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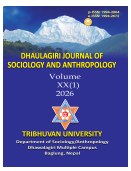

Climate Change Hazards: Socio-economic Vulnerabilities and Indigenous Resilience in the Lower Karnali Watershed Region (LKWR), Bardiya, Nepal

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Abstract

This paper examines climate change-induced hazards, socio-economic vulnerabilities, and traditional indigenous resilience practices in the Lower Karnali Watershed Region (LKWR), Nepal. Specifically, it focuses on Geruwa and Madhuwan among marginalized and under-represented minorities such as women, Dalits, and other indigenous ethnic groups who are highly affected by climate-related hazards and stresses. This study employs a "mixed method" approach, using household surveys (N=120), key informant interviews, and focus group discussions as data-collection tools to gather primary data. Primarily, this paper analyzes how gender, caste, and indigenous communities are affected by climatic hazards and cope with environmental stress in the study areas. Meteorological data from 1994 to 2024 are also incorporated to validate climate variability and change. In the study area, the temperature trend indicates steady warming, with minimum temperatures rising faster while maximum temperatures increase at night. Although there is little long-term linear trend in precipitation records, there is significant inter-annual variability, with drought years scattered with unexpectedly high-rainfall years. Local experiences of rising summer temperatures, erratic rainfall, declining water supplies, floods, droughts, and more volatile livelihoods are all linked to these climatic shifts. The findings highlight declining agricultural productivity, livelihood challenges, frequent flooding, river erosion, heat waves, droughts, and wildfires as major hazards resulting from climate change. While flooding remains the leading hazard in Geruwa-3, drought and river erosion severely affect Madhuwan-2. These hazards disproportionately impact the socio-economic status of the marginalized communities. To cope with climate-induced shocks and hazards, the indigenous communities in these areas, particularly the Tharu, rely heavily on traditional social-ecological knowledge such as Badhghar and Kulopani Chaudhariya water governance institutions. In this regard, this paper highlights the need to integrate indigenous practices with modern scientific approaches to create resilient and equitable long-term solutions for disasters and sustainable development.

Keywords: climate change, vulnerabilities/barriers, Indigenous communities, Indigenous knowledge, water management

Introduction

Climate change is defined as long-term shifts in global climate patterns, primarily driven by human activities such as fossil fuel combustion, deforestation, and industrial greenhouse gas emissions (NASA, 2022). The contemporary world has been facing the challenges of climate change and greenhouse gases for more than a century. Since the late 19th century, the planet's surface temperature has increased significantly, with average global temperatures rising by approximately 0.6 $\pm$ 0.2°C (IPCC, 2001; Lenssen et al., 2024). Its potential to significantly alter the climate, however, has only lately attracted significant scientific attention.

Communities around the world are vulnerable due to climate change, which has worsened pre-existing social, cultural, and ecological issues (Nash et al., 2019). Vulnerability is the inability to cope with arising adverse situations created from disasters and hazards (Proag, 2014). Natural systems and human livelihoods have been under major threat due to environmental hazards such as floods, droughts, and erratic weather patterns. Marginalized and indigenous communities, particularly, are more vulnerable to climate due to limited access to resources, lack of infrastructure, and economic dependence on climate-sensitive sectors like agriculture, forestry, and fisheries (Barange et al., 2018; Rural Reconstruction Nepal, 2025).

Many Dalits and indigenous groups in Nepal lack formal land ownership, a structural barrier that severely limits their capacity to adapt and leaves them highly vulnerable during climate disasters (Pariyar & Kumar, 2024). During severe hazards, these communities are frequently displaced (Maharjan et al., 2023), triggering a complex set of vulnerabilities that disrupt not only tangible assets and livelihoods but also intangible cultural bonds, kinship networks, and local support structures (Khattri, 2021; Spoon et al., 2021). Furthermore, these marginalized groups are bound by distinct cultures, languages, and ancient ways of life that deeply anchor their resilience. To accurately interpret their adaptive capacity, it is vital to understand this holistic worldview; their relationship to the landscape functions as an interconnected web of physical, spiritual, social, and socio-ecological dimensions (United Nations, 2023). Rather than viewing recurrent environmental hazards purely as risks, their place-based cultural traditions and communal reliance on local ecosystems frequently provide distinct social and economic advantages that allow them to absorb shocks and adapt to shifting environments (Paudel et al., 2026).

Culture heavily influences how communities respond to climate change. When designing adaptation strategies, local indigenous knowledge, agricultural techniques, and community-based resource management offer invaluable insight (Berkes, 2009). However, marginalized and resource-poor communities bear the brunt of climate extremes; policy implementation frequently overlooks these vital local knowledge systems as well as the critical contribution of women (Aryal, 2025).

Climate-induced hazards are not experienced equally; rather, their effects are deeply intertwined with structural vulnerability, systemic marginalization, and unequal access to social, economic, and institutional resources (IPCC et al., 2023). In Nepal, indigenous and marginalized groups like the Tharu community are among the most vulnerable due to their direct, historical reliance on climate-sensitive, subsistence-based traditional agriculture, and their low capacity to adapt to escalating hazards such as the Babai River flooding and erratic monsoons (Chaudhary et al., 2021; Chaudhary et al., 2022). Moreover, they are severely affected by forest fires, floods, landslides, river erosion, and droughts (Dhami, 2025). Furthermore, extreme events such as the Babai River flooding and increasingly erratic monsoons severely impact these communities, forcing them to rely heavily on localized knowledge and autonomous coping strategies for flood disasters in downstream river basins (Deshar et al., 2021). Their socio-economic characteristics and geography make them highly susceptible to environmental change and prolonged economic instability (Chaudhary et al., 2018; Maharjan et al., 2023).

The Tharu community, one of Nepal's largest Indigenous ethnic groups (6.6%), resides in regions similar to the Lower Karnali Watershed Region (LKWR) (NSO, 2021b). The Tharu are rich in indigenous knowledge of land, water, and natural resource management, but their adaptation practices remain under-recognized in climate policy and planning (Chaudhary et al., 2021; Chaudhary et al., 2025). This community has a long history of reliance on agriculture, fishing, and forest-based livelihoods. These livelihoods depend on a stable climate and are largely affected by climate-induced hazards, especially recurrent floods and droughts. Hence, changing climates have increased their vulnerability to climate stress and livelihood insecurities (Gentle & Maraseni, 2012; Müller-Böker, 1991). In this context, climate vulnerability should not be understood solely as environmental exposure but should also be examined in terms of livelihood dependence, social marginalization, and local adaptive capacity (Proag, 2014; Turner et al., 2003). This study uses a social vulnerability lens to view hazards not only as natural disasters with physical and economic destruction but also as events that disproportionately impact people due to socio-economic conditions, power dynamics, institutional neglect, and unequal access to resources (Scandlyn et al., 2012; Zaman, 1999).

Climate change in Nepal is not only a physical or environmental crisis; it is also a social one. Disaster studies also show that floods and erosion become disasters when natural events meet poverty, land insecurity, weak housing, and unequal access to resources (Zaman, 1999). It is connected with realities surrounding land ownership, caste, gender, agricultural livelihoods, water access, and the role of local institutions (Onta & Resurreccion, 2011). Various studies from Nepal, such as those by Onta, & Resurreccion (2011) and Paudel et al. (2026), provide evidence of climate vulnerability shaped by social inequality and access to resources. According to Onta, & Resurreccion (2011), gender and caste influence climate

adaptation in Nepal. Whereas Sujakhu et al. (2019)'s findings show Indigenous and disadvantaged households become more vulnerable because of natural resource dependency, weak financial assets, and limited social networks.

Similarly, R. Pandey (2024) argues that climate vulnerability should be understood as a social-ecological process where climatic and non-climatic stresses interact with household livelihoods. The Tharu people in Bardiya use hybrid knowledge (Indigenous and scientific) to respond to water-related hazards amid rising temperatures and changing rainfall (Chaudhary et al., 2021; Chaudhary et al., 2022). However, there is limited research on how climate hazards affect marginalized and Indigenous communities in the Lower Karnali Watershed Region. Floods, droughts, river erosion, heat waves, water scarcity, and cold waves are not just natural events here. They shape everyday life and affect the livelihoods of locals. Floods affect women, men, poor households, and resource-rich families differently because access, mobility, and privacy are unequal (Khattri, 2021).

In this context, this study focuses on Geruwa and Madhuwan of Bardiya district. The objective of this study is to examine climate-induced hazards, socio-economic vulnerabilities, and Indigenous resilience practices among marginalized communities. It also explores how local knowledge, traditional institutions, and community-based coping practices help people respond to climate stress and how local experiences correspond with observed temperature and precipitation trends.

This study investigates climate-induced hazards affecting the people in Geruwa–3 and Madhuwan–2 and their impacts on well-being. It also explores how Indigenous and institutional knowledge systems are working to cope with climate stress. Finally, it explores the relationship between local narratives and observed climatic data, examining how community perceptions correspond with empirical evidence.

Methods and Materials

Research Design

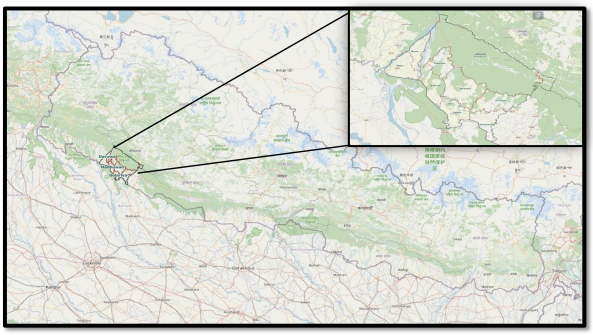
This study used a mixed-method research design to study climate change vulnerability in the study area, which is both measurable and lively. In addition, Household surveys helped to collect numerical information on hazard impacts, migration, livelihood loss, and coping practices. Key informant interviews and focus group discussions helped to understand memories, meanings, local explanations, and Indigenous practices. Secondary climate data from the Department of Hydrology and Meteorology were used to compare local narratives with observed temperature and precipitation trends.

Study Area

The study was conducted across two distinct ecological contexts within the Lower Karnali Watershed Region: Geruwa, and Madhuwan, located in the Bardiya district. These specific sites were purposively selected to capture contrasting climate-risk profiles and analyze a spectrum of vulnerabilities. Geruwa-3, situated in close proximity to the primary Karnali River system, is highly exposed to recurrent, high-velocity riverine flooding. Conversely, Madhuwan-2 represents an inland site predominantly affected by progressive drought, water scarcity, and severe riverbank erosion. This dual-site design establishes a comparative analytical framework used throughout the results section to explicitly examine how localized, hazards-specific exposure shapes distinct socio-economic vulnerabilities and community-level adaptation responses. Both areas are inhabited by marginalized and Indigenous communities, especially Tharu households, small farmers, fishers, women, and wage-labor-dependent families (NSO, 2021a; NSO, 2021b).

Figure 1

Map of the Study Area



Source: Google Earth, 2024

Sampling and Respondent Selection

A total of 120 household respondents were selected for the study, 60 from Geruwa-3 and 60 from Madhuwan-2. A sample size of 120 households was chosen due to logistical constraints and fieldwork feasibility, while ensuring we met the minimum threshold for conducting reliable statistical comparisons between the two sites. Equal numbers were taken from both sites to make comparison possible between two different local climate-risk contexts. The study first identified settlements where marginalized and Indigenous groups were highly represented. After that, households were randomly selected from those settlements. In this study, using KIIs, we have defined "marginalized" as people and households with limited land ownership, low income, poor housing, limited access to education, dependence on climate-sensitive livelihoods, and restricted access to formal support systems. "Indigenous" primarily refers to Adivasi/Janajati groups, particularly the Tharu communities, who have long historical, cultural, and livelihood ties to the Tarai landscape. 74 Women, 4 Dalits, 55 small farmers, and 1 fisher were also included because they experience climate hazards through unequal social and economic conditions. This selection of 60 respondents from each site follows an equal allocation stratified sampling design to establish a balanced comparative framework between the two distinct climate-risk contexts. Rather than relying on qualitative metrics, this structured sample size was chosen

to capture practices. This balanced distribution optimizes the power of cross-site statistical tests to identify significant differences in how unequal socio-economic conditions shape climate risk experience across both wards.

Data Collection Process

Fieldwork was conducted from October 16 to November 15, 2024. The process followed a chronological order. First, the study sites and climate-affected settlements were identified. Second, household surveys were conducted with 120 respondents. Third, key informant interviews were conducted with knowledgeable individuals. Finally, focus group discussions were organized to verify and deepen the household survey findings. The household survey was conducted through face-to-face interaction using a structured questionnaire. It collected information on socio-demographic profiles, climate hazards, livelihood impacts, migration, education disruption, water scarcity, economic loss, and coping practices. Similarly, Key informant interviews were also conducted face-to-face, but they were different from household surveys. KIIs were not general household interviews rather they were in-depth interviews with people who had special knowledge of the community, climate history, river changes, water governance, farming, local institutions, and disaster experience. Key informants included 4 elderly farmers , 2 Badghar leaders,1 local teachers , and 3 NGO representatives. In addition to the KIIs, Focus group discussions were conducted with community members, including women and small farmers. These discussions helped to understand shared experiences of floods, droughts, drinking water problems, displacement, sanitation difficulties, gendered burdens, and Indigenous coping practices. Likewise, Secondary meteorological data were collected from the Department of Hydrology and Meteorology. Temperature and precipitation data from 1994 to 2024 were used to examine long-term climate variability. Data from the nearest available station were used to compare scientific records with local perceptions. Additional information on disaster loss and damage was collected from municipal records and disaster-related sources such as the BIPAD portal.

Data Analysis

Quantitative data obtained from household surveys were coded, cleaned, and analyzed using MS Excel and SPSS version 27. Frequencies and percentages were applied to present patterns of hazards, impacts, and coping practices. Where respondents provided multiple answers, the tables were treated as multiple-response items and interpreted accordingly. Qualitative data from KIIs and FGDs were analyzed thematically. The main analytical themes included climate hazards, livelihood vulnerability, educational disruption, migration, water scarcity, gendered burdens, Indigenous water governance, food security, and traditional coping mechanisms. Finally, the study employed data triangulation by cross-examining household survey results, qualitative narratives, and empirical meteorological data. This integrated approach connected numbers with local stories and grounded experiences with observed climate trends.

Results and Findings

The findings are organized around the study questions. First, the socio-demographic profile shows the social basis of vulnerability. Second, climate-induced hazards are compared between Geruwa-3 and Madhuwan-2. Third, livelihood, social, educational, economic, and migration-related impacts are discussed. Finally, Indigenous coping practices and meteorological trends are linked with local narratives.

Socio-demographic status of the respondents

The socio-demographic profile helps explain why some households are more vulnerable to climate hazards than others. Gender, caste/ethnicity, education, livelihood, income, housing, and migration status shape people's ability to prepare for, respond to, and recover from floods, droughts, river erosion, and water scarcity.

Table 1
Socio-Demographic Profile of Respondents

Categories	Items	Frequency	Percent
Age	15–24	30	25
	25–34	25	21
	35–44	35	29
	45–54	21	18
	55-above	9	8
Sex	Male	45	38
	Female	75	63
Religion	Hindu	118	98
	Christian	2	2
Caste/ethnicity	Brahmin/Chhhetri	7	6
	Janajati/Adivasi	109	91
	Dalits	4	3
Marital Status	Unmarried	4	3
	Married	112	93
	Widow	4	3
Family Type	Nuclear Family	120	100
Education Status	Unable to read and write	57	48
	Able to read and write	27	23
	Primary Education (1–8)	13	11
	Secondary Education (9–12)	13	11
	Higher Education (Bachelor, Master)	9	8
	Informal Education	1	1
Occupation	Business	9	8
	Skilled Laborer	33	28
	Unskilled laborer (Farm worker)	55	46
	A worker in a factory	13	11
	Office Staff	10	8
Temporary Migration during Flood	Yes	106	88
	No	14	12
Housing Status	Own Home	50	42
	Temporary housing	70	58
	Total	120	100

Source: Field Survey, 2024.

The socio-demographics of the 120-household survey demonstrate that climate vulnerability within the study area is structurally and socially rooted. The high concentration of female (63%) and Janjati/Adivasi (91%) respondents is a deliberate outcome of the study's purposive sampling design, which centers marginalized voices. The dataset contains clear indicators of heightened socioeconomic and physical

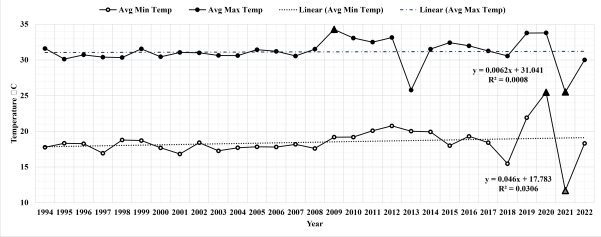
vulnerability. Notably, 58% of the sampled households live in temporary housing, leaving them highly exposed to environmental shocks that directly force 88% of respondents to migrate temporarily during flood events. This vulnerability is further compounded by low human and financial capital reserves, as 48% of respondents are unable to read and write, and 46% depend on unskilled labor.

Temperature and Precipitation Variability of the Study Area

Variation in Temperature

Figure 2

Annual Temperature Trend



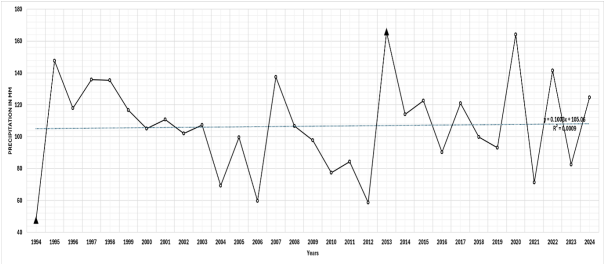
Source: Department of Hydrology and Meteorology, 2024

This study of the overall temperature trend in Rani Jeruwa between 1994 and 2024 reveals that average maximum and minimum temperatures increased by 0.0062°C/yr and 0.046°C/yr, respectively. The maximum temperature shows a very minor rate increase, described by the linear formula ($R^2 = 0.0008$). On the other hand, minimum temperature shows a much stronger upward trend, with $y = 0.046x + 17.783$ ($R^2 = 0.0306$), indicating that nighttime temperature increases almost seven times faster than daytime temperature. Locals have also strongly agreed with these findings. About 13 percent of households reported increased summer heat waves and winter cold waves (*sit lahar*). In Bardiya, this variation has severely disrupted the local community's daily outdoor work. The thermal shifts have caused drying of hand pumps, crop damage, and scarcity of clean drinking water during the monsoon. The community has perceived these temperature fluctuations as a cause of increased financial vulnerabilities. This asymmetric thermal warming aligns with regional assessments indicating pronounced nighttime warming across the Terai region of Nepal (MoFE, 2018). Consequently, nighttime heat retention is a major problem for rural farming systems and indigenous Tharu livelihoods (Chaudhary et al., 2021; V. P. Pandey et al., 2019).

Variation in Precipitation

Figure 3

Annual Precipitation Trend



Source: Department of Hydrology and Meteorology, 2024

The long-term precipitation record (1994–2024) exhibits high variability with a weak, non-significant linear trend, where $y = 0.1003x + 105.06$ ($R^2 = 0.0009$). Over the 30-year observation period, mean annual rainfall rose slightly from 105 mm to 108 mm. This small change caused extreme shocks to the area, intensifying volatility from a historic low of 47 mm in 1994 to a maximum of 166 mm in 2013. Severe deficit years are usually followed by heavy rainfall surges, such as 164 mm in 2020 following droughts in 2004 (69 mm), 2006 (60 mm), and 2012 (59 mm). The locals have reported floods as the primary hazard of Geruwa-3 (42%) and Madhuwan-2 (33%), while drought is more common in Madhuwan (12%). These unpredictable distributions provoke locals (88%) into temporary migration to elevated areas like Orali Bazar or community schools during flooding. This coincides with scientific data indicating that the internal monsoonal distribution has become extremely unpredictable across western Terai plains (V. P. Pandey et al., 2019). Thus, short-duration, high-intensity events cause frequent localized disasters rather than affecting multi-decadal totals (Chaudhary et al., 2021; MoFE, 2018).

Types of Hazards

A hazard is a potential source of harm arising from interactions with the environment and social and human activities that can cause loss of life, injury, property damage, or severe environmental degradation. Within the scope of the study, respondents identified several distinct categories of localized climate threats, led primarily by riverine floods and riverbank erosion. In addition, the surveyed households reported experiencing less frequent but highly disruptive extreme weather events, including intense heat waves, severe cold waves, wildfires, and lightning strikes.

Table 2

Types of Hazards occurred in Study Areas

Hazard	Madhuwan-2		Geruwa-3	
	Freq.	%	Freq.	%
Flood	20	33	25	42
River Erosion	10	25	7	18
Heat Waves	8	13	8	13
Drought	7	12	6	10
Lightning/ Thunder	3	5	4	7
Wildfire	7	12	6	10
Cold Wave	5	8	4	7
Total	60	100	60	100

Source: Field Survey, 2024

Floods are the primary hazards across both sites; the empirical data highlight distinct, site-specific risk profiles rooted in localized micro-geographies. Geruwa-3 experiences higher exposure to sudden-onset flooding (42% vs 33%) due to its immediate proximity to the active Karnali River channels, whereas Madhuwan-2 faces slow-onset, compounding crisis driven by elevated rates of land-stripping river erosion (25%) and drought (12%). The divergence interprets how climate risk is fundamentally localized, shifting household vulnerabilities from episodic area destruction in Geruwa-3 to chronic depletion of agricultural land and adaptive capacity in Madhuwan-2.

The findings show that climate risk is spatially uneven within the same watershed. Geruwa-3 needs stronger flood preparedness, while Madhuwan-2 requires more attention to drought, irrigation, and riverbank protection.

Social Impacts of Climate Hazards

The social impacts are non-material phenomena that compound with vulnerabilities such as poverty, limited access to resources, governance, and existing health conditions, making a population less able to prepare for, respond to, and recover from climate hazards.

Flood's Socio-Economic Impacts

Among the various hazards flood is dominant in both study areas. However, Geruwa-3 faced slightly higher level of vulnerabilities and marginalization compare with Madhuwan-2 in Bardiya District, Nepal.

Table 3

Flood Induced Livelihood Impacts on surveyed household

Impact on Livelihood	Flood (Yes)	Total
Agriculture and Cattle	4	4
Asset Loss / Limited Recovery	11	16
Mixed crops-livestock	6	9
Crops And Waters	3	3
Deforestation	6	8
Destruction of Properties	2	2
Heat-Related Illnesses	6	8
Income Loss	3	3
Increasing Health Cost	10	16
Land Degradation	2	2
Migration and Displacements	13	19
Mortality of Livestock	2	2
Resources Scarcity	6	8
Water Shortage	8	12
Waterborne Disease	5	8
Total	87	120

Source: Field Survey, 2024

Flood impacts appear as a chain of vulnerability. Displacement, asset loss, health costs, water shortage, and livestock damage are connected. When floods damage crops, households lose food and income. When families move, children miss school and women's care burden increases.Qualitative research with local teachers and badghar leaders confirms that flood displacement disrupts education, causing children to miss weeks of school as classrooms are routinely repurposed into temporary emergency shelters. In parallel, field interviews reveal an exponential increase in breakdowns that force them to travel long distances to secure water resources ($n = 12$; (Onta & Resurreccion, 2011)). Ultimately, this shows that flood displacement converts a biophysical hazard into a structural crisis of social inequality. Whereas children's education and compounding women's unpaid care burden, these climate shocks actively entrench long-term socioeconomic vulnerability across the watershed region.

Table 4

Social Consequences of Climatic Hazards

Categories	Frequency	%
Education disruption	20	17
Water scarcity	30	25
Increased inequality	2	2
Migration and displacement	13	11
Loss of traditional living	30	25
Resource scarcity for local craft	25	21
Total	120	100

Source: Field Survey, 2024

Water scarcity, and loss of traditional living were the

most reported and higher in social impacts. This present that climate change affects not only income but also culture, daily routines, and Indigenous ways of life. For Tharu and other local communities, water, forests, farming, fishing, crafts, and rituals are closely connected. When natural resources decline, both livelihood and cultural continuity are weakened.

Escaping the flood: Temporary Migration destination

Floods are becoming a major issue in low-lying and riverside areas, creating huge vulnerability in livelihoods and the daily lives of the local people. One of the biggest problems is saving lives and urgent belongings. For that reason, people instantly run away and migrate temporarily to shelter until the flood is over.

Table 5
Temporary Migration Areas During Floods and Droughts

Location	Floods		Droughts	
	Freq.	%	Freq.	%
Community	28	23.33	0	0.00
Schools				
Government	1	0.83	12	10.00
Office				
Gulariya	15	12.50	34	28.33
Higher Grounds	0	0.00	15	12.50
(Muni.)				
Higher School	7	5.83	7	5.83
(+2)				
Municipality	17	14.17	0	0.00
Ground				
Nepalgunj	9	7.50	9	7.50
NGOs	5	4.17	0	0.00
Orali Bazar,	35	29.17	0	0.00
Madhuwan				
Public Shelters	0	0.00	3	2.50
Rajapur	0	0.00	27	22.50
Shelter House	2	1.67	5	4.17
Temple	1	0.83	0	0.00
Total	120	100.00	112	100.00

Source: Field Survey, 2024

Temporary migration shows how climate hazards disturb settlement security. During floods, people move to Orali Bazar, schools, municipality grounds, and other safer public spaces is search of safer grounds and availability of resources such as food and shelter. During droughts, migration is more closely linked to access to water and the search for livelihoods. Thus, migration is both a coping strategy and a sign of deeper climate vulnerability.

Vulnerabilities to Livelihood

A livelihood comprises the capabilities, assets (including both material and social resources), and activities required for a means of living. However, during disasters, normal life becomes stressful and directly hampers health, water, sanitation, food, clothes, fuel, social networks, education, and so on.

While taking qualitative data, the story of Mr. Regmi (49), a local person who is a farmer from Geruwa-3, narrates the vulnerabilities during the climate crisis as follows:

> Geruwa has been facing irrigation problems and issues every year during both summer and winter. The drought starts around the month of Chaitra, and unlike before, there is hardly any rainfall by a very small margin. As a result, drinking water sources dry up, hand pumps stop working, and streams and canals no longer provide sufficient water...

Additionally, while taking a key informant, Mr. Poudel (55), a park ranger, also mentions:

> Water scarcity is also making life difficult for wildlife during the dry season. It also creates human-animal conflict every year. While the streams and canals are drying up, wild animals come to the residential area searching for water, which is very dangerous for both humans. In Madhuban Wards numbers 1, 2, and 3, nearly 15 to 20 people have been killed by tigers.

Mr. Tharu (40), another key informant, explains that:

> During the summers, the sun dries up the land and ruins our crops. At the same time, armyworm infestation creates terror by damaging our crops. This worm is very active when the earth is heated to a very extreme level and has minimal rain. Additionally, flooding is also a frequent problem here. There is a severe shortage of clean drinking water because the water level is about five to six feet during monsoon season in our surroundings.

Likewise, Miss Tharu (33) from Geruwa-3 says:

> When floods come, we must go far to fetch clean water. Sometimes, we even end up drinking water we have bought after walking long distances. When floods come, it becomes very difficult for children and the elderly. They require special care. Last year, during the flood, while trying to transfer an elderly person on a buffalo, both the buffalo and the elderly person fell into a ditch. The elderly person was injured, and it took a long time to recover.

In this way, Miss Chaudhary (26) also states to me during the interview that:

> For the cold wave called 'sit lahar,' it starts from Mangsir to Magh (November–January), making it extremely difficult for us to work. The cold became intense at that time. The sun doesn't appear for days, sometimes even for an entire week. The cold wave also affects our crops, including wheat, vegetables, and lentils. But what can we do? It is all nature playing a vital role, and we have no control and power over it.

These narratives show the various experiences with climate stress in everyday life from the effects of drought in irrigation and drinking water, floods in the destruction of houses, crops, water sources, and mobility. Furthermore, it also indicates that cold waves reduce work capacity and harm winter crops, and

water scarcity also increases human-wildlife conflict. These experiences connect climate change with livelihood, health, safety, and household survival.

Educational Vulnerabilities

Education is strongly affected by climate hazards. School absenteeism due to floods and droughts was the major educational barrier identified by local households.

Table 6
Educational Barriers

Categories	Frequency	%
School Absenteeism (Floods/Droughts)	50	42
Loss of School Infrastructure	20	17
Economic Loss → Dropouts	15	12
Limited Access to Higher Education	15	12
Limited Vocational Training	5	4
Malnutrition Impacting Learning	15	12
Total	120	100

Source: Field Survey, 2024

Flooded roads, damaged schools, household labor needs, and displacement interrupt children's learning. The narratives below also show gendered effects. Girls often carry extra household duties during crises, and lack of privacy, sanitary materials, and safe shelter during floods creates further difficulties for adolescent girls and women.

The Rising Tide: Education in the Era of Climate Shocks

Floods severely disrupt education by damaging schools, displacing students, and interrupting learning, while simultaneously reinforcing gender inequalities, as girls are often more likely to drop out to support the household, as most household responsibilities fall on the daughters.

In this regard, Mr. Khatri (46), one of the key informants, shared the narrative that:

> Floods have a harsh impact on students. When flooding arises between their homes and schools, their studies are greatly disrupted. It also has an emotional impact on them psychologically, causing fear, and many students, especially those from marginalized backgrounds, suffer from food shortages...

Additionally, Mrs. Tharu (45) said:

> ...Bipad (disasters) are directly imposing on us outside of school, establishing a cycle of missed education and early marriage. When a flood or drought hits our village, crushing our crops, our parents must leave for distant places to find labor to support the family. This absence means the daughters have to take on all the household responsibilities. Which makes it difficult to attend school and continue to study... As a result, we begin to lose interest in education slowly. This substantial problem often leads our ancestors to arrange early marriages for us as we grow young.

Miss Tharu (25) said:

> When floods occur during menstruation, we are unable to use pads or cloths. There is no dry place to dry the cloth used during menstruation, and because of this we feel itching and infections around our private parts. During such times, when the situation worsens, we don't even have access to essential clothes. During those times access to sanitary pads during menstruation is more valued than having food. Even now, during menstruation, people treat us as if we are untouchable. Temples are not allowed to take shelter during floods if we are menstruating...

All narratives and experiences show that floods create significant barriers and vulnerabilities to education and learning among youth. Particularly, girls and young children face more barriers and burdens during this critical time. They have to take on extra household duties and responsibilities. Not only that, but they are also forced into early marriages by their own parents to avoid disaster-related casualties and risks.

Impact of Climatic Hazards on Economic Condition

Climate change profoundly impacts global economic conditions by acting as a risk multiplier and a direct source of physical damage, ultimately threatening long-term growth and stability. The primary economic impacts stem from increased frequency and intensity of extreme weather events (floods, droughts, heatwaves, and wildfires) that destroy essential infrastructure. They also disrupt global supply chains and cripple climate-sensitive sectors like agriculture, tourism, and fisheries.

Table 7
Impact of Hazards on Economic Conditions

Categories	Frequency	%
Agriculture loss	40	33
Livestock decline	25	21
Rise in food prices	20	17
Jobless	12	10
Infrastructure damage	5	4
Increased recovery expenditures	18	15
Total	120	100

Source: Field Survey, 2024

Economic impacts are concentrated in agriculture and livestock. Crop losses, livestock declines, rising food prices, joblessness, and recovery costs show that climate hazards affect both production and household consumption. Poor households face longer recovery periods because they lack savings, insurance, secure land, and access to easy credit. In this sense, climate hazards act as a poverty multiplier.

While KII, the following stories by Mr. Tharu (69) also depict the loss and devastation of hazards:

> ...the flood in my village destroyed between fifty and

> sixty homes, leaving nothing but hopelessness in the area. I can still picture the devastating scene. Families from our community lost almost everything in front of them. It was heartbreaking to see them in pain. No one could remain unmoved by their suffering. Even the money earned during the rainy season was not enough to rebuild their homes. It was very difficult to get a loan from the bank, and there was no help available from anywhere.

Similarly, another KII from NGOs, who had seen the 'Bheri Environmental Excellence' (BEE group) adds that it made them aware during the research;

> In October 2021, severe flooding in the Karnali catchment area of western Nepal resulted in the loss of at least 103 lives. In the Mahakali River basin, the disaster displaced 2,600 people and caused significant agricultural damage, affecting more than 126,282 hectares of paddy fields. High-value crops like vegetables and aquaculture were also heavily impacted.

In conclusion, climate change is causing major economic losses at the local level. As Mr. Tharu's accounts show, floods clean out homes and essential goods related to livelihoods. Community people are compelled to live in utter despair, which collectively increases the community's financial vulnerability and risk. Overall, to protect communities and economies, investments in climate-resilient infrastructure, sustainable, locally knowledge-based agriculture, and financial aid programs are essential. Without immediate intervention, the growing economic burden of climate change will continue to bridle vulnerable populations for a long time.

Traditional/Indigenous Water Management Practices

Traditional water management activities encompass time-tested, often community-driven methods developed over time to sustainably conserve, harvest, store, and distribute water resources, relying heavily on local ecological knowledge and simple, nature-based infrastructure. These practices are fundamentally focused on maximizing the retention of water runoff within a local area, primarily by capturing rainwater and enhancing groundwater recharge.

Table 8
Traditional Water Management Practices

Traditional Water Management	Frequency	%
Canal water	81	67.5
Dams and Ponds	12	10
Traditional Wells	10	8
Water Storage in Clay Pots	8	7
Water Recycling in Households	5	4
Water User Collectives	4	3
Total	120	100

Source: Field Survey, 2024

Canal-based water management remains the main local water practice. It is both a technical and social system because it depends on cooperation, rules, labor sharing, and local leadership. However, strong dependence on canals also creates risk. If canals are damaged by floods or receive less water during droughts, many households become vulnerable at once.

Traditional/Indigenous Water Governance

There are various traditional watershed management cultural systems among indigenous communities worldwide. This system is particularly based on local knowledge and is community-driven. This helps promote local knowledge and sustainable development without hampering the natural surroundings. In the study area of the LKWR region, indigenous women and culturally practiced ancestral activities play a vital role in the conservation and management of watershed areas. In this regard, the following stories by Mr. Tharu (47) depict the scenario while doing KII:

> Over a century ago, our ancestors successfully built a canal from the Karnali River, and to this day, we continue to practice the 'Kulopani Chaudhariya' ritual to sustain and create our own water management approach. Each village has a local leader known as a 'Badghar' or 'Bhalmansa', who is in authority to oversee community affairs, including water management and related issues. Similarly, thirteen villages are nominated by an administrative leader, with Kulopani Chaudhariya serving as the head. The Chaudhariya is nominated through a democratic process by all the village Badghars, granting him the authority to supervise canal water efficiently.

Another informant, while collecting qualitative data, Mr. Tharu (62), one of the KII I have done from Badghar Head, gave further details.

> In cases of water scarcity, alterations may be made to the main canal. If this does not resolve the issue, it becomes the Chaudhariya's responsibility to establish a rotational water access schedule for farmers. To address any canal damage, the Chaudhariya calls a meeting with the Badghars and Bhalmansas, during which farmers from each village bring tools like spades, pickaxes, and sickles to contribute to maintenance work. Some villages have around 100 farmers, while others have as few as 25. In such cases, the Chaudhariya distribute the workload fairly through a system known as Naan, where farmers dig assigned sections of the canal according to the planned structure. If someone refuses to participate in the maintenance work, they must pay a penalty called Khara.

He also highlighted the cultural performance to manage water as such,

> We worship nature and our ancestors by viewing water as a deity (Devta). The ritual starts with 'Dhodiya Puja', followed by 'Hereri Puja', which is performed for the well-being of people, land, and future crops. Farmers offer cow's milk and incense to the water, believing that spreading incense around the fields and pouring milk at

the canal's center helps protect crops from pests...

The Badghar and Kulopani Chaudhariya systems show that Indigenous resilience is institutional. These systems manage water distribution, canal repair, rotational irrigation, labor contribution, and conflict settlement. Rituals such as Dhodiya Puja and Hereri Puja also show the cultural value of water. Yet these systems are under pressure from irregular rainfall, drought, migration, and changing livelihoods.

Traditional/Indigenous Food Security Practices

Traditional food security performances in many local or Indigenous communities center on diversified, resilient, and localized food systems rooted in generational knowledge. These practices typically involve agro-biodiversity, cultivating an array of indigenous and local crops and livestock breeds that are adapted to the microclimate and soil conditions, ensuring a reliable harvest even if one crop fails.

Table 9

Traditional Food Security Activities in the Study Area

Methods	Frequency	Percent
Food Storage & Preservation	55	45.83
Indigenous Farming	30	25
Community-Based Food Sharing	20	16.67
Forest and Wild Food Utilization	15	12.5
Total	120	100

Source: Field Survey, 2024

Traditional food security practices remain important during climate stress. Food storage, Indigenous farming, community sharing, and use of forest foods help households cope with crop failure, floods, droughts, and market disruption. However, these practices are weakening today due to changing dietary habits, declining local crops, reduced access to forests, and weaker collective support.

Traditional & Indigenous Climate Resilience

Local coping strategies combine ecological knowledge with practical action. Bamboo, mud, and sandbag embankments reduce flood damage, while Amriso and Khar support soil protection and household use. Rainwater collection, elevated foundations, climate-resilient housing, and social networks also help. Still, these practices cannot fully address large floods, severe droughts, and river erosion without formal support.

Table 10

Local Coping Strategies Across Study Areas

Strategy	Geruwa-3	Madhuwan-2	Total	%
Embankments (sandbags/ bamboo/mud)	18	15	33	28
Resilient plants (*khar*, *Amriso*)	14	13	27	23
Rainwater gathering	10	12	22	18
Traditional Disaster Foresight	8	9	17	14
Climate-resilient housing	6	5	11	9
Social networks & communal sharing	4	6	10	8
Total	60	60	120	100

Source: Field Survey, 2024

Indigenous people are real knowers of nature and its rules. Climate resilience begins with safeguarding natural systems that functionally regulate the ecosystem. In the study areas, Tharu people consider bamboo trees indispensable and inseparable in their everyday life. These are directly related to the culture, housing, and income generation activities of the study communities. This fact is validated by Mr. Tharu (55), a Badghar leader, as follows:

> In our Tharu culture, bamboo is taken as a vital product. We integrate this into nearly every aspect of our lives. From constructing our house and making its roofs to minor daily chores, bamboo is essential. Thus, we build mud and bamboo embankments around our surroundings and along the riverside to protect them from floods and soil erosion. Unfortunately, this vital resource 'amriso' is now becoming scarce, likely due to both over-utilization and the devastating loss caused by the great flood of 2040 B.S. To combat this decline, the community has proactively launched a bamboo preservation project...

Likewise, Miss Chaudhary (33) from the Sonaha women's group remarked:

> In the past, our village had a lot of 'Ameriso' (saccharum grass) and 'khar' (thatching grass), which helped protect us during floods because it absorbed and served as a water barrier and broke the minor flood perfectly. But nowadays, wild animals come out of the forest and eat all the 'Amriso' that we planted for flood protection and cultural uses. That makes us more at the mercy of flooding as well as wildlife conflict. Most of the people of our community have stopped planting

> 'Amriso' and 'Khar' due to the fear of wild animals; because of this, we are compelled to depend on the nearby market for the 'kucho' brush used for sweeping and rituals made by 'Amriso'.

These stories reflect that traditional knowledge is deeply rooted in this study community. This knowledge relies on indigenous people who place ecological knowledge and social networks first. Their ideas integrate the construction of makeshift embankments in modern practices with the planting of flood- and drought-resistant crops and water conservation.

Discussion

The findings show that climate change in the Lower Karnali Watershed Region is not only an environmental process. It is also a social and livelihood issue. Floods, droughts, river erosion, heat waves, cold waves, and water scarcity affect people through farming, livestock, drinking water, schooling, migration, health, and household economy. These impacts are stronger among households with weak housing, income, and education and high dependence on agriculture and natural resources. The study also shows that climate risk is spatially uneven. Geruwa-3 is more exposed to flooding, while Madhuwan-2 faces more severe problems with drought, river erosion, and water scarcity. This supports the argument that adaptation planning should not treat the entire watershed as a single uniform risk zone. Each locality needs different responses. Geruwa-3 requires flood shelters, early warning, embankment maintenance, and safe evacuation routes. Madhuwan-2 needs drought management, irrigation support, groundwater recharge, and riverbank protection. This reflects Nepal's wider disaster governance challenge, where response, risk reduction, climate adaptation, and federalized governance still overlap (Vij et al., 2020).

Gender, caste/ethnicity, and livelihood position shape how people experience climate hazards. Females face additional burdens during disasters because they often manage water, food, care work, sanitation, and household survival. The findings on school absenteeism, menstrual difficulties during floods, and increased household duties show that climate stress can deepen existing gender inequalities. This supports Onta, & Resurreccion (2011) argument that climate adaptation in Nepal is shaped by gender and caste relations, not only by physical exposure to hazard. It also matches Sujakhu et al. (2019)'s finding that Indigenous and disadvantaged households are more vulnerable because of resource dependency and limited financial and social assets.

Indigenous knowledge remains a major source of resilience in the study area. The Badghar system, Kulopani Chaudhariya water governance, canal repair, rotational irrigation, food storage, community sharing, bamboo and mud embankments, and use of Amriso and Khar show how local people respond through collective and ecological knowledge. These practices are practical and cultural. Water rituals such as Dhodiya Puja and Hereri Puja show that water is understood not only as a resource but also as part of social and spiritual life. This also connects with Nepal's disaster policy, which emphasizes local knowledge, social inclusion, early warning, climate-adaptive infrastructure, and community-based risk reduction (Government of Nepal, 2018).

However, these Indigenous systems are under pressure. More irregular rainfall, drought, floods, migration, human-wildlife conflict, and changing livelihoods are weakening traditional coping systems. This reflects what Hoffman (2019) calls the gap between disaster knowledge, policy, and practice, in which local knowledge is often recognized but not adequately translated into action. This finding relates to Chaudhary et al. (2021), who show that Tharu communities in Bardiya use both Indigenous and scientific knowledge to respond to climate-related water hazards, but traditional practices alone are not suitable in the present situation. It also coincides with R. Pandey (2024)'s social-ecological view that climate vulnerability in Nepal emerges from both climatic and non-climatic pressures. The comparison between local narratives and meteorological data supports the findings. Temperature data show a rising trend, especially in minimum temperature, while precipitation shows high variability. Local people described hotter summers, drying water sources, irregular rainfall, crop damage, floods, drought, and cold waves. This shows that people experience climate change not only through annual averages but also through timing, intensity, uncertainty, and everyday disruption.

Conclusion

Climate change has become a lived reality in the Lower Karnali Watershed Region, visibly disrupting the everyday lives of locals. In Geruwa-3 and Madhuwan-2, communities' exposure to various hazards such as floods, droughts, heatwaves, and riverbank erosion is gradually weakening livelihoods. The environmental changes are intersecting with existing social and economic inequalities. Agricultural productivity, food systems reliability, water availability, and social stability quietly erode under these constant stresses. Long-term temperature rise and irregular rainfall patterns demonstrate that such alterations are more than perceptions; they are supported by measurable climatic trends.

Communities in the study are not just passive to these pressures. They are using indigenous knowledge systems to guide adaptation and offer practical and culturally rooted responses. Community-based water governance, traditional food storage, crop diversification, and collective support system practices remain central to survival strategies. However, these coping mechanisms are becoming increasingly strained as the frequency and intensity of climate-related risks surpass their designed capacity. A critical connection between local knowledge and formal policy frameworks is required. Indigenous practices are recognized as a topic of discourse, but they are rarely integrated into planning and governance. This gap limits the effectiveness of wider adaptation processes. An inclusive framework is required for building sustainable and equitable resilience systems that synthesize modern technology

and indigenous knowledge. These integrated systems can support climate-sensitive infrastructure and strengthen participatory decision-making at the grassroots level.

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The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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