Journal of Environment Sciences (2026), **Volume XII**, 52-65
https://doi.org/10.3126/jesv12i1.96879

Assessment of Flood Induced Loss and Damage in Roshi River Basin of Panauti Municipality, Kavrepalanchok, Nepal

Aashma Shrestha[1], Praveen Kumar Regmi[1], Rajesh Shrestha[1], Dharma Raj Sorali[1]
[1] School of Environmental Science and Management (SchEMS),
Faculty of Science and Technology, Pokhara University, Nepal
*Correspondence: praveenkumarregmi@gmail.com

Abstract

Flood has been identified as a frequently occurring natural disaster, with extensive capacity to cause economic and non-economic loss and damage. The main purpose of the research study in the Roshi River Basin of Panauti Municipality-12 is to analyze temperature and precipitation trends, assess economic and non-economic loss and damage, and identify key adaptive measures adopted by community in response to September 2024 flood. Households Survey, Focused Group Discussion (FGD), Key Informant Interview (KII), Climatic Data Analysis and Field Observation were conducted to obtain the objectives of the study considering 187 households from the most severely affected communities. Findings indicated that the average minimum temperature increased by approximately 0.0345^{0}C per year, while maximum temperature rose by 0.093^{0}C per year, resulting in an overall annual increase of 0.064^{0}C. Precipitation exhibited a declining trend of 1.16 mm/year over the past three decades. The devastating flood event in September 2024 was attributed to the extreme concentration of rainfall under changing climatic conditions, causing an estimated total loss and damage of NPR 536.178 million (USD 3.81 million approximately). The highest impacts were recorded in agricultural land and housing, followed by livestock, crops and other sectors. Statistical analysis revealed a significant correlation between economic loss and damage and household income, whereas association with ethnicity and family size were found to be insignificant. Non-economic impacts, including loss of life and disruption of basic services, underscored the severe social consequences of flooding. Livelihood diversification emerged as the most effective adoptive measure, with moderate resilience in insurance utilization and community groups' engagement. Conversely, settlement planning and riverbank management were identified as low priority areas, highlighting the need for strict enforcement of resilient infrastructure standards, and strengthened multi stakeholder coordination to enhance long term community resilience.

Keywords: *Flood, Roshi River Basin, precipitation, loss and damage, adaptive measures.*

Introduction

Flood has been identified as a frequently occurring natural disaster, with extensive capacity to cause economic and non-economic loss and damage (Lamichhane et al., 2025b). Also, floods impact the livelihood and wellbeing of the vulnerable communities specifically residing near the riverbanks. These magnitudes may be exaggerated by the climate change consequences with increased frequency and intensity of slow onset and extreme climatic events causing substantial challenges to basic facilities, infrastructure, livelihood, ecosystem, and human health (Rahman, 2014). In response to the impacts, UNFCCC recognized loss and damage in the Paris Agreement emphasizing the need for global action to address these impacts (Nugroho, 2023). The history of the loss and damage in the context of climate change dates back to the 1990s when discussions, led by the Alliance of Small Island States and Vanuatu in particular, about an insurance pool circulated (UNFCCC, 1991). However, it has only been in recent years that concrete policy has emerged (McNamara & Jackson, 2019). Loss and damage derived by climate induced disasters like floods are increasingly being flagged as the third pillar of international climate policy, together with mitigation and adaptation measures (Roberts & Pelling, 2016). The mechanism was established at the Conference of the Parties to the UNFCCC in 2013 on the grounds that "a residual domain exists wherein climate change adaptation, disaster risk reduction and public/private risk transfer mechanisms are insufficient for peoples and places overwhelmed by climate impacts" (Wrathall et al., 2015). The definition shows unable to cope with the climate related stressors and the costs related to existing coping and adoptive measures. Loss and damage can be a physical material or nonmaterial, as well as economic and non-economic, with some intersection between both the categories (Serdeczny, 2019).

In Nepal, floods represent as one of the most recurrent and damaging climate related hazards, heightening vulnerabilities of communities mainly residing in the bank of river basins. The study on the Melamchi flood, 2021 estimated total economic losses of USD 5 million, with affected households incurring an average loss of USD 51,733, while significant non-economic impacts including mental health challenges, disruptions to education and damage to cultural sites were also documented (Parajuli, 2023). Likewise, in Terai region of Nepal, an unseasonal 2021 flood inundated over 144 hectares of agricultural land in Rajapur Municipality of Bardia Nepal, reflecting an increasing trend in flood frequency and severity over three decades (Paudel et al., 2025). In the Kamala River Basin, despite community awareness of early warning systems and nature-based solutions, resilience remains insufficient due to weak local disaster risk reduction institutions and poor policy implementation (Pandey, 2025). Also, in the Narayani River Basin, a noticeable rise in precipitation events has impacted on significant portions of cultivated land vulnerable to inundation, emphasizing the urgent need for early warning systems and risk mapping for communities residing near the river (Maharjan, 2024). These recurring flood incidents across Nepal are closely tied to its monsoon driven precipitation regime, which itself has been intensifying with climate change. Approximately 80% of annual monsoon precipitation is obtained during the period of June and September, with the most significant rainfall recorded during the central two months of the interval (Karki et al., 2017).

The heavy and rigorous rainfall of September 26 to 28, 2024 resulted in large scale flooding and landslides in Nepal and the Bagmati province has been affected the most. This stirred the Government of Nepal to declare 11 municipalities within Kavrepalanchok district as a crisis area which also included Panauti Municipality. The landslides and localized damage caused by high precipitation were observed due to continuous 3-days rainfall from September 26 to 28, 2024, resulted in economic losses that exceeded 1% of the entire GDP of the country and 250 casualties documented (MoEWRI, 2024). Severe damage was concerted in the Kavrepalanchok District and its surrounding locations including Kathmandu and Dhading (Lamichhane et al., 2025a).

Hence, the research study area of Panauti Municipality ward-12 is one of the highly floods affected communities near the bank of Roshi river. Most of the people are engaged in agriculture, livestock and small-scale business retaining their livelihood after facing the challenges derived from extreme flood of September 2024 resulting in the economic and non-economic loss and damage. Therefore, the study analyzes trends in precipitation and temperature over the past decades contributing to the increasing flood, economic and non-economic loss and damage experienced by the affected communities of Panauti Municipality ward-12 due to September flood and identify the adaptive measures of affected communities of Panauti Municipality ward no.12 in response to and recovery from flood-related loss and damage.

Materials and Methods

Study Area

The study was carried out in the Roshi river basin area of Panauti Municipality ward-12, Kavrepalanchok District of Bagmati Province, a former Kolanti Bhumedanda VDC (Ward 1 to 9). The Roshi River originated from the Mahabharata range and flows from Phulchowki forest area to downstream though multiple settlements before merging with the Punyamata River near the Panauti Bazar. The highly flood affected communities considered for the research covering around 5km^2 downstream sites of Roshi Riverbank within the

Panauti municipality-12. The study area is situated at around 1506 m elevation and is located at Longitude of 85^0 29'16''E and Latitude of 27^0 34'19''N. The annual average temperature is 21.86^0C (High) and 11.02^0C (Low) and average annual precipitation accounted 337.4mm.

Methods

The study employed a mixed methods approach to obtain the objectives, integrating formal institutional coordination with comprehensive primary and secondary data collection. To formalize and facilitate support in the research study works, official letter was submitted to the Panauti Municipality Office from SchEMS (School of Environmental Management and Science), and the Panauti Municipality issued letter to the ward number 12 Office for the support. A total of highly flood affected 187 households (100%) within the Roshi river basin of Panauti Municipality ward No.12 was surveyed. The study identified components of loss and damage, a similar approach made by Parajuli (2023) in which economic loss and damage covered households, agricultural land, crops and livestock. Likewise, non-economic loss and damage included loss of life, impact on health, human mobility, business disruption, impact on education, and basic services. For overall information on both economic and non-economic loss and damage caused by flood of September 2025 along with adaptive measures implemented for the research study, survey was conducted within 15 days (from July 25, 2025 to August 10, 2025) using structured questionnaire to highly flood affected households identified by Panauti Municipality and ward 12 Office through rapid damage assessment.

Data Collection

Primary Data Collection: The data collection methods in this study comprised of households questionnaire survey, key informant interview (KII), focused grouped discussions (FGDs) and study area observation. A total of highly flood affected 187 households were surveyed using structured questionnaire containing the information of demographic profile, economic and non-economic loss and damage along the adaptive measures undertaken by the communities of Panauti municipality ward no. 12 to cope with flood of September 2024.

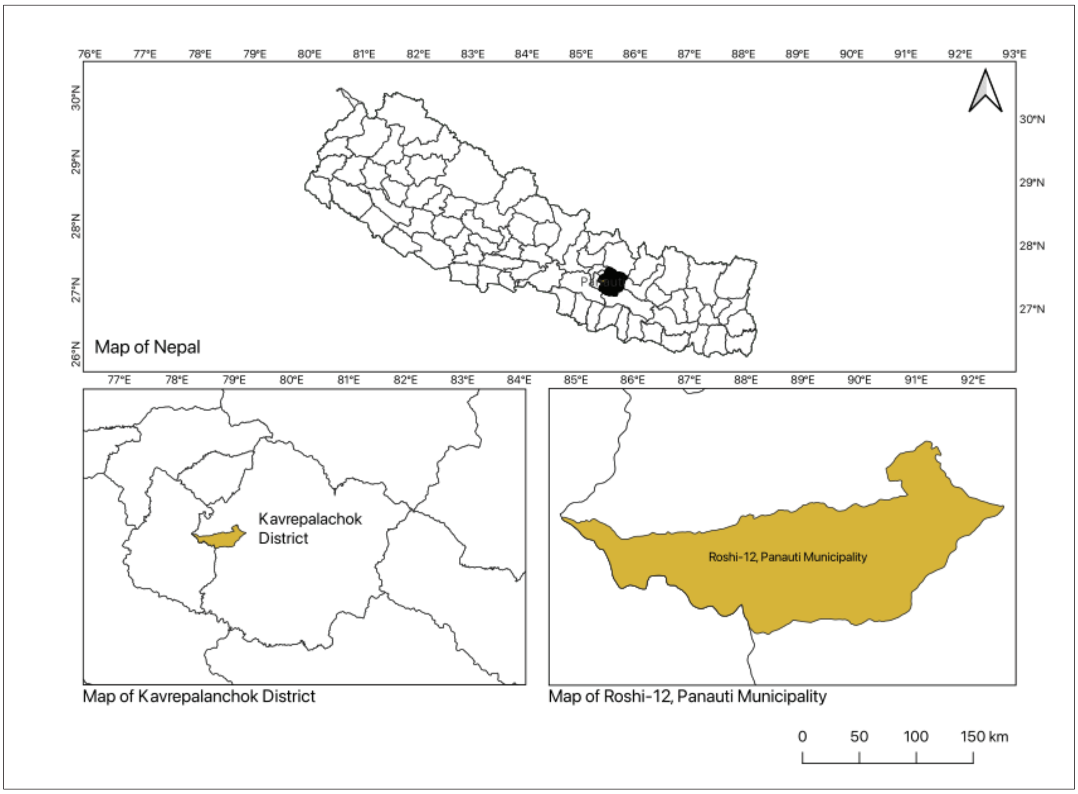

Figure 1: Map of the study area

Likewise, key informant interview was conducted with representatives from Panauti Municipality. A total of four informants were interviewed, including the Mayor, the Director of the Education Section, the Chief of the Livestock Section and the Chairperson of Ward-12, Panauti Municipality. Also, focused group discussion was conducted with the 15 representatives of community people residing in highly vulnerable communities of Panauti municipality Ward-12. The representation of participants included members from mothers' group, water supply and sanitation users' committee, forest users group as well as elderly community people, female health workers, students, and agricultural workers. Along with this, transit walk was also conducted with the community people to observe loss and damage, adaptive measures undertaken by the communities.

Secondary Data Collection: Highly flood affected households' details identified by Panauti Municipality and ward-12 Office through rapid damage assessment were obtained for the research study. Also, various published, unpublished reports, articles, research paper, journals, and both published and unpublished reports were used for the study. Moreover, data on temperature and precipitation was gathered from the Department of Hydrology and Meteorology for the nearest representative stations over a 29 years period (1995-2024). The temperature data was sourced from the Dhulikhel station (Station Index: 1024), located at 27.61592 latitude and 85.56545 longitude, with an elevation of 1552 m. Precipitation data was obtained from the Khopasi station (Station Index: 1049), situated at 27.5722 latitude and 85.5285 longitude, with an elevation of 1442m. The collected dataset includes information on maximum, minimum and average temperature, as well as monthly and yearly average precipitation.

Data Analysis

After the data was collected from the primary and secondary survey, Microsoft Excel 2022 was used to analyze both qualitative and quantitative data and to interpret the data in terms of tables, bar graph, pie chart, doughnut chart and spider diagram. Also, QGIS was used to prepare map and survey map were used to extract the data for map generation.

Analysis of Hydrological and Meteorological Data: The temperature and precipitation data from the year 1995-2024 were collected from DHM. For temperature, the annual minimum, maximum and average trend were analyzed and linear trend line was performed. Similarly, for precipitation annual average precipitation period of 30 years (1995-2024) obtained from DHM, average precipitation of September, 2024 and annual average precipitation of year 2024 and linear trend line was performed.

Analysis of Loss and Damage: The household's data collected from the research location were documented and organized and relationship between economic loss and damage with ethnicity, family size and income were calculated and plotted on the graph. The scatter graph was plotted with linear regression on loss and damage with family size and income amount. Here, loss and damage are dependent variable (Y) and Income and family size represented are independent variable (X). Likewise, Loss and damage and ethnicity was analyzed using box and whisker plot in excel and Anova test was performed. Ethnicity has been categorized as Dalit, Indigenous and BCT (Brahman, Chettri and Thakuri). The exchange rate was chosen as per the date of data analysis i.e., August 28, 2025 which was 1USD=140.70NPR.

Results and Discussion

Demographic Profile of the Respondents

There were more male respondents (58%) than female (42%). The respondents were BCT (63%), Dalit (4%) and Indigenous (33%) respectively. Likewise, 22% of the households have less than 4 family members, 74% have in between 4 to 8 members of family, while 4% of the respondents have more than 8 members in their family. Moreover, 8% of households have per month income of less than NPR 20,000, 58% of households have monthly income range of NPR 20,000-50,000. While the remaining, 34% of the households have per month income of more than 50,000. The table 1 shows the demographic profile of the respondents:

Table 1: Demographic Profile of the Respondents

Factors	Categories	Total respondents (N=187)	Percentage (%)
Gender	Male	108	58%
	Female	79	42%
Ethnicity	Dalit	8	4%
	Indigenous	62	33%
	BCT	117	63%
Family Size	<4	42	22%
	4-8	138	74%
	>8	7	4%
Income (NPR)	<20000	15	8%
	20,000-50,000	109	58%
	>50,000	63	34%

Climate trend analysis

Minimum Temperature Trend: The trend of average minimum temperature from 1995 to 2024 showed a slight increasing trend, though with weak variation (R^2=0.08). Despite fluctuation, including a lowest around 2001 and highest in 2018, the overall trend suggested a marginal rise at the rate of about 0.0345 ^{0}C per year in the average minimum temperature between 1995 and 2024.

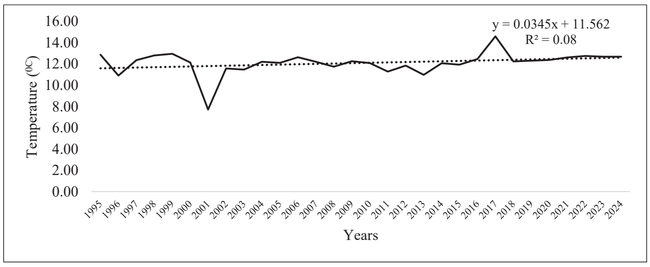

Figure 2: Average minimum temperature trend

Maximum Temperature Trend**:** The trend analysis indicates a statistically positive trend from 1995 to 2024, with an overall warming rate of approximately 0.093^{0}C per year. While remained relatively stable until 2010, a lowest occurred around 2014-2015, followed by a sharp rise and stabilisation at higher levels after 2016.

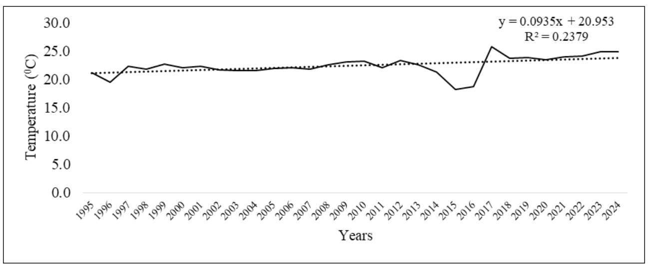

Figure 3: Average maximum temperature trend

Average Temperature Trend: The average annual temperature showed an increasing trend by about 0.064^{0}C per year to nearly 1.9^{0}C over the 30-year period (1995-2024) with notable inter annual fluctuations. Despite, year to year fluctuations in temporal data including a sharp rise around 2017-2018, the overall trend suggested a modest but consistent warming trend.

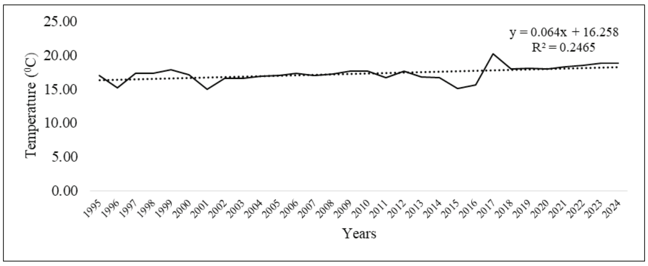

Figure 4: Average temperature trend

Precipitation

Annual Average Precipitation: The analysis of annual average precipitation indicated in the decreasing trend over 30-year period from 1995 to 2024. The regression equation indicated that precipitation decreased by approximately 1.16 mm per year. However, value of R^2 showed a very weak linear relationship.

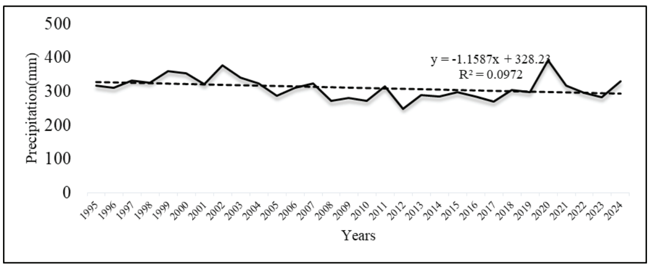

Figure 5: Annual average precipitation trend

Monthly Average Precipitation of 2024: The monthly average precipitation data of year 2024 indicated a slight increasing monthly precipitation trend (11.6 mm/month), with rainfall concentrated mainly in July to September, September rainfall is comparatively higher and minimal in other months.

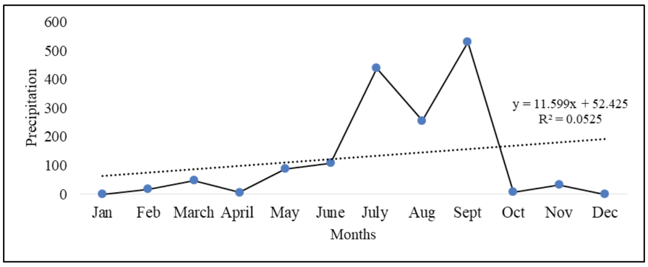

Figure 6: Monthly average precipitation trend

Average Precipitation of September 2024: The analysis of average precipitation of September, 2024 accumulated precipitation in month of September showed a slight increasing trend (1.93mm/day). Precipitation remained relatively low and scattered throughout the month, except for a sharp peak around September 28, 2024 which contributed disproportionately to the monthly total. This showed that the extreme rainfall events rather than consistent daily precipitation dominated rainfall pattern of September, 2024.

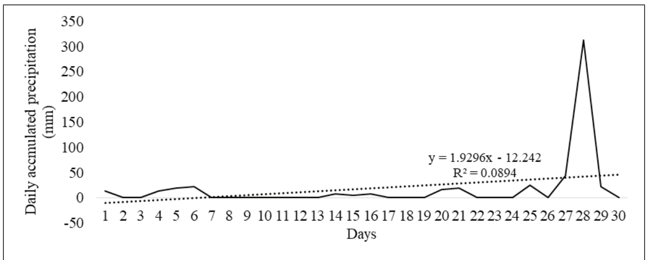

Figure 7: Average precipitation trend of September 2024

Loss and Damage

Economic Loss and Damage : The economic loss and damage caused by the September,2024 Flood showed a significant loss and damage on houses, agricultural land, livestock and crops reaching approximately NPR 536.178 million. A total of 187 houses were fully damaged, amounting to a cost of NPR 9,25,00,000. A total of 189.6 hectares of agricultural land was affected which valued at NPR 37,37,73,260. Likewise, livestock losses resulted to a cost of NPR 1,41,47,000 and crop losses were valued at NPR 5,67,57,652 .

Therefore, 45% of economic loss and damage contributed to agriculture land, 35% on houses while 10% economic loss and damage documented in livestock and 7% on crops. Likewise, remaining 3% economic loss and damage on other assets such as goods, furniture, vehicles, gold, etc.

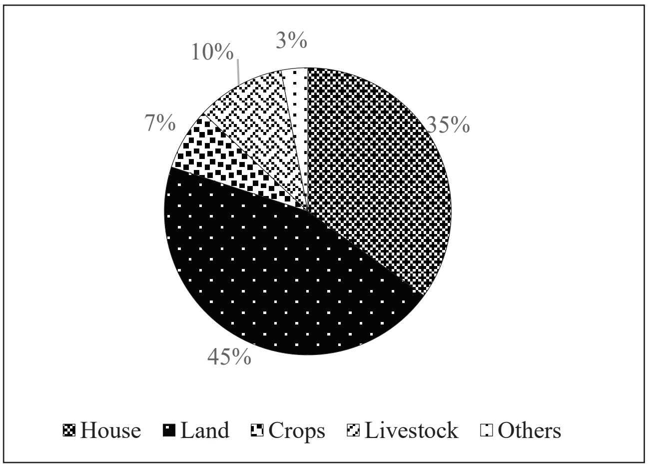

Figure 8*:* Economic loss and damage by survey respondents

Table 2: Estimated economic loss and damage of Panauti Municipality Ward-12

Category	Estimated Loss & Damage	Cost (NPR)	Cost (USD)
Total house loss	187	9,25,00,000.00	6,57,427.15
Total agricultural land loss	189.6184 Hectar	37,27,73,260.00	26,49,419.05
Total livestock loss	(3,446 chickens, 158 goats, 43 buffalos,30 cows,1 boar)	1,41,47,000.00	1,00,547.26
Total crop loss	(Paddy, Potato, Maize, Vegetables, Mustard, Fruits, and others)	5,67,57,652.05	4,03,394.83
	Total	**53,61,77,912**	**38,10,788.29**

(Source: Panauti municipality ward-12 Office)

Association between economic loss and damage and income: The graphical values of economic loss and damage, and income showed that there is statistically significant relationship in between economic loss and damage and income (P<0.05). However, the relationship is very weak (r^2= 0.0285) indicating that income explains only a small proportion of the variation in loss and damage. Also, the regression equation suggest that economic loss increases by 3.53 units for every one unit rise in Income.

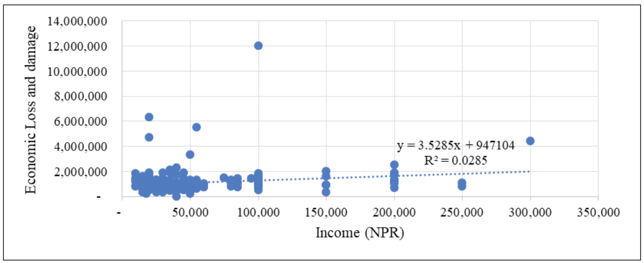

Figure 9: Association between economic loss and damage and income

Association between economic loss and damage and ethnicity: There is no statistical association between ethnicity and economic loss and damage (p-value>0.5, df=183, f= 0.3). Dalit households were observed to have higher economic loss and damage compared to Indigenous and BCT families.

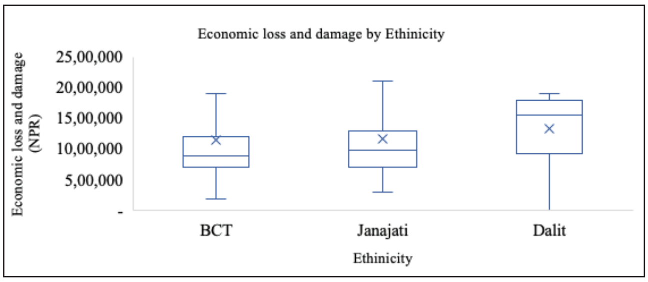

Figure 10: Association between economic loss and damage and ethnicity

Association between economic loss and damage and family size: The statistical analysis showed no significant relationship between family size and economic loss and damage (P>0.05). Also, linear regression further indicated a very weak relationship (R^2= 0.0092) suggesting that family size does not explain variation in economic loss and damage.

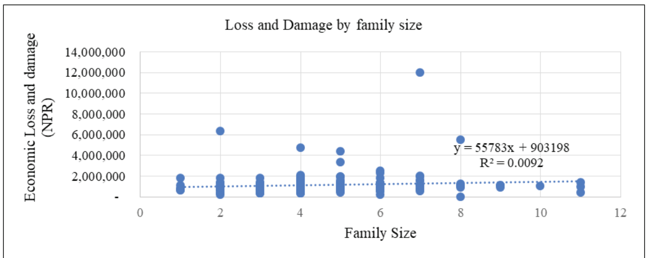

Figure 11: Association between economic loss and damage and family size

Non-economic Loss and Damage

The analysis of non-economic loss and damage as perceived by the respondents showed in the radar chart indicated the loss of life and disruption of basic services received the highest rating 3. Likewise, impact on heath, human mobility and business disruption were considered as moderately affected, rating 2 whereas, impact on education assigned the lowest rating of 1 due to immediate recovery of education in schools by constructing Temporary Learning Centres (TLC) during the vacation of prominent festivals of Nepal, Dashain and Tihar.

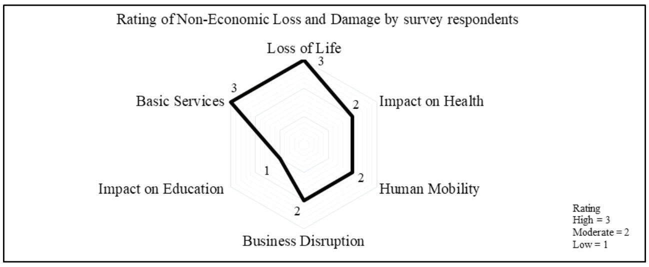

Figure 12: Rating of non-economic loss and damage by survey respondents

Loss of Life: Based on KII and FGD, it was revealed that, out of 774 affected population, 5 individuals including four male and one female loss their life due to the flood.

Impact on Health: About 60 % of respondents had severe physical injury and 20% respondent had minor injury, while 20% households had no injury. Likewise, 4% respondents revealed that the children and adolescent still possess fear even during the normal rainfall. Moreover, the health services were disrupted for 2 days due to the flood.

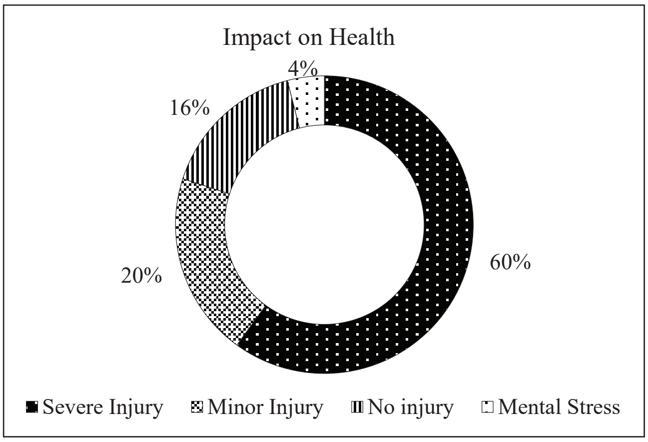

Figure 13: Impacts on health

Human Mobility: Nearly 43% households temporarily displaced from their houses for 10 days, while 57% of households population permanently migrated to new place which significantly decreased the overall residing population of the communities.

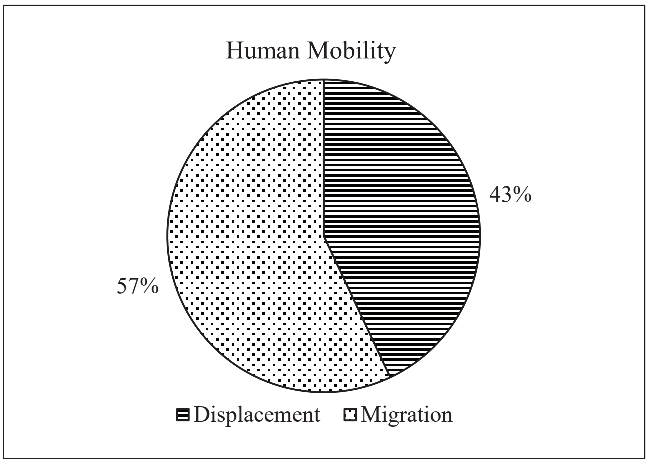

Figure 14: Effects on human mobility

Business Disruption: The household survey showed that 10% of small-scale businesses such as tea shops, general stores, dairy enterprises etc. were disrupted with their products either swept away or damaged due to flood. Likewise, the community's local stone mining sector experienced substantial disruption, as 10 mining crushers were destroyed, resulting in significant impact on livelihoods of nearly 25% daily wages labourers depended on this industry. Besides, the flood disaster of September, 2024 significantly affected major household's income sources engaged in livestock (28%) and agricultural business (32%). Additionally, around 5% of households engaged in transportation business were adversely affected due to debris deposition on roads.

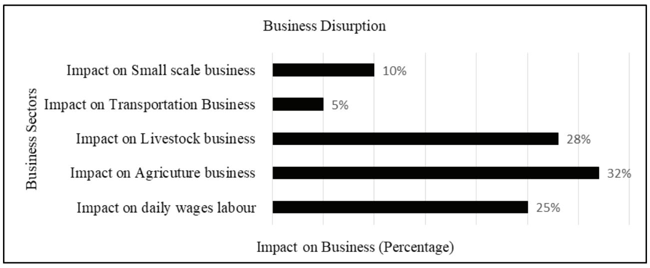

Figure 15: Business disruption form the flood

Impact on Education: Due to significant damage on the Indradevi Basic School, students were impacted with disturbance in education for about 10 days excluding the festive holidays. The education was not highly impacted due to flood because of the festival holidays (Dashan and Tihar). However, the damaged building was replaced by constructing TLC (Temporary Learning Centre) with support of Panauti Municipality and international donor.

Basic Services: According to the KII, the flood damaged 8 intakes, 4 reservoir tanks, 17,200 meters of transmission and distribution pipelines, cutting off safe water access for affected households and nearby communities. About 2500 meter irrigation canal and 200 meters of pipelines were destroyed, impacting agricultural lands. Additionally, around 300 electrical poles were swept away resulting in one month power outrage in highly affected areas. Damage to roads and bridges further disrupted livelihoods and access to services.

Adaptive Measures

According to the survey, livelihood diversification was considered as the most effective adoptive measure, receiving a high ranking of 3. Community groups and insurance mechanism were identified as moderately effective, with a rating of 2. Similarly, relief support provided by NRCS/UN agencies and the local government was also rated as 2. In contrast, structural and long-term measures such as riverbank area allocation and settlement planning were considered less effective, receiving a low rating of 1.

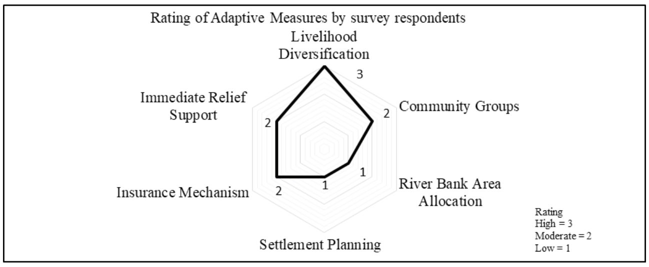

Figure 16: Rating of adaptive measures by survey respondents

Livelihood Diversification: The research findings showed that 67% of households engaged in multiple activities to generate income while, 33% of households were dependent on single source of income.

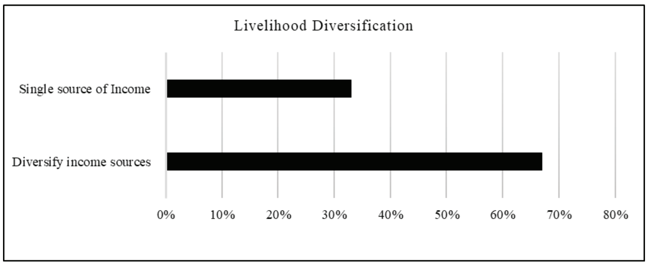

Figure 17: Livelihood diversification of households

Within the livelihood diversification category, 41% of households reported to have multiple income sources, including agriculture, livestock, business, and services, while 32 % of households were engaged in small scale businesses, daily wages, foreign employment and the remaining 27% relied on entrepreneurship, service, or pensions.

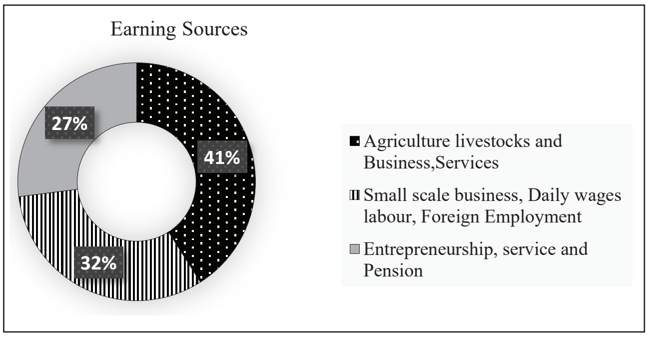

Figure 18: Earning sources of households

Community Groups: Survey results indicated that 35% of respondents perceived community groups as highly functional during the disaster, while 40% considered them moderately functional. In contrast, 25% reported that the groups were not effective during the disaster response period.

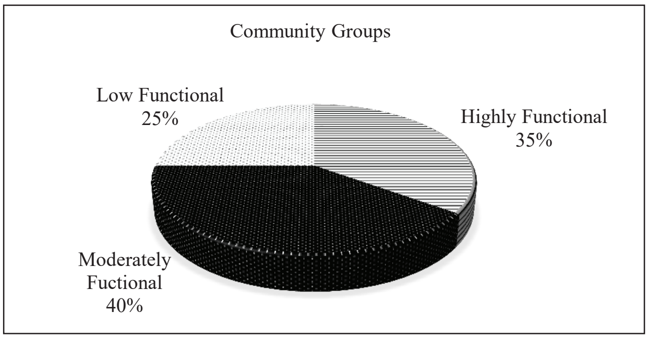

Figure 19: Perception towards ccommunity groups

Riverbank Area Allocation: Field observations indicated that the municipality have enforced a mandatory setback of 20-50m from river, within which construction activities are strictly prohibited. According to representatives, they have been using standard guidelines from the riverbank area allocation after the flood event of September 2024.

Settlement Planning : FGD and transect walk observations revealed that while 80% of old houses maintain safe distances from the riverbank and are built on elevated land, many new houses are located closer to the riverbank with lack of proper elevation.

Insurance Mechanism: According to KIIs and FGDs, 100% of the households had health insurance and 90% had livestock insurance before the flood. Claims were paid to the injured persons and livestock losses, but no coverage existed for agricultural land and basic services like water supply, irrigation and others.

Immediate relief Support*:* Conferring to KIIs, Panauti Municipality provided NPR 50,000/- per household for the reconstruction, with an initial instalment of NPR 25,000/- and the remainder paid after the completion of house construction. Also, NRCS provided NPR 15,000/- per household for food, health, education, and WASH services; while relief organisations, including UN agencies supplied immediate support.

Trend Analysis

The analysis of temperature data from 1995-2024 revealed a clear warming trend. Average minimum temperature increased by approximately 0.0345^{0}C per year, while maximum temperature rose by 0.093^{0}C per year, resulting in an overall annual increase of 0.064 ^{0}C. This asymmetric warming pattern, with maximum temperatures increasing faster than minimum, mirrors findings align with various research studies conducted before in the River Basins of Nepal. Shrestha et al. (2017) in the Koshi River Basin and Puri et al. (2024) across Nepal reported significant increase in both minimum and maximum temperatures, with maximum temperature raising faster than minimum similar to the findings of this study. The result also aligns with the DHM, 2017 which observed a national maximum temperature increase of about 0.056^{0}C per year though the magnitude of this study is comparatively higher. However, this findings differ from national scale analysis where minimum temperature trends were weak or insignificant.

Precipitation trends showed a slight decreasing pattern (-1.16mm/year) over 30 years, though with high inter annual variability. The September 2024 event, however, was dominated by extreme rainfall concentrated around 28 September, contributing disproportionately to monthly total. This reflects the increasing occurrence of intense rainfall events under climate change, even in regions with relatively stable average precipitation, a phenomenon documented globally by (Zhang et al., 2021), who demonstrated that nearly 68% of global land areas are experiencing amplifies rainfall variability across multiple time scales, even in locations where average precipitation is stable. Similarly, Talchabhadel et al. (2019) documented that extreme single-day rainfall events can disproportionately dominate monthly totals in Nepal where a single wet day accounted for 10% of the mean annual precipitation. This indicated a shift in the direction of extreme rainstorms as opposed to evenly distributed rainfall that greatly exaggerate flood risks. Hence, high flood disaster of September 2024 in Panauti Municipality was the result of an immediate consequence of this intense concentration of extreme rain at the end of the September 2024.The findings underscore that climate change is a critical driver of flood risk in Panauti, amplifying hazard intensity and reducing predictability of extreme events.

Loss and Damage

Economic loss and damage: The September 2024 flood caused losses exceeding NPR 536 million, with agricultural land accounting for the largest share (45%) followed by housing (35%). This is consistent with Shrestha et al. (2024), who reported that agricultural land as the most heavily impacted sector during the 2017 Terai flood. Also, Koirala (2021) emphasized housing damage during the 2021 Melamchi flood. Global studies like Jongman et al. (2012) also highlighted that agricultural land is disproportionately affected during riverine floods due to its direct exposure and limited protection. Moreover, Shrestha et al. (2024) emphasized that even though livestock and crop losses often contribute less to the total monetary valuation, they reflect important agricultural non-economic and livelihood dimensions of loss and damage, especially in the riverbank settlements.

Loss and damage are likely to be driven by exposure, location, and intensity of hazard, quality of houses, preparedness, livelihood, assets, and access to support. Besides, the households with higher income tend to experience greater loss and damage, a similar finding observed in (Dahal, 2012) where households with higher income levels experienced greater economic losses from landslides, as they owned more assets and infrastructure. However, with the family size increased, economic loss and damage has no significant alteration observed. Likewise, research study showed the disproportionate impact on Dalit households, who experienced higher losses compared to Indigenous and Brahmin/ Chettri/Thakuri (BCT) groups. This may be due to settlement patterns. Mostly, Dalit families residing near to the riverbank were facing higher exposure to flooding. Furthermore, the finding of the study displayed that flood induced loss and damage in the study area is not only an economic phenomenon but also a deep socially structured process.

Non-Economic Loss and damage: Non-economic impacts were equally severe, with mortality, disruption of drinking water, irrigation, electricity, and mobility receiving the highest ratings. These findings are comparable to Wisner et al. (2015), who argued that mortality and infrastructure breakdown constitute core dimensions of social vulnerability in floods. Similarly, Kelman et al. (2015) further emphasized that immediate non-economic consequences are often more disruptive than financial losses. The relatively lower impact on education aligns with observations by Shrestha et al. (2025), who reported that school closures during floods are often brief and less economically and socially disruptive compared to mortality and essential service interruptions, particularly where temporary learning centres are introduced. However, the displacement of 57% of households in Panauti indicated a more severe mobility impact than national average reported in earlies floods, pointing to the intensity of the September 2024 event. Also, the findings also followed the objectives of the Sendai Framework for Disaster Risk Reduction (2015-2030) which identifies mortality reduction, protecting people's lives and basic services as core global objectives. The persistence of high non-economic losses in Panauti suggests that achieving these targets remain a critical challenge at the community level.

Adaptive Measures: Livelihood diversification emerged as the most effective adaptive strategy, consistent with Ellis (2000), who argued that diversified income sources enhance household resilience to shocks. Similar findings in South Asia such as highlighted that rural households increasingly pursue off-farm income to buffer against the climate risks. This showed that resilience on a single livelihood exposes households to higher vulnerability, while diversifying provides resilience against the possible economic vulnerability. While insurance mechanism and community groups were moderately effective, Panauti Municipality has supported every flood affected household with health insurance. This revealed that the partial acceptance of insurance mechanism is an understanding of their potential role in risk reduction. Insurance is widely recognised as an important financial tool for transferring and sharing risks but in many developing contexts, its effectiveness is hindered by affordability, limited coverage and weak institutional trust. Similarly, community groups were also moderately functional, echoing findings by Shaw (2012), who stressed the need for stronger local institutions in disaster response. In contrast, structural measures such as settlement planning and riverbank zoning were poorly prioritized, despite being recognized in global literature as critical long-term strategies for risk reduction (Birkmann & von Teichman, 2010). The weak enforcement and community acceptance in Panauti suggest gaps between policy frameworks and local implementation, highlighting the need to strengthen institutional capacity and governance structure that can enhance the legitimacy and effectiveness of these mechanisms. Additionally, as part of an immediate relief support, the NRCS provided NPR 15,000 to each totally affected households, while local government support included an initial NPR 25,000 for house reconstruction, with an additional NPR 25,000 to be disbursed upon the completion of construction. Such short term financial and material assistance played a crucial role in addressing urgent recovery needs. However, the one-off nature of these interventions underscores their limitations in fostering long term resilience. This highlights the importance of integrating relief assistance into broader, sustainable resilience building and disaster risk reduction strategies, rather than relying solely on temporary support mechanisms.

Conclusion

The study concluded that the flood was triggered by highly uneven rainfall distribution between July and September 2024, with one single extreme rainfall event on September 28 controlling the monthly total and leading directly to the devastating flood in the Roshi River Basin. This climatic trigger confirmed the increasing role of extreme rainfall variability in intensifying flood risks in the region. The flood caused an estimated economic loss of NPR 536.178 million (USD 3.81 million approximately). Houses and agricultural land were the most affected, revealing both the structural vulnerability of settlements and the centrality of agriculture to rural livelihoods. While crop and livestock losses were smaller in monetary terms. Moreover, family income had a significant but weak association with economic loss and damage, suggesting wealthier households suffered greater asset-related losses. In contrast, family size and ethnicity did not show statistical associations, but disproportionate exposure of Dalit families living near riverbanks showed how spatial settlement patterns and social marginalisation drive vulnerability, confirming the socially structured nature of loss and damage. Non-economic losses, primarily loss of life and essential services disruption ranked highest demonstrating impacts beyond financial costs to directly effect on human security and adoptive capacity of communities. Educational disruption ranked lowest due to Temporary Learning Centres and seasonal school breaks. Furthermore, the study found single livelihood dependency increases exposure to higher risks while insurance and community support remain limited by affordability, institutional trust and weak coordination. Low priority for settlement planning and riverbank management highlights a critical a gap in long-term risk reduction strategies.

Thus, the study emphasizes the need to improve the capacity of flood prone vulnerable communities ensuring rapid restoration of basic services. Likewise, community-based adaptation should be prioritized through skill training, small business promotion and non-farm income opportunities through strengthened multi stakeholder coordination to enhance long term community resilience. In a long run, strict enforcement of resilient infrastructure standard, settlement planning, hazard zoning, and riverbank management should be integrated into municipal development plans.

Acknowledgement

We are thankful to Panauti Municipality and Ward-12 Office for providing with necessary data and facilitation support during the study period. Also, we are grateful who directly or indirectly supported and contributed to our work, including the authors and scholars whose work we cited.

References

Birkmann, J., & von Teichman, K. (2010). Integrating disaster risk reduction and climate change adaptation: Key challenges, scales, knowledge, and norms. *Sustainability Science, 5*(2), 171–184.

Conference of the Parties to the United Nations Framework Convention on Climate Change. (2013, November 22). *Warsaw international mechanism for loss and damage associated with climate change impacts: Proposal by the President (FCCC/CP/2013/L.15).* United Nations Framework Convention on Climate Change. https://unfccc.int/resource/docs/2013/cop19/eng/l15.pdf

Dahal, R. K. (2012). Rainfall-induced landslides in Nepal. *International Journal of Erosion Control Engineering, 5*, 1–8. https://doi.org/10.13101/IJECE.5.1

DHM. (2017). *Observed climate trend analysis in the Districts and Physiographic Regions of Nepal (1971-2014).* Department of Hydrology and Meteorology, Kathmandu. https://www.dhm.gov.np/uploads/dhm/climateService/Observed_Climate_Trend_Analysis_Report_2017.pdf

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press. https://doi.org/10.1093/oso/9780198296959.001.0001

MoEWRI. (2024). *Situational report on extreme precipitation and flooding event of 27–29 September 2024.* Government of Nepal https://www.dhm.gov.np/uploads/dhm/downloads/Situational_Report_on_Extreme_Precipitation_and_Flooding_Event_of_27-29_September_2024.pdf

Jongman, B., Kreibich, H., Apel, H., Barredo, J. I., Bates, P. D., Feyen, L., Gericke, A., Neal, J., Aerts, J. C. J. H., & Ward, P. J. (2012). Comparative flood damage model assessment: Towards a European approach. *Natural Hazards and Earth System Sciences, 12*(12), 3733–3752. https://doi.org/10.5194/nhess-12-3733-2012

Karki, R., ul Hasson, S., Schickhoff, U., Scholten, T., & Böhner, J. (2017). Rising precipitation extremes across Nepal. *Climate, 5*(1), 4. https://doi.org/10.3390/cli5010004

Kelman, I., Gaillard, J.-C., & Mercer, J. (2015). Climate change's role in disaster risk reduction's future: Beyond vulnerability and resilience. *International Journal of Disaster Risk Science, 6*(1), 21–27. https://doi.org/10.1007/s13753-015-0038-5

Koirala, J. (2021). Understanding Melamchi Flood 2021 of Nepal. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.3888685

Lamichhane, K., Biswakarma, K., Acharya, B., Karki, S., KC, R., Subedi, M., & Sharma, K. (2025a). Preliminary assessment of September 2024 extreme rainfall-induced landslides in Central Nepal. *Landslides.* https://doi.org/10.1007/s10346-025-02577-w

Lamichhane, K., Karki, S., Sharma, K., Khadka, B., Acharya, B., Biswakarma, K., Adhikari, S., KC, R., Danegulu, A., Bhattarai, S., Regmi, A., Subedi, M., & Bhattarai, P. K. (2025b). Unraveling the causes and impacts of increasing flood disasters in the Kathmandu Valley: Lessons from the unprecedented September 2024 floods. *Natural Hazards Research.* https://doi.org/10.1016/j.nhres.2025.04.001

Maharjan, K. (2024). Climate change and flood vulnerability analysis in the Narayani River of Nepal. *Journal of Geoinformatics, Nepal, 23(1), 55-70.* https://doi.org/10.3126/njg.v23i1.66047

McNamara, K. E., & Jackson, G. (2019). Loss and damage: A review of the literature and directions for future research. *WIREs Climate Change, 10*(2), e564. https://doi.org/10.1002/wcc.564

Nugroho, K. P. (2023). Rethinking climate crisis solutions in Asian cities by harnessing local evidence. *PLOS Climate, 2*(7), e0000255. https://doi.org/10.1371/journal.pclm.0000255

Pandey, C. L. (2025). Climate change, floods, and community resilience: A study of the Kamala River Basin, Nepal. *Journal of Flood Risk Management, 18*(2), e70069. https://doi.org/10.1111/jfr3.70069

Parajuli, B. P., Baskota, P., Singh, P. M., Sharma, P., Shrestha, Y., & Chettri, R. P. (2023). *Locally-led assessment of loss and damage finance in Nepal: A case of Melamchi Flood 2021.* Prakriti Resources Centre.

Paudel, S., Khanal, S. N., Mathema, A. B., Maharjan, P., & Bhatta, S. (2025). Assessing agricultural vulnerability to climate change: A study on flood-induced loss and damage in Rajapur, Bardiya, Nepal. *International Journal of Disaster Risk Management, 7*, 265–282. https://doi.org/10.18485/ijdrm.2025.7.1.15

Puri, B. P., Adhikari, T. R., Sigdel, M., Devkota, B., & Shrestha, S. (2024). Spatial and temporal variations of surface air temperature (1962–2022) across physiographic regions in the Koshi Basin, Nepal. *Journal of Hydrology and Meteorology, 12*(1), 46–57. https://doi.org/10.3126/jhm.v12i1.72654

Rahman, S. U. (2014). *Impacts of flood on the lives and livelihoods of people in Bangladesh: A case study of a village in Manikganj District.*

Roberts, E., & Pelling, M. (2016). Climate change-related loss and damage: Translating the global policy agenda for national policy processes. *Climate and Development, 10*(1), 4-17. https://doi.org/10.1080/17565529.2016.1184608

Serdeczny, O. (2019). Non-economic loss and damage and the Warsaw International Mechanism. In R. Mechler, L. M. Bouwer, T. Schinko, S. Surminski, & J. Linnerooth-Bayer (Eds.), *Loss and damage from climate change: Concepts, methods and policy options* (pp. 205–220). Springer. https://doi.org/10.1007/978-3-319-72026-5_8

Shaw, R. (Ed.). (2012). *Community-based disaster risk reduction* (Vol. 10). Emerald Group Publishing. https://doi.org/10.1108/S2040-7262(2012)10

Shrestha, A. B., Bajracharya, S. R., Sharma, A. R., Duo, C., & Kulkarni, A. (2017). Observed trends and changes in daily temperature and precipitation extremes over the Koshi River Basin, Nepal (1975–2010). *International Journal of Climatology, 37*(2), 1066–1083. https://doi.org/10.1002/joc.4761

Shrestha, A., McCrone, A., Láng-Ritter, J., Gautam, S., Taka, M., & Varis, O. (2025). Bridging gaps, saving lives: Integrating communities' voices and impact mapping into flood early warning systems in rural Nepal. *International Journal of Disaster Risk Reduction, 118*, 105238. https://doi.org/10.1016/j.ijdrr.2025.105238

Shrestha, P., KC, A., Karki, D. K., Shrestha, N., Bharati, A., & Giri, S. (2024). Impact of climate change on agriculture in Nepal and strategies for farmer adaptation and economic resilience. *Journal of Multidisciplinary Research Advancements, 2*, 130–137. https://doi.org/10.3126/jomra.v2i2.73080

Talchabhadel, R., Karki, R., Yadav, M., Maharjan, M., Aryal, A., & Thapa, B. R. (2019). Spatial distribution of soil moisture index across Nepal: A step towards sharing climatic information for the agricultural sector. *Theoretical and Applied Climatology, 137*(3–4), 3089–3102. https://doi.org/10.1007/s00704-019-02801-3

UNFCCC. (1991). *Negotiation of a framework convention on climate change: Elements relating to mechanisms. Vanuatu: Draft annex relating to Article 23 (Insurance) for inclusion in the revised single text on elements relating to mechanisms (A/AC.237/WG.II/Misc.13).* United Nations Framework Convention on Climate Change. https://unfccc.int/documents/4309

Wisner, B., Gaillard, J.-C., & Kelman, I. (2015). Framing disaster: Theories and stories seeking to understand hazards, vulnerability, and risk. In *Disaster prevention* (pp. 44–62). Routledge.

Wrathall, D. J., Oliver-Smith, A., Fekete, A., Gencer, E., Reyes, M. L., & Sakdapolrak, P. (2015). Problematising loss and damage. *International Journal of Global Warming, 8*(2), 274–294. https://doi.org/10.1504/IJGW.2015.071962

Zhang, W., Furtado, K., Wu, P., Zhou, T., Chadwick, R., Marzin, C. & Sexton, D. (2021). Increasing precipitation variability on daily-to-multiyear time scales in a warmer world. *Science Advances, 7*(31), eabf8021.