate Change Policy and NAPA provide the MoFE with the responsibility of the overall functional coordination, but local government officials at the implementing unit are more accountable to the Ministry of Federal Affairs and Local Development (MoFALD) [35]. There is an argument that the DCC/ local government tends to consider itself as the local agency of the MoFALD rather than being a local government, and this ministry (which is responsible for local government) does not perceive climate change as their mandate, too. This may have discouraged other ministries to rely on the local government in delivering their climate change-related programs [35].

The Climate Change Policy has promised that at least 80% of the climate change funds will reach the local communities. However, it does not provide a concrete mechanism of fund disbursement earmarked for the local communities. Interviews with project staff and policy makers suggested that the allotted 80% project fund has reached at least the district headquarters but not the local communities. Expert opinion who closely worked on adaptation program estimated that about 50% of the climate fund has reached the local communities to implement locally identified climate adaptation activities. An increasing number of discussions such as workshops, seminars, and meetings squandered a large share of the fund at the district level for two important reasons: first, due to the lack of clear procedure to get the budget delivered to the target beneficiaries, and second, climate change activities are not clearly defined for the allocation of fund. Nepal introduced a climate change budget code in the 2012 [100]; however, the criteria to apply for the climate change code remains unclear, and it influences the realistic estimate [101].

5.3.2. Insufficient Information, Knowledge and Capacity Related to Climate Change Impacts and Adaptation Measures for Policy Implementation

The NAPA was formulated based on the vulnerability assessment using an Intergovernmental Panel on Climate Change (IPCC) framework [60]. However, due to the absence of reliable location specific meteorological data, the NAPA used expert judgment in ranking the vulnerability of different districts [61]. The views of experts may not represent the real climate impacts experienced by local people. This is possibly the biggest limitation of NAPA; thus, it has been challenging for policy makers, climate experts, and practitioners to identify appropriate local adaptation measures. The role of climate science, analyzing climate change impacts and the intervention of technologies for location-specific adaptation measures have been key issues in the planning process [34]. Therefore, we urge for an in-depth study of local perceptions of climate change and their consistency with local meteorological records to have a full range of impacts assessment. Where there is dearth of climatic records or limited observational climate data, local people's understandings provide a foundation to determine changes in climate variables and trends [47].

Local people are very sensitive to climate change and its impacts, thereby exploring adaptation measures from their intuitive understanding gained through their constant interactions with daily weather change [90]. Community requires knowledge and practical ideas to deal with the critical periods of stresses within their farming system and livelihoods. The Climate Change Policy 2019 speaks about ensuring food security through agricultural interventions. However, it is hardly reflected in the local-level adaptation plan and actions. In addition to some practices of drought-tolerant crops and kitchen gardens for vegetables on private land, CAPA has also failed to implement any profound activities on food production and security. Increasing food insufficiency in the studied community in 2017 over 2011 confirms the severity of the issue. The community has been facing extreme impacts such as crop failure, declining crop productivity due to drought, pest and diseases, health, and the depletion of resource issues.

The poor performance of agriculture has been triggered by multiple factors including climate change, low incentives to intensification, poor market access, unfavorable topography, and poor soils [102]. Most poor and developing countries are located in the tropics and semi-desert areas exposed to rising temperature and a water shortage [103], and they face severe climatic threats to crop production due to their geographical location [60]. The FAO anticipates that the decline in agricultural production is likely to affect the availability of food in South Asia and sub-Saharan Africa, where the majority of the population are already vulnerable due to poverty and weak coping capacities to climatic stresses [104]. Most of the African governments have already initiated governance for various adaptation strategies including improvement of technologies and infrastructure, livelihoods' options, and agriculture diversification [60].

In Kenya, farmers are encouraged to practice crop management such as use of diversified crop cultivars, planting of early maturing crops during short rainy seasons, planting of drought-tolerant cultivars, and the use of low planting densities during the dry season [105], soil and water conservation through land contouring and terracing, mulching, conservation tillage practices, and integrated soil fertility management [106]. Replacing water resource-intensive systems (e.g., rice–wheat system) with less water-intensive cropping systems (e.g., maize–wheat system) can increase the adaptation of water stress in agricultural production [107]. Crop diversification improves a buffering of crop production under climatic stress by reducing the chances of pathogen transmission that may arise due to increased climatic variability [107]. For example, Lin [108] found that the planting of disease-susceptible rice varieties in mixtures with resistant varieties had 89% more yield and 94% reduced the occurrence of fungal blast when planted in monoculture. Georgopoulou et al. [109] found that there is a clear distinction between northern and southern Greece in terms of losing and winning agricultural yields in a changing climate. They suggested that climate change adaptations on agriculture need to be tailored to both geography and crop diversity even in a comparatively small country. Given these examples, the community-based adaptation plan of Nepal principally requires an adjustment with cropping pattern change and agriculture diversifications pertaining to the regional and topographical variations.

The limited capacity of the local governments for climate change adaptation planning and implementation poses a major constraint for translating national policy into local plans/actions. The capacity of the government authority, staff, and stakeholders working on climate change issues is not adequate for effective implementation of the climate change adaptation activities at the local level. A discussion with experts (policy makers, climate change specialists) and group discussions suggested that there is a capacity and knowledge gap among different stakeholders that has led to the development of poor linkages between national plan and local needs about climate change, causing some of the urgent local needs to be unaddressed. Khatri, Bista and Gurung [59] also showed that the local government in Nepal lacks capacity to make the best use of available climate change information and knowledge. There are critical gaps on the capacity within the government planning sector in addressing climate change as cross-cutting issues [110,111]. Dongol and Heinen [112] argued that the shortage of adequate staff (both qualitative and quantitative) for the management and enforcement of policy across multiple layers of government and institutions can lead to a failure of policies by making implementation unfeasible. McLaughlin [73] highlighted two broad factors: local capacity and will. He added that although the capacity is undeniably a difficult issue, policy can address it by furnishing missing expertise but will or the attitudes, motivation, and beliefs that inhibit an implementer's response to a policy's goal is less manageable for policy intervention.

Eriksen, Nightingale and Eakin [32] theorize the politics of adaptation and propose the concepts of authority, knowledges, and subjectivities to analysis of adaptation, emphasizing a socio-political process that mediates how individuals and collectives deal with multiple and coexisting environmental and social changes. They highlighted how "power and politics" shape resource access, control, and distribution, which is insufficient even if adaptation policies and program explicitly focus on it.

Authority in climate change adaptation draws the attention to formalized institutions and organizations at different scales [113]. Knowledge increases an accuracy in making decisions related to adaptation [114], and subjectivity helps to link the exercise of power to uneven social connection and individual agency [32]. The interactions between these three elements are fundamental to the explanation of climate science [115], diversification of resources, targeted populations and regions, and knowledge about the critical issue of survival in climate change stress and to implement adaptation activities [32].

The struggle between these three components is believed to be influenced by how policy is formulated and implemented such as top–down and bottom–up. The top–down approach identifies a community of interest organizations on the basis of the thought of political activities in relation to ongoing policy processes [116], and bottom–up identifies the size and composition of entire interest groups and all potential organizational entities which are politically active but are not essentially engaged actively in seeking actual policy influence [116,117]. Analysis of the key climate change policies of Nepal suggests that the policy formulation process and implementation of Nepal is hybrid, showing the necessity of greater flexibility in the design of programs and initiatives for local adaptation. The study from Indonesia also found that the local influence of ideas and preferences to the upward central level policy was limited, suggesting the need to pay attention to local actors engaged in the planning processes to inform decision making at higher jurisdictional levels [118].

Overall, this study highlights profound climate change impacts faced by CFUG households at the local level. The impacts are directly and indirectly linked with agriculture-based livelihoods facing water shortage, increased drought intensity, and landslides escalation. The implementation of both CFUG's Community Forest Operational Plan and CAPA have shown noticeable contributions to address such issues reflecting national climate change policy's aspiration at the local level.

Out of the approximately 2500 CAPAs in Nepal, most CAPAs prepared and implemented by the CFUGs include adaptation activities related to drinking water, irrigation water, protection from landslide, afforestation, and forest protection. The prioritization of similar activities may be constrained by the available budget and time frame provided by the adaptation projects. CFUGs, particularly in the middle and high Mountain regions, tend to respond to the most pressing problems at first such as water scarcity, landslides, and climate-induced consequences to agricultural crops. In this context, the findings of this study are equally applicable to the wider geographical contexts of Nepal as well as similar community-based adaptation practices with analogous geographical and livelihood systems around the developing world.

6. Conclusions

In this paper, we have attempted to assess coherence between national climate change policies/plans, and local adaptation plans and actions. We have explored the localization of national policies in Nepal. The Climate Change Policy 2019, NAPA, PAPA, and LAPA exhibit both coherent and contradictory characters. Particularly, climate change policies are coherent for targeting vulnerable communities, households, or individuals but found to be deviated for recommending an appropriate implementing unit. The LAPA and PAPA consider the local government as implementing units while the NAPA puts an emphasis on the local community group for implementation. Our policy document analysis and fieldwork in a local community in rural Nepal suggested that national policies deviate from each other, creating confusion among the local communities over the implementation of climate change adaptation plans.

As this paper has shown, the local adaptation measures implemented by local community groups are directly and indirectly linked to most of the thematic areas identified in the Climate Change Policy 2019 and NAPA 2010. It suggests that national policies' priorities are reflected in local actions. The majority of the local adaptation measures in the Rajdevi CFUG were applied for landslides control and water scarcity management. Moreover, we found that the local communities are sensitive enough to amend and change the local rules and regulations in order to maintain and enhance social justice and distributional equity in the context of natural resource management and growing climate change impacts at the local level. While the national Climate Change Policy discusses ensuring food security through agricultural interventions, our findings show that the focus on food security is poorly reflected in the local level adaptation plan and actions. We also found that the capacity of the government authority, staff, and stakeholders working on climate change issues is inadequate for effective implementation of the climate change adaptation activities at the local level.

The major challenges of national policy implementation are a lack of coordination and accountability between local government, line ministries, and corresponding thematic offices. Ambiguously defined implementing units at the local level and unclear institutional responsibility throughout the delivery process set the example. Climate change policies, rules, and regulations are supposed to be consistent and understandable among its implementers and delivery agents to find a broad acceptance among the population. When the policies cause confusion, the acceptance suffers, leading toward failure. We suggest that only if the real impacted people and appropriate implementing units are identified can the policies and strategies be successful with a broader desirable impact to reduce vulnerability at local level.

The Paris Agreement (PA) within the United Nations Framework Convention on Climate Change (UNFCCC) highlights the need for evaluations and lessons learned from past programs and projects to enhance support for promoting and replicating approaches that are most effective in helping communities to adapt [119]; this paper has analyzed and documented ground experiences and practices to inform better policy design.

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Annex III: List of further publications

Darjee, K. B. and Ankomah, G. O., 2017. Climate Change Adaptation Practices of Forest Dependent Poor People: Comparative Study of Nepal and Ghana. The science policy gap regarding informed decisions in forest policy and management. What scientific information are policy makers really interested in?: In Proceedings of the 6th International DAAD Workshop. Cuvillier Verlag. Santiago, Chile, 12–20 November 2016.

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