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Nature-Based Solutions: Mitigating Flood Effects on Forest Tree Biodiversity and Societal Factors

Bhawani Neupane[1], Rajeev Joshi[2 *], Santosh Ghimire[3], Sewak Bhatta[1], Manoj Panta[1]

[1]*School of Environmental Science and Management (SchEMS), Faculty of Science and Technology, Pokhara University, Nepal*
[2]*College of Natural Resource Management, Faculty of Forestry, Agriculture and Forestry University, Katari-56310, Udayapur, Nepal*
[3]*Faculty of Forestry, Agriculture and Forestry University, Hetauda-44107, Nepal*
**Email: joshi.rajeev20@gmail.com*

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Abstract

Nature-based solutions (NBS) effectively address climatic hazards such as floods, droughts, landslides, and broader global sustainable development challenges. However, research on this subject is limited in Nepal. Thus, this study was meticulously designed to evaluate the impact of floods on forest tree biodiversity, social features, and the spatial dynamics of nature-based solutions. The research focused on three community forests—Marka Urra, Kalikhola, and Bhaunijhora in Mahottari districts - where a total of 90 plots were established. Social data collection involved 5 key informant interviews, 3 focus group discussions, and 90 household surveys with photographs and GPS coordinates. The study revealed that while flooding occurrences were frequent, their impact on communities and forest areas reduced significantly following NBS implementation. Notably, the species' evenness and richness for trees and poles remained similar, indicating that floods predominantly affect saplings and seedlings. The study analyzed rainfall patterns from 2009 to 2021, recording the highest rainfall of 2142 mm in 2021 and the lowest of 355.3 mm in 2013. At affected sites, the average Shannon diversity for saplings and seedlings varied, with the highest and lowest values being 0.84±0.07, 0.75±0.10; 1.20±0.08, 0.67±0.09, respectively. Similarly, species evenness and richness showed varying trends among saplings and seedlings. The highest IVI values were recorded for trees, poles, saplings, and seedlings (*Shorea robusta*) at 218.14, 232.06, 44.26, and 28.16, respectively, while the lowest values were observed for *Shorea robusta* (212.02, 215.93) and other species like *Senegalia catechu, Bidens pilosa,* and *Elusine indica*. The study indicated an increasing trend in the extent and severity of flood events, causing escalating damage to infrastructure, livelihoods, agriculture, forestry, and various sectors. The NBS employed in these community

forests included tree plantations, hedges, bamboo fencing, dykes, dams, and gabion walls. This research contributes valuable insights into understanding the effectiveness of nature-based solutions in community forests.
Keywords: Community forest, Shannon diversity, Species evenness, Species richness

Introduction

A natural approach to flood control involving the restoration of the alluvial floodplain presents a viable alternative to technical solutions. Its primary benefits include offering comparable flood protection at reduced costs while delivering additional societal advantages and promoting biodiversity (Turkelboom et al., 2021). This nature-based approach serves as a "no-regret solution," capable of addressing future challenges such as climate change. By harnessing natural resources, it tackles issues arising from inadequate resource use, land utilization, climate change, and societal complexities. Such solutions often lead to long-term economic, social, and environmental benefits by enhancing existing natural or human-made infrastructures. Climate change represents a critical challenge affecting our world today, initially impacting both rural and urban areas, where cities serve as microenvironments experiencing extreme temperature and rainfall gradients. Its consequences significantly influence ecosystem functionality and human welfare. The rise in occurrences of heatwaves, droughts, and floods not only diminishes the distribution of native species but also affects society through health-related implications and socio-economic disruptions (DeBuys, 2012; Kabisch et al., 2017).

Europe is anticipated to encounter substantial challenges in adjusting to and mitigating the impacts of extreme weather events (Kreibich et al., 2015). According to the Intergovernmental Panel on Climate Change (IPCC), the global climate system has undergone unprecedented warming since the 1950s, primarily attributed to increased greenhouse gas (GHG) emissions from human activities. This warming has led to decreased snow and ice cover on land, accompanied by rising sea levels. Continuation of GHG emissions will intensify warming and cause further alterations in climate components. IPCC projections indicate unequal changes in the global water cycle due to warming. Precipitation disparities between wet and dry regions, as well as between wet and dry seasons, are expected to become more distinct. While regional variations might occur, the IPCC forecasts a likelihood of increased intensity and frequency of extreme precipitation events, particularly over wet tropical regions, by the end of this century (Kundzewicz & Schellnhuber, 2004).

The concept of nature-based solutions concentrates on the broader ecology that supports a community, encompassing socioeconomic connections. To be considered a comprehensive EbA (Ecosystem-based Adaptation) strategy and differentiate itself from other adaptation methods, it must adhere to five key principles: reducing social and environmental vulnerabilities, delivering societal benefits within the context of climate change adaptation, restoring, maintaining, or enhancing ecosystem health, aligning with multi-level policy support, and fostering fair governance and community capacity to undertake EbA activities. These criteria establish a framework for defining performance indicators to monitor adaptation efforts. EbA advocates for the sustainable management of forests, grasslands, wetlands, and coastal zones to mitigate adverse effects of climate hazards, such as changing rainfall patterns, temperature fluctuations, intensified storms, and varying climatic conditions (Gilruth et al., 2021). Vegetation plays a pivotal role in reverting urban climates closer to their predevelopment state. Urban green infrastructure (UGI) and nature-based solutions (NBS) are fundamental concepts in this pursuit, emphasizing nature's potential in offering numerous services to urban populations (Pauleit et al., 2017). Notably, by integrating NBS within urban landscapes, the manifold benefits linked to climate change adaptation and mitigation are increasingly acknowledged as influential factors in human health and well-being (Barredo, 2009). These benefits extend to the provision and enhanced accessibility of urban green spaces, potentially leading to improved mental and physical health (Kreibich et al., 2015). Furthermore, in many instances, NBS may offer more efficient and cost-effective solutions compared to traditional technical approaches (EU, 2007). Finding cost-effective and efficient solutions to address climate change is crucial, and nature-based solutions stand as one viable global option. These solutions for societal challenges are defined as cost-effective approaches that yield environmental, social, and economic benefits, fostering resilience and drawing inspiration from nature. Tailored to local contexts, resource-efficient, and systematic, such solutions introduce increased and varied natural elements and processes into cities, landscapes, and seascapes (EU, 2007; Cohen-Shacham et al., 2016). The development, restoration, enhancement, and maintenance of existing vegetation systems, along with the creation of an integrated urban green infrastructure network, could serve as valuable assets for implementing innovative NBS to tackle local climate change effects. NBS can significantly contribute to establishing a livable and sustainable community (Emilsson, & Ode Sang, 2017). The Terai region in Nepal spans approximately 17% of the country's landmass, covering an area of 25,000 km^2 and situated on the northern edge of the Indo-Gangetic plain. Often dubbed the country's garden, the Terai boasts mostly flat geography, gradually sloping southward and ranging in elevation from 65 to 300 meters above sea level, spanning 20 to 45 kilometers in width. It features a subtropical climate with an average temperature of 25 degrees Celsius and receives an annual rainfall ranging from 1,200 to 3,000 mm, including intermittent showers and cloudbursts. Notably, all Nepalese rivers flow into the Terai plain at the foothills of the Churia and Siwalik ranges (Adhakari, 2013). Nepal faces significant challenges with floods, causing damage to settlements and infrastructure, particularly roads and electricity lines, on an annual basis. To address these issues, efforts are being made at the local level, such as the restoration of forest ecosystems in flood-prone areas, using specific plant species like *Alnus nepalensis*, Bamboo spp., *Eulaliopsis binata*, *Senegalia catechu*, and *Dalbergia sissoo*. Mahottari district, in particular, grapples with severe flooding issues, causing extensive damage to infrastructure, human settlements, and agriculture. However, studies regarding these challenges have not yet been explored. Climate change has already begun affecting the livelihoods of communities in Mahottari, posing the potential for increased negative impacts. Hence, communities need to comprehend climate change patterns, foresee potential implications, and employ nature-based solutions to avert adverse effects.

Understanding the changing climate is crucial for future planning, especially for protecting Mahottari from climate change impacts, particularly flooding. Nature-based solutions, focusing on flood mitigation through measures such as dykes, bioengineering, bamboo fencing, diversions, drainage, soil cover improvement, and water storage areas, are gaining prominence. Despite this, there has been a lack of research on nature-based solutions against flooding. Consequently, this study's main objective is a comprehensive assessment of flooding impacts on both forest tree biodiversity and social characteristics. Additionally, it aims to explore the spatial dynamics associated with nature-based solutions. This is accomplished through specific objectives: a) analyzing flood repercussions on forest tree diversity, b) examining flood effects on social aspects, and c) understanding the spatial intricacies linked with nature-based solutions.

Materials and Methods

Study Site

The research was conducted within Bardibas Municipality, situated in the Mahottari District of Nepal. Specifically, three community forests named Marka Urra, Kalikhola, and Bahunjhora, located near the Ratu River, were chosen as study sites (Fig. 1). The latitude and longitude coordinates range from 26° 37' 43" to 27° 8' 3" N and from 85° 46' 13" to 85° 58' 47" E, encompassing a total study area of 532 km^2. Elevation within this region varies from 136m to 774m. Bardibas Municipality shares its borders with Dhanusha district to the east, Sarlahi district to the west, Sindhuli district to the north, and shares a boundary with India to the south. The Ratu River originates in the Chure and meanders through the Terai region of Nepal, acting as a natural border between Dhanusha and Mahottari districts. Flooding emerges as a significant recurring disaster in this area, with the Ratu River being prone to frequent inundation. However, the implementation of nature-based solutions has mitigated flood risks in both the community areas and forest regions.

The Ustrorthents, primarily developed on sedimentary rocks in the Siwaliks, constitute shallow soils overlaying the parent material. These soils possess a loamy texture, facilitating rapid surface drainage, and exhibit variable pH levels. Terai Forest soils are categorized as Us ochrepts and Haplustolls, predominantly consisting of sandy loam to clay loam textures, occasionally interspersed with silty clay loam and silty clay textures. During the monsoon season, the Siwaliks' soil structure often gets eroded, resulting in downstream flooding.

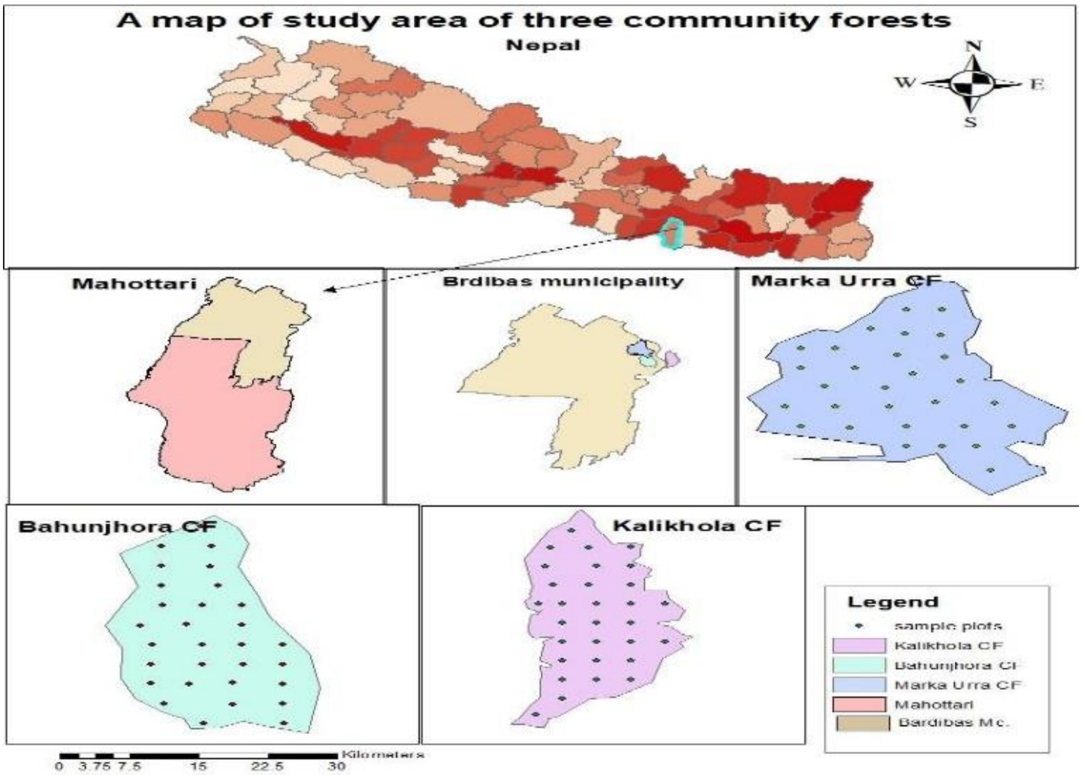

Figure 1. Map of study area of three community forests

Data collection

Primary data was collected through various social data collection methods, including household surveys, focus group discussions (FGD), and key informant interviews (KII) (Table 1).

Table 1. Social data collection methods and its description

Data Collection Methods	Description
Household Survey	In total, 90 household surveys were conducted, with 30 surveys carried out in each of the community forests, involving interviews with local residents.
Focus Group Discussions (FGD)	Three focus group discussions (FGDs) took place within each community forest, with more than 10 participants engaging in each discussion. The participants included ward chairpersons, CFUG members, and local community members.
Key Informant Interview (KII)	Five KII were taken. DFO, ward chairpersons, old people were interviewed.

Forest Sampling

To evaluate the effectiveness of nature-based solutions post-flood, the site was segregated into two categories: affected forest sites (experimental) and non-affected forest sites (control). A total of 90 sample plots were gathered from three community forests. For trees, poles, saplings, and seedlings, 30 quadrants were established in each site, with dimensions of 25×20 m^2, 10×10m^2, 5×5m^2, and 2×1 m^2, respectively. These plots were utilized to measure species biodiversity and the importance value index. Stem diameter at breast height and height for trees, poles, saplings, and seedlings were recorded, along with species-specific frequency and density for each plot. Primary data collection at the sample plots encompassed tree enumeration, tree species identification, measurement of tree height and diameter at breast height, and pinpointing sample plot locations using a handheld GPS device.

Secondary data collection

Data regarding precipitation was obtained from the Department of Hydrology and Meteorology (DHM) spanning the years 2009 to 2021. Other information was gathered from various sources including books, journals, articles, published and unpublished reports sourced from Bardibas Municipality and the Division Forest office.

Data Analysis

Analysis of Biodiversity and importance value index

Field-collected data underwent coding, classification, and the creation of variables. Both qualitative and quantitative data from diverse sources underwent processing and analysis. Computer software such as Microsoft Excel was utilized to process and analyze the data, producing the desired outcomes. The assessment of biodiversity at control and experimental sites aimed to reveal disparities in species values. Additionally, the comparison involved evaluating the Importance Value Index (IVI), calculated as the sum of relative density, relative frequency, and relative dominance (Curtis & Mcintosh, 1950). Furthermore, diverse indices, including the Shannon-Wiener index and Evenness index, were employed to measure diversity, although determining the optimal method remains challenging due to numerous available indices. The assessment also included comparing and contrasting the Importance Value Indexes of both sites. For instance, the Shannon-Wiener index, expressed as H= ∑si=1- (Pi × ln Pi), evaluated diversity where Pi represents the fraction of the population composed of species I, S denotes the number of species encountered. Similarly, the Evenness index (e) was calculated using H' (Shannon Wiener Diversity index) divided by log S, with S representing the number of species. Additionally, species richness, computed as S/√N, factored in the number of species and the total individuals across the community.

Analysis of Rainfall data

Initially, the rainfall data was classified into four distinct seasons: winter, pre-monsoon,

monsoon, and post-monsoon. Utilizing indices formulated by the Expert Team on Climate Change Detection and Indices, the data was further categorized based on total rain days, heavy rainfall days, and very heavy rainfall days. The total number of rainfall days throughout the year was calculated, followed by an analysis of rainfall percentage and the rate of rainfall per day (Table 2).

Table 2. Threshold description of climate index

Climate Index	Threshold Description
Total wet-day precipitation	Total precipitation in wet days PCP ≥ 1mm
Days with heavy precipitation	Number of days when PRCP ≥ 10 mm
Days with very heavy precipitation	Number of days when PRCP ≥ 20 mmdays

Results

The analysis of rainfall patterns spanned from 2009 to 2021, revealing noteworthy variations (Table 3). The highest recorded rainfall occurred in 2021, reaching 2142 mm, while in 2020, it was 1897.52 mm. Conversely, the lowest precipitation, just 355.3 mm, occurred in 2013, marking a year with only 17 rainy days. In the pre-monsoon phase, the most substantial rainfall of 121 mm transpired in 2020 across 7 days, an event within the average span of 89 pre-monsoon days. In 2019, 12.22% of the total rain days were registered (Table 4). The monsoon season of 2020 witnessed a noteworthy rainfall of 1229.3 mm over 41 rain days, constituting 44.57% of the total rain days. Contrastingly, the lowest monsoon rainfall, 144.4 mm over 15 days, was documented in 2000. Post-monsoon records showcased 42 rainy days, with 919.91 mm rainfall in 2021 and merely 101.3 mm over 7 days in 2013. The winter of 2021 reported the highest rainfall at 14.7 mm, the first occurrence of wintertime precipitation after an absence from 2009 to 2018 (Table 5, Fig. 2, 3 & 4).

Table 3. Variations in rainfall patterns

Year	Total No of Days	Pre-Monsoon					Monsoon					Post Monsoon					Winter					Total rainy days in year
		No Rain	Wet	Heavy Rain	Extreme Rain	Total Rainy Days	No Rain	Wet	Heavy Rain	Extreme Rain	Total Rainy Days	No Rain	Wet	Heavy Rain	Extreme Rain	Total Rainy Days	No Rain	Wet	Heavy Rain	Extreme Rain	Total Rainy Days	
2009	365	89	0	0	0	0	77	10	2	3	15	74	7	7	4	18	92	0	0	0	0	33
2010	365	87	1	0	1	2	79	4	3	6	13	79	3	3	7	13	92	0	0	0	0	28
2011	365	90	0	0	1	1	63	8	7	14	29	80	2	3	7	12	92	0	0	0	0	42
2012	366	90	0	0	0	0	74	5	7	6	18	76	5	3	8	16	92	0	0	0	0	34

2013	365	89	0	0	0	0	82	2	4	4	10	85	4	1	2	7	92	0	0	0	0	17
2014	365	88	0	1	0	1	78	3	7	4	14	74	3	6	9	18	92	0	0	0	0	33
2015	365	88	0	0	1	1	80	6	2	3	11	78	4	4	6	14	92	0	0	0	0	26
2016	366	90	0	0	0	0	64	10	6	12	28	83	2	5	2	9	92	0	0	0	0	37
2017	365	80	2	7	0	9	68	12	1	11	24	79	7	1	5	13	92	0	0	0	0	46
2018	365	83	4	0	2	6	66	4	9	13	26	70	11	3	8	22	92	0	0	0	0	54
2019	365	79	8	1	2	11	73	7	1	10	18	74	8	3	7	18	91	1	0	0	1	48
2020	366	83	2	3	2	7	51	12	9	20	41	66	11	7	8	26	90	2	0	0	2	76
2021	365	86	3	0	0	3	35	26	13	18	57	50	18	10	14	42	90	1	1	0	2	104

Table 4. Percentage of rainy days in different season

Year	Pre-Monsoon			Monsoon			Post Monsoon			Winter		
	Total No of Days	Total Rainy Days	No of Rainy days in %	Total No of Days	Total Rainy Days	No of Rainy days in %	Total No of Days	Total Rainy Days	No of Rainy days in %	Total No of Days	Total Rainy Days	No of Rainy days in %
2009	89	0	0.00	92	15	16.30	92	18	19.57	92	0	0.00
2010	89	2	2.25	92	13	14.13	92	13	14.13	92	0	0.00
2011	90	1	1.11	92	29	31.52	92	12	13.04	92	0	0.00
2012	90	0	0.00	92	18	19.57	92	16	17.39	92	0	0.00
2013	89	0	0.00	92	10	10.87	92	7	7.61	92	0	0.00
2014	89	1	1.12	92	14	15.22	92	18	19.57	92	0	0.00
2015	89	1	1.12	91	11	12.09	92	14	15.22	92	0	0.00
2016	90	0	0.00	92	28	30.43	92	9	9.78	92	0	0.00
2017	89	9	10.11	92	24	26.09	92	13	14.13	92	0	0.00
2018	89	6	6.74	92	26	28.26	92	22	23.91	92	0	0.00
2019	90	11	12.22	91	18	19.78	92	18	19.57	92	1	1.09
2020	90	7	7.78	92	41	44.57	92	26	28.26	92	2	2.17
2021	89	3	3.37	92	57	61.96	92	42	45.65	92	2	2.17

Table 5. Rate of rainy days of different seasons

Year	Pre-Monsoon			Monsoon				Post Monsoon			Winter			Year	
	Total Rain (mm)	Total Days	Total Rainy Days	Total Rain(mm)	Total Days	Total Rainy Days	Rate of Rain per Day	Total Rain (mm)	Total Rainy Days	Rate of Rain per Day	Total Rain (mm)	Total Days	Rate of Rain per Day	Total Rainy Days	Total rain (mm)
2009	0	89	0	144.4	92	15	9.63	317.4	18	17.63	0	92	0	0	461.8
2010	42	89	2	320.5	92	13	24.65	328	13	25.23	0	92	0	0	690.5
2011	40	90	1	708.3	92	29	24.42	438	12	36.5	0	92	0	0	1186.3
2012	0	90	0	329.7	92	18	18.32	546.8	16	34.18	0	92	0	0	876.5
2013	0	89	0	254	92	10	25.4	101.3	7	14.47	0	92	0	0	355.3

2014	16	89	1	318	92	14	22.71	528.5	18	29.36	0	92	0	0	862.5
2015	23	89	1	211.1	91	11	19.19	382.2	14	27.3	0	92	0	0	616.3
2016	0	90	0	715.6	92	28	25.56	189.8	9	21.09	0	92	0	0	905.4
2017	111.4	89	9	476.4	92	24	19.85	252.7	13	19.44	0	92	0	0	840.5
2018	103.4	89	6	743.2	92	26	28.58	425.4	22	19.34	0	92	0	0	1272
2019	109.6	90	11	645.4	91	18	35.86	419.3	18	23.29	1.3	92	0.07	1	1175.6
2020	121	90	7	1229.3	92	41	29.98	530.22	26	20.39	17	92	0.65	2	1897.52
2021	19	89	3	1188.8	92	57	20.86	919.91	42	21.9	14.9	92	0.35	2	2142.61

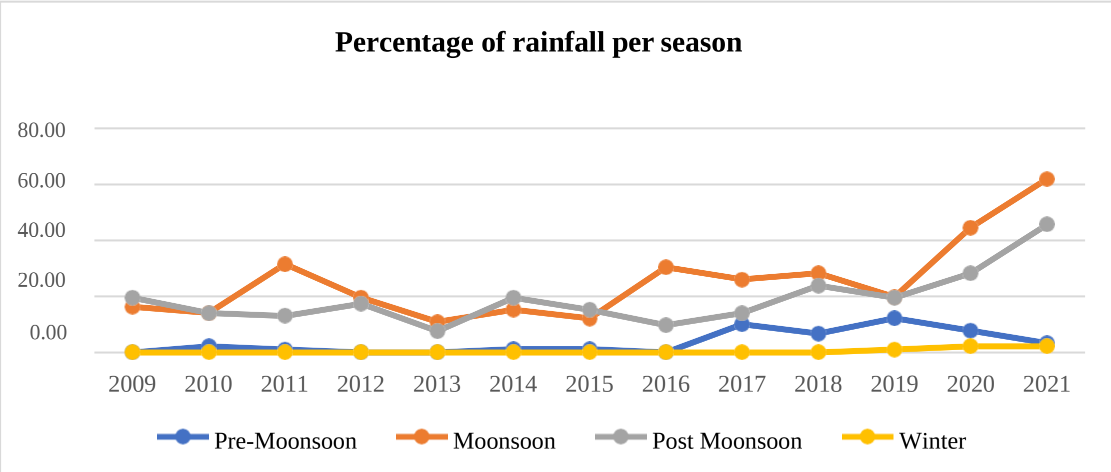

Figure 2. Analysis of number of rainy days

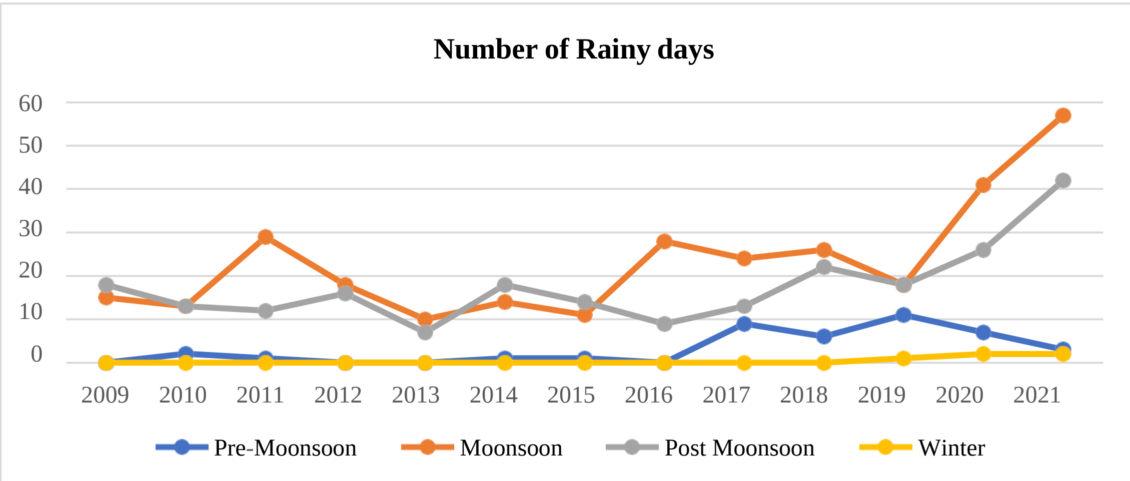

Figure 3. Analysis of Percentage of rainfall per season

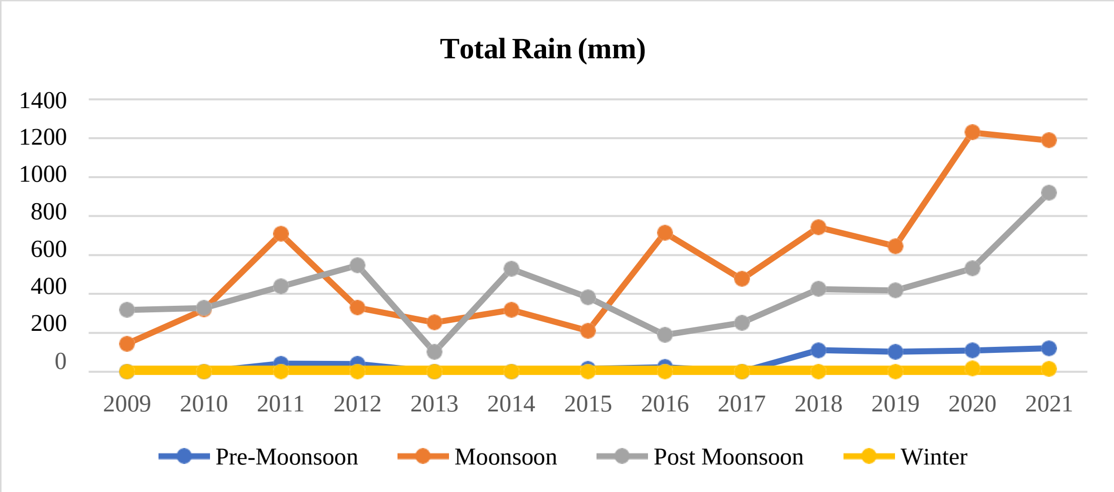

Figure 4. Analysis of Total rain in mm

Species biodiversity in flood affected and non-affected area

The examination involved analyzing the Shannon-Wiener index values for trees, poles, saplings, and seedlings across the three community forests—Marka Urra, Kalikhola, and Bahunijhora—in both the affected and non-affected zones (Table 6).

(a) Descriptive analysis of Shannon wiener index

i. Marka Urra CF: the mean±SE value for tree was found to be 0.7±0.15 in flood affected areas and 0.70±0.09 in non-affected areas. The standard deviation (SD) in flood affected area and non-affected areas were found to be 0.44 and 0.12 respectively. For the pole, the mean±SE was found to be 0.75±0.12 and 0.69± 0.07 in flood affected and non-affected areas. The SD were found to be 0.27 and 0.33in affected and non-affected area. The proportion of *Shorea robusta* was higher in compare to other species. The mean±SE value for sapling was found to be 0.75±0.10 in flood affected areas and 1.15±0.08 in non-affected areas. The SD in flood affected area and non-affected areas were found to be 0.2 and 0.47 respectively. For the seedling, the highest mean±SE was found to be 1.20±0.08 in flood affected area and 1.10±0.07 in non-affected areas. The SD was found to be 0.16 and 0.38 in affected and non-affected area.

ii. Kalikhola CF: the mean±SE value for tree was found to be 0.75±0.07 in flood affected areas and 0.73±0.05 in non-affected areas. The SD in flood affected area and non-affected areas were found to be 0.19 and 0.21 respectively. For the pole, the mean±SE was found to be 0.88±0.1 in flood affected area and 0.8±0.7 in unaffected area. The SD was found to be 0.28 in both non-affected and affected area. The mean±SE value for sapling was found to be

0.83±0.08 in flood affected areas and 1.08±0.06 in non-affected areas. The SD in flood affected area and non- affected areas were found to be 0.2 and 0.33 respectively. For the seedling, the mean±SE value was found to be 0.67±0.09 in flood affected area, in non-affected area the value .03±0.05 were found. The SD were found to be 0.22 and 0.27 in affected and non-affected area respectively.

iii. Bahunijhora CF: the mean±SE value for tree was found to be 0.73±0.04 in flood affected areas and 0.69±0.03 in non-affected areas. The SD in flood affected area and non-affected areas was found to be 0.16 for both sites. For the pole, 0.63±0.04 in flood affected area and 0.65±0.03 in unaffected area. The SD were found to be 0.11 and 0.09 affected and unaffected area. The mean±SE value for sapling was found to be 0.84±0.07 in flood affected areas and the value was found to be 1.05±0.05 in unaffected area. The SD in flood affected area and non-affected areas was found to be 0.23 in both sites. For the seedling, the mean±SE value was found to be 0.82±0.10 in flood affected area, in non-affected 0.9±0.03 was found. The SDwas found to be 0.23 and 0.18 in affected and non-affected area respectively.

In three community forests, it was discovered that the values of the trees and poles were nearly the same in affected and unaffected areas but values of the saplingsand seedlings were higher in non-affected areas than in affected areas. This indicates that flood impacts on saplings and seedlings rather than trees and poles (Fig. 5, 6 & 7).

Table 6. Shannon wiener index in flood affected and non-affected area

Shannon Weiner Index																	
CFUG	**Area**	**Tree**				**Pole**				**Sapling**				**Seedling**			
		Mean ± SE	**Min**	**Max**	**S.D.**	**Mean ± SE**	**Min**	**Max**	**S.D.**	**Mean ± SE**	**Min**	**Max**	**S.D.**	**Mean ± SE**	**Min**	**Max**	**S.D.**
Marka Urra	**Flood affected area**	0.8 ± 0.15	0.23	1.80	0.44	0.69 ± 0.07	0.30	1.19	0.27	0.75 ± 0.10	0.6	1.05	0.2		1	1.34	0.16
	Flood non affected area	0.7 ± 0.09	0.05	1.80	0.12	0.75 ± 0.12	0.30	1.19	0.33	1.15 ± 0.08	0.63	2.21	0.47	1.103 ± 0.07	0.48	2.59	0.38
Kalikhola	**Flood affected area**	0.75 ± 0.07	0.41	1.05	0.19	0.88 ± 0.1	0.52	1.41	0.28	0.83 ± 0.08	0.6	1.04	0.2	0.67 ± 0.09	0.4	1.04	0.22
	Flood non affected area	0.73 ± 0.05	0.41	1.05	0.21	0.8 ± 0.07	0.52	1.41	0.28	1.08 ± 0.06	0.71	1.81	0.33	1.03 ± 0.052	0.41	1.61	0.27
Bahuni Jhorra	**Flood affected area**	0.73 ± 0.04	0.46	1.10	0.16	0.63 ± 0.04	0.69	0.78	0.11	0.84 ± 0.07	0.6	1.04	0.2	0.82 ± 0.10	0.6	1.04	0.23
	Flood non affected area	0.69 ± 0.03	0.41	1.10	0.16	0.65 ± 0.03	0.55	0.78	0.09	1.05 ± 0.05	0.60	1.28	0.23	0.9 ± 0.03	0.49	1.29	0.18

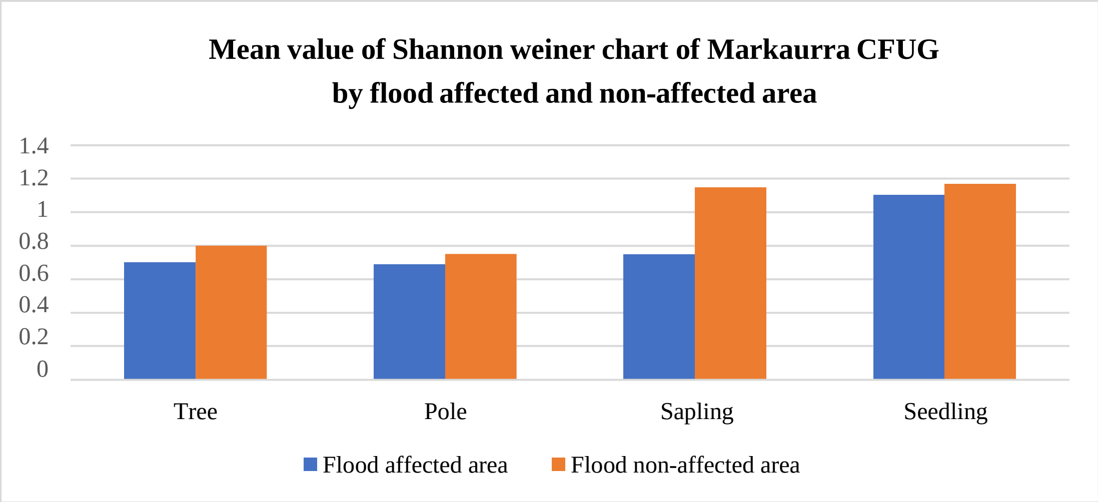

Figure 5. Mean value of Species Richness chart of Bahuni Jhorra CFUG by flood affected and non-affected area

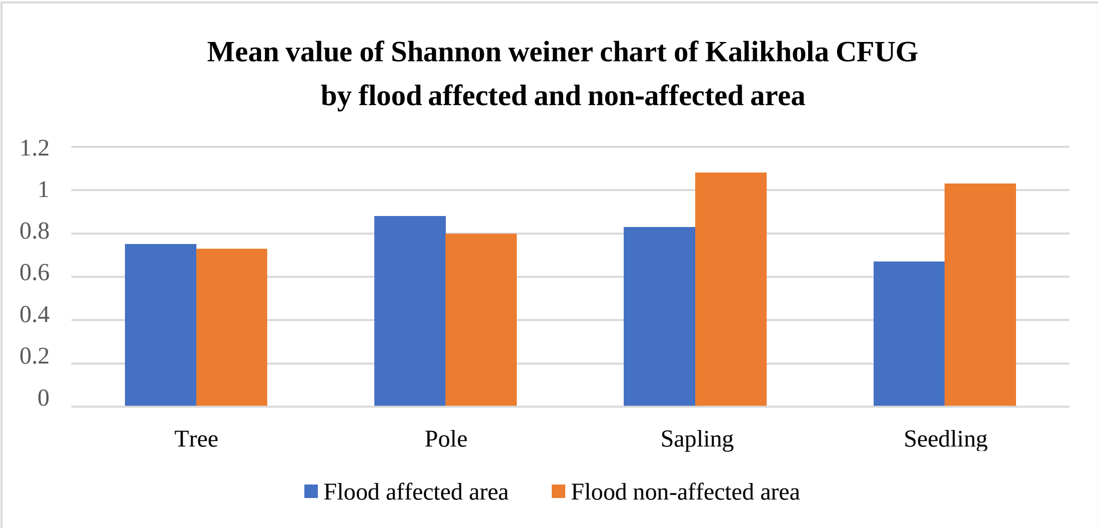

Figure 6. Mean value of Shannon weiner chart of Kalikhola CFUG by flood affected and non-affected area

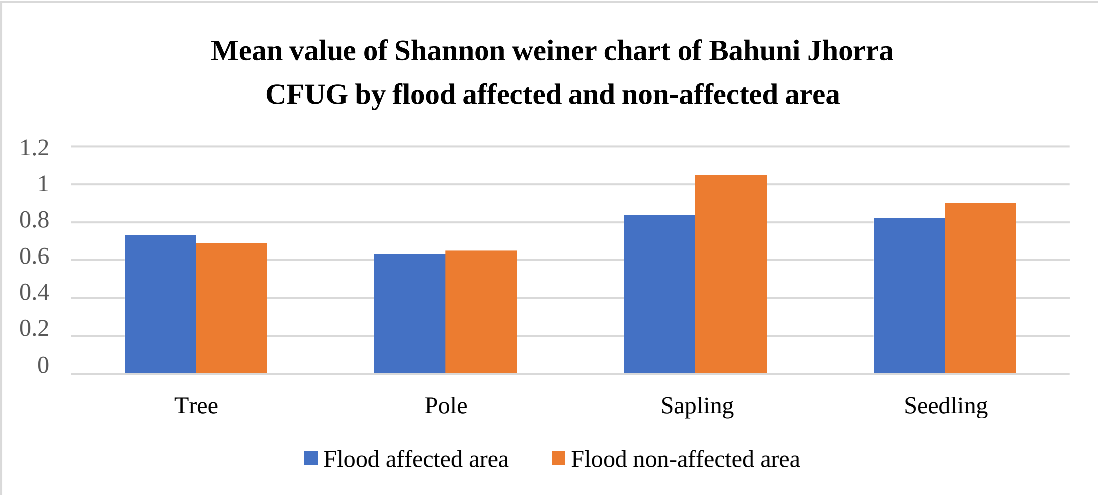

Figure 7. Mean value of Shannon weiner chart of Bahuni Jhorra CFUG by flood affected and non-affected area

(b) Descriptive analysis of evenness index

i. Marka Urra CF: the mean±SE value for tree was found to be 0.22±0.03 in flood non-affected areas and 0.22±0.02 in affected areas. The standard deviation (SD) inflood non-affected area and affected areas were found to be 0.13 and 0.12 respectively. For the pole, the mean±SE were found to be 0.29±0.02 and 0.28±0.01 in flood non-affected and affected areas. The SD were found to be 0.26 in both in non-affected and affected area. The proportion of *Shorea robusta* was higher in compare to other species. The mean±SE value for sapling was found to be 0.25±0.03 in flood non-affected areas and 0.26±0.07 in affected areas. The SD in flood non-affected area and affected areas were found to be 0.1 and 0.04 respectively. For the seedling, the highest mean±SE was found to be 0.34±0.01 inflood non-affected area and 0.23±0.05 in affected areas. The SD was found to be 0.01 and 0.028 in non-affected and affected area (Table 7, Fig. 8, 9 & 10).

ii. Kalikhola CF: the mean±SE value for tree was found to be 0.3±0.02 in flood non-affected areas and 0.3±0.01 in affected areas. The standard deviation (SD) in flood non-affected area and affected areas were found to be 0.04 and 0.05 respectively. For the pole, the mean±SE was found to be 0.29±0.01 in both flood non-affected and affected areas. The SD were found to be 0.02 and 0.03 in non-affected and affected areas. The mean±SE value for sapling was found to be 0.28±0.03 in flood non-affected areas and 0.23±0.04 in affected areas. The SD in flood non-affected area and affected areas were found to be 0.1 and 0.03 respectively. For the seedling, the highest mean±SE was found to be 0.30±0.04 inflood non-affected area and 0.23±0.06 in affected areas. The SD was found to be 0.09 and 0.041 in non-affected and affected areas (Table 7, Fig. 8, 9 & 10).

iii. Bahunijhora CF: the mean±SE value for tree was found to be 0.27±0.01 in flood both non-affected areas and affected areas. The standard deviation (SD) in flood non-affected area and affected areas were found to be 0.03 and 0.05 respectively. For the pole, the mean±SE was found to be 0.26±0.01 and 0.25± 0.01 in flood non-affected and affected areas. The SD were found to be 0.03 in both in non- affected and affected area. The proportion of *Shorea robusta* was higher incompare to other species. The mean±SE value for sapling was found to be0.28±0.02 in flood non-affected areas and 0.23±0.05 in affected areas. The SD in flood non-affected area and affected areas were found to be 0.1 and 0.03 respectively. For the seedling, the highest mean±SE was found to be 0.31±0.02 in flood non-affected area and 0.2±0.05 in affected areas. The SD was found to be 0.35 and 0.30 in non-affected and affected area (Table 7, Fig. 8, 9 & 10).

Table 7. Descriptive analysis of species evenness index in flood unaffected areas

Evenness Index																	
CFUG	Area	Tree				Pole				Sapling				Seedling			
		Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.
Marka Urra	Flood non affected area	0.22 ± 0.03	0.12	0.36	0.13	0.29 ± 0.02	0.15	0.33	0.06	0.27 ± 0.03	0.2	0.35	0.1	0.34 ± 0.01	0.3	0.36	0.01
	Flood affected area	0.22 ± 0.02	0.02	0.34	0.12	0.28 ± 0.01	0.15	0.33	0.6	0.26 ± 0.07	0.13	0.31	0.04	0.23 ± 0.05		0.297	0.028
Kalikhola	Flood non affected area	0.3 ± 0.02	0.21	0.36	0.04	0.29 ± 0.01	0.26	0.32	0.02	0.28 ± 0.03	0.2	0.35	0.1	0.30 ± 0.04	0.1	0.35	0.09
	Flood affected area	0.3 ± 0.01	0.21	0.34	0.05	0.29 ± 0.01	0.26	0.32	0.03	0.23 ± 0.04	0.16	0.27	0.03	0.23 ± 0.06	0.18	0.282	0.041
Bahuni Jhorra	Flood non affected area	0.27 ± 0.01	0.23	0.34	0.03	0.26 ± 0.01	0.21	0.30	0.03	0.28 ± 0.02	0.2	0.35	0.1	0.31 ± 0.02	0.2	0.35	0.05
	Flood affected area	0.27 ± 0.01	0.23	0.34	0.05	0.25 ± 0.01	0.21	0.30	0.03	0.23 ± 0.05	0.18	0.30	0.03	0.2 ± 0.05	0.14	0.305	0.046

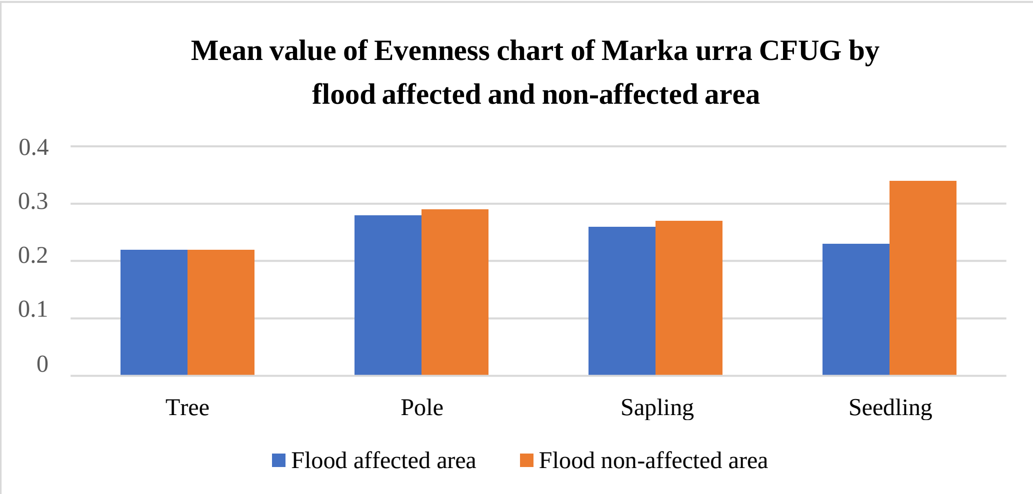

Figure 8. Mean value of Evenness chart of Marka urra CFUG by flood affected and non-affected area

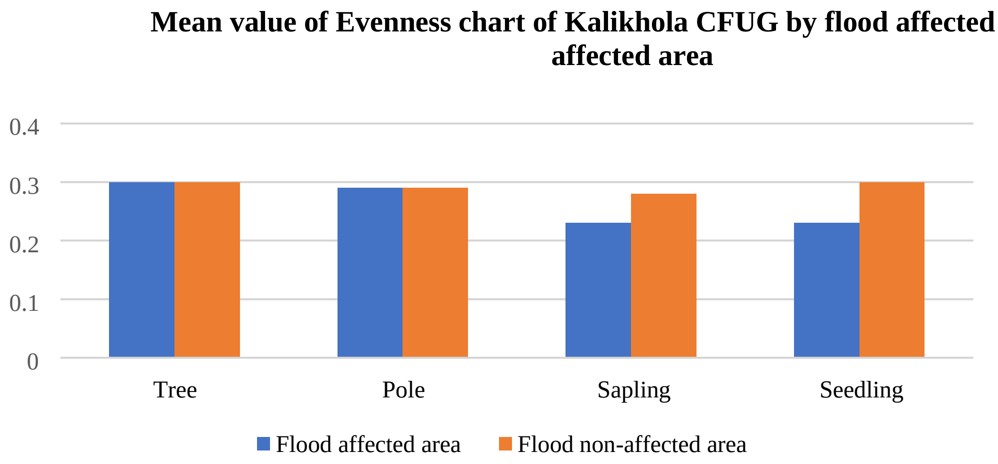

Figure 9. Mean value of Evenness chart of Kalikhola CFUG by flood affected and non-affected area

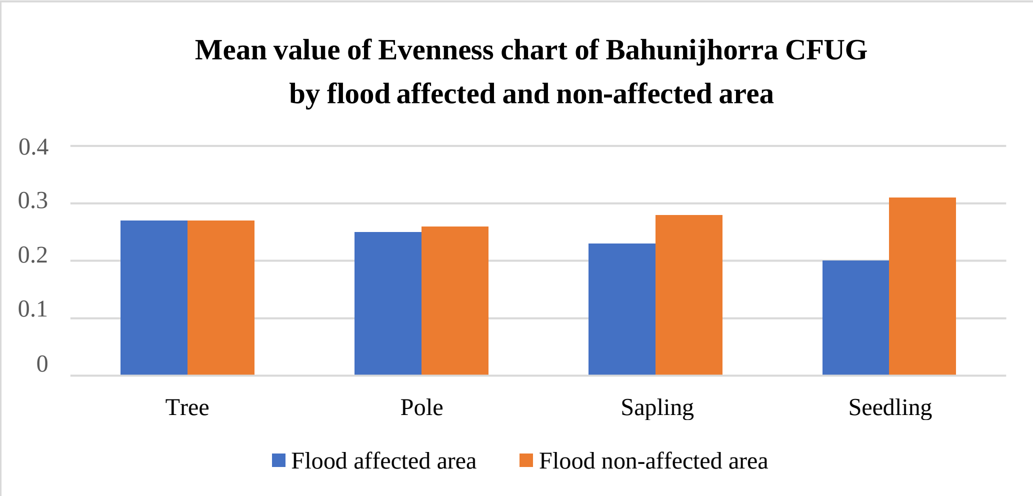

Figure 10. Mean value of Evenness chart of Bahunijhorra CFUG by flood affected and non-affected area

(c) Descriptive analysis of richness index

i. Marka Urra CF: the mean±SE value for tree was found to be 0.88±0.42 in flood affected areas and 2.9±0.21 in non-affected areas. The standard deviation (SD) in flood affected area and non-affected areas were found to be 1 and 0.42 respectively. For the pole, the mean±SE was found to be 2.57±0.36 and 2.41± 0.22 in flood affected and non-affected areas. The SD were found to be 0.79 and 0.98 in affected and non-affected area. The mean±SE value for sapling was found to be 2.25±0.25 in flood affected areas and 4.41±0.32 in non-affected areas. The SD in flood affected area and non- affected areas were found to be 0.5 and 1.71 respectively. For the seedling, the highest mean±SE was found to be 3.5±0.29 in flood affected area and 4.67±0.32 in non-affected areas. The SD was found to be 0.58 and 1.41 in affected and non-affected area (Table 8, Fig. 11, 12 & 13).

ii. Kalikhola CF: the mean±SE value for tree was found to be 2.5±0.26 in flood affected areas and 2.38±0.18 in non-affected areas. The SD in flood affected area and non-affected areas were found to be 0.65 and 0.76 respectively. For the pole, the mean±SE was found to be 3±0.37 in flood affected area and 2.75±0.27 in unaffected area. The SD was found to be 0.97 and 1 in affected and non-affected area. The mean±SE value for sapling was found to be 2.42±0.20 in flood affected areas and 4.64±0.29 in non-affected areas. The SD in flood affected area and non-affected areas were found to be 0.5 and 1.40 respectively. For the seedling, the mean±SE value was found to be 2.33±0.21 in flood affected area, in non-affected area the value .4.32±0.23 were found. The SD were found to be 0.52 and 1.09 in affected and non- affected area respectively (Table 8, Fig. 11, 12 & 13).

iii. Bahunijhora CF: the mean±SE value for tree was found to 2.69±0.17 in floodaffected areas and 2.55±0.13 in non-affected areas. The SD in flood affected area and non-affected areas was found to be 0.60 and 0.63 for both sites respectively. For the pole, 2.4±0.24 in flood affected area and 2.6±0.16 in unaffected area. The SD were found to be 0.52 and 0.55 affected and unaffected area. The mean±SE value for sapling was found to be 2.5±0.20 in flood affected areas and the value was found to be 4.5±0.23 in unaffected area. The SD in flood affected area and non-affected areas was found to be 0.5 and 1.20 in both sites respectively. For the seedling, the mean±SE value was found to be 2.67±0.21 in flood affected area, in non-affected 4.46±0.13 was found. The SD were found to be 0.52 and 0.22 in affected and non-affected area respectively (Table 8, Fig. 11, 12 & 13).

Table 8. Descriptive analysis of species richness index in flood affected areas

Species Richness Index																	
CFUG	Area	Tree				Pole				Sapling				Seedling			
		Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.	Mean ± SE	Min	Max	S.D.
Marka Urra	Flood affected area	2.88 ± 0.42	2.00	6.00	1.00	2.57 ± 0.36	2.00	4.00	0.79	2.25 ± 0.25	2	3	0.5	3.5 ± 0.29	3	4	0.58
	Flood non Affected area	2.9 ± 0.21	2.00	6.00	0.42	2.41 ± 0.22	2.00	4.00	0.98	4.41 ± 0.32	2.00	8.00	1.71	4.76 ± 0.32	2.00	7	1.418
Kalikhola	Flood affected area	2.5 ± 0.26	2.00	4.00	0.65	3 ± 0.37	2.00	5.00	0.97	2.42 ± 0.20	2	3	0.5	2.33 ± 0.21	2	3	0.52
	Flood non Affected area	2.38 ± 0.18	2.00	4.00	0.76	2.75 ± 0.27	2.00	5.00	1.00	4.64 ± 0.29	3.00	8.00	1.40	4.32 ± 0.23	2.00	5	1.095
BahuniJhorra	Flood affected area	2.69 ± 0.17	2.00	4.00	0.60	2.4 ± 0.244	2.00	3.00	0.52	2.5 ± 0.20	2	3	0.5	2.67 ±0.21	2	3	0.52
	Flood non Affected area	2.55 ± 0.13	2.00	4.00	0.63	2.6 ± 0.16	2.00	3.00	0.55	4.5 ± 0.23	2.00	6.00	1.20	4.46 ± 0.13	4.00	6	0.224

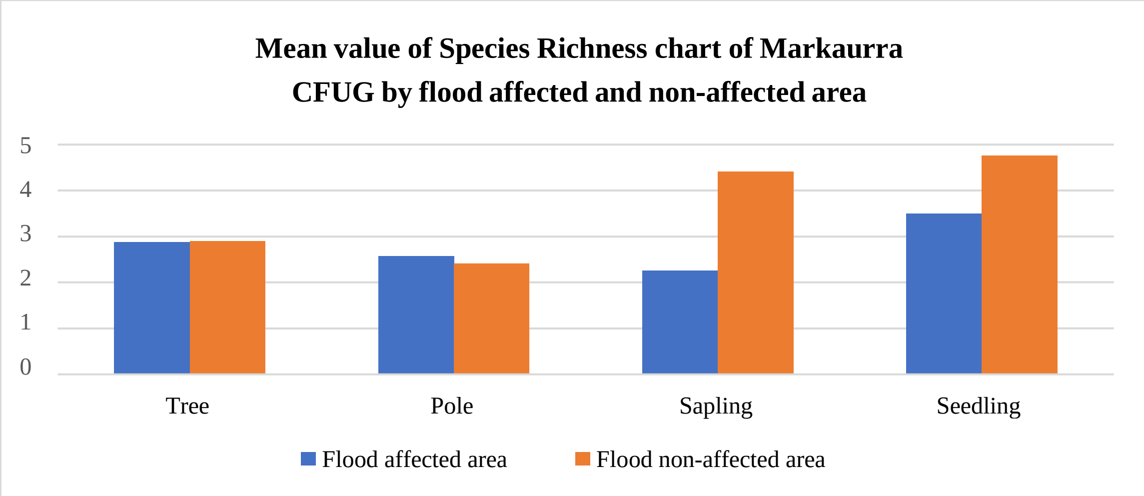

Figure 11. Mean value of Species Richness chart of Markaurra CFUG by flood-affected and non-affected area

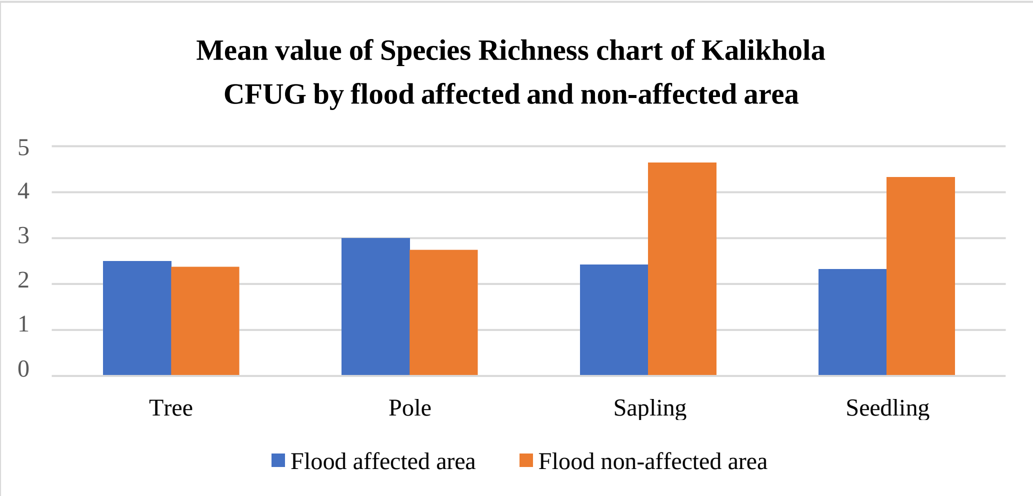

Figure 12. Mean value of Species Richness chart of Kalikhola CFUG by flood affected and non-affected area

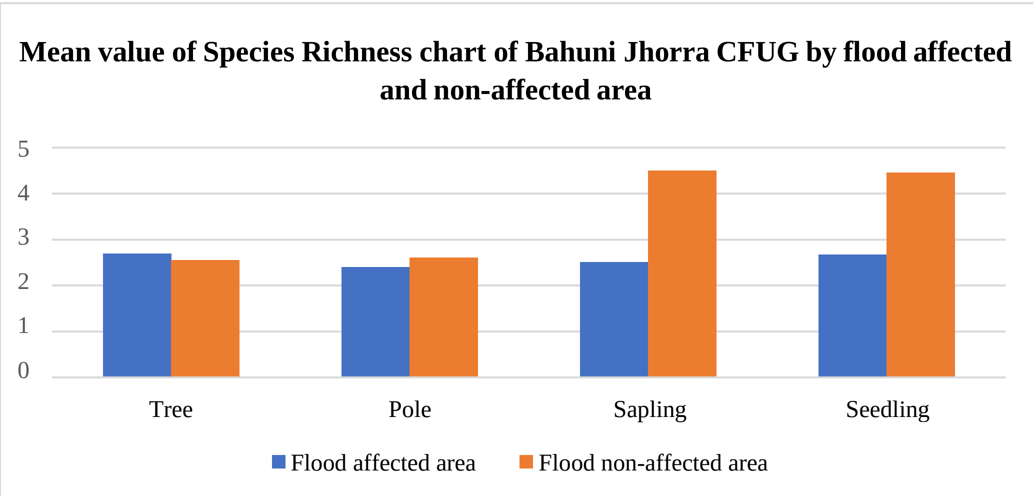

Figure 13. Mean value of Species Richness chart of Bahuni Jhorra CFUG by flood affected and non-affected area

Importance value index of tree, pole, saplings and seedlings

a) The importance value index of tree species in community forest

The IVI of tree species in three different community forest was compared. The *Shorea robusta* has the highest relative frequency at Kalikhola CF with a value of 58.33. And the lowest value of relative frequency was found at Bahunijhora CF for the *Shorea robusta* with a value of 40.68. Similarly, the highest relative density, dominance, and IVI were found to be 83.08, 90.28, and 218.14 respectively for *Shorea robusta* in Marka Urra CF. *Phyllanthus emblica* species has the lowest relative frequency, density, dominance, and IVI was found 1.49,0.50, 0.10 and 2.09 respectively in Marka Urra CF. Other tree species *Albizia lebbeck* was observed in the Kalikhola CF and *Quercus leucotrichophora*, *Terminalia chebula*, and *Dracontomelon dao* were in Bahunijhora CF (Table 9).

Table 9. The importance value index of pole species in community forest

	Marka Urra				Kalikhola				Bahunijhora			
Species	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**
Shorea robusta	44.78	83.08	90.28	218.14	58.33	79.37	74.35	212.05	40.68	66.67	55.53	162.88
Terminalia bellirica	7.46	2.99	1.79	12.24	4.17	1.59	3.30	9.06	10.17	7.69	5.55	23.41
Eucalyptus	11.94	4.48	2.23	18.64	6.25	3.17	3.68	13.11	8.47	6.41	3.76	18.64
Syzygiium cumini	11.94	4.48	1.52	17.94	6.25	6.35	3.27	15.87	6.78	7.69	6.19	20.67
Cleistocalyx operculata	14.93	6.47	2.31	23.71	14.58	8.73	8.24	31.55	8.47	10.26	7.60	26.33
Magnifera indica	7.46	2.99	1.77	12.21	8.33	3.97	6.38	18.69	8.47	7.69	9.01	25.18
Phyllanthus emblica	1.49	0.50	0.10	2.09								
Albizia lebbeck					2.08	0.79	0.76	3.64				
Dracontomelon dao									5.08	3.85	3.26	12.19
Terminalia chebula									5.08	6.41	6.40	17.89
Quercus leucotrichophora									6.78	6.41	2.70	15.89

(b) The importance value index of pole species in community forest

The IVI of tree species in three different community forest was compared. The *Shorea robusta* has the highest relative frequency, relativedensity, dominance, and IVI were found to be 60.48, 86.03, 85.55 and 232.06 respectively at Marka Urra CF. And the lowest value of relative frequency, relative density, dominance, and IVI were found to be 2.13, 0.71, 0.24 and 3.08 respectively for *Albizia lebbeck* in Kalikhola CF. The pole species *Albizia procera* was only in Kalikhola CF (Table 10).

Table 10. The importance value index of pole species in community forest

	Marka Urra				Kalikhola				Bahunijhora			
Species	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**
Shorea robusta	60.48	86.03	85.55	232.06	55.32	82.14	83.21	220.68	57.78	76.84	81.31	215.93
Cleistocalyx operculata	10.80	4.41	5.27	20.48	17.02	8.57	7.67	33.27	6.67	3.16	2.94	12.77
Syzygiium cumini	15.12	5.15	2.73	23.00	14.89	5.00	4.56	24.45	8.89	5.26	4.05	18.20
Dracontomelon dao	4.32	1.47	5.08	10.87	2.13	0.71	1.44	4.28	2.22	1.05	1.47	4.75
Eucalyptus	4.32	1.47	1.17	6.96	4.26	1.43	1.44	7.12	2.22	2.11	1.47	5.80
Terminalia bellirica	4.97	1.47	0.20	6.63	2.13	0.71	0.48	3.32	2.22	1.05	0.29	3.57
Quercus leucotrichophora					0.00	0.00	0.00	0.00	4.44	3.16	1.84	9.44
Albizia lebbeck					2.13	0.71	0.96	3.80	2.22	1.05	1.10	4.38
Albizia procera					2.13	0.71	0.24	3.08				

(d) The importance value index of sapling species in community forest

The IVI of tree species in three different community forest was compared. The *Shorea robusta* has the highest relative IVI was found to be 44.24 in Kalikhola CF. And the lowest value of IVI was found 0.33 for *Eucalyptus* in Kalikhola CF.

Table 11. The importance value index of saplings species in community forest

	Marka Urra				Kalikhola				Bahunijhora			
Species	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**	**Relative Frequency**	**Relative Density**	**Abundance**	**IVI**
Artemisia vulgaris	1.82	1.54	1.54	4.90	1.61	1.82	1.82	5.25	3.68	4.51	4.51	12.69
Shorea robusta	4.20	16.26	14.46	34.92	20.16	20.52	3.56	44.24	13.24	12.23	12.23	37.70
Phyllanthus emblica	0.91	0.66	0.66	2.23	3.23	2.34	2.34	7.90	8.09	7.30	7.30	22.68
Melastoma malabathrica	6.39	4.40	4.40	15.18	5.65	4.68	4.68	15.00	0.74	0.86	0.86	2.45
Vachellia nilotica	4.56	0.44	0.44	5.44	1.61	2.08	2.08	5.77	2.21	2.15	2.15	6.50
Phyllanthus emblica	7.30	7.47	7.47	22.24	2.42	1.82	1.82	6.06	2.21	3.00	3.00	8.21
Eupatorium cannabium Linn	1.82	0.66	0.66	3.14	2.42	2.86	2.86	8.13	0.74	0.86	0.86	2.45
Trema orientalis	7.30	6.15	6.15	19.61	3.23	2.86	2.86	8.94	4.41	4.29	4.29	13.00
Syzygiium cumini	1.82	1.98	1.98	5.78	4.84	5.45	5.45	15.75	5.88	5.79	5.79	17.47
Cleistocalyx operculata	5.47	5.27	5.27	16.02	6.45	7.79	7.79	22.04	5.15	4.51	4.51	14.16
Walichiana thistle	14.60	14.29	14.29	43.17	8.06	10.39	10.39	28.84	8.82	8.80	8.80	26.42
Imperata cylindrica	1.82	1.98	1.98	5.78	0.81	0.78	0.78	2.36				
Bamboo spp.	5.47	5.93	5.93	17.34					0.74	1.07	1.07	2.88
Dalbergia sissoo	1.82	1.32	1.32	4.46	1.61	2.08	2.08	5.77				
Albizia lebbeck	0.91	1.32	1.32	3.55					2.21	1.93	1.93	6.07
Lagerstroemia speciosa	1.82	1.76	1.76	5.34					0.74	0.86	0.86	2.45
Pogostemon benghalensis	0.91	0.66	0.66	2.23					0.74	0.64	0.64	2.02
Thysanolaena maxima	0.91	0.88	0.88	2.67								
Dracontomelon dao	0.91	0.44	0.44	1.79	0.81	0.52	0.52	1.85				
Sapium insigne					1.61	1.56	1.56	4.73	2.94	3.00	3.00	8.95
Himalayacalamus asper					0.81	1.30	1.30	3.40				
Asteraceae					0.81	1.04	1.04	2.88				
Schleichera oleosa					5.65	3.12	3.12	11.88				
Magnifera indica					0.81	0.52	0.52	1.85	1.47	1.72	1.72	4.90

Eucalyptus spp.					0.81	0.26	0.26	1.33	1.47	1.50	1.50	4.47
Artemisia vulgaris					0.81	0.52	0.52	1.85	1.47	0.86	0.86	3.19
Busseola fusca					0.81	0.26	0.26	1.33				
Acorus calamus									2.21	1.50	2.05	5.76
Tinospora cordifolia									0.74	0.86	0.86	2.45
Pterocarpus marsupium									1.47	1.07	1.07	3.62
Schleichera oleosa									5.88	5.58	5.58	17.04
Termenalia elliptica									0.74	0.64	0.64	2.02
Careya arborea									0.74	0.64	0.64	2.02
Bamboo spp.									0.74	1.07	1.07	2.88
Terminalia chebula									2.21	2.36	2.36	6.93
Terminalia bellirica									0.74	0.64	0.64	2.02
Albizia procera									2.21	1.93	1.93	6.07

The relative frequency of *Imperata cylindrica* was highest in Marka Urra CF with a value 11.27 and lowest in Kalikhola with a value of different species such as *Millettia extensa*, *Phyllanthus emblica*, *Syzygium cumini*, *Himalayacalamus asper*, *Ageratum conyzoides* was 0.70. Marka Urra CF had the highest IVI value for *Imperata cylindrica* 28.16, followed by *Shorea robusta* from Kalikhola CF 22.77. Kalikhola CF had the lowest IVI value for *Bidens pilosa* and *Elusine indica* was 0.98. The highest value of *Imperata cylindrica*of relative density was found 12.30 in Kalikhola CF and lowest value ofrelative density for *Bidens pilosa* was of 0.23 from Kalikhola CF.

Table 12. The importance value index of saplings species in community forest

Species	Marka Urra				Kalikhola				Bahunijhora			
	Relative Frequency	Relative Density	Abundance (Relative Abundance)	IVI	Relative Frequency	Relative Density	Abundance (Relative Abundance)	IVI	Relative Frequency	Relative Density	Abundance (Relative Abundance)	IVI
Ageratum conyzoides	2.11	2.36	4.69	9.16	0.75	0.92	0.52	1.67	0.75	0.52	2.12	3.39
Argemon mexicana	10.56	10.47	4.17	25.2	6.72	10.83	2.34	17.55	5.26	5.21	3.03	13.5
Artemisia vulgaris	2.11	2.36	4.69	9.16	1.49	1.61	0.52	3.11	3.76	5.21	4.24	13.21
Bidens pilosa	4.23	3.93	3.91	12.06	0.75	0.23	1.82	0.98				
Cinnamomum camphora	2.11	2.62	5.21	9.94	3.73	2.76	2.86	6.5	6.02	4.17	2.12	12.3
Eulaliopsis binata	2.82	2.88	4.3	9.99	0.75	0.23		0.98				
Eupatorium cannabium Linn	4.23	4.71	4.69	13.63	2.99	0.92	0.26	3.91	3.76	4.69	3.82	12.26
Imperata cylindrica	11.27	12.3	4.59	28.16	5.97	7.37	4.68	13.34	6.02	7.55	3.84	17.41
Indigofera hetarantha	0.7	0.26	1.56	2.53	1.49	0.92	0.52	2.41	0.75	0.52	2.12	3.39
Lyonia ovalicolia	2.11	3.14	6.25	11.5	2.99	2.3	7.79	5.29	0.75	0.52	2.12	3.39
Millettia extensa	0.7	0.52	3.13	4.35	0.75	0.46	0.78	1.21				
Pogostemon benghalensis	1.41	1.83	5.47	8.71	2.99	3.69	1.3	6.67				
Shorea robusta	8.45	10.21	5.08	23.74	11.94	10.83	2.08	22.77	9.02	7.29	2.47	18.79
Syzygium cumini	0.7	1.57	9.38	11.65	2.99	3.46	2.86	6.44	2.26	1.56	2.12	5.94
Syzynium operculata	8.45	1.57	0.78	10.8	1.49	1.38	2.08	2.88	1.5	1.04	2.12	4.67
Thysanolena maxima	0.7	0.52	3.13	4.35	3.73	3.69	1.56	7.42	5.26	6.77	3.94	15.97
Phyllanthus emblica	0.7	0.26	1.56	2.53					5.26	5.21	3.03	13.5
Himalayacalamus asper	0.7	0.26	1.56	2.53								
Albizia lebbeck					1.49	1.38	1.04	2.88	3.01	1.56	1.59	6.16
Bambusoieae					0.75	0.92	5.45	1.67	0.75	0.52	2.12	3.39
Dalbergia sissoo					0.75	1.61		2.36				

Eupatorium cannabium Linn					3.73	3.46	10.39	7.19				
Schleichera oleosa					9.7	6.45	3.56	16.15	7.52	5.99	2.44	15.95
Terminalia bellirica					0.75	0.46	3.12	1.21				
Terminalia elliptica					0.75	0.92	0.26	1.67				
Cinnamomum tamala									1.5	1.3	2.65	5.46
Elusine indica									2.26	2.08	2.83	7.17

Impacts of flood on social features and nature-based solution

Table 13. Losses and damages due to flood in Markaurra CFUG

Year	Losses and damages due to flood in Markaurra CF								Remarks
	Human	Livestock	Forest (%)	Agricultural Land (%)	Hospitals	Schools	Telephone Accessories	Buildings	
2009	1	5	20	46	Partially Damaged (No exact losses)	Partially Damaged (No exact losses)	1	2	
2010	-	-	22	39			-	1	
2011	-	-	18	36			-	-	
2012	-	2	14	28			1	-	
2013	-	-	16	41			-	-	
2014	-	-	22	38			-	2	
2015	-	1	15	45			-	-	
2016	-	-	14	40			-	-	
2017	1	-	21	35			-	-	
2018	-	-	24	32			-	-	
2019	-	-	25	46			-	1	
2020	-	3	22	37			-	-	
2021	-	2	21	39			-	-	

Table 14. Losses due to flood in Kalikhola CFUG

Year	Losses due to flood in Kalikhola CF								Remarks
	Human	Livestock	Forest (%)	Agricultural Land (%)	Hospitals	Schools	Telephone Accessories	Buildings	
2009	-	-	15	29	-	-	-	-	
2010	-	3	12	35	-	1	-	-	
2011	-	1	18	24	-	-	-	-	
2012	-	-	23	31	-	-	-	-	
2013	1	-	25	39	-	-	-	2	
2014	-	-	24	38	-	-	-	-	

2015	-	5	27	29	1	-	1	-	
2016	-	-	26	35	-	-	-	-	
2017	-	2	21	38	-	-	-	1	
2018	-	3	29	32	-	-	-	-	
2019	1	-	26	36	-	-	1	-	
2020	-	5	18	39	-	-	-	-	
2021	-	2	17	36	-	-	-	-	

Table 15. Losses due to flood in Bahunijhorra CFUG.

Year	Losses due to flood in Bahunijhorra CF								Remarks
	Human	Livestock	Forest (%)	Agricultural Land (%)	Hospitals	Schools	Telephone Accessories	Buildings	
2009	-	2	16	28	-	-	-	-	
2010	-	-	15	31	-	-	-	-	
2011	-	1	18	36	-	1	-	-	
2012	-	-	22	38	-	-	-	-	
2013	-	1	17	34	-	-	-	1	
2014	-	-	21	35	-	-	-	-	
2015	-	-	23	39	-	-	-	-	
2016	-	-	15	40	-	-	-	-	
2017	-	-	18	42	-	-	-	2	
2018	1	-	20	35	-	-	-	-	
2019	-	2	26	41	-	-	-	-	
2020	-	-	24	38	-	-	-	-	
2021	-	4	21	45	-	-	-	-	

Though respondents do not recall exact figure of damages caused to houses, animal sheds, standing crops and employment and income opportunities, these factors produce immediate stress to livelihood as these have direct impact on wellbeing. The damage caused to agricultural land has implication to loss in the productive asset on one hand and increase in the expenditure of time, energy and financial resources in the reclamation of the damaged land on the other. Health risks resulting from floodingand inundation and consequently increases in the medical expenditure for treatment and cure brings additional burden to the distressed livelihood at the time of flooding. With regards to the study area, the damage caused to the agricultural land has been through stream bank erosion and stream channel entering into the cultivated area and deposition of sand and coarse aggregates in the agricultural lands, thus rendering the land unsuitable for crop cultivation for several years. Considering that agricultural lands and houses are the most important livelihood assets for the people, the process of reclamation and reconstruction begins right after the passage of the damaging floodevents. The households try mobilizing resources from internal and external sources to build a house to meet the shelter needs of family members.

The people first concentrate their time and energy on those lands that can be repaired to begin with the cultivation of crops in the forthcoming crop season. They turn their focus on reclaiming more severely damaged lands only after the less severely damaged lands have been reclaimed. The land damaged more severely due to gully formation or river channel entering into the crop land or due to deposition of thick sand and gravel takes longer time and investment to reclaim. People resort to a systematic approach of crop rotation, biomass and organic matter management to restore the soil fertility in the land damaged by deposition of coarse sediments. The damage to the standing crop was revealed to be resulting from prolonged duration of inundation of the crops and also mechanical damages caused to the crop stand due to high velocity of flowing water. The farmers at the four locations were found to have strong perception of losses caused to the standing crops, resulting from different durations of flooding. The respondents at all the four locations invariably revealedthat flooding and inundation of rice for a duration less than 5 days does not cause any yield loss but when the duration of inundation exceeds two weeks, the losses causedto the productivity of the crops becomes very large.

Three community forest user groups, including Marka Urra, Kalikhola, and Bahunijhora, were asked about the extent, magnitude and trend of flood events. In a Marka Urra CF, 15% of the respondent said that they observed a similar trend of the flood as in previous years before the implementation of NBS. 75% of the respondents have observed an increasing trend of flooding events and 10% of the respondent observed decreasing trend of flooding events in comparison to previous years. Likewise, in the Kalikhola CF, 25% of the respondents experienced a similar kind of flooding event trend as in previous years, 60 % of the respondents observed an increasing flooding trend, and 15% observed decreasing flooding events incomparison to the years before the implementation of nature-based solutions. In the Bhunijhora CF, out of the total respondents, 25% of respondents found similar kind offlooding events, 66% said they observed more flooding events in comparison to the previous years. Whereas 12% of the respondents observed fewer flooding events when compare to previous years. Though, the extent and magnitude of flood events is in increasing, the loss and damage caused by the floods in infrastructures, lives, agriculture, forestry and other sectors have been decreasing.

Table 16. People perception about Flood magnitude during past 10 years and now

CFUG	Flood Magnitude		
	Same (%)	More (%)	Less (%)
Marka Urra	15	75	10
Kalikhola	25	60	15
Bahunijhora	25	66	14

Nature-based flood mitigation strategies

In response to frequent flooding, the Marka Urra CFUG, Kalikhola CFUG, and Bahunijhora CFUG have implemented various nature-based flood mitigation techniques. Community Development and Advocacy Nepal, a social organization specializing in forest and environmental initiatives, has constructed dykes, diversions, gabion walls, among other measures. Additionally, the organization has undertaken tree and hedge planting, along with the cultivation of seedlings and saplings to enhance soil quality. The installation of bamboo fences and bioengineered walls along riverbanks has proven to be an effective method in managing flood risks within the community forest area.

Table 17. Nature based flood mitigation strategies

S.N.	NBS Strategies	CFUG		
		Marka Urra CFUG	Kalikhola CFUG	Bahunijhora CFUG
1	**Dyke**	15	10	14
2	**Diversion**	14	14	16
3	**Improve Soil cover**	40	40	45
4	**Plant trees and hedges to improve soil quality**	45	48	47
5	**Bamboo fence / Bio- engineering**	50	48	45
7	**Gabions**	20	40	45
8	**Plantation of seedling and saplings**	60	65	70

Support received during the flood

Table 18. Institutional support from different organizations

Unit	Post Flood	Marka Urra			Kalikhola			Bahunijhora		
		Quantity	Monetary value in USD	Percentage of benefited group	Quantity	Monetary value in USD	Percentage of benefited group	Quantity	Monetary value in USD	Percentage of benefited group
Kg	**Pulses**	22	21.648	73.33	73.33	30.5	70	51	50.136	80
Packet	**Oil**	39	38.376	86.67	30	29.52	70	29	28.536	76.66
Packet	**Salt**	26	4.264	86.67	21	3.44	70	22	3.6	76.66

kg	**Rice flakes**	85	34.85	86.67	65	26.65	70	71	29.11	76.66
Box	**Noodles**	30	134.07	100	30	134.07	100	28	164.25	96.66
$	**Others**		1476	100		1476	100		1426.8	100
Total			1709.208			1700.18			1702.432	

During the flood, the municipality, in partnership with the Nepal Red Cross Society and various other organizations, extended aid to three community forest user groups. Immediate assistance totaling $1709.208, including rice, pulses, salt, oil, rice flakes, noodles, medicines, and other essentials, was provided to the residents of Marka Urra CF. Similarly, Kalikhola CFUGs received support materials valued at $1700.18, and Bahunijhora CFUGs received aid amounting to $1702.432. Throughout the flood, community schools remained closed, posing challenges in carrying out daily activities. Post-flood, farmers within the CFUG reported a reduction in agricultural yield.

Table 19. Immediate support received during flood

During Flood	**CFUG**		
	Marka Urra CFUG	**Kalikhola CFUG**	**Bahunijhora CFUG**
Schools Remain Closed	100%	100%	100%
Agricultural yield	4%	5%	4%

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Application of Nature Based Solution in Marka Urra CF

The Marka Urra CF spans across a total area of 471.32 hectares. Its adoption of nature-based strategies includes constructing dykes, diversions, dams, bioengineered walls, gabion walls, and planting various trees, poles, saplings, and seedlings. This approach has directly benefited over 90% of the population. The implementation of these nature-based solutions significantly reduced losses and damages to lives, infrastructure, forests, agriculture, and livestock. Similarly, the Kalikhola CF covers an area of 451.628 hectares. Within this CF, nature-based solutions encompass tree plantation, hedges, bamboo fencing, dykes, dams, and gabion walls. Likewise, the Bahunijhora CF occupies a total area of 286.76 hectares. The community forest in this area has implemented nature-based solutions such as tree and hedge plantation, bamboo fencing, dams, diversions, dykes, and gabion walls.

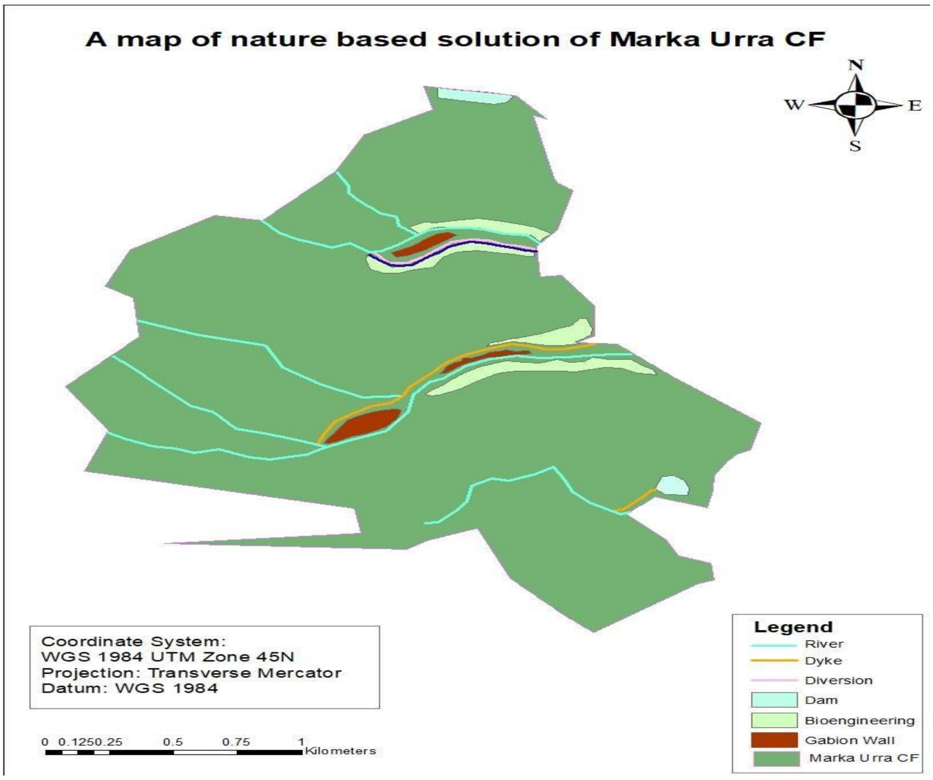

Figure 14. A map of nature-based solution of Marka Urra CF

Table 20. Attribute Table of Figure 14

Nature based solutions	Length (m) and area (m^2)
Dyke	1,554.18 m
Diversion	709.88 m
Dam	29,740.2 m^2
Bioengineering	140,840.08 m^2
Gabion Wall	221.63 m

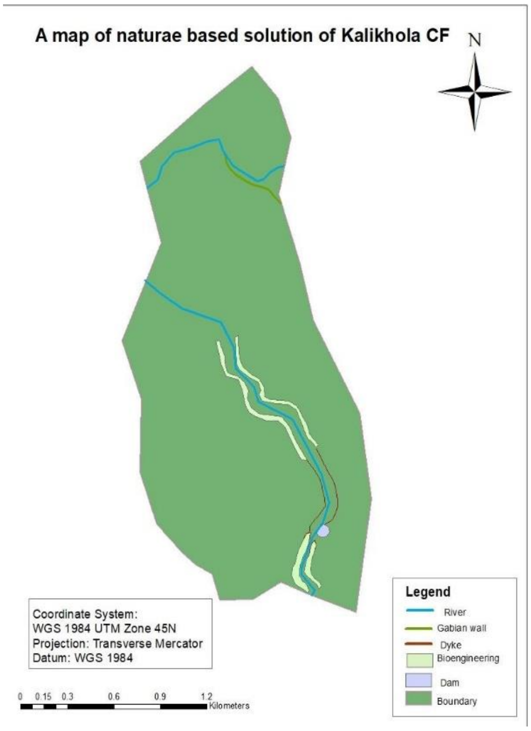

Figure 15. A map of nature-based solution of Kalikhola CF

Table 22.

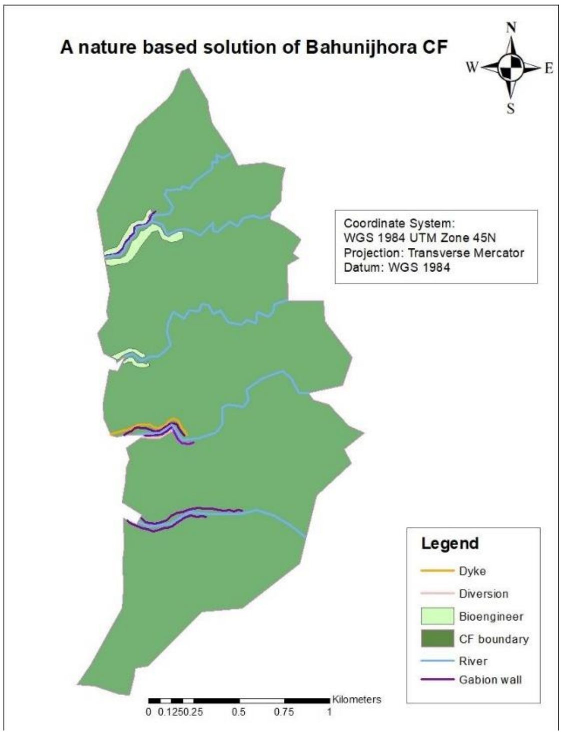

Figure 16. A map of nature-based solution of Bahunijhora CF

Table 21. Attribute Table of Figure 15

Nature based solutions	Length (m) and area (m2)
Dyke	499.10 m
Dam	4531.14 m^2
Bioengineering	25,206.5 m^2
Gabion Wall	1,398.72 m

Table 22. Attribute Table of figure 16

Nature based solutions	Length (m) and area (m2)
Dyke	502.46 m
Diversion	190.13 m
Bioengineering	40,224.48 m^2
Gabion Wall	2,178.39 m

Discussion

Variation in rainfall pattern

The Terai region experiences an annual rainfall ranging between 1,200 mm to 3,000 mm, characterized by intermittent showers and occasional cloudbursts. Nepal's river systems converge in the Terai plain at the base of the Churia and Siwalik ranges, serving as a vital water source for livelihoods in this region. Throughout the monsoon months spanning June to September, these rivers swell, leading to flooding and inundation in various Terai areas. Climate change, alongside alterations in rainfall patterns and intensity, has exacerbated the severity of flooding and inundation in the Terai, as noted in (Dakari & Ristani, 2013). Despite a gradual increase in rainfall patterns over the past 12 years with intermittent fluctuations, this study suggests minimal impacts, attributed to the implementation of nature-based solutions. These solutions play a crucial role in mitigating the adverse effects of disasters.

Impacts of flood on tree biodiversity

The examination of flood impacts on tree biodiversity revealed that mature trees and poles remain largely unaffected by floods, whereas saplings and seedlings experience notable effects. This disparity is reflected in the Shannon Wiener's values, indicating nearly equal impacts in affected and non-affected areas among mature trees and poles. Flood-unaffected sites exhibited higher levels of tree diversity, species richness, and evenness compared to flood-affected areas. The reduced diversity in flood-affected regions may stem from topsoil removal, leading to the loss of crucial soil nutrients. Floods impede the growth and diversification of newly established plants, slowing down succession and resulting in lower plant species diversity and Importance Value Index (IVI) in saplings and seedlings. These findings were corroborated by (Wusheng et al., 2015), underscoring how soil loss in affected areas diminishes plant species diversity and IVI. Inverse correlations were observed between species diversity and both erosion and flooding. The average Simpson diversity index stood at 0.95, while the average Shannon diversity index was 2.71. Flood-affected areas exhibited lower Shannon and Simpson diversity compared to unaffected sites. Disturbed sites showed lower diversity (2.47), indicating higher disturbances, while control sites demonstrated higher diversity (2.95), suggesting lower disturbance levels. Specifically, at affected sites, Shannon diversity was 2.47, Simpson diversity was 0.94, species richness was 1.75, and evenness was 0.7, contrasting with higher values at unaffected sites (Shannon diversity: 2.95, Simpson diversity: 0.97, species richness: 2.02, and evenness: 0.72). These outcomes align with (Jiao et al., 2009), emphasizing higher Shannon diversity at control sites due to increased species diversity and natural invasion, contrasting with lower Shannon diversity at affected sites owing to diminished vegetation cover.

Similar conclusions were drawn by Uniyal et al. (2016) who found higher species numbers in less affected areas and lower numbers in more affected regions (Das et al., 2018). A substantial dissimilarity (77.02) between control and disturbed sites was noted, indicating distinct disturbance levels (Alfaro et al., 2009). The rehabilitation of degraded ecosystems relies significantly on vegetation restoration or nature-based solutions. Recovery post-disturbance indirectly influences flooding and soil erosion rates (Dar et al., 2018). Torok et al. (2010) highlighted the contribution of successfully cultivated grass species on degraded land to ecological restoration. Increased vegetation growth in flooded areas enhances soil aggregate stability (Dar et al., 2018). Notably, fewer seedlings and saplings were observed in non-affected areas.

Implementation of NBS in societal features

Nature-based solutions are increasingly pivotal in tackling the impacts of climate change, particularly in mitigating flood-related challenges. Measures like constructing dams, dykes, diversion channels, and implementing tree and bamboo planting have proven successful in reducing flood hazards. Despite a rise in the frequency of flood events, their severity has notably decreased, as observed in household surveys and FGDs. The adoption of nature-based solutions stands as an effective strategy for both flood risk management and the preservation of tree diversity. Within the study area, tree and hedge plantations, bamboo cultivation, bamboo fencing, bioengineering embankments, gabion walls, dams, dykes, and diversions emerged as some of the most widely embraced nature-based solutions. These interventions not only aid in managing flood risks but also contribute to bolstering biodiversity and enhancing the quality of soil, air, and water. Nature-based solutions offer a multifaceted approach to addressing climate change, promoting human well-being, and safeguarding the environment. Safeguarding biodiversity and investing in natural solutions are crucial endeavors, as they play a significant role in mitigating the adverse effects of climate change.

Conclusion

Examining the rainfall trend spanning 2009 to 2021 reveals a fluctuating yet overall increasing pattern. Concurrently, flooding events have become both more frequent and severe. Notably, impacts on various societal sectors such as infrastructure, buildings, schools, and hospitals have diminished. Agricultural losses and damages have also notably decreased. The implementation of nature-based solutions (NBS) in forested regions has shown promise in enhancing and safeguarding biodiversity. Comparative analyses between affected and unaffected biodiversity areas indicate lower diversity in affected sites, while flood-unaffected regions exhibit higher species richness, evenness, and diversity. Moreover, IVI values for saplings and seedlings are lower in affected areas. Overall, the utilization of diverse nature-based solutions has spurred vegetation growth and mitigated impacts. Numerous studies and research affirm that employing nature-based solutions remains the most effective approach to reducing natural calamities.

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