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Article

Assessing Agricultural Vulnerability to Climate Change: A Study on Flood-Induced Loss and Damage in Rajapur, Bardiya, Nepal

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ABSTRACT

More frequent and severe extreme climate events have caused both economic and non-economic losses to local communities in disaster-prone areas due to climate change. This study examines the economic loss and damage to agriculture caused by an unseasonal flood in October 2021 in Rajapur Municipality, located along the Karnali River. The lower Karnali basin is highly prone to flooding, and Rajapur, situated between two arms of the river, has a long history of such events. Using household surveys, focus group discussions (FGDs), key informant interviews (KIIs), and secondary literature, the study assessed flood-related losses among small, medium, and large farmers based on key indicators from the Building Information Platform Against Disaster (BIPAD), including agricultural land, paddy production, stored grains, livestock, and farm machinery. The October 2021 flood, which occurred just before harvest, caused significant economic losses. Small farmers incurred a loss of $21,709.77, medium farmers faced a loss of $50,225.24, and large farmers experienced a loss of $32,393.49, resulting in a total production loss of $104,328.10. Small and medium farmers suffered greater impacts on their livelihoods, income, and food security than large farmers. Coping mechanisms included purchasing rice, consuming wheat instead of rice, taking loans, working as labourers, abandoning education, and cultivating spring-season rice. While adaptation measures, such as early warning systems and embankments, have helped prevent human casualties, mitigating agricultural losses remains a challenge as floodwaters continue to devastate farmlands, underscoring the need for improved flood management strategies to safeguard agricultural productivity and rural livelihoods.

KEYWORDS

Climate change; flood damage; agricultural loss; economic loss; coping mechanisms; adaptation strategies.

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1. Introduction

The sixth assessment report by the Intergovernmental Panel on Climate Change (IPCC) concludes that humans have altered the climate system, and its impact on ecosystems, lives, and livelihoods is inevitable (IPCC, 2021). The climate-induced loss (irreversible change) and damage (repairable, recoverable impact), both economic and non-economic (such as loss of culture, identity, ecosystem services, and biodiversity), will continue to rise (Oxfam, 2022). Floods are one of the most prevalent disasters, posing a significant threat to millions of people worldwide. They are defined as the overflow of a stream or other body of water beyond its usual boundaries or the buildup of water in areas that are typically dry (Oates, 2007). The frequency of floods is increasing, resulting in massive losses of lives, livelihoods, agriculture, infrastructure, public services, and property, with the scale of damage also growing each year (Tripathi, 2015).

The Loss and Damage (L&D) discourse began in 1991 within the global climate change negotiations, when the Alliance of Small Island States (AOSIS) proposed an international insurance pool to compensate for irrecoverable losses resulting from sea level rise that exceeded physical and social adaptation limits (INC, 1991). Loss and damage cover both sudden catastrophes, such as floods and cyclones, and gradual phenomena, like sea-level rise and glacial retreats (UNFCCC, 2013). Flood is the second most impactful disaster in terms of their impact on agriculture after drought. It has resulted in a loss of USD 21 billion in Least Developed Countries (LDCs) and Low-Middle-Income countries (LMICs) from 2008 to 2018. Climate factors, such as temperature rise, glacier melting, extreme precipitation, and sea level rise, as well as anthropogenic factors like development projects, land-use and land-cover changes, and river encroachment, have also contributed to flooding events (Huggel, 2020; Bronstert, 2003; UNEP, 2020).

According to the World Bank's Climate Change Group, flooding is not only the most common disaster but also the one with the most significant financial and humanitarian impact in terms of the number of people affected and financial asset exposure. Approximately 1.46 billion people worldwide are directly exposed to flood hazards, with about 1.37 billion residing in South and East Asia (Rentschler & Salhab, 2020). Extreme climate events have threatened the global food security. Worldwide extreme events, such as the flooding in the U.S. in 2019, the 2010 Pakistan floods, and the 2017 South Asian floods, have had negative impacts on crop production (Shirzaei et al., 2021). South Asia is home to major rivers, including the Brahmaputra and Ganges, which are located in the Hindu Kush Himalayan region. In the rainfed lowlands of South and Southeast Asia, flash floods completely submerge plants for 10–15 days, which reduces rice production (Septiningsih et al., 2009).

Nepal is considered one of the global hot spots for climatic disasters. In the top twenty poorest countries, Nepal ranks fourth and thirteenth in terms of climate change impacts and flood risk, respectively (Oxfam, 2023). Floods are one of the most devastating events in Nepal, accounting for 7,599 deaths and costing billions of dollars between 1954 and 2018. (EMDAT 2019). Climate change significantly impacts rain-fed agriculture and the livelihoods of subsistence farmers, directly affecting food production. The Terai region is severely affected by climate change, including droughts, floods, and landslides (Huggel, 2020). In Nepal, the concept of loss and damage is relatively new in the context of climate change policy. Only a few references have been made in legal and policy documents, where more emphasis is given to research and studies to enhance knowledge of climate-induced loss and damage. However, this has failed to provide a clear understanding of adaptation and loss and damage (Practical Action, 2021). A report published by the Ministry of Forest and Environment in 2018 describes Nepal's vulnerability to climate change and disasters (MoFE, 2021).

Nepal ranks 10th in the Long-Term Climate Risk Index (CRI), which identifies the 10 countries most affected from 2000 to 2019 (Eckstein & Kreft, 2021). Furthermore, 50 out of 77 districts are vulnerable to the effects of climate change (Ministry of Finance and Economics, 2021). The research domain by Aryal and his colleagues in 2019 mapped hazard and assessed risk areas on both the east and west banks of the Karnali River that are vulnerable to flooding for different returns year periods. They found that flood erosion of agricultural land poses a threat to food security and has a direct impact on the livelihoods of people (Aryal et al., 2020). In 2017, flood losses in the agricultural sector were valued at around USD 69.5 million, whereas recovery needs were estimated at USD 61.6 million (NPC, 2017). Rajapur municipality and Geruwa rural municipality in the Bardiya district have been designated as rice super zones by the Prime Minister's Agriculture Modernisation Project (PMAMP) (PMAMP, 2022) due to their high agricultural productivity. The people of this area are heavily reliant on agriculture, which is the primary source of their livelihood. Frequent flooding can have a profoundly detrimental impact on agricultural production, compromising food security. Rajapur Municipality, situated in the Bardiya district of Lumbini Province, is located in a low-lying region of Karnali and has a long history of flooding (DWIDP, 2014). Karnali River's annual overflow has had both economic and non-economic impacts on the livelihood of people in the Karnali basin. The unprecedented rainfall in October 2021 affected thousands of farmers, resulting in loss and damage to agricultural production, as well as to their lives and livelihoods.

This study was conducted to assess the loss and damage to crops caused by the 2021 flood, which resulted from unprecedented rainfall, and to explore the coping mechanisms employed by farmers in dealing with agricultural loss and damage. For the study, wards 1, 3, 4, and 7, located alongside the Karnali River branch, were selected based on their exposure to and severity of flood impacts in previous years (Rajapur Municipality, 2021; Practical Action, 2021). This study aims to estimate the loss and damage incurred by three different types of farmers in the Rajapur area, namely small, medium, and large holders, with landholdings of 0.038 ha, 2.28 ha, and above 2.28 ha, respectively. This study aims to fill the gap in assessing the loss and damage to crops caused by unseasonal flooding events.

2. Materials and methods

2.1. Study site

The research was conducted in Rajapur Municipality, situated in Bardiya District, Lumbini Province, Nepal. The Municipality is located between two flood-prone branches of the Karnali River, which originates on the Tibetan Plateau, traverses through Nepal, and ultimately merges with the Ganges in India. Rajapur shares its eastern boundary with Geruwa Rural Municipality, its western boundary with both Kailali District and Geruwa Rural Municipality, and borders the Indian State of Uttar Pradesh to the south. The Municipality spans a latitude of 28°21'25.16" N to 28°29'43" N and a longitude of 81°03'25.63" E to 81°12'52" E (Source: LDCRP, 2021) and is located between 142 and 154 meters above sea level covering an area of 127.08 km2.

Bardiya, situated in the flood-prone lower Karnali region, was selected due to its history of experiencing devastating floods in 1983, 2009, 2013, 2014, 2017, and 2021. Indigenous and vulnerable communities in this region, with limited adaptive capacity, are disproportionately affected, deepening the socio-economic inequality. While numerous flood-related studies have been conducted in Rajapur municipality, research on agricultural loss and damage remains underexplored. This gap underscores the importance of the present study, which focuses on four wards - 1, 3, 4 and 7 of Rajapur Municipality were selected due to their proximity to the right branch of the Karnali River and their historical exposure to frequent flooding events. These wards contain villages that are vulnerable to seasonal riverine floods, which have caused repeated damage to agricultural livelihoods and infrastructure (DEOC, 2021) (Rajapur Municipality, 2021).

Agriculture dominates land use in Rajapur Municipality, accounting for approximately 57.89% of the total land area. Most of the population practices subsistence farming, with key crops including rice, wheat, maise, mustard, and pulses. Given its geographic exposure and dependence on climate-sensitive agriculture, the area represents a critical site for examining the impacts of flood-related hazards on rural livelihoods (Fig. 1).

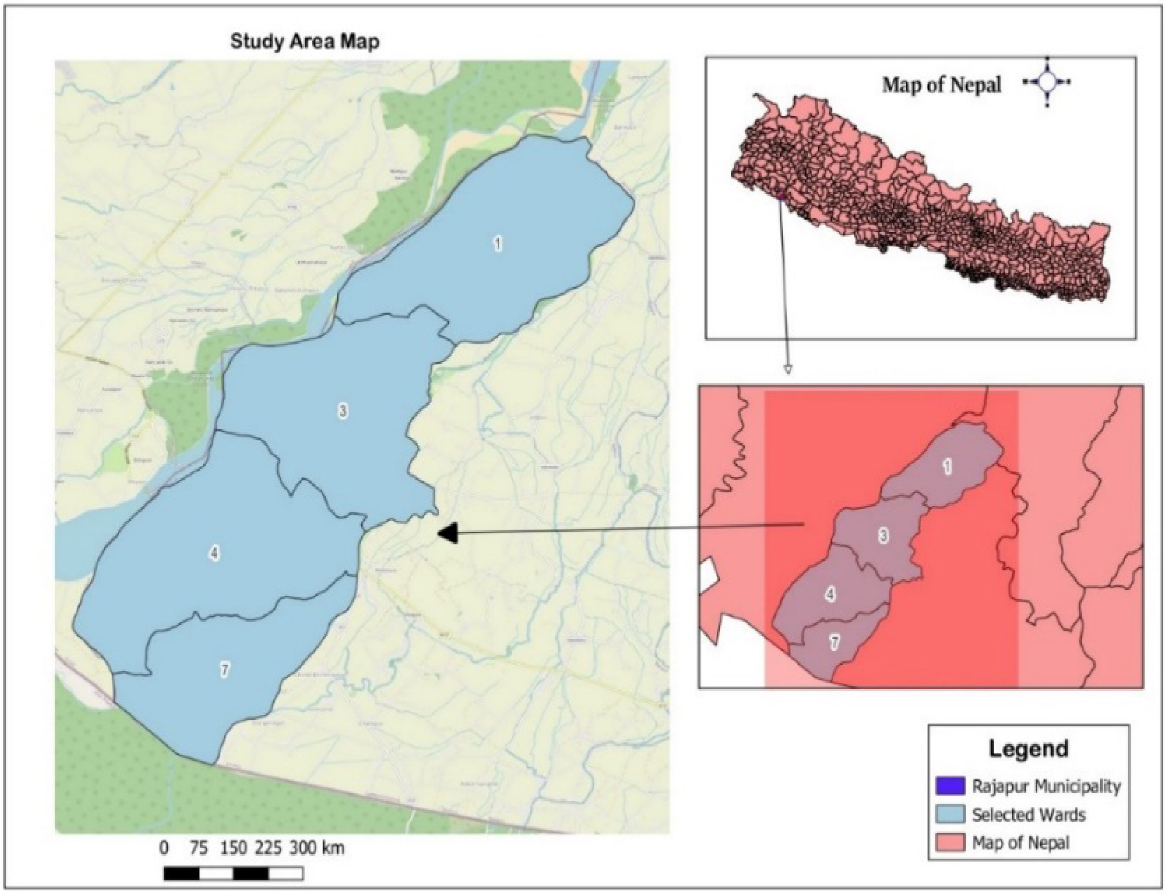

Figure 1. The study area comprises wards 1, 3, 4, and 7 of Rajapur Municipality.

2.1. Data collection

Primary data were collected through a multistage sampling approach. In the first stage, a total of 160 households were selected from four wards of Rajapur Municipality, with 40 households sampled from each ward using Cochran's formula to determine an appropriate sample size (see Table 1). In the second stage, the sampled households were categorised into three types of farmers: large (n = 20), medium (n = 54), and small (n = 86), based on landholding size and local classifications. To ensure comparability across categories, losses and damages (L&D) were calculated on a per-household basis.

Table 1: Data collection using different formulas.

Data collection	Formulae
Sample size	*Cochran's formula* $n_o = Z^2pq/e^2$ Where, Z = statistical value corresponding to the level of confidence required (1.96) P = the (estimated) proportion of the population which has the attribute in question (0.95) q = 1 – p (0.05) e = the margin of error (5%)
Sample Size Calculation in Smaller Populations	Modification for the Cochran Formula for Sample Size Calculation in Smaller Populations $N = (n_0/(1+((n_0-1)/N))$. Where, $n_{0=}$ Cochran sample size N = household number N = sample size

Primary data were obtained through a structured, questionnaire-based household survey and direct personal observations using a simple random sampling technique. To enrich the quantitative data and validate findings, qualitative methods were also employed. These included focus group discussions (FGDs) and key informant interviews (KIIs) conducted with local farmers, community leaders, ward representatives, government officials, members of the Karnali River Management Committee, and representatives from national and international governmental and non-governmental organisations (I/NGOs).

Secondary information was obtained from a range of published and unpublished sources, including academic articles, research theses, official reports, policy documents, journals, and relevant websites. Hydrological and meteorological data were sourced from the Department of Hydrology and Meteorology (DHM), Nepal. Additional supporting data were collected from various institutional sources, including Rajapur Municipality, the local office of the Department of Agriculture, the District Emergency Operation Centre (DEOC), and reports produced by national and international governmental and non-governmental organisations (NGOs).

Table 3. Hydrological and Meteorological Stations were used in this study.

S.N.	Station Name	Latitude	Longitude	Elevation (m)	Parameters
1	Tikapur	28°32′ N	81°6′ E	149	Temperature
2	Rajapur	28°26′ N	81°5′ E	133	Precipitation
3	Chisapani	28°38′ N	81°17′ E	201	Discharge

2.2. Data analysis

The study conducted a comprehensive quantitative and statistical analysis of climatological time-series data (1992–2021) and field survey data, focusing on Nepal's four seasons: Winter, Pre-monsoon, Monsoon, and Post-monsoon (DHM, 2017). Hydrological and meteorological data, including temperature, precipitation, and discharge, were analysed using MS Excel and SPSS. Temperature trends were evaluated by examining the minimum and maximum seasonal trends, with linear trendlines applied to days with temperatures below or above average. Precipitation data were categorised using indices from the Expert Team on Climate Change Detection and Indices (ETCCDI) (Yu et al., 2013). Seasonal discharge trends were also analysed, and flood event trends were derived from rainfall, discharge data, field surveys, and secondary information sources.

The analysis of loss and damage focused on household data, organised under themes such as agricultural land, production, stored grains, livestock, and farm machinery. Losses were estimated using indicators from the Building Information Platform against Disaster (BIPAD) (Tamrakar & Bajracharya, 2020; FAO, 2020) (Table 2), with local units (kattha and NPR) converted to hectares and USD (1 NPR = 0.0082 USD as of March 25, 2022). Descriptive statistics, including mean, standard error, and standard deviation, were calculated. A framework for assessing unavoidable climate change impacts (Fig. 2) was developed to evaluate the impacts on agricultural land, production, stored grains, livestock, machinery, and income (Table 3). Coping mechanisms were analysed, and their percentages were presented in a bar graph, providing insights into adaptation measures and their effectiveness.

3. Results

3.1. Variation in Temperature, Rainfall, and Discharge

The study reveals significant temporal variations in temperature, precipitation, and river discharge patterns across the selected meteorological and hydrological stations.

At the Tikapur meteorological station, analysis of data from 1992 to 2021 revealed a declining trend in minimum temperatures during the winter, monsoon, and post-monsoon seasons. In contrast, maximum temperatures have shown an increasing trend in all seasons except the post-monsoon season. Notably, extreme temperature events were recorded, with the highest temperature reaching 45 °C in 2012 and the lowest dropping to 0 °C in both 2013 and 2021. The frequency of days exceeding 40 °C has shown a marginal decrease, declining at a rate of –0.004 days per year (Fig. 2).

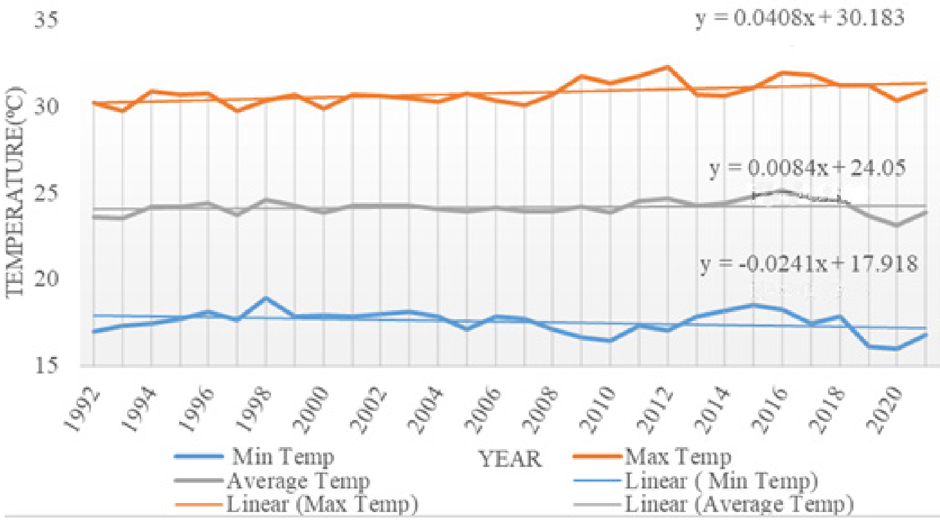

Figure 2: Annual trends in minimum, maximum, and average temperature (1992-2021), Tikapur Station.

In the Rajapur area, seasonal temperature trends demonstrate that maximum, minimum, and average temperatures are generally increasing at a rate of 0.30°C per year. However, minimum temperatures are decreasing at a rate of 0.09 °C per year across all seasons except for the pre-monsoon season. These patterns suggest an increasing prevalence of extreme temperature conditions, thereby increasing the risk of prolonged droughts and heat waves in the region.

Rainfall trends also show a notable shift. The Rajapur region is experiencing an overall increase in annual rainfall, with a higher frequency of intense downpours replacing historically consistent rainfall patterns. Concurrently, periods of extended drought have become more common, a trend likely to be exacerbated by ongoing climate change. Quantitative analysis indicates an upward trend in total annual rainfall, increasing at a rate of 8.806 mm per year. The highest recorded annual precipitation occurred in 2007, while the lowest was observed in 2019 (Figure 4 and Table 5). As global temperatures rise, the hydrological cycle intensifies, resulting in more extreme precipitation events and an increased risk of flooding.

The overall trend in discharge over the past thirty years indicates a decline in the annual discharge of the Karnali River, with a decrease of -2.665 m^3/s per year. While discharge decreased during the winter, pre-monsoon, and monsoon seasons, it showed an increasing trend in the post-monsoon season at 1.370 m^3/s per year. This rise in post-monsoon discharge heightens the risk of unseasonal floods. Record highs were observed in 1998, while the lowest discharges were recorded between 2011 and 2016 (Fig. 5 and Table 6).

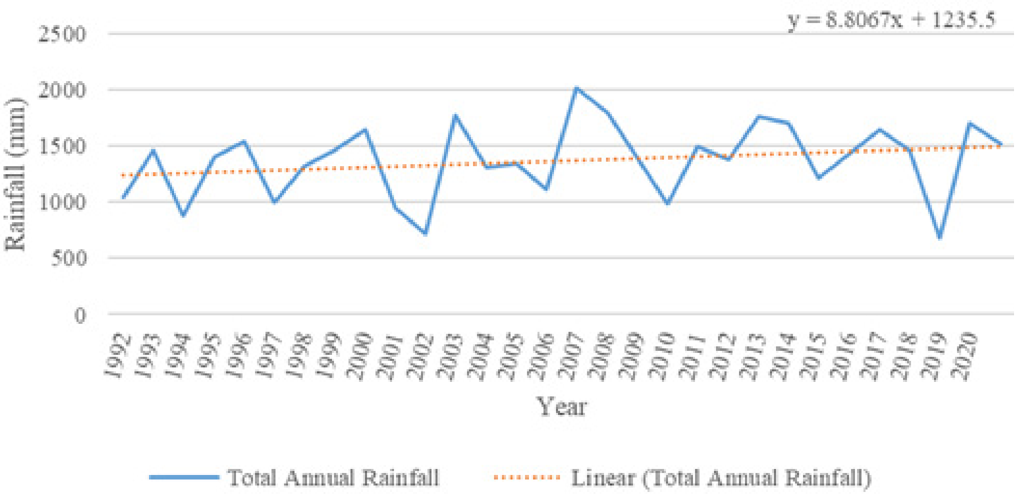

Figure 3: Annual Rainfall Trend in Rajapur Area (1992 - 2021)

3.2. Flood Event Trend

The analysis of flood events in Rajapur, Bardiya, from 1992 to 2021 revealed an increasing trend in the frequency of major floods (Figure 4). Over the past 30 years, 16 significant flood events have been recorded, with minor flooding and seasonal inundation reported almost annually. The most catastrophic flood occurred in 2014, reaching a peak discharge of 17,900 cubic meters per second, resulting in extensive socio-economic and environmental damage. Notably, post-monsoon flooding events in 2009 and 2021 resulted in substantial losses, particularly in the agricultural sector, with paddy fields being severely impacted. The increasing trend in both frequency and intensity of flood events underscores the growing vulnerability of the region to climate-induced hydrological extremes.

3.3. Analysis of Loss and Damage in Agriculture

The unseasonal flood event that occurred between October 17 and 21, 2021, had severe socio-economic impacts on agriculture in Rajapur, Bardiya. A total of 144.81 ha of land was inundated, affecting farmers across all scales of production. Large-scale farmers incurred losses of 17.79% (11.523 ha), medium-scale of 7.13% (7.131 ha), and small scale of 16.98% (3.240 ha). The estimated paddy production losses were 86 metric tons for large-scale farmers, 79.2 metric tons for medium-scale farmers, and 31.7 metric tons for small-scale farmers, corresponding to yield reductions of 34.67%, 41.27%, and 53.39%, respectively.

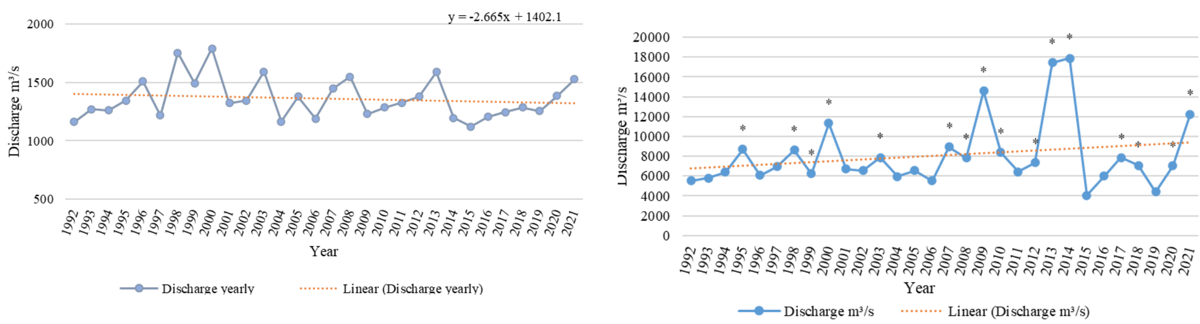

Figure 4: Annual seasonal discharge of the Karnali River and Flood Events for the duration of 1992 - 2021

The economic valuation of these losses was substantial, with large farmers losing an estimated USD 19,407.10, medium farmers USD 17,872.59, and small farmers USD 7,153.55. In addition to paddy yield losses, large farmers suffered disproportionately high losses in livestock, farm equipment, and food grain storage, with 32.57 metric tons of stored grain destroyed, resulting in storage losses of USD 9,924.93 and livestock losses of USD 9,569. These damages had profound implications for food security: large farmers reported a food deficit lasting 3.8 months, medium farmers for 4.93 months, and small farmers for 3.11 months.

Losses in farming inputs were also critical. A total of 9.04 metric tons of paddy seeds, valued at USD 4,841.69, and 18.67 metric tons of fertilisers, valued at USD 6,591.46, were destroyed. Moreover, labour disruptions translated to wage losses of USD 19,204.40. Income losses across farmer categories were deeply skewed, with large farmers experiencing a 40.22% drop, while medium and small farmers suffered significantly higher proportional losses—88.74% and 91.75%, respectively. On a per-farmer basis, income losses amounted to USD 809.76 for large farmers, USD 217.32 for medium farmers, and USD 19.62 for small farmers. Restoration costs for affected farm machinery totalled USD 483.80, with large farmers incurring USD 270.60, medium farmers incurring USD 131.20, and small farmers incurring USD 82.00.

Despite these impacts, the delay in disbursing compensation significantly hindered recovery efforts. Accelerated and targeted compensation mechanisms would have provided vital support for the early restoration of livelihoods, particularly for small and medium-scale farmers who were disproportionately affected (see the table below). These findings underscore the need for adaptive disaster risk reduction strategies and the timely mobilisation of post-disaster recovery support to safeguard rural livelihoods in flood-prone areas.

Table 3: Analysis of loss and damages to the agriculture of the study area.

Loss and damage on agricultural land					**Input to paddy production (mt)**				
Farmer's Type	Large	Medium	Small	Total	Farmer's Type	Large	Medium	Small	Total
Total land (ha)	64.763	60.9717	19.0714	144.806	Sowed seed (mt)	3.87	3.413	1.753	9.036
L&D (ha)	11.523	7.131	3.24	17.452	Fertilisers (mt)	8.4	6.84	3.429	18.669
L&D (%)	17.793	11.695	16.988	12.052	Total Input (mt)	12.27	10.253	5.182	27.705
No. of farmers	20	54	86	160	No. of farmers	20	54	86	160
Damage per farmers (ha)	0.576	0.132	0.038	0.746	L&D per farmers (mt)	0.614	0.19	0.06	
Total Loss and Damage ($)	1726	26875.5	9860.5	38462	***Input to paddy production (in USD)***				
L&D per farmer ($)	86.3	497.694	114.657		Farmer's Type	Large	Medium	Small	Total
Loss and damage in paddy production					sowed seed	2062.71	1819.129	959.851	4841.69
Farmer's Type	Large	Medium	Small	Total	Fertilisers (mt)	2886.4	2467.872	1237.183	6591.455
Previous Year (mt)	248	191.9	71.45	511.35	Wages	10332	5428.4	3444	19204.4
This Year (mt)	162	112.7	33.3	308	Total Input cost	15281.11	9715.401	5641.034	30637.55
Loss and Damage (mt)	86	79.2	38.15	203.35	No. of farmers	20	54	86	160
L&D %	34.677	41.271	53.394	39.767	L&D per farmers	764.056	179.915	65.593	
No. of farmers	20	54	86	160	***Sell details***				
Production damage per farmer (mt)	4.3	1.467	0.444	6.21	Farmer's Type	Large	Medium	Small	Total
L&D ($)	19407.1	17872.59	8609.082	45888.77	PY sell (mt)	133	58.6	8.15	199.75
L&D per farmer ($)	970.355	330.973	100.105	286.804	TY expected to sell (mt)	133	58.6	8.15	199.75
Loss and damage of stored grains					TY total sell (mt)	79.5	10.7	0.8	91
Farmer's Type	Large	Medium	Small	Total	Loss and Damage (mt)	53.5	47.9	7.35	108.75
No. of farmers	20	54	86	160	No. of farmers	20	54	86	160
L&D (mt)	10.13	14.065	8.37	32.565	L&D per farmers (mt)	2.675	0.887	0.085	
L&D per farmers (mt)	0.507	0.26	0.097		L&D (mt) %	40.226	81.741	90.184	
L&D ($)	3437.588	3738.751	2748.588	9924.926	***Income details***				
L&D per farmer $	171.879	69.236	31.96		Farmer's Type	Large	Medium	Small	Total
Loss of livestock					PY income $	29823.92	13140.46	1827.556	44791.94
Farmer's Type	Large	Medium	Small	Total	TY's expected income of $	30013.31	13223.91	1839.162	45076.38
L&D ($)	7552.2	1607.2	409.6	9569	TY's total income is $	13818.15	1488.398	151.7	15458.25

Loss and damage on agricultural land					Input to paddy production (mt)				
No. of farmers	20	54	86	160	Loss and Damage ($)	16195.16	11735.51	1687.462	29618.14
L&D per farmer ($)	377.61	29.763	4.763		No. of farmers	20	54	86	160
Farm machinery damage					L&D per farmer	809.758	217.324	19.622	
Farmer's Type	Large	Medium	Small	Total	L&D ($) %	53.96	88.745	91.752	
Farm machinery damage	270.6	131.2	82	483.8	***Support Received***				
L&D per farmers	13.53	2.43	0.953	16.913	Farmer's Type	Large	Medium	Small	Total
Loss of Food Sufficiency					USD ($)	832.79	3209.73	5167.16	9209.68
Farmer's Type	Large	Medium	Small		Note: $ - US dollar PY – Previous year mt – metric tons TY – This year ha - Hectare				
PY average (Month)	12	11.444	6.721						
TY average (Month)	8.2	6.556	3.279						
Loss (Month)	3.8	4.849	3.442						

Table 4: Descriptive statistics.

Indicators	Large				Medium				Small			
	Mean± SE	**SD**	**Min**	**Max**	**Mean± SE**	**SD**	**Min**	**Max**	**Mean± SE**	**SD**	**Min**	**Max**
land (ha)	0.576 ± 0.147	0.658	0	2.004	0.132± 0.029	0.215	0	1.002	0.037±0.009	0.086	0	3.239
USD	86.31± 22.48	100.53	0	328	497.69± 170.042	1249.551	0	5781	114.66± 76.89	713.09	0	5756.4
Production (mt)	4.3 ± 0.658	2.94	1.5	12	1.466± 0.147	1.085	0	5	0.443± 0.041	0.385	0	1.5
USD	970.35± 148.56	664.40	338.50	2707.968	330.974± 33.321	244.859	0	1128.32	100.106± 9.370	86.897	0	338.496
Food (month)	3.8± 1.047	4.686	0	12	4.849± 0.539	3.929	0	12	3.686± 0.261	2.422	0	10
Stored (mt)	0.506± 89.191	1.102	0	4.3	0.260± 0.077	0.57	0	3.2	0.097± 0.024	0.227	0	1
USD	171.88± 89.19	398.88	0	1637.13	69.236± 21.194	155.749	0	810.439	31.960± 7.453	69.12	0	331.116
Machinery (USD)	8.2± 6.379	28.53	0	123	2.429± 1.307	9.608	0	49.2	0.953± 0.582	5.398	0	41
Livestock (USD)	377.61± 289.14	1293.053	0	5740	29.762± 17.626	129.529	0	820	4.762± 2.270	21.058	0	160

3.4. Coping Strategies and Socioeconomic Consequences among Farming Households

The farming community in Rajapur has adopted a range of short-term coping strategies to address the recurrent loss and damage caused by unseasonal flooding. As a direct response to the disruption in paddy production, many farmers have opted to purchase rice from the market to ensure household food security. Additionally, there has been a noticeable shift toward cultivating alternative crops, such as wheat, and an increased emphasis on spring-season rice production, an initiative promoted by the Prime Minister's Agricultural Modernisation Project (PMAMP). Farmers have also reduced the sale of their paddy harvests instead of conserving it for subsistence, reflecting heightened vulnerability and concerns about food security.

Despite these adaptive responses, the broader socioeconomic impacts remain severe, particularly among smallholder farmers. The study found that approximately 70% of small farmers resorted to taking loans from local cooperatives and women's groups (mother groups). In comparison, 10% reported withdrawing their children from school due to financial constraints. Labour migration has become a dominant survival strategy, with nearly 90% of smallholder families reporting that at least one family member had migrated for work, primarily to urban centres in Nepal and India. This pattern highlights the growing economic precarity driven by climate-related disruptions to agriculture.

Furthermore, rather than selling wheat to generate income, smallholders are now retaining it for household consumption—an indication of both declining income streams and eroding food self-sufficiency. These farmers are also disproportionately reliant on humanitarian assistance, receiving essential supplies such as food, water, shelter materials, and hygiene kits. In contrast, medium and large-scale farmers received less aid, likely due to their relatively higher asset base and coping capacity.

A significant point of concern is the delay in government compensation for flood-related losses. As of August 2022, no compensation had been disbursed, and available schemes appear skewed in favour of landowners, primarily large farmers, excluding vulnerable groups such as landless sharecroppers and small tenant farmers. This systemic exclusion exacerbates existing inequalities and undermines the resilience of the most affected populations.

4. Discussion

4.1. Temperature, Rainfall and Discharge Analysis

The analysis of climatic variables and hydrological trends in Rajapur highlights a significant shift in seasonal weather patterns over the past two decades. The observed variation in temperature, rainfall, and river discharge aligns with broader regional and global climate change projections (IPCC, 2020). Notably, the minimum temperature in the winter and post-monsoon seasons has reached 0°C in recent years, a phenomenon that has not been previously recorded. This emerging pattern of colder winters and post-monsoons may signal greater climatic variability and an increased risk of frost damage to winter crops. Conversely, the increasing trend in minimum temperature during the pre-monsoon and monsoon seasons, along with a persistent rise in maximum temperature across all seasons, underscores a shift toward overall warming, supporting the findings of Gyawali (2019) and Khatiwada et al. (2015) in other regions of Nepal.

Such thermal variations have direct implications for agroecosystems and crop calendars, particularly affecting the germination, flowering, and harvesting phases of staple crops such as paddy and wheat. Elevated temperatures during the monsoon and pre-monsoon periods can also intensify evapotranspiration and soil moisture loss, thereby compounding the vulnerability of rain-fed agricultural systems, which are predominant in regions like Rajapur.

Precipitation analysis reveals increasing trends in total annual rainfall and wet-day precipitation during all seasons except the pre-monsoon season. These shifts in rainfall dynamics suggest a heightened risk of extreme weather events and associated hydrological hazards. The increasing precipitation, however, does not uniformly translate to increased water availability, as evidenced by declining annual discharge trends in the Karnali River at Chisapani station, corroborating the findings of Khatiwada et al. (2016).

This decoupling between rainfall and discharge may be attributable to several factors, including changes in land use and land cover, increased surface runoff due to reduced infiltration, and disruptions in natural water retention capacity. Moreover, the study indicates that the discharge trend decreases during the winter, pre-monsoon, and monsoon seasons, while an anomalous increase is observed during the post-monsoon period. This pattern strongly suggests the growing influence of glacial meltwater in sustaining river flow during the late monsoon and post-monsoon periods—an assertion supported by higher discharge levels in Chisapani station after August, even when rainfall subsides.

The linkage between increased post-monsoon discharge and unseasonal flooding events is particularly concerning. The 2021 flood events in multiple districts, including Melamchi (Sindhupalchowk), Manang, Mustang, and Gorkha, were triggered by extended monsoon activity that arrived two weeks earlier than usual and lingered beyond its typical duration (World Bank, 2022). These unseasonal and compound climate events caused catastrophic impacts, including the loss of lives, damage to critical infrastructure, agricultural destruction, and disruption of livelihoods. The recurrence of such events highlights the need for enhanced early warning systems, improved glacial monitoring, and the integration of seasonal forecasts into planning and agricultural decision-making.

Overall, the climatic and hydrological patterns observed in Rajapur reflect a broader climatic disequilibrium, underscoring the need for adaptive and resilient management of water and agricultural resources. Without robust intervention, continued shifts in precipitation and discharge regimes will exacerbate flood risks and water insecurity, posing long-term challenges to food security and rural livelihoods in the Karnali Basin and beyond.

4.2. Flood Dynamics and Impacts

The analysis of flood events in Rajapur Municipality over the past three decades reveals an alarming trend of increasing frequency and severity, with profound implications for both human well-being and agricultural productivity. While floods have long been a recurring hazard during the monsoon season, recent years have seen an intensification in their magnitude and impacts, consistent with broader hydrometeorological changes attributed to climate change. The most catastrophic event in recent memory occurred in 2014, when a peak discharge of 17,900 m^3/s resulted in 12 fatalities and an estimated USD 24.6 million in physical damages (Practical Action, 2021). While monsoon rainfall remains the dominant driver of these flood events, post-monsoon floods are also becoming increasingly common. They are often exacerbated by accelerated glacial melt due to rising temperatures in the upstream catchments (Khatiwada et al., 2016).

A particularly illustrative example occurred in October 2021, when an unseasonal post-monsoon flood caused significant damage to the agricultural sector. Over 20 hectares of farmland were eroded or buried, leading to direct losses estimated at over USD 38,000. Cumulatively, more than 460 hectares of productive agricultural land have been lost to riverbank erosion and flood damage, with wards 1, 3, 4, and 7 of Rajapur Municipality identified as the most severely affected areas (Rajapur Municipality, 2021). These localised findings support broader regional studies that document the intensification of flood hazards across the Karnali Basin (Bhawani et al., 2023; Dugar, 2016).

The increasing recurrence and destructiveness of flood events in Rajapur present a serious threat to food security, land tenure, and rural livelihoods. This is particularly concerning in a socio-economic context where a large proportion of households rely on subsistence agriculture and lack the financial capacity to recover from repeated shocks. This situation calls for urgent intervention through the development and implementation of integrated flood risk management strategies. This includes investment in upstream watershed conservation, community-based early warning systems, climate-resilient crop diversification, and the enforcement of land-use zoning to reduce exposure. Without such measures, the vulnerability of Rajanpur's agrarian communities will continue to grow in parallel with climate-induced hydrological extremes.

4.3. Loss and damage

This study highlights the disproportionate financial and livelihood impacts of flooding across different farmer categories in Rajapur Municipality. In this rice-growing region, agriculture, particularly paddy cultivation, forms the backbone of the local economy. While all farmer groups were affected, small and medium-scale farmers suffered the most severe livelihood losses relative to their capacity to absorb shocks. Although large farmers experienced the highest proportion of land damage (17.93%), the per capita L&D value was significantly higher among medium and small farmers, at USD 497.69 and USD 114.66 per farmer, respectively, compared to USD 86.30 among large farmers. This discrepancy is attributed to the greater vulnerability of smallholders residing in high-risk floodplains adjacent to the Karnali River, where exposure is highest (Newar, 2014).

The impact on paddy production further underscores the asymmetric burden borne by smaller farmers. Losses in paddy yield were estimated at 34.67% for large farmers, 41.27% for medium farmers, and 59.39% for small farmers, significantly undermining food security and income generation. Compounding this, the quality of harvested grains deteriorated due to waterlogging and sediment deposition, forcing farmers to sell at reduced market prices. While large farmers also suffered notable losses of livestock and machinery, their greater access to capital and diversified income sources enabled a more rapid recovery. In contrast, small and medium farmers, often reliant on single-season harvests and lacking formal safety nets, faced prolonged hardship, including the loss of up to five months' worth of staple food supply.

Significantly, the vulnerability of smallholder farmers is exacerbated by prevailing land tenure arrangements. Many operate under shared cropping systems such as *Adhiya* and *Bataiya*, wherein landless or resource-poor households cultivate land owned by larger landholders, absorbing a disproportionate share of agricultural risks (Kocanda & Puhakka, 2012). As a result, small farmers lost over 88% of their annual agricultural income in the aftermath of the flood due to both yield reduction and damage to stored grain reserves. These findings are consistent with broader patterns observed in South Asia, where marginalised groups often reside in flood-prone zones with limited adaptive capacity.

Given these dynamics, the study emphasises the importance of targeted post-disaster support mechanisms, including direct financial aid, land rehabilitation, access to improved seed varieties, and the promotion of flood-resilient agricultural practices to enhance the resilience of small and medium-scale farmers. Addressing these inequities is essential not only for food security but also for long-term sustainable development in climate-sensitive agrarian regions like Rajapur.

4.4. Adaptation Measures and Strategies

Floods significantly disrupt agricultural livelihoods in Rajapur Municipality, compelling farmers, particularly those with limited landholdings, to adopt various coping and adaptation strategies in the aftermath of disasters. As highlighted by Jha (2017), such events degrade land quality and reduce agricultural productivity, forcing smallholder farmers to adjust employment and livelihood strategies to ensure survival. Common adaptive responses include purchasing rice for household food security, shifting to wheat as a dietary substitute, cultivating spring-season rice, storing paddy instead of marketing it, taking out informal loans, and engaging in short-term labour migration. Small farmers, in particular, emerge as the most vulnerable group, often demonstrating limited adaptive capacity even during non-flood years due to their marginal economic status and dependency on subsistence farming (Amarnath & Saikia, 2017).

The financial insecurity of smallholders often results in school dropouts, loan dependence, and manual wage labour. Male members of affected households frequently migrate to urban areas for seasonal work. These households also lack access to mechanised equipment, resulting in dependency on sharecropping agreements, often with relatively resource-rich Tharu landowners (Kocanda & Puhakka, 2012). While the Nepal Red Cross Society, in collaboration with several I/NGOs, provided immediate relief worth approximately USD 9,210, this fell short of compensating for the extensive damages to agricultural assets and livelihoods. Moreover, government compensation schemes suffered from bureaucratic delays, which prevented timely access to essential agricultural inputs, such as seeds and fertilisers, thereby constraining farmers' ability to recover in subsequent planting seasons.

Despite these challenges, several community-level and institutional adaptation measures have been implemented. The Karnali River Management Project has constructed a 17-kilometer-long embankment along the Karnali and Geruwa Rivers, providing partial protection to flood-prone areas. However, these structures remain insufficient against high-magnitude events, as evidenced by the 2020 breach of a 500-meter section in Tihuni village and the 2021 overflow incident, which caused widespread agricultural damage (Boyd et al., 2017). The Early Warning System (EWS) linked to the Chisapani gauge station, triggering alerts when water levels exceed 9 meters, has proven effective in reducing human casualties, complemented by sirens and mobile alerts. Over time, societies have employed various methods to mitigate the impact of natural disasters. Early Warning Systems (EWSs) are widely valued as a key non-structural tool for enhancing preparedness and reducing risks (Sukhwani et al., 2019). However, the design and effectiveness of these systems can vary significantly depending on a country's level of scientific, technological, and economic development, impacting their performance in different scenarios (Cvetković et al., 2021).

Traditional flood mitigation strategies, such as machan (elevated dwellings), raised wells, and thatis (double-story homes for storing essentials), remain in use. Community-based mechanisms, including Community Disaster Management Committees (CDMCs), local search and rescue teams, youth groups, and trained volunteers, are actively mobilised during emergencies (Practical Action, 2021). Adaptive agricultural practices are also evolving. Farmers are increasingly shifting to less flood-sensitive crops, such as vegetables and sugarcane, and using hybrid seed varieties (albeit at the cost of local genetic diversity), while also experimenting with spring paddy cultivation. Though rare, some have initiated tree plantations along field boundaries for erosion control. Other structural and agronomic adaptations include the installation of improved drainage systems and the expansion of sharecropping arrangements to manage labour and land use during recovery periods.

Collectively, these strategies reflect both reactive coping and proactive adaptation in response to escalating climate risks. However, gaps in institutional support, inadequate infrastructure, and social inequities continue to hinder long-term resilience, particularly among the most vulnerable farmer groups.

The study faced several limitations. Climatological and hydrological data were sourced from a single station due to time and financial constraints, and the analysis focused on a single year's flood event, limiting a broader temporal perspective. Additionally, the study concentrated on economic loss, overlooking the non-economic impacts that are crucial to understanding livelihoods. The flood's occurrence during the paddy harvesting season resulted in a primary focus on paddy, with limited attention to other crops.

5. Conclusion

The Rajapur area is experiencing an increasing frequency and severity of extreme weather events, particularly flooding and inundation, driven by observable trends in rising temperatures and erratic precipitation. These climatic shifts have caused extensive economic loss and damage (L&D) in agriculture, affecting lives, livelihoods, property, and critical infrastructure. This study estimates economic losses due to land degradation (L&D) by calculating the market value of losses related to land, paddy production, stored grains, livestock, and agricultural machinery while deliberately excluding non-economic losses. Although adaptation mechanisms, such as Early Warning Systems (EWS), have reduced human casualties, agriculture-dependent communities continue to face heightened risks, particularly due to the erosion of arable land, sediment deposition, and declining yields linked to unsustainable practices, including the overuse of chemical fertilisers.

Embankments, although providing limited protection, have failed to withstand large-scale floods, with dam failures resulting in catastrophic losses. Smallholder farmers remain the most vulnerable group, enduring profound impacts on landholding, production, and income. Medium-scale farmers also report losses in food security and stored grain stocks. In contrast, large-scale farmers, despite comparatively less direct crop damage, have incurred notable losses to farm machinery and livestock. These stratified impacts underscore the urgent need for differentiated policy responses.

Despite the growing relevance of climate-induced labour and development (L&D), it remains a nascent concept in Nepal's policy landscape. Incorporating this framework into national and local strategies is crucial, particularly in addressing the vulnerabilities of marginalised, agriculture-reliant communities. Sharecroppers, often overlooked in compensation schemes, invest heavily in cultivation but suffer disproportionately during floods. Current compensation mechanisms primarily benefit large landowners, exacerbating inequalities and leaving small farmers more susceptible to chronic poverty. Equitable compensation systems must be revised to reflect the actual burden borne by those most affected.

Importantly, non-economic L&D, though harder to quantify, often results in deeper, long-term consequences. These include the loss of education (due to school dropouts), increased indebtedness from emergency loans, psychological distress, and weakened social cohesion. Broadening the scope of L&D assessments to include these dimensions will lead to more accurate and just adaptation policies. Future research should also explore underexamined sectors such as forestry, rural infrastructure, and transportation networks, which are integral to agricultural resilience.

Adaptation strategies must be strengthened through targeted awareness programs and farmer training focused on climate-resilient practices, including the use of flood-tolerant and short-duration crops, spring-season paddy cultivation, and efficient irrigation techniques. Promoting nature-based solutions, such as bio-engineering interventions and riparian afforestation, offers sustainable avenues for managing flood risk. Furthermore, building institutional capacity to provide incentive grants, technical support, and localised research in L&D can empower communities to adapt proactively.

Lastly, government programs like the Prime Minister's Agriculture Modernisation Project should undergo a critical reassessment to ensure equitable access and responsiveness to the specific needs of smallholder and sharecropping farmers. By prioritising investments in disaster risk reduction, livelihood resilience, and inclusive adaptation planning, Nepal can better safeguard its vulnerable farming communities from the escalating threats posed by climate change.

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Annexes

Proposed Indicators in BIPAD

Sector	Subgroup	Indicators	Description
Productive	Agriculture	Land	Area of crop field destroyed and damaged
			Economic loss
		Productivity	Amount of production lost
			Economic value of production loss
		Stored Grains	Amount of stored grains lost
			Economic value of stored grains
		Livestock	Number of livestock dead
			Economic value of dead livestock
		Farm machinery	Economic loss due to damaged/destroyed productive assets in the agricultural sector

Assessment of Loss and Damage of agricultural land

Sectors	Assessment
Land Area	Loss and Damage (ha) = Total Land-(Land loss+ Land Damage) Loss and Damage ($) = Lost land value + restoration cost
Production	Loss and Damage (mt) = Previous year yield- This year's net yield Loss and Damage ($) = Economic value of expected yield – economic value of this year's yield.
Stored Grains	Loss and Damage (*mt*) = Quantity of stored grains* pre-disaster value of destroyed stored grains
Livestock	Loss ($): Pre-disaster value of dead animals
Farm Machinery Damage/ Asset damage:	Repair cost of partially or fully destroyed assets
Food sufficiency	Loss (Month): Average sufficiency month pre-disaster – average sufficiency month post-disaster
Income	Loss and Damage: Previous year's total sell – This year's total sell Loss and Damage ($) = Previous year income – (This year's selling price* total sell)
Input	Loss and Damage: Input used*Input prices
(Inputs are considered as seeds that are used for sowing, fertilizers used, and labor wages)	

Total wet day precipitation, Days with heavy precipitation and Days with very heavy precipitation.

Details	Winter	Year	Pre-Monsoon	Year	Monsoon	Year	Post-monsoon	Year
Total Rainfall (mm)	1943.55		2811.9		34903.05		823.8	
Total wet day Precipitation (PCP ≥ 1 mm)	228	1997	215.5	2011	1839.1	2007	220.1	1998
Days with heavy Precipitation (PRCP ≥ 10 mm)	52.5	1996	104.2	2011	228.8	2008	39.4	1997
Days with very heavy precipitation (PRCP ≥ 20 mm)	198.3	1997	143	2021	1688.8	2007	214.5	1998

Seasonal Discharge (High, low, and average)

Details	Winter	Year	Pre-Monsoon	Year	Monsoon	Year	Post-Monsoon	Year
High Discharge (m^3/s)	438	2020	750	1998	4085	2000	2008	2021
Low Discharge (m^3/s)	285	2012	337	2016	2203	2015	679	2015
Average Discharge (m^3/s)	372		487		2931		997	