CAUSES, IMPACT AND MANAGEMENT OF TLAWNG RIVER FLOOD IN SAIRANG AND BAIRABI TOWNS, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

LALREMRUATI

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By

LALREMRUATI

CENTRE FOR DISASTER MANAGEMENT

NAME OF SUPERVISOR

Prof. LALDINPUIA

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Disaster Management of Mizoram University, Aizawl

CENTRE FOR DISASTER MANAGEMENT

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

MIZORAM UNIVERSITY

SUPERVISOR'S CERTIFICATE

This is to certify that **Lalremruati**, a Ph.D. scholar having MZU Registration No. **2109071** and Ph.D. Registration No. **MZU/Ph.D./1890 of 19.08.2021** has completed a thesis entitled **"Causes, Impact and Management of Tlawng River Flood in Sairang and Bairabi towns, Mizoram"** under my supervision and the same has been submitted to the Mizoram University, Aizawl, Mizoram, for the degree of Doctor of Philosophy.

To the best of our knowledge, this thesis as a whole has not been submitted earlier to any other institution for any degree.

(Prof. LALDINPUIA)

Supervisor

CENTRE FOR DISASTER MANAGEMENT

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

MIZORAM UNIVERSITY

DECLARATION

I, **Lalremruati**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the Degree of Doctor of Philosophy in Disaster Management.

(LALREMRUATI)

(Prof. BENJAMIN L. SAITLUANGA)
Head

(Prof. LALDINPUIA)
Supervisor

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(LALREMRUATI)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

Eqn. No.	Equations
3.1	$P = \frac{m}{N+1}$
3.2	$T = \frac{1}{P}$
3.3	$y = a.\ln(x) + b$
3.4	$X_T = X_M + K_{T^{\sigma}-1}$
3.5	$K_T = \left[\frac{Y_T = Y_n}{S_n}\right]$
3.6	$Y_T = -ln\left[ln\frac{T}{T-1}\right]$
3.7	K = (Obs – exp)/(1 – Exp)
3.8	$n' = \frac{n}{1 + \frac{z^2 \times \hat{p}\,(1-\hat{p})}{\varepsilon^2 N}}$
3.9	$FVI = \frac{E+S}{R}$
3.10	$SVI = f\left[\frac{FwChd + FwSrCtzn + FwPwds + FdScr + WtrScr + Sdis + EPD + ComProb + InsHC}{PrtDmT + EW}\right]$
3.11	$EVI = f\left[\frac{InCm + HsTyp + PerEvc + TemEvc + StgJob}{RecoTm + RlfBnfc}\right]$
3.12	$PVI = f\left[\frac{SlpAgle + Ele + SvrInd + PrtlInd}{PreDgSh + StrMtg}\right]$
3.13	$\text{EnVI} = f\left[\frac{Fldfq + Rain + Soil + Defr + Settlmt}{Forest}\right]$
3.14	$\text{OFVI} = \frac{\text{SVI} + \text{EVI} + \text{PVI} + \text{EnVI}}{4}$

LIST OF ABBREVATIONS

ADMR	Annual Daily Maximum Rainfall
CBDRM	Community-based disaster risk management
DGPS	Differential Global Positioning System
DM Act	Disaster Management Act
EVD	Extreme Value Distribution
FFA	Flood Frequency Analysis
FVI	Flood Vulnerability Index
GIS	Geographic Information System
IMD	Indian Meteorological Department
IPHS	Indian Public Health Standards
LISS-III	Linear Imaging Self-Scanning Sensor 3
NDMA	National Disaster Management Authority
NGO	Non-Governmental Organisation
PHC	Primary Health Centre
SWIC	State Water Informatics Centre
UN	United Nations
USD	United States Dollar
YMA	Young Mizo Association

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The emergence of disaster situations is historically attributable to the existence of mankind. The word ‘disaster’ is derived from a blend of two French words, ‘*des*’ and ‘*astre*’, which means bad or evil star. In ancient times, disaster was thought to be caused by an unfavourable alignment of a star or planet (Alcántara et al., 2022; Goel, 2006). Although the terminology related to disasters has changed over time, it is evident that some catastrophes lie beyond human influence (Harrison & Williams 2016). Global reports of disasters have increased their frequency and intensified the curse. However, to tackle this calamity, an attempt was made to mitigate the disaster risk from a different perspective using a different approach (Lindell, 2013). Irrespective of the techniques or methodology employed, all studies target the same goal: Disaster Management (Coppola, 2015).

The United Nations Office for Disaster Risk Reduction (UNDRR) defines disaster as (Bhandari et al., 2020) ‘a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.’ A disaster event usually arrives rapidly and unexpectedly, which demands a prompt, collaborative, and efficient response by stakeholders to meet the needs of victims, thereby providing a speedy recovery. The consequences of either natural or man-made disaster, can be profound and extensive, causing adversity to human lives, social, economic, environmental, health, and political aspects (NDMA, 2009; Okuyama & Santos, 2014). To address the global disaster risk, the Sendai Framework for Disaster Risk Reduction 2015-2030 outlines seven clear targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience and; (iv) Enhancing disaster preparedness for effective response, and to 'Build Back Better' in recovery, rehabilitation and reconstruction (UNDRR, 2015).

The Disaster Management Act, 2005 (DM Act 2005) defines Disaster Management as "a continuous and integrated process of planning, organising, coordinating and implementing measures which are necessary or expedient for— (i) prevention of danger or threat of any disaster; (ii) mitigation or reduction of risk of any disaster or its severity or consequences; (iii) capacity-building; (iv) preparedness to deal with any disaster; (v) prompt response to any threatening disaster situation or disaster; (vi) assessing the severity or magnitude of effects of any disaster;" Hence, Disaster Management encompassed all phases of the disaster management cycle: preparedness, prevention, response and recovery (López-Carresi et al., 2014).

The High Powered Committee (HPC) on Disaster was constituted in 1999 by the Government of India with a view to drawing a structured, all-encompassing, and holistic approach to disaster. (Pal & Shaw, 2018). As shown in Table 1.1, the HPC has identified disasters into five (5) types (World Bank, 2024).

Table 1.1 Disasters identified by High Powered Committee

I	WATER AND CLIMATE RELATED DISASTERS	Floods and Drainage Management, Cyclones, Tornadoes and Hurricanes, Hailstorm, Cloud Burst, Heat Wave and Cold Wave, Snow Avalanches, Droughts, Sea Erosion, Thunder and Lightning
II	GEOLOGICALLY RELATED DISASTERS	Landslides andMudflows, Earthquakes , Dam Failures/ Dam Bursts, Mine Fires
III	CHEMICAL, INDUSTRIAL AND NUCLEAR RELATED DISASTERS	Chemical and Industrial Disasters, Nuclear Disaster
IV	ACCIDENT RELATED DISASTERS	Forest Fires, Urban Fires, Mine Flooding, Oil Spill, Major Building Collapse, Serial Bomb Blasts , Festival related disasters, Electrical Disasters and Fires, Air, Road and Rail Accidents, Boat Capsizing, Village Fire.
V	BIOLOGICALLY RELATED DISASTERS	Biological Disasters and Epidemics, Pest Attacks, Cattle Epidemics, Food Poisoning

[Source: The report of High-Powered Committee on Disaster Management, 2011]

Floods are recurrent phenomena of the earth's hydrological system (NIDM, 2023), which either way based on its magnitude, has both positive and negative impacts (Erçetin & Sen, 2019) on the physical, social, economic, and environmental settings. Characterised by an overflow of water beyond the basin, submerging the dry surface area (WHO), it is the most alarming and devastating natural disaster in terms of frequency, intensity, and area coverage. Floods of various types, like riverine floods, flash floods, urban floods, Glacial lake outburst floods, and coastal floods (Schraven et al., 2020; UNISDR, 2017), are naturally the reactions of water bodies (WMO, 2024) behaving in accordance with meteorological and climatological conditions over a specific area. The stretch of inundation period depends upon various factors such as the size of the river catchment area, relief feature, amount and duration of precipitation, rate of infiltration, type of soil, etc. (Fischer, 2020). While floods propitiously provide fertile soil for farmers, which is suitable for agricultural practices, excessive floods could, on the contrary, be a serious threat.

The situations when an increase in water volume develops to be devastating, disrupt the normal life and activities of an individual or a society, it becomes a disaster (Singh, 2015). It is a paradox that flood is a natural disaster, since the global issues of climate change have vastly increased their occurrence, manifested through the hazard return period and severity. There is no doubt that river flooding is predominantly the response of the river to the intensity and amount of rainfall, cloudbursts, or rapid snow melt, where the capacity of river banks is inadequate to carry the deluge (BMTPC, 2010 & UNISDR, 2017). However, the human activities of modifying nature eloquently contribute to climate change, thus accelerating the frequency and magnitude of floods and other disasters (Bhattacharjee & Behera, 2017; Mohanty et al., 2020). The year 2023 was the hottest year with a 1.45 ± 0.12 °C increase in the average global mean near-surface temperature (Simard & Austin, 2010) during 1890 and 1990 (; WMO, 2024).

The consequences of the perilous change on Earth's climate are predicted to shoot up henceforth (Wang et al., 2023), which will eventually force more population to be exposed to several hazards. Global climate change has a huge adverse impact (McGee & Penning, 2022) on the pattern and distribution of rainfall (Sengar & Sengar, 2014). Owing to the variability, there is a huge diversity among places in the world, some regions receiving excessive rainfall while deficit becomes a threat to many other regions at the same time (IPCC, 2021). Regions of South Asia, South-East Asia, and the western Amazon experienced an increase in rainfall, escalating the susceptibility to flooding (Eccles et al., 2019).

The intensity and impact of flood hazard are largely accentuated by human actions within the river system (Yin et al. 2001). The human interventions that possibly aggravate the impacts of floods, such as an increase in population in the floodplain resulting in rapid urbanization, climate change, deforestation, etc., are estimated to increase the degree of vulnerability of the global population to 2 billion by 2050 (UNESCO, 2012). The proliferating greed of man, leading to encroachment of floodplains, along with climate change and unprecedented weather, has intensified the curse of flooding.

Floods have become the most disastrous and costliest calamity, disrupting an extensive area. Considering the total fatalities caused by different types of natural disasters, 70% deaths arise from water-related disasters. Floods and other water-related hazards showed a tremendous increase of 134% since 2000 (WMO, 2021). Out of the world's total geographical area, about 3.5% is covered by floodplains encasing 16.5% of the world's population (Singh, 2015). Between 1998- 2017 (Battersby, 2022), more than 2billion people globally were affected by flood hazard, where the economic losses amounted to $656 billion. Of all the disaster events in the world, 44% were flood disasters, and the economic loss from flood events contributes 31% of the total loss. At the current pace of socio-economic transformation and environment degradation, the global flood impact is expected to amount to $1triliion by 2030 unless profound mitigation is addressed (Ding & Wu, 2023).

Vulnerability to different types of hazards, India is highly prone to flooding. This is evident that out of the overall landmass, 40 million hectares (Oladokun et al., 2023) are prone to floods (NDMA, 2008; Petiwale, 2013). Consequently, it was reported that during the years 1953- 2010 (Pal & Shaw, 2018), different intensities of flood had affected 49.815Mha (Pal & Shaw, 2018; NITI Aayog, 2021). The diverse climatic conditions and topography result in susceptibility of varying magnitudes of floods in the sub-continent. The flood-prone region in India can be broadly divided into 4 regions: i) The Brahmaputra River Plains, ii) The Ganga River Plains, iii) The North-West River Plain, and iv) The Central India and Deccan Region (NDMP, 2013; BMTPC, 2010).

Every year, when monsoon arrives, the country experiences floods, causing widespread casualties and property damaged. In India, the average annual loss from disasters tunes up to 9.8 billion USD, where damage from floods alone accounts for

7.4 billion USD (UNISDR, 2015). Annually, on average, flood disasters claimed 1654 human lives, damaged 1.2 million houses, and monetary loss was reported to have reached around ₹ 5649 crores (NITI Aayog, 2021). Such huge losses for developing countries could hinder the socio-economic development process. Incessant monsoon rainfall, cloudburst, rapid snowmelt, riverbank erosion, etc., are the natural leading causes of floods in India. While anthropogenic factors such as deforestation, population growth, and rapid urbanization aggravate the intensity (Mohanty et *al.*, 2020).

To reduce the nation's susceptibility to multi- hazards, the Government of India is endeavouring to enact and implement various initiatives. The introduction of the Disaster Management Act in 2005 transformed India's disaster management framework, shifting emphasis from post-disaster relief to proactive mitigation. As mandated by the Disaster Management Act, 2005, the National Disaster Management Authority (NDMA), the Prime Minister-led apex body (Andharia, 2020), was created to set policies and create plans and guidelines for managing disasters (Singh, 2017). The Central Government, in collaboration with the State Government, several working groups, NGOs, and the community, collectively strives towards building a disaster-resilient India (NDMA, 2008).

Of all the river basins, the maximum number of floods was experienced in the Ganga and Brahmaputra River basins (Mohanty et al., 2020). The state of Mizoram, along with other north-eastern states, is confined to the Brahmaputra River Plains.

Situated in the north-east India, Mizoram is drained by numerous rivers and streams flowing in either north or south direction (Jain et al., 2007), conforming the north-south trending ridges (Pachuau, 1994). The river regime covers an area of 89.84sq.km in Mizoram, whereas the flood-prone area covers 37.25sq.km, i.e., 0.17% of the state area (DM&R, 2021).

Under the direct influence of the south-west monsoon, Mizoram receives an adequate amount of rainfall during the summer monsoon. Mizoram received an annual rainfall of 1693.5mm, and the heaviest rainfall was recorded in July (Agriculture Statistics, 2020). The heavy and prolonged rainfall during monsoon in the state of

Mizoram in India results in river floods of varying magnitude. Regardless of the amount, the continuous rainfall has long been the main culprit for several disasters in Mizoram.

The spatio-temporal variation of flood intensity was characterized by the altitude, relief feature, size of the basin, and catchment area of the river (Jain et al., 2007). However, the flood frequency has delineated an enormous alteration in the river of Mizoram. Consequently, the indigenous knowledge and perception of floods have been drastically changed, leaving the people, especially farmers, bemused.

Among the many rivers subjected to flooding in the state, floods of the Tlawng River and Khawthlangtuipui River have been a perpetual headline in the wake of the summer monsoon. The reason is that the curse eventually exceeds the coping capacity of the society. The Mizos (inhabitants of Mizoram) areas, being a close-knit society, have greatly accommodated the hardship in times of adversity through the exercise of communal labour. Be that as it may, with limited knowledge and resources, a suitable strategy to combat the risk of hazards can hardly be guaranteed. The mere cyclic operation of evacuation and re-establishment during and after every flooding contradicts the UN risk reduction strategies to ‘Build Back Better’. Thus, adopting, implementing, and executing flood management measures that encompass both structural and non-structural mitigation measures (Mirza et al., 2003) is an urgent and absolute necessity.

The recurrent prevalence of river floods has become one of the most destructive disasters in Mizoram. According to Disaster Management & Rehabilitation (DM & R), Government of Mizoram, during 2007- 2023 (Table 1.2), from 2007 to 2023, Mizoram experienced recurrent flood disasters with varying degrees of impact. In total, 1297 villages were affected during this period, with the highest number recorded in 2007, when floods hit 520 villages. Other years, such as 2017-2018 (186 villages), 2019-2020 (77 villages), and 2015-2016 (47 villages), also saw considerable village-level impacts. A total of 42 lives were lost across the 17 years, with the highest fatality years being 2009 and between 2016-2017, both recording 7 deaths. The number of injured individuals stood at 61, with spikes in years like 2008 and 2010.

Floods also caused significant damage to housing infrastructure. A total of 1432 houses were fully damaged, 567 were severely damaged, and 3587 were partially damaged. The worst year in terms of fully damaged houses was 2016–2017, when 910 homes were destroyed, followed by 2019–2020 with 345 fully damaged houses. The years 2022–2023 and 2010 also showed notable impacts, with 258 and 35 fully damaged houses, respectively. Severe and partial damages were consistently reported over the years, highlighting the vulnerability of the built environment to recurring flood events.

Agricultural land also suffered heavy losses. A total of 1812.44 hectares of land were damaged, with the largest impact occurring in 2021–2022, affecting 521.4 hectares. Other notable years include 2015–2016 and 2016–2017, with 242.12 and 235.97 hectares affected, respectively. The estimated crop loss during the entire period was valued at 212.745 lakh rupees. In financial terms, the cumulative loss from floods between 2007 and 2023 amounted to 17.46 crore rupees. The most economically damaging year was 2017–2018, with 5.83 crore in reported losses, followed by 2018–2019 with 3.81 crore and 2015–2016 with 1.39 crore.

In the recent years of 2023–2024 and 2024–2025, floods continued to affect the state. In 2023–2024, 2 lives were lost and 7 houses were reported as partially damaged. Around 147.53 hectares of agricultural land were affected, resulting in crop loss worth 13.17 lakh rupees and a total financial loss of 0.21 crore. In 2024–2025, floods impacted 39 villages, damaging 61 houses fully and 3 severely. Agricultural losses were also reported, with an estimated crop loss of 16.68 lakh rupees and an overall financial loss of 0.22 crore rupees. Notably, Cyclone Remal in May 2024 brought intense rainfall that triggered flooding in Mizoram. The town of Sairang experienced flood levels that surpassed the previous high flood mark recorded in 2017, signifying the increasing intensity and frequency of flood disasters in the region.

Table 1.2 Flood Data of Mizoram (2007- 2023)

Year	No. of Villages affected	No. of lives lost	No. of person injured	No. of House damaged			Agriculture damaged		Loss in terms of money (in crore)
				Fully	Severely	Partially	Area (in ha)	Estimated crop loss (in lakh)	
2007	520	2	8	5	200	1500	0.02	0.045	0.32
2008	53	2	25	5	1	150	200	14	0.67
2009	32	6	7	2	-	-	12	4.5	0.02
2010	68	7	14	35	14	25	25.19	9	0.27
2011-2012	32	6	7	7	3	-	12	4.5	0.02
2012-2013	2	-	-	3	3	2	12.25	2	0.15
2013-2014	-	-	-	-	-	-	-	-	-
2014-2015	2	-	-	3	3	2	12..25	2	0.15
2015-2016	47	-	-	-	-	114	242.12	1.89	1.39
2016-2017	47	7	-	910	41	551	235.97	13	0.86
2017-2018	186	3	-	89	14	597	129.4	55.7	5.83
2018-2019	59	4	-	17	29	179	0.085	0.29	3.81
2019- 2020	77	5	-	345	1	435	390	24.4	2.21
2020- 2021	41	-	-	-	-	1	12	44	0.39
2021- 2022	71	-	-	4	-	1	521.4	37.14	0.4
2022- 2023	60	-	-	7	258	30	20	0.28	0.97
TOTAL	**1297**	**42**	**61**	**1432**	**567**	**3587**	**1812.4**	**212.745**	**17.46**

[Source: Department of Disaster Management and Rehabilitation, Government of Mizoram]

1.2. STUDY AREA

Tlawng, the longest river, which measures about 186 kilometres in the state of Mizoram in India, originates from Zopuitlang near Lunglei town in the southern part of the state. Flowing in a northward direction, it forms part of the Barak basin, where numerous tributaries laterally confluence along its course. With the rolling of an undulated hill, the basin is characterised by steep slopes at the upper course and gentle slopes towards the lower course. After flowing through the 5 districts of Mizoram, namely- Lunglei, Serchhip, Aizawl, Mamit, and Kolasib, it finally drained into the River Barak in Cachar district of Assam, where it was renowned by the name ‘Dhaleswari’ river.

As present in Figure 1.1, the study area comprises two towns within the Tlawng river basin, namely Sairang and Bairabi towns, located in the district of Aizawl and Kolasib, respectively.

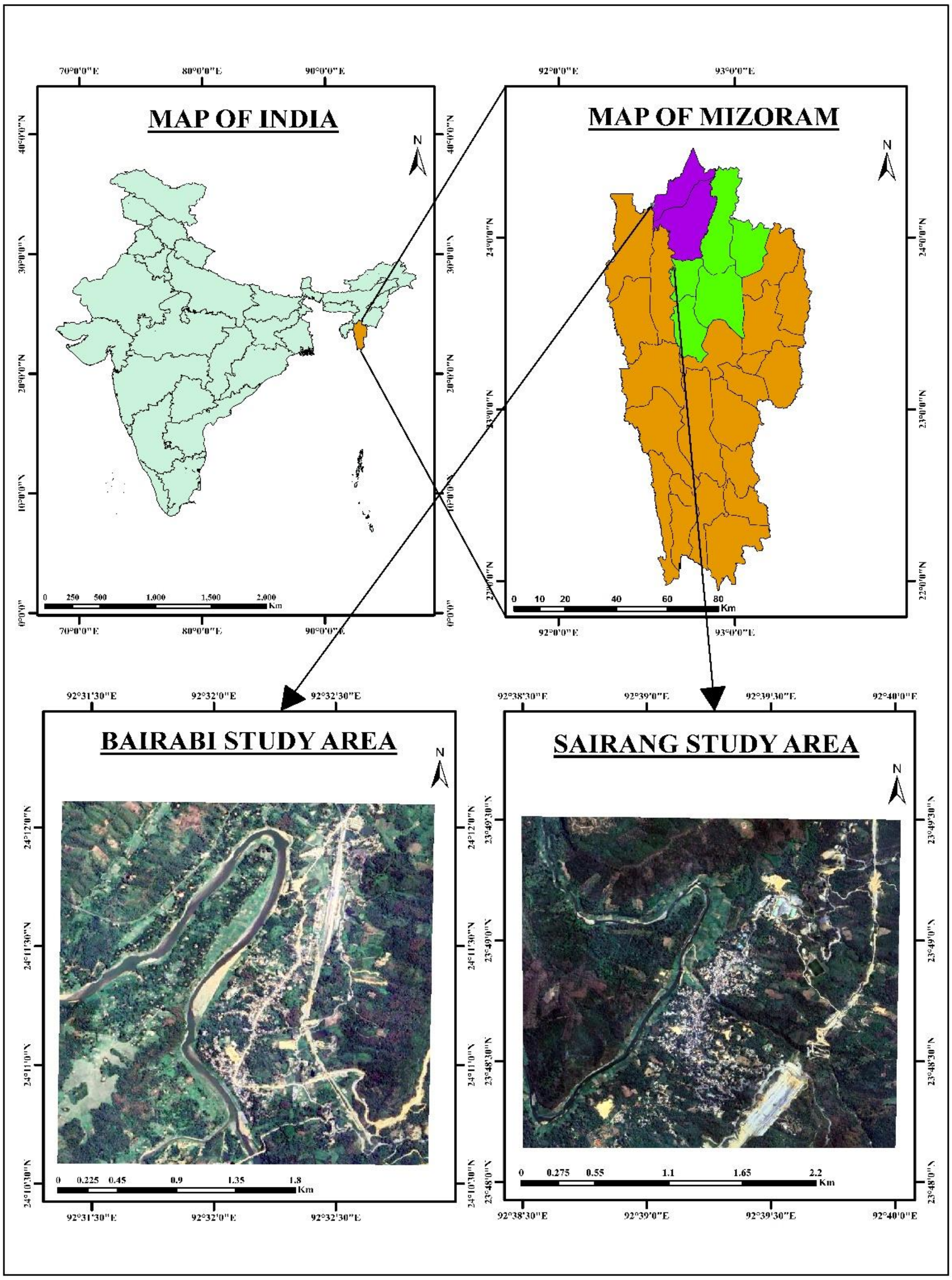


Figure 1.1 Study Area Map

1.2.1. PROFILE OF SAIRANG STUDY AREA

- ***Location:*** Sairang, located at 23.8°N 92.67°E, is a notified town in Aizawl district. It is situated in the north-western part of the state of Mizoram in India. The town borders Aizawl district from Mamit district in the west. Sairang marks the first place in the state where merchants from Bengal start trading after the British invasion.

- ***Connectivity:*** The town is easily accessible by road through National Highway 6 (NH 6), which connects NH 108 linking Aizawl in the east and Mamit district in the west, and NH 306 in Kolasib. With a 14-kilometer distance, it is the nearest town with a river to the capital city, Aizawl. A new broad-gauge line of 51 km connecting Bairabi Railway Station to Sairang is under construction. It lies in close proximity to the only airport in the state, which is 4 km away, located in the neighbouring town of Lengpui.

- ***Physical Features:*** Sairang's topography is distinguished by its hilly terrain, river systems, and the interaction of natural and human forces that shape the environment. The elevation of the study area varies substantially over the region, ranging from 56- 300 m above sea level (Figure 1.2). Characterised by hilly and rugged topography, Sairang is dominated by steep slopes and a narrow valley. The hills are part of the Patkai mountain range, which contributes to the rugged landform. Extending between 23°48'0” N latitude and 92°40'12” E longitude, the river Tlawng stretches along the entire western part of the town. The valley curved by the River Tlawng provides a flatter area where most of the settlements are confined.
- ***Climate:*** Based on the Köppen climate classification, Sairang town in Aizawl district features a humid subtropical climate (Cwa) characterized by short winters and long summers with heavy rainfall (Rai, 2009). During summer, temperatures remain moderately warm, typically ranging between 20°C and 30°C (68–86°F). In contrast, winter daytime temperatures are relatively cooler, averaging between 11°C and 21°C (52–70°F). Aizawl District falls under the direct influence of the South West Monsoon. The district receives an adequate amount of rainfall, where an

annual average rainfall is 2453mm. The rainy season typically starts from the month of May and lasts until September or October.

- ***Socio-Economic structure:*** According to the 2011 census, the town has a total population of 5,950, where males comprise 50.28% and 49.75% females. Out of which 16.5% are children below the age of 6 years, where the child sex ratio is 1019. Attaining a higher than the state average, the female sex ratio is 989. The literacy rate of 97.95% also exceeds the state average, which is 91.33%.

With 95.14%, the Scheduled Tribe constitutes the majority of the population, while the Scheduled Caste comprises 0.44%. Religion in Sairang town consists of Hindu, Muslim, Christian, Sikh, and Buddhist. With 94.92%, the majority are Christian of various denominations.

The town is divided into 4 election wards. The total number of households in Sairang town accounts for 1,308 houses. The primary sector of agriculture and allied activities is the main occupation. The tertiary sector, including both public and private establishments, contributes to the economy at large. Out of the entire population, 1835 males and 1476 females making a total of 3311 are engaged in works and business of varied activities. The total working population of 3311 involves 73.18% workers engaged in main work and 26.82% in marginal work.

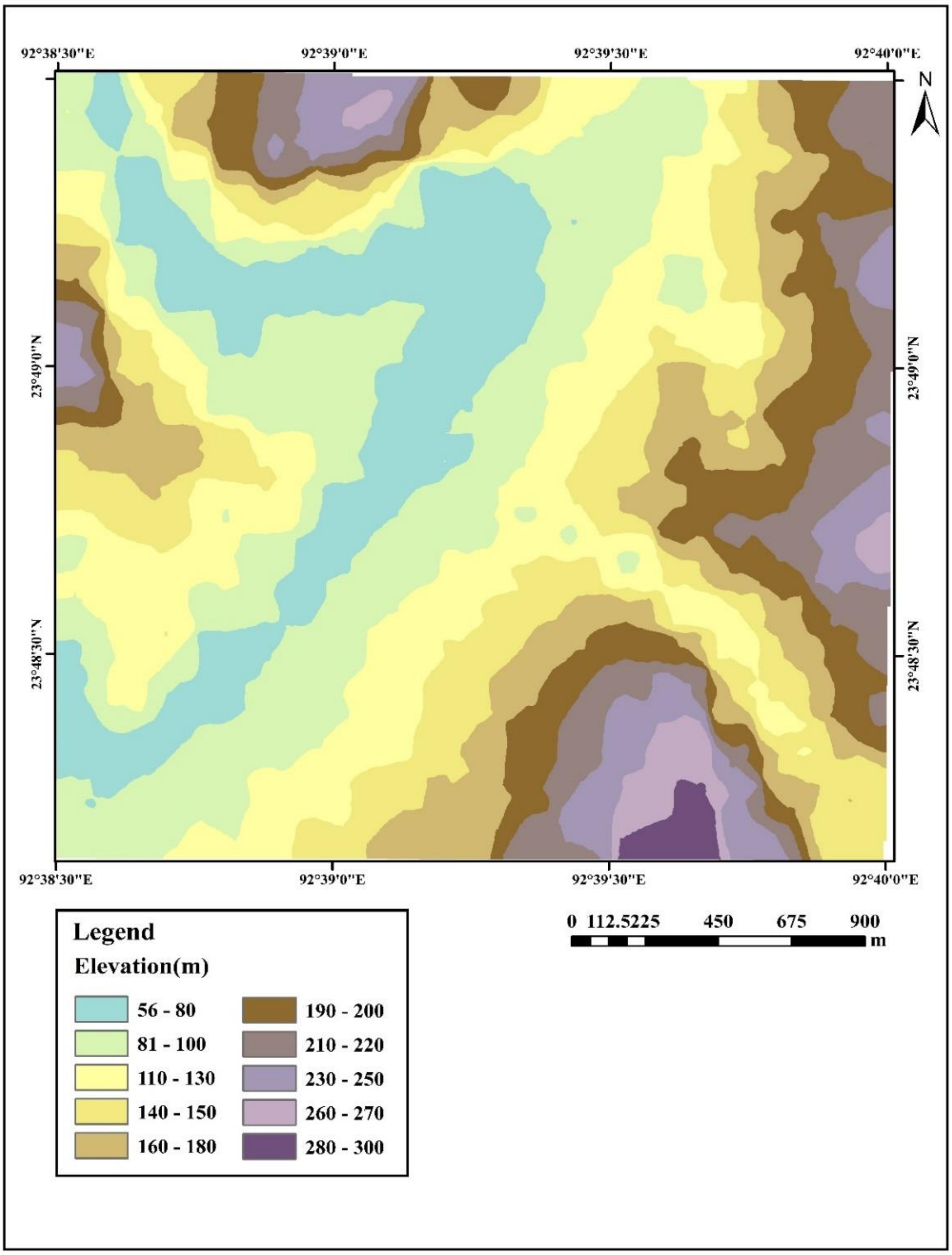


Figure 1.2 Elevation map of Sairang Study Area

1.2.2. PROFILE OF BAIRABI STUDY AREA

- ***Location:*** Bairabi is a small town located at 24.23°N 92.52°E in the Kolasib district of Mizoram, India. Bairabi, a census town in Kolasib District situated in the north-western part of Mizoram. The Bairabi Railway station, which is situated in one of India's north-eastern states, marks the last stop of the Indian Railways' voyage for many decades.

- ***Connectivity:*** Bairabi is located 117 kilometres away from the capital city of Mizoram, Aizawl. National Highway passes through the town connecting Aizawl and linking NH 108 in Mamit district. The town is situated near the border with Assam and serves as a key point for transportation and trade between Mizoram and neighbouring states. Bairabi is currently Mizoram's only railhead, connected by a broad-gauge line. The Katakhal–Bairabi rail line, marked as a national project, was upgraded from metre gauge to broad gauge. As of June 2024, the daily Passenger Special connects Bairabi and Silchar in around 3 hours and 30 minutes.

- ***Physical Features:*** Bairabi, like most parts of Mizoram, is characterized by hilly terrain with an elevation that varies between 26 and 220 m above sea level (Figure 1.3). The region forms part of the larger Lushai Hills, which is part of the broader Patkai Range. Dominated by undulating hills and valleys, the area is characterized by a series of parallel hill ranges with steep slopes and narrow valleys.

  The Tlawng River extends between 24°14'9.24” N latitude and 92°31'16.68” E longitude in Bairabi town, creating distinct river valleys that contribute to the region's physiographic diversity. These valleys, with fertile soil, support agriculture and habitation. Traverse along the western part of the town; the Tlawng River is considered to be the natural interstate border with Assam. River Teirei, a major tributary confluence the Tlawng River in Bairabi before its merger with the Barak River in the Cachar district of Assam.

- ***Climate:*** Bairabi in Kolasib district has a humid subtropical, dry winter climate (Classification: Cwa). Owing to its tropical location, the district enjoys a moderate climate throughout the year with an average temperature of 24.74ºC (76.53ºF), which is -1.23% lower than India's averages. The temperature does not differ significantly across seasons. However, the average high temperature is 30.78°C while the average low temperature is 14.5°C. During the past decade, 35°C in July was the highest temperature observed.

On average, the district receives about 2438mm of total annual rainfall. Under the direct influence of south- west monsoon, the district receives an adequate amount of rainfall during the summer monsoon. The highest amount of rainfall is usually recorded during July and August.

- ***Socio-Economic structure:*** According to the Census of India 2011, Bairabi has a total population of 4,320. Out of which, 2178 are males, while the female population accounts for 2142, and the female sex ratio is 983. The population of children between 0-6 age group numbered 754, constituting 17.45% of the gross population. In addition, the child sex ratio for the town is getting on for 995. Lower than the state average, the literacy rate of the town is 90.77%. While male literacy is around 92.72 %, the female literacy rate score 88.79%. The town is divided into 2 election wards and consists of approximately 863 houses of different structures and types.

  Of the total population, 90.09% belongs to the Schedule Tribe community while the Schedule caste constitutes 0.28%. Regarding religious practices, Christianity, with 87.73, is the most prevalent religion in Bairabi town. Subsequently, 2.85% of the population are identified as Hindu, 8.77% Muslim, and 0.23% Buddhist.

With a large population engaged in the primary sector, agriculture and allied activities are the main dependent of Bairabi town for livelihood and sustenance. Employment generated through the existence of public and private entities largely contributes to the engagement of workers in the secondary and tertiary sectors. Thus, it largely defines the town's economy, besides agriculture. The working population in Bairabi town accounts for 1421, where 61.37% engaged in main work and 38.63% in marginal work. Out of the total working population, 914 were males and females engaged in work or business accounts for 507.

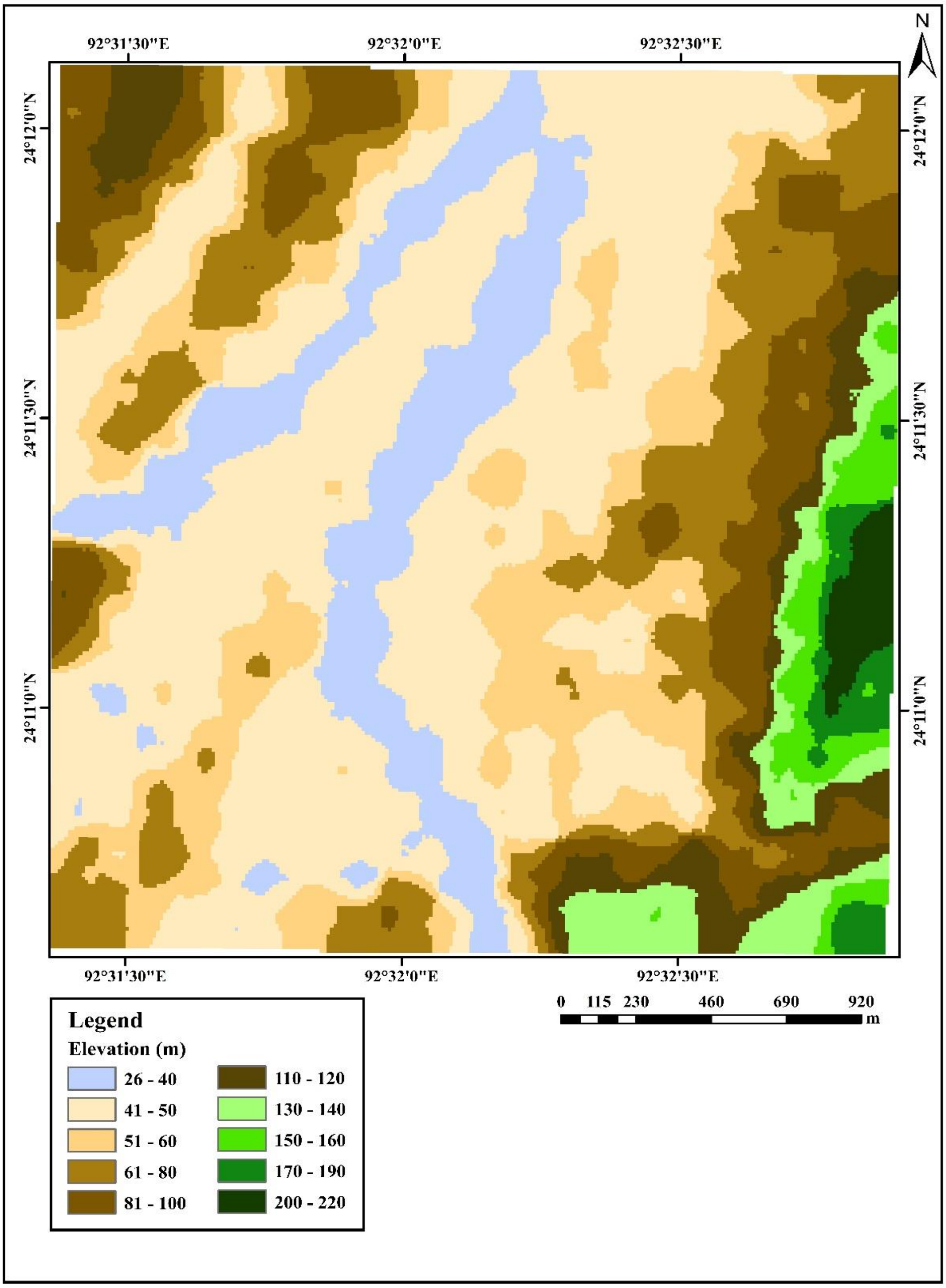


Figure 1.3 Elevation map of Bairabi Study Area

1.3. STATEMENT OF RESEARCH PROBLEMS

Although admitting its significance, the flood of the Tlawng river has been one of the most massive and destructive calamities in the north-western belt of Mizoram. The worst-affected areas are the towns in the flood high-risk zone, i.e., Sairang and Bairabi (DM&R, 2021). Flood hazards with great intensity hit the towns in 1929, 1989, 1993, 2007, 2017, 2018, and 2024. These calamities have greatly affected the physical infrastructure, social fabric, and economic stability of the towns. A vast area was eroded, destroying public and private buildings. Despite the recurrence of floods, strategies to combat the flood risk and vulnerability seldom exist.

Since time immemorial did floods have created havoc in the towns, the indigenous knowledge of management being the only practice to rely on. The absence of adequate mitigation measures forced the inhabitants to apply the limited knowledge. Traditional ways of responding to the flood are merely strategies developed instead of adopting preventive measures. The process of evacuating during inundation and re-entering when it recedes becomes a normal function for many families. As these actions usually call for an urgent operation, the victim's families immensely require support and assistance. Thus, it instantaneously creates societal problems to a great extent.

In prior times, the inhabitants, based on their experience, could predict the impending event of flooding. The intensity of the flood can be reasonably expected through the indigenous techniques of observing the rainfall and flow of the river. But at the present state, the local perception of the nature and characteristics of floods, their interval of occurrence, and intensity is becoming irrelevant. Enduring a perpetual flooding hardship, the communities of the two study areas anxiously wait for the blow of the next crisis.

Figure 1.4 (a) & (b) The 2017 flood of Tlawng River in Sairang town

[Source: Milestone Picture]

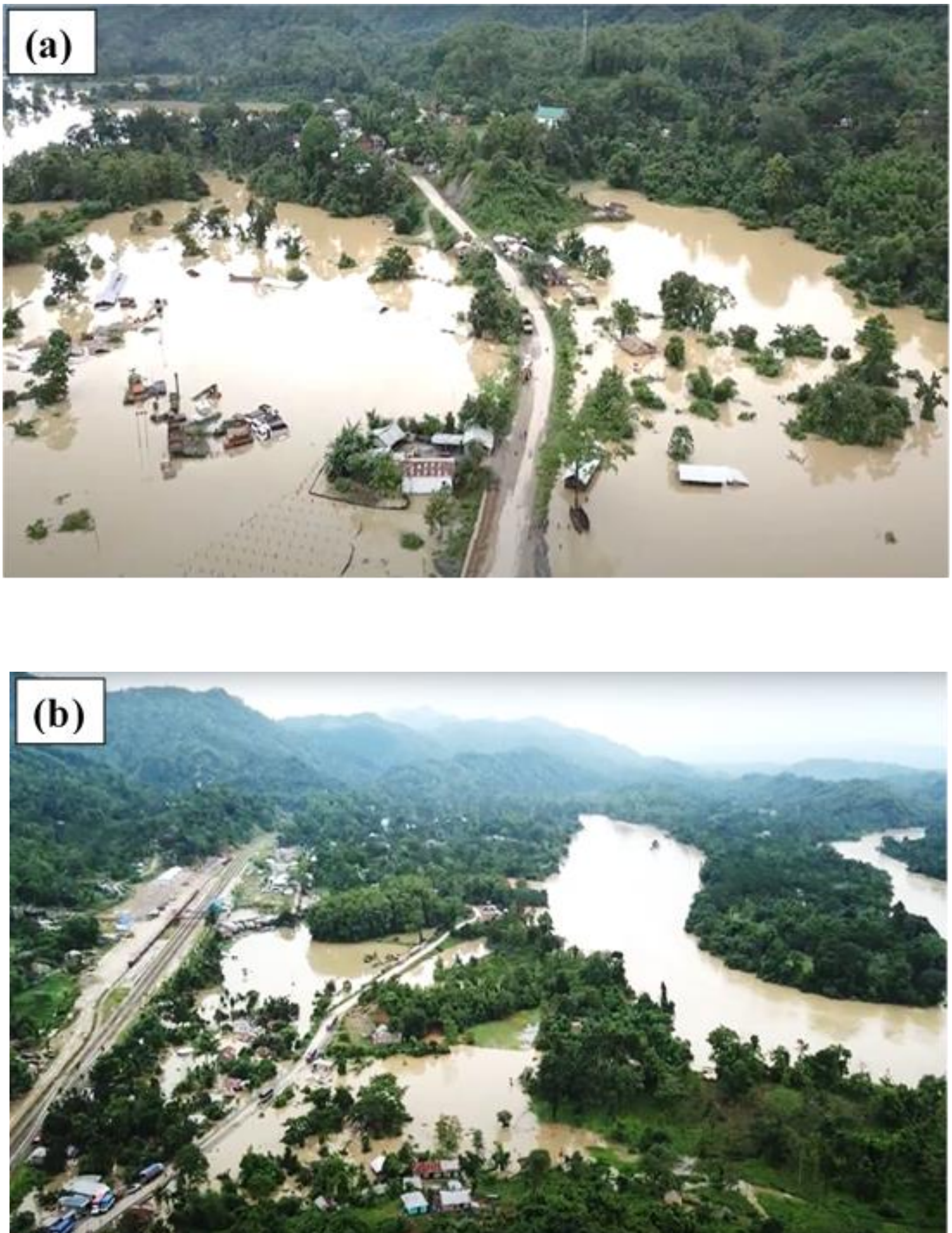


Figure 1.5 (a) & (b) The 2018 flood of Tlawng River in Bairabi town

[Source: Raltek Video Production]

1.4. SCOPE OF THE STUDY

The main aim of the research is to provide a comprehensive investigation of flood hazards in the Tlawng River basin, with a particular focus on the settlements of Sairang and Bairabi in Mizoram. The scope encompasses the investigation of factors contributing to flood occurrences, the analysis of historical flood frequency and rainfall patterns, and the evaluation of physical and social vulnerabilities.

The study is geographically confined to the two towns, Sairang and Bairabi, which are located along different sections of the Tlawng River and have experienced recurring floods of varying intensities in recent decades. By focusing on these locations, the research seeks to uncover how localized topography, soil characteristics, land use changes, and river behaviour contribute to differing flood impacts and risks within the same watershed system (Mishra & Singh, 2010).

While the study provides an in-depth analysis at the local level, its methodology and findings also contribute to the broader understanding of flood risks in other monsoon-influenced riverine environments across Northeast India. However, the scope is limited to secondary data for rainfall and discharge, with primary data collection focused on field surveys, soil testing, and local observations. Long-term hydrological modelling is beyond the scope of this research, but it is recommended for future studies.

1.5. OBJECTIVE OF THE STUDY

1. To identify the causes of flood hazard in the Tlawng River.
2. To study the impact of the flood in Sairang and Bairabi towns.
3. To determine the actions and measures adopted for flood management.
4. To prepare a Vulnerability Map and formulate mitigation strategies.

CHAPTER 2

REVIEW OF LITERATURE

The complexity and peculiarities of flooding have been studied through a variety of approaches. Despite the abundance of flood-related research publications accessible, the current study areas are narrowly focused. There have been a few studies on the Tlawng River Basin, but this research is the first to look at the Tlawng River flood from the perspective of disaster management. Although the limited availability of literature in the research area presents challenges, this research has the definite goal of obtaining comprehensive results. Reviewing research publications has acted as a guide, from area selection to deciding which methodologies and strategies to employ. It also provides an opportunity to obtain a deeper understanding of the subject matter and concept of flood studies. Hence, forming the basis for this research, the following are the scholarly papers reviewed:

International:

Changnon and Demissie (1996) conducted a comparative analysis of annual mean flows and peak flows in Midwestern river basins in the United States, examining the combined effects of precipitation and anthropogenic changes for 50 years. Their study focused on two pairs of basin- one situated in rural areas and the other in urbanized regions. The findings revealed that urban basins exhibited a stronger hydrological response to changes in precipitation than their rural counterparts. Moreover, the study emphasized that human –induced modifications over time played a more significant role than temporal precipitation variations in explaining observed changes in both mean and peak flows. The authors advocate for comprehensive assessments that consider natural basin characteristics, land use changes, drainage modifications, and varying precipitation patterns to accurately evaluate the impacts of rainfall on hydrological behaviour.

Salter (1997) presents his findings which concerns principles on management of risk, vulnerability, and the evolving nature of emergency management services. The study mentioned the importance of an effective disaster risk mitigation framework that emerges within the emergency management business. According to the research, a qualitative vulnerability profile is critical in disaster management since economic, social, legal, and political factors influence decisions regarding acceptable risk and response options. He also stated that focusing on vulnerability provides a flexible framework for addressing community exposure to major threats and implementing socially significant remedial measures.

Yue et al. (1999) introduced Gumbel mixed model to study how related flood characteristics behave together, such as flood peaks with volumes and volumes with durations. The model was applied and validated using empirical flood data from the Ashuapmushuan River basin in Quebec, Canada. They noted that their findings could make a meaningful contribution to addressing key challenges in hydrological engineering design and management, particularly in areas like spillway construction and flood regulation. The proposed model supports risk analysis and evaluation for such hydrological issues.

Yin H and Li C (2001) have pointed out the probable causes and impact of floods, which were accentuated by human intervention. The proportion of forest cover and the total eroded area within the river basin were analysed across multiple flood years. They have found out that deforestation is a curse that intensifies the impact of floods in the long term. Strategies given to minimize flood impacts include integrating flood control infrastructure with environmental conservation, reinforcing levees through regulated consolidation, and implementing coordinated management of rivers and lakes, cooperative tackling, and high-tech decision-making systems. Additional strategies involve controlling soil erosion, establishing flood diversion zones, and constructing flood control reservoirs.

Plate (2002), with a focus on flood risk, explores existing risk management strategies for natural and man-made disasters. Risk management is carried out at three different levels: operational, project planning, and design. It emphasizes the dynamic nature of flood protection, which is influenced by both natural and human factors. By observing China's efforts on the Yangtze and Yellow rivers, this paper discusses the ongoing need for adaptive mitigation measures to address long-term flood control approaches. He emphasized that the goal of preparedness is to minimize residual risk by implementing early warning techniques and promoting measures to minimize the impacts of flood disasters.

Kron (2005) mentioned that an increase in population results in higher exposure to flood risk. He stated that rising levels of hazard, exposure, and vulnerability collectively lead to an increase in flood risk. He discussed the significance of well-designed and cautious utilization of basements in residential buildings in flood-prone areas, which could minimize the value of infrastructure damage. He has computed risk by the product of hazard, exposure, and vulnerability.

Jonkman et al., (2008) classified the destruction of floods into tangible and intangible damage, considering the direct and indirect damage caused by the flood. They opined that loss of life is the major determinant of the intensity of any calamity. They have laid down a three-step procedure for estimation of loss of life, viz., analysis of flood characteristics, estimation of exposure, and assessment of the mortality to those exposed.

Balica et al. (2009) proposed a method for calculating the Flood Vulnerability Index using a set of indicators to assess damage across different geographical scales. This approach distinguishes characteristics at each scale, enabling a detailed analysis and interpretation of localized conditions. It also helps identify flood-prone zones. The final output is a standardized value between 0 and 1, indicating the degree of flood vulnerability from low to high. International river basin organizations can apply the FVI to develop targeted flood response plans and enhance decision-making by strategically identifying and implementing measures to reduce vulnerability at multiple administrative levels.

Du W et al. (2009) conducted studies on the health impact of floods by extensively analysing existing literature. Common themes were identified, and findings and views of experts were highlighted. The periodically based direct and indirect health consequences of floods were categorised into immediate, medium, and long-term. They have described the probable and existing health impacts, like direct physical injuries and, to the extent of mental health, which flood-affected communities/individuals could develop.

Atta-ur-Rahman et al. (2011) attempted to examine the causes and impacts of floods on the socio-economic components in the Hindukush region of Pakistan. They have mentioned the significance and importance of non-structural mitigation measures to minimise the intensity and effects of floods. The studies mainly rely on data collected through questionnaire surveys, interviews, and personal observations. A separate questionnaire was designed for each of the Individual households, Focused Group Discussions (FGDs), and Government Departments. Face-to-face interviews with the flood victims also form a major part of data collection.

Deshmukh et al. (2011) aim to create a conceptual framework to explore how infrastructure serviceability influences community resilience in the aftermath of flooding. Using a mixed-methods approach - qualitative interviews and quantitative surveys, the study included site visits in five U.S. cities. The findings show that inhabitants' social and economic activities were significantly disrupted, owing mostly to problems in the electricity and road infrastructure. The investigation identified two crucial interrelationships between infrastructure and activities: the availability of alternative infrastructure and the lack of alternatives for critical services. This study emphasizes the relevance of severity assessment in assisting city administrators and emergency responders in resource allocation and mitigation strategy creation, which ultimately contributes to community recovery and resilience following catastrophes.

Flanagan et al. (2011), in their attempts to improve the components of the disaster cycle, have developed the social vulnerability index (SVI). By utilizing secondary data, the SVI encompasses four major disciplines- socio-economic, household structure, ethnicity and languages, and resource availability. They have mentioned that identifying the vulnerable population in society is a crucial task, yet often neglected. Various challenges arising for stakeholders were pointed out, and they have suggested carrying out the assessment of social vulnerability beforehand. It was stated that acknowledging the vulnerability status of the society significantly helps in framing the preparedness plan and facilitates the recovery process.

Dinh et al. (2012) conducted a flood hazard, risk, and vulnerability assessment for the Long Xuyen Quadrangle in Vietnam's Mekong Delta, focusing on both current (2010) and future (2050) scenarios. Their approach involved applying a one-dimensional hydrodynamic model to simulate an extreme flood event, with the results used to derive a Flood Vulnerability Index (FVI). They employed the Coastal Area FVI to evaluate the degree of susceptibility of low-lying, sediment-rich deltaic regions. The findings demonstrate that the CCFVI is an effective tool for visualizing and mapping flood risk. Their study stresses on the relevance of integrating vulnerability maps with hazard assessments to improve flood risk evaluation and support the development of targeted mitigation strategies.

Wilby and Keenan (2012), in their flood risk studies, focus on enabling and implementing strategies and analysing adaptation activities at various levels. They claimed that data sharing, institutional transformation, bridge organizations, regular monitoring, insurance, legal incentives, flood predictions, and emergency planning were examples of enabling. Climate safety considerations, infrastructure improvements, operational regulation modifications, development control, flood forecasts, and adaptive management are all implemented. Their review on the 11/2010 flooding in Victoria, Australia, emphasized the need for a two-level system to cope with the impact of low-level but high-impact floods and further research into extreme floods. Their findings indicated that adaptation management was the best way to reduce flooding risks in unpredictable social and physical environments.

Doocy et al (2013) studied the cursed of floods on mortality, injury, and displacement, while also identifying associated risk factors. Their analysis revealed that over 2.8 billion people were affected by flood between 1980 and 2009. Incidents such as drowning was identified as the primary cause of death, with factors such as male gender and car ownership in high-income countries contributing to higher fatality rates. The study emphasizes the need for stronger monitoring systems, improved mitigation strategies, and more effective communication with civic authorities to reduce future flood-related losses.

Esteves (2013) investigates the limitations of the most commonly used methodologies for high rainfall analysis as well as their implications for flood defence design and protection. The study analysed rainfall data from three locations in southeast England to depict how different probability distributions (PDs) influence the estimation of extreme rainfall. She mentioned that variability can be found all around the world, especially if local features influence rainfall distribution over small areas and/or rainfall measurements are within a limited time series. By claiming the possibility of improvement in designing flood resilience, utilizing a variety of models is suggested in the study of intense rainfall.

Solomon and Prince (2013) conducted a study on the Osse River, which used flow observations from Iguoriakhi, and examined flood frequency using Gumbel's distribution to protect downstream lives and property. The annual maximum discharge was calculated for 20 years using Gumbel's distribution. They affirmed that findings are useful for storm management and the engineering design of hydraulic structures that safeguard downstream properties.

Stefanidis and Stathis (2013) introduced two flood hazard indices that incorporate both natural and human-induced factors contributing to flooding. Their study utilized the Analytic Hierarchy Process (AHP) in conjunction with Geographic Information System (GIS) tools to highlight flood risk and support floodplain management. The natural parameters include land uses, geological subsoil, mean watershed slope, major stream bed slope, watershed morphology, and hydrographic network density. Stream bed encroachment, narrowing of beds in flood plains, stream covering, development inside channel beds, and inadequate technical works were among the anthropogenic issues evaluated. They quantified these parameters and utilized them to create flood hazard maps on a watershed scale. The investigation found that anthropogenic sources have a significant impact on flood risk.

Kundzewicz et al. (2014) present a comprehensive analysis of the SREX report's findings on changing flood hazards, supplemented with contemporary literature. The study focuses on the numerous natural and anthropogenic elements that influence flood risk, as well as future flood frequency and amplitude projections. Heavy precipitation events are projected to become more frequent, especially in high-latitude and tropical locations. They stated that limited research indicates probable increases in flood frequency and size. Due to climate change, flood-related economic losses are estimated to accelerate in the future (McGee & Penning, 2022) and greater exposure, with significant geographical variation. To effectively control flood risk, it is recommended to take a preventive approach and continually enhance flood adaptation and management measures.

Nepal et al. (2014) primary aim of their research is to synthesize existing knowledge and identify the implications for integrated water resource management (IWRM) among upstream and downstream communities. Key findings indicate a complex relationship between forest cover and hydrological dynamics; while reduced forest cover may initially increase downstream flows, long-term erosion risks could undermine soil and water availability. Owing to climate change (Srivastava, 2020), alterations in the hydrological system are projected, resulting in increasing discharge during monsoon seasons but potentially decreasing it during dry periods. This study recommends the adoption of a conceptual framework for integrated systems analysis and investigation of payment for ecosystem services (PES) as a method to encourage sustainable practices in upstream communities.

Hammond et al. (2015) present an advanced literature analysis on flood impact assessment in metropolitan areas. They discussed the limitations in approaches used to evaluate impacts, particularly in terms of infrastructure vulnerability. They have mentioned that the vulnerability of crucial infrastructure networks is poorly understood, as is the impact of floods on the overall economy, as well as indirect, tangible harm. Quantifying losses with regards to the number of people affected or monetary value is recommended, as it could help prioritize flood impacts. They observed that a lack of high-quality flood impact complicates the assessment of all consequences, creating validation and calibration issues.

Romali et al. (2015) examine the problems of poor flood damage assessment methodologies in Malaysia, where flood insurance awareness is low and government incentives are constrained. The study aims to present a systematic way to quantify flood damage that determines both tangible and intangible aspects. Their review looks into the methodologies used to construct stage-damage function curves, focusing on two main approaches: the empirical approach, which analyses historical flood damage data, and the synthetic approach, which collects damage data through interviews or questionnaires. The findings indicate that the development of a synthetic stage-damage function is crucial, particularly in developing countries with limited historical flood data.

Nasiri et al. (2016) reviewed the most commonly applied methods for vulnerability assessment, highlighting four key approaches. They have suggested the method of indicator-based assessment to assess vulnerability and described the wide utilization and effectiveness for the stakeholders. They have mentioned that vulnerability is characterized by the socio-economic and environmental conditions of a specific population in a given area.

Bubeck and Weichselgartner (2017) in their study discussed the huge impact of floods on cultures around the world, resulting in loss of life, economic devastation, ecosystem ruin, and long-term health impacts. They mentioned how critical floods were for millions in developing countries, particularly those that rely on natural resources. Negative flood effects were classified into direct, indirect, tangible, and intangible losses. However, they stressed the little focus laid on the indirect and intangible consequences of floods. Collaboration with professionals and experts is suggested for developing context-appropriate flood management measures. They also discussed the need for constant monitoring and modification over the dynamic nature of floods and human systems.

McEwen et al. (2017) attempted to understand the adaptive capabilities of the community towards flood risk, stating that the speedy return to normalcy and effective pre-disaster planning result in disaster resilience. They have mentioned that a community-based flood study should consider the source of the community's knowledge, how it is perceived, and its effectiveness. A study was carried out by in-depth semi-structured interviews among the flood-affected community. An off-road interview was conducted to develop an informal interview, and an e-survey was also implemented.

Faisal and Khan (2018), in their critical review of Flood Management in Bangladesh, have discussed the importance of incorporating Remote Sensing (RS) and Geographic Information System (GIS) in Disaster Management. They mentioned that RS imagery and interpretation in a GIS environment could provide an effective mitigation strategy. They have also identified the importance of RS and GIS applications for different phases of Disaster Management.

According to Šakić Trogrlić *et al. (2019),* stakeholders often overlook the need to identify local knowledge while managing flood risks. The state of local knowledge in Malawi was critically explored utilizing qualitative research methods. Their study involved 15 focus group discussions, 36 individual interviews, and field observations, all of which were examined through thematic analysis. Evacuation protocols and environmental degradation were selected as the most important aspects of local knowledge. The community's awareness was deemed to be beneficial in mitigating the effects of annual flooding. The study reveals that local communities possess a nuanced body of knowledge that significantly enhances their resilience across multiple aspects of flood risk management.

Tazen et al. (2019) explore the rising frequency of flood events in Burkina Faso, particularly in metropolitan areas, with the goal of identifying the primary anthropogenic drivers of flooding. Historical flood data from newspaper stories and daily rainfall time series in Ouagadougou are analysed to determine the link between flood occurrence and extreme rainfall occurrences. The relationship between human activities and excessive rainfall, which causes floods, was investigated. Observing that many floods are caused by normal rainfall rather than unusually heavy rainfall, they emphasized the importance of inadequate drainage infrastructure, urbanization, and poor waste management in worsening flood exposure. This study highlights the critical necessity for more robust flood mitigation techniques and improved infrastructure to protect urban areas from future flood damage.

Díez-Herrero and Garrote (2020) carried out a comprehensive bibliometric review of Flood Risk Assessment (FRA) literature using data from the Web of Science database. Their analysis highlights the evolution of FRA research, revealing its well-established historical foundations, strong current relevance, and promising potential to contribute innovative solutions for reducing the impacts of natural disasters. Their review identifies the need for incorporating uncertainty analysis and integrating exposure and vulnerability with flood hazards in future research. It emphasizes the importance of transferring complex methodologies to the private sector for practical applications.

Munawar's (2020) research focuses on global flood risks and assesses the performance of existing flood management measures. This paper reveals gaps in current disaster management technology, particularly the accuracy and efficiency of GPS and satellite imaging systems. To address the deficiencies of current technologies, he proposes a more durable and efficient approach to flood management. This system incorporates image processing and machine learning to study flooded areas, identify affected areas, and allow for prompt rescue efforts. The procedure involves identifying locations in aerial shots and comparing pre- and post-flood images to evaluate flood damage. He believed that if the suggested solutions were adopted, flood mitigation strategies would become more effective.

Pathak et al. (2020), in their studies among farmers in Nepal's Saptari district, investigate community-level responses to flood vulnerability. Their findings show that the degree of vulnerability varies across households, with the majority falling between medium and high on the vulnerability index. Factors such as access to credit, migration, proportion of females, and knowledge of flood disaster were found to have a significant influence on vulnerability. While a negative correlation was detected with gender, livestock ownership, wealth, adaptation measures, and distance to water bodies. They argued that typical flood control measures were insufficient and suggested investment in river management strategies. The study emphasized the necessity of adaptive flood response strategies, and community-focused interventions.

Glago (2021), with a focus on the immediate causes, consequences, and mitigation strategies, investigates the widespread nature of flood disasters. The study discussed several types of floods and their impact. The notion of sustainable flood management is proposed to lessen the harmful effects of flooding. Technological improvements in flood disaster management are also addressed, with a particular emphasis on the Flood Decision Support System (FDSS), which includes Geographic Information Systems (GIS), remote sensing, and hydrologic models. This paper mentioned the need to utilize modern technical tools in flood disaster management to improve preparedness and mitigate the negative effects of flooding on the communities.

Merz et al. (2021) outline the interplay of atmospheric conditions, land surface processes, and socio-economic drivers that collectively lead to river floods with significant impacts. They have stated that severe floods are often triggered by mechanisms that are fundamentally different from those leading to non-severe floods, such as a typical yet recurring atmospheric circulation pattern or the breakdown of flood defences, resulting in significant damage due to their unexpected nature for both residents and flood management officials. However, the decrease number of fatalities and impacted individuals since the mid-1990s is the result of risk-reduction initiatives such as increased risk awareness and structural flood defences. They have also mentioned that reducing vulnerability is an effective flood mitigation measure.

Wang et al. (2022) asserted that climate change and socioeconomic developments are increasing factors of flood frequency and severity. They stressed the importance of flood management to reduce adverse consequences. Observing the focus on a more resilient and sustainable approach in recent studies, they mentioned that from 2000 to 2021, research has transitioned from flood control to flood resilience. This shift, according to them, involves integrating resilience into risk management, ensuring appropriate options and decisions are made before, during, and post-disaster to reduce adverse consequences using risk, resilience, and sustainability theories.

According to *Nguyen et al. (2023)*, vulnerability exhibits a vital role in managing flood hazard. The primary objective of flood risk assessment, according to their studies, are to offer a scientific foundation for more effective policymaking. They discussed how flood impact varies by geography, system, and society, and that susceptibility differs among research objects. While several methods have been developed to assess vulnerability, the indicator-based approach is regarded as more effective in capturing overall flood vulnerability. This is because it synthesizes data from multiple dimensions—physical, environmental, economic, and social—to produce coherent representations of the spatial patterns of vulnerability.

Priyatna et al. (2023) investigate the Barito watershed in South Kalimantan, which experienced severe flooding in early 2021, resulting in huge socio-economic losses. Flood inundation area was detected from Sentinel-1 imagery and modification of land cover from Landsat-8 imagery. This study finds that primary and secondary forests, rice fields, and bushes have declined significantly in the Barito watershed, whereas plantations, bare ground, and water bodies have increased. The findings emphasize the role of land cover changes in amplifying flood hazards and underscore the necessity for sustainable land use management and flood mitigation techniques. This study recommends implementing appropriate land use policies and management measures to reduce future flood impacts.

Sörensen et al. (2024) present the development of the DSI concept, which aims to distinguish different indicators' purposes and to establish a framework for their usage. The DSIs are based on the correlation between rainfall and hydro-climatic changes in the basin. The framework is primarily based on seven case studies representing different temporal and spatial scales. They categorised DSIs into three types: Hydro-climatic DSIs, Impact-based DSIs, and Event-based DSIs. They have mentioned that the decision support indicators are used to assess flood magnitudes and the socioeconomic implications for inundated areas along rivers. The findings show that decision support indices are useful for assessing and planning responses to predicted events.

National:

Gupta et al. (2003) investigate the incidence and impact of floods in India. This research investigates the effectiveness of flood protection systems in the country, with a focus on the most flood-prone region of eastern India. The study focuses on structural measures like embankments, dams, and drainage improvements, as well as non-structural alternatives including flood plain zoning, flood proofing, and early warning systems. Despite these efforts, they discovered that flood control measures are still inadequate, particularly in high-risk locations. The analysis shows that, while protection has improved, it has failed to keep pace with population growth and environmental degradation, aggravating the country's vulnerability to flooding. The study emphasizes the importance of effective resource usage, timely project implementation, and community participation in flood management.

Mohapatra and Singh (2003) examine India's flood-related challenges by categorizing them into four major flood-prone regions: the Brahmaputra, Ganga, North-West Rivers, and Central India–Deccan River Basins. The authors highlight specific flood issues, including dam break flows and persistent waterlogging in Tal areas. They review the advancements made in both structural and non-structural flood management strategies, while emphasizing that despite these efforts, flood-related problems continue, primarily due to insufficient investment and implementation. The study calls for more goal-oriented and time-bound strategies, suggesting that legislative frameworks, such as floodplain zoning, should be developed in collaboration with local authorities. Additionally, they recommend the establishment of a dedicated task force to enhance flood management planning and execution.

Sanyal and Lu (2005) in their studies of a massive flood in West Bengal they have assessed vulnerability based on the location of human settlement. RS and GIS were used to investigate the non-flooded area for evacuation, extract the high flood depth zone, and demarcate human settlements of the flooded area.

Pande, R.K. (2010), through observations and analysing existing scholarly works, examines the flash flood of Uttarakhand. To urge disaster managers, he pointed out the gaps in stakeholders' attitudes towards Disaster Management. To assess the frequency and intensity of flash floods, using a tabular form, he has compiled the history of floods for different districts and supported it with pictures. He has also laid out the mechanisms of flash floods and set forth the mitigation measures.

Guhathakurta et al. (2011) examine extreme rainfall trends in India by utilizing extensive rain gauge station data ranging from the year 1901 to 2005. The research problem involves gaining insight into the risk of flooding resulting from climate change. A one-day extreme rainfall analysis was conducted to determine the change in flood risk. The findings show that the frequencies and distribution of rainfall differ spatially, with wet days decreasing in central and northern India but increasing in peninsular India. Temporal variability was recorded for fixed decades, and return period analysis shows the changing chance of extreme rainfall and accompanying flood risks.

Mili et al. (2013) investigated the causal factors and impact of flood on the social and economic aspects. They also studied the river bank erosion along the river of the Dhansiri. The socio-economic impact was determined using questionnaires and household surveys, which were analysed and divided into subheadings like Displacement, Economic Loss, Psychological impact, Communication problems, and Health and Educational impact. Factors affecting the intensity and frequency of floods and erosion were assessed through a field study and an analysis of secondary sources of data. Suggestions for mitigation measures were set out from the findings of the studies.

Ahmed & Rao (2014) evaluate the drainage characteristics and erosional status of the Sairang sub-basin for land use and water resource planning and management. By employing Geographic Information System (GIS) techniques, they have estimated morphometric parameters and performed hypsometric analysis. The study reveals that the increase in surface run-off was the consequence of high values of drainage density, channel frequency, and rate of infiltration, which reveal the region to have impermeable subsurface materials, sparse vegetation, and high relief. The findings of this research indicate the crucial need for integrated watershed management methods to reduce erosion and improve water conservation in the Sairang sub-basin.

Tripathi (2015), in his studies of flood disasters in India, claimed that floods, due to their recurrent prevalence, are the most miserable and destructive natural disaster. He pointed out that the variation in unequal rainfall distribution in India has resulted in disastrous flooding in non-flood-prone areas. He opined that human actions like modification of river catchment area due to deforestation, urbanization, population growth in floodplain area, and climate change are intensifiers for flood calamity.

Kumavat and Tapkire (2016) aim to address difficulties caused by river flooding in the Arunavati River while also recommending precautionary measures. An experimental inquiry was conducted utilizing a Total Station to survey a river line. The survey activity includes a river cross-section survey, a river longitudinal survey, and the creation of a topographic map. A longitudinal river survey was done along the river line to establish the existing and old river edge lines, which were defined by flood plains. The investigation showed significant broadening along the riverbank's left and right borders as a result of flooding episodes during the last decade. They stated that using a total station in river surveys is both affordable and effective for detecting change.

Bhagat (2017) conducted a flood frequency analysis of the Lower Mahi River using the Gumbel distribution method, applying it to 30 years of annual maximum discharge data from the Wanakbori Weir (1980–2009). The study found that the Gumbel distribution effectively estimates peak flood discharges for various return periods. The average instantaneous flow was calculated at 10,242 m^3/s, corresponding to a return period of approximately two years. The findings demonstrate the model’s reliability in forecasting flood magnitudes, which is essential for the planning and design of hydraulic infrastructure and for managing emergency evacuations during severe flood events.

Bhattacharjee and Behera (2017) studies emphasizes that forest degradation negatively affects both economic and environmental systems. It highlights the important yet underexplored role of natural forests in mitigating floods in India by absorbing rainfall and gradually releasing it into waterways, thus reducing flood frequency and severity. To address this gap, the researchers analysed secondary data from 1998 to 2011 using Poisson and OLS regression models. Their analysis revealed that higher forest cover is associated with lower flood damages. Additionally, socio-economic variables such as literacy rate, per capita net state domestic product, and population size also play a significant role in determining flood impact. They highlighted the significance of investments in afforestation and reforestation in order to protect human lives and properties. They advocate for strengthened efforts in forest conservation to protect communities and assets.

Ranjan (2017) has assessed the vulnerability of flood disasters in SAARC countries. He mentioned the dynamic nature of floods and the need for appropriate strategies to combat the impacts. Considering the vulnerability of India to floods, the floods of the worst-impacted regions in India were analysed. After the initiatives and measures adopted by the Government were studied, he systematically outlined the flood management strategies for different phases of the flood disaster. He examined the effectiveness of early warning systems and highlighted the valuable role of Geographical Information Systems (GIS) and Remote Sensing (RS) technologies in enhancing flood analysis and management.

Singh and Kumar (2017) analysed flood events, frequency, number of deaths, injuries, missing, and economic damage from 1978 to 2006, revealing that 2,443 flood events claimed 44,991 lives, with an average of 1,551 deaths per year. They found out that the most fatalities occurred during severe flood events, with the frequency being 19% compared to heavy rainfall events. This study reveals that the highest fatalities due to floods occurred in Uttar Pradesh. The country's cumulative flood-related economic loss was estimated to be about 16 billion US$ between 1978 and 2006, with a maximum loss of 1.6 billion US$ in 2000 alone. The reason for highly vulnerable of India to floods is claimed to be the high temporal and spatial variability of rainfall. They also stated that recurring floods cause unplanned development and environmental degradation, hindering overall development.

Pandey et al. (2018) conducted to assess the flood frequency of the Betwa River at three gauging stations, using 20 years of maximum daily discharge data (1993–2012). The analysis applied Gumbel's Extreme Value Distribution and Log-Pearson Type III Distribution to estimate peak discharges for different return periods. Results indicated considerable variation in the average one-day maximum discharge among the stations. While the Log-Pearson Type III Distribution was identified as the most favourable model for the entire Betwa catchment, Gumbel's distribution was more suitable for individual stations. The study emphasizes the necessity of catchment treatment in the Mohana and Shahijina areas to reduce the risk of future flood events.

Periyasamy et al. (2018) stressed that floods may lead to consequences that persist in both the immediate and extended future. They have mentioned the natural and anthropogenic causes of flood hazard. The reason for the increase in intensity and frequency of floods was claimed to be climate change, which results in higher rainfall in certain places. They have set a criterion for vulnerability mapping by indicating different aspects to be considered in the layer, the phenomenon, significance, and sources. Using RS and data from Government offices, data were collected, analysed, and operated in a GIS dataset to derive a vulnerability map for the study area.

Ali et al. (2019) in their study address the limited knowledge surrounding flood risk in the Indian subcontinent by assessing how the frequency of floods and extreme precipitation events may change under different emission scenarios. The research utilizes historical data spanning 1966 to 2005, along with future climate projections for the periods 2020–2059 and 2060–2099, to evaluate shifts in extreme precipitation and flood occurrences. The findings reveal significant variability in the relationship between extreme rainfall and flooding under a warming climate. This research highlights the urgent need to integrate climate factors and human interventions into future flood risk management plans and policies.

Conducted a region-wise study of floods, *Mohanty et al. (2020)* examined the flood management strategies implemented in India. They have criticized the Government's policies, stating that stress was specifically laid on Structural mitigation measures, which are not adaptive for the respective states. They have suggested imparting non-structural measures like hazard mapping, vulnerability assessment, and promoting awareness and training of people and stakeholders. They stated that Disaster Resilience = Levels of Preparedness × Relief × Recovery × Reconstruction.

Bera et al. (2021) in their attempt to analyse and manage the flood in Mangalore Block of West Bengal, described and illustrated the effectiveness of Remote Sensing and Geographical Information System. They have mentioned that an integrated approach is a prerequisite in order to reduce the adverse effect of floods. They discussed the significance of non-structural mitigation measures for flood-like forecasting, mapping, and zoning. Slope map, soil map, drainage map, Rail and road communication map were prepared, and a graphical representation of monthly average temperature and rainfall for several years was also incorporated.

Nanditha and Mishra (2021) discussed how floods have tremendously influenced India's population during the monsoon season, disrupting socioeconomic conditions, causing significant destruction to infrastructure and cropland, and increasing human death and economic losses. They highlighted the adoption of both structural and non-structural safeguards to alleviate the effects of flooding. However, they have discovered that the limitations and possibilities for practical flood forecasting systems in India have not been fully assessed. While acknowledging India's substantial advancements in developing an ensemble prediction system for precipitation forecasting, the study critiques its limitations in addressing smaller catchments and urban regions susceptible to flash floods. It emphasizes the need for enhancing both spatial and temporal resolution, along with strengthening early warning systems. The hydrologic ensemble prediction system is recommended to be transformed to include meteorological forecasts and processing. They have suggested improved inflow estimates, which are critical to flood management decisions.

Pathak et al. (2021), using Data Envelopment Analysis (DEA), assess flood vulnerability for 21 districts in the Narmada basin. The analysis revealed that 14 districts were the most vulnerable, with the majority being the least developed and having dense urbanization, which may contribute to their disaster-proneness. It was indicated that districts with low economic development and high population densities are particularly vulnerable. The study suggests that an integrated approach considering socio-economic and physical aspects is needed to reduce flood risk in vulnerable districts. Recommendations for effective flood disaster management comprise a multi-faceted approach, including micro-zoning and resource allocation.

Sam et al. (2021) investigated food security among households in flood-prone rural regions of India by developing an index encompassing multiple dimensions of food security. Their findings revealed that approximately 75% of the surveyed households experienced some level of food insecurity. Factors such as joint family structures, ownership of physical assets, and access to employment schemes were found to enhance food security. In contrast, female-headed households and those incurring property losses due to flooding were more vulnerable. The study emphasizes the necessity for integrated approaches to mitigate food insecurity, particularly in light of increasing flood severity. These insights offer valuable guidance for policymakers in India and other regions facing similar flood-related challenges.

Kansal and Singh (2022) in their study emphasized the natural and manmade causes of floods, the topic of climate change and its negative consequences on severe precipitation. The research also examines flood management problems such as complex geography, limited legislation, insufficient data and infrastructure, and the need to integrate climate change and flood management efforts. It advises implementing an adequate flood risk management plan, with an emphasis on districts such as Chamoli, Pithoragarh, Rudraprayag, and Uttarkashi. The use of nature-based solutions, such as wetlands, has been recommended for effective flood management. In hilly areas, enhancing flood control requires coordinated efforts between local, state, and central authorities, supported by a well-integrated communication system. The research also proposes establishing and enhancing forecasting and early warning dissemination.

Vabeihmo, C. (2022), by utilizing Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) techniques, mapped the Flood susceptibility of the Tlawng River in Sairang village. Toposheet maps and satellite images from various sources serve as the basis for identifying the risk and vulnerable sectors of the study area. Variables such as slope, elevation, topographic curvature, drainage density, flow accumulation, rainfall, land use, and soil vegetation were considered and weighted to achieve their objective. Based on the outcomes, zones were categorized into five classes, and they have come up with the results, mentioning that one-third of the watershed area was vulnerable to floods.

Sati, V. P. (2022), through field observations and interviews, examined the causes and consequences of debris blow/ flash flood in Uttarakhand. Vulnerability was analysed by real ground damage assessment, by measuring the volume of boulder and debris, and by drawing a cross-section of the flood-deposited soil. He observed that several hydropower projects constructed in the river valley are accelerating the intensity and vulnerability of the community.

Ramamurthy et al. (2024) assessed flood risk, vulnerability factors, and coping measures to reduce the threat of future floods. The researchers used the IPCC's definitions of vulnerability and risk to conduct an integrative risk assessment for the Pathanamthitta district. The risk, vulnerability, and coping capacity were assessed through AHP and GIS approaches. They have pointed out that areas with higher population density, females, unemployment, agriculture-dependent population, SC-ST population, and a higher proportion of low-quality houses are most susceptible to flooding. The regions which suffered less access to safe and proper drinking water, hygiene, and settlements near road-river intersections were also considered to be highly vulnerable. The study emphasizes the difference between projected and actual rainfall, underscoring the need for better forecasting and preparation.

CHAPTER 3

METHODOLOGY

This study employed a variety of methods to achieve its objectives. Both current phenomena and historical records were collectively considered to improve the reliability of the findings. Primary data were collected through extensive field surveys conducted 12 times across different seasons, while a substantial amount of secondary data was obtained from the relevant department office of the Government of Mizoram.

Chapters were organized against the study objective, i.e., causes, followed by impacts, management, and vulnerability assessment. Every chapter, yet interdependent, utilized separate approaches and research techniques.

3.1 METHODS FOR THE CAUSES OF FLOOD

3.1.1 RAINFALL ANALYSIS

The daily rainfall data during 2007- 2023 observed in the districts of both the study area, i.e., Aizawl and Kolasib districts, were obtained from the State Meteorological Centre, Department of Science and Technology, Government of Mizoram. The 17 years of rainfall data were analyzed to produce total annual rainfall, monthly average rainfall, and annual daily maximum rainfall.

3.1.2 WEIBULL'S FORMULA FOR EXCEEDANCE PROBABILITY

The average time of an extreme event of given magnitude/ intensity equaled or exceeded at least once is termed the recurrence interval/ return period (Patra, 2001). In this study, the rainfall recurrence interval for the amount of annual daily maximum rainfall of 17 years, i.e., 2007- 2023, was determined using Weibull's method. The rainfall series was first arranged in descending order, and ranks were assigned to each rainfall. Probability of exceedence and recurrence interval were obtained using Weibull's formula.

Since, recurrence period is based on the possibility of a flood equaled or exceeded in any given year, the probability of the amount of maximum rainfall magnitude for each year was computed using the formula-

$$P = \frac{m}{N+1} \qquad \text{(Equation 3.1)}$$

Where,

- P = Probability of exceedence
- m = rank
- N = Number of years of record.

The recurrence interval for each amount of annual maximum rainfall magnitude of a given year was calculated by the given formula:

$$T = \frac{1}{P} \qquad \text{(Equation 3.2)}$$

Where,

- T = Recurrence interval/ Return period

3.1.3 TRENDLINE FITTING

A logarithmic regression model was fitted to the recurrence interval vs. rainfall magnitude plot using:

$$y = a.\ \ln\ (x) + b \qquad \text{(Equation 3.3)}$$

Where,

- y = recurrence interval
- x = rainfall (mm)
- a, b= constants derived via regression

High R^2 values (e.g., 0.99 for Aizawl) indicate strong model reliability.

3.1.4 RIVER MORPHOLOGY AND SEASONAL PROFILE ANALYSIS

To determine the water level and extent of inundation during dry and monsoon seasons, river-line surveys were carried out in both study areas. The elevation of water level at several points of coordinates was detected along the river line using Differential Global Positioning System (DGPS) (Trimble R12) and Total Station (South N6). Owing to its accuracy, the utilization of DGPS for surveying and mapping has globally increased (Jha et al., 2016). Consequently, the employment of Total Station is effective for river-line monitoring, especially in remote areas (Kumavat and Tapkire, 2016)

Longitudinal river line surveys during dry seasons are conducted using DGPS for both the east and west banks. Coordinate points were taken at close random intervals from the east and west banks, respectively. However, during monsoon, due to inaccessibility arising from floods, a survey using DGPS could not be performed on the west bank. For such reason, a Total Station survey was successfully carried out to perform the same on the west bank of the river in both the study areas.

With the accurate and reliable positioning data achieved through the instruments employed, i.e., DGPS and Total station, a river profile graph was generated in ArcGIS. All the data points during monsoon and pre-monsoon were intersected in a separate shape file. The layers of the two seasons were overlaid in a single layout depicting the true profile of the river. The graphical representation of the river profile unveiled the extent of differences and changes that prevailed during the pre-monsoon and monsoon season s within the river system of the study area.

3.1.5 FLOOD HYDROGRAPH CONSTRUCTION

A flood hydrograph is a graph that gives vital information about the river and its basin. The estimation of flood hydrograph is an important and essential task to perform in flood studies as well as designing structures along the river basin (Mediero et al., 2010). It is a graph representing the reaction and response of river discharge, depicting the intensity and duration of precipitation prevailing over certain places (Rodda, 2021). The significance of generating a hydrograph in flood determination is the capability of discerning the lag time.

The key elements analyzed:

- Peak Rainfall- The time of the recorded highest rainfall
- Peak Discharge- The highest level of stream flow
- Rising Limb- an increased rate in river discharge
- Lag time- The time interval between peak flow and peak discharge
- Recession Limb- The fall/recession in river discharge
- Base Flow- Identifies the persistence of runoff

In this study, the flood hydrograph was estimated from the amount of rainfall and river discharge for June 2017 for Sairang, and 18th June 2018 for Bairabi. These specific periods were selected for consideration after the massive flood experienced in both study areas. The graph comprises rainfall amount (in mm) and the amount of river discharge on its x-axis. The interval of selected days was placed along the y-axis.

3.1.6 TOPOGRAPHIC AND SOIL ANALYSIS

❖ ***Contour Map***

Contours are the most significant method to present the relief features of an area (Guilbert, 2013). Generating contour maps largely contributes to assessing a comprehensive understanding of disaster phenomena (Mizukoshi and Aniya, 2002). A field survey is the fundamental step in the generation of maps for the study area. The points of coordinates were taken from several places in the study area. This forms the guide and base for the boundary of the area selection. The collected points were plotted in Google Earth, where the desired areas were created using the polygon tool. The path tool was used to draw a path covering the whole area. The path was then converted to points using GPS Visualizer, and after all, ArcGIS was employed to perform the job. The steps involve-

- Using the GPX to Feature tool, points created through GPS visualizer were plotted in ArcGIS 10.8.2.
- The points were interpolated using the IDW tool.
- Based on the level of elevation, a contour map was generated with a 10m interval.

❖ ***Geotechnical Analysis of Soil***

The type of soil has greatly influenced the intensity of floods by increasing the peak discharge (Basri et.al. 2022). Soil samples were collected from the riverbank of both the study areas, i.e., Sairang and Bairabi. Samples were sent to the Geotechnical Laboratory, Department of Geology, Pachhunga University College.

Soil samples were analysed in the laboratory to determine:

- Texture (silty, clay)
- Plasticity index
- Shear strength
- Cohesion and angle of shearing resistance

Results were used to infer infiltration rates, erosion potential, and slope stability.

3.1.7 GUMBEL’S METHOD OF FLOOD FREQUENCY ANALYSIS

Named after the inventor, Emil Julius Gumbel (1891–1966), the Gumbel distribution is the Type-I method of Extreme Value Distribution (EVD). It is a method that is widely employed to predict and model the value distributions of hydrological events such as floods (Pandey et al., 2018).

Flood frequency analysis was computed using the Gumbel method, conducted separately for Sairang and Bairabi using historical discharge data collected from State Water Informatics Centre, Government of Mizoram. The analysis was performed to estimate peak discharges for various return periods under natural hydrological conditions. The equation for the Gumbel distribution is expressed as:-

$$X_T = X_M + K_{T^{\sigma}}{}_{-1} \qquad \text{(Equation 3.4)}$$

Where,

X_T = Discharge magnitude corresponding to Return Period (T)

X_M= Mean discharge

K_T = Frequency factor, which is expressed as

$$K_T = \left[\frac{y_T - y_n}{S_n}\right] \qquad \text{(Equation 3.5)}$$

In which,

Y_T= Reduced variate

Where,

$$Y_T = -ln\left[ln\frac{T}{\mathrm{T}-1}\right] \qquad \text{(Equation 3.6)}$$

The values of Yn and Sn were obtained from the Gumbel Distribution table, based on the size of the samples.

- Sn = reduced standard
- Yn = reduced mean
- σ = Standard Deviation

The procedure of applying this method to this study follows the steps-

Step 1- The values of the highest peak flow for every observed year were sorted out and arranged in descending order.

Step 2- Ranks were assigned to each value.

Step 3- Mean, Standard deviation, and skewness were computed for the distribution values.

Step 4- Probability (P) and Return period (T) are calculated using

$P=m/n+1$ and $T= 1/P$.

Step 5- From the observed T, the reduced variate (Y_T) is computed using equation 3.6.

Step 6- The frequency factor K_T is computed using equation 3.5.

Step 7- Using equation 3.4, the magnitude of peak flow is computed.

The observed discharge and predicted discharge were plotted against the return period. A logarithmic trendline was added to the predicted values. If these plots suggest a straight line, the conclusion can be drawn that the Gumbel distribution is a good fit (Bhagat, 2017; Phipps & McEntire, 2024).

3.1.8 CHANGE DETECTION

Change detection is the classification of multi-temporal problems and differences that take place over the areas under investigation (Volpi et al., 2013). The identification of change prevailed on the environment exhibits the interdependency of humans and nature. The subject has arisen to become a topic of consciousness where numerous researchers around the globe have laid focus on (Zhou and Kurban, 2008). Typically, change detection is performed using either a supervised or unsupervised method. As the change distinction could be produced using a supervised method, it is more advantageous than an unsupervised method (Castellana et al., 2007).

The study has followed the listed steps to generate a change detection map for the study areas-

- LISS-III images of selected years for both the study areas were downloaded from USGS EarthExplorer.
- The downloaded images were processed in ArcGIS.
- The images were classified using interactive supervised classification to produce and classify classes.
- The same procedures were performed on all the images for the desired years.

3.1.9 ACCURACY ASSESSMENT FOR CHANGE DETECTION

To ensure the reliability of classifications used in the change detection analysis for Sairang and Bairabi, an accuracy assessment was conducted. Accuracy assessment is essential in remote sensing studies as it quantifies the agreement between the classified data and reference data (Edosa & Nagasa, 2024), thereby validating the quality of classifications used for further spatial analysis and interpretation (Foody, 2002; Olofsson et al., 2014).

The assessment was performed using confusion matrices (error matrices), which compare the classified classes against reference data obtained from high-resolution Google Earth imagery and field verification points. The matrices detailed the number of correctly and incorrectly classified samples for each class, providing the basis for computing overall accuracy and the kappa coefficient (K).

The overall accuracy is calculated as the proportion of correctly classified samples relative to the total number of reference samples, providing a straightforward measure of the classification's correctness. In contrast, the kappa coefficient measures the agreement between the classified and reference data (Choudhury et al., 2023), while adjusting for the agreement that could occur by chance, thus offering a more robust evaluation of classification reliability (Pontius & Millones, 2011). The kappa coefficient ranges from 0- 1, with values above 0.80 indicating almost perfect agreement, and values between 0.61 and 0.80 indicating substantial agreement (Clement et al., 2012; Landis & Koch, 1977). (Detailed test results can be accessed from Appendix A.)

It is defined in terms of the error matrix as given below:

$$K = (Obs - exp)/(1 - Exp) \qquad \text{(Equation 3.7)}$$

Where,

- Obs = Observed correct, it represents accuracy reported in the error matrix (overall accuracy)
- Exp = Expected correct; it represents correct classification.

Accuracy assessment is calculated as:

Step 1: Construction of error (confusion) matrix

Step 2: Calculation of observed correct

Grand total = Sum of rows and columns

Total correct = Sum of the diagonal

Observed correct = Total correct / Grand total

Hence, Overall accuracy is obtained.

Step 3: Calculation of expected correct

Grand total = Sum of products of row and column marginal

Total correct = Sum of products of diagonal

Expected correct = Total correct / Grand total

(For the calculation of expected correct, an error matrix showing products of row and column marginal were prepared in step 1)

Step 4: Calculation of K

K= (Observed – Expected) / (1 – Expected)

3.2. METHODS FOR IMPACT AND MANAGEMENT OF FLOOD

The impact of floods and existing management strategy and resources in the study areas was investigated by incorporating multiple studies.

3.2.1 PRIMARY DATA COLLECTION

3.2.1.1 Key Informant Interviews

Interview forms the initial stage of this research. It was conducted among the local community leaders using semi- semi-structured design of interview. The interview questions were predominantly on the historic phenomenon of the Tlawng river flood in the study area. Focus was laid on the flood impacts on different sectors. The measures adopted to tackle the calamity and actions towards response were also given due importance. Furthermore, the available management strategy for different phases of disaster and the expected road ahead were discussed during the interview session.

Since the intensity of suffering was basically of the historical phenomena, the researcher had to rely heavily on the responses to interview questions. For such cases, the selection of interviewees was mindfully pre-determined and purposively selected. As mentioned above, the local community leaders are the targeted focus group to be interviewed. The Office Bearers and Senior Advisers of Young Mizo Association, Sairang Branch, were interviewed for Sairang study area. While in Bairabi study area, an interview was held with the elected members of the Village Council, Bairabi South.

The rationale behind the selection of the mentioned respondents was-

i) All the community leaders being the residents of the study area was advantageous.
ii) Working with the community, they could express the locals' knowledge and perceptions on flooding and other disasters.
iii) They were consistently the first responder to any calamity by promoting voluntarism.
iv) Through their actions rendered and experiences gained, they have the potential to identify the areas and degrees of vulnerability, coping capacity, and address the lacks and gaps towards mitigation.
v) They represent the people's voice and serve as a link to the government's officials and other stakeholder.

3.2.1.2 Structure of Interview Questions

A semi-structured, open-ended question was listed and organized the sequence systematically for each component. The desired respondents were contacted in advance, describing the purpose of the research interviews. After an agreement were made between the researcher and the respondents, the time and venue for conducting the interview were arranged by the respondents as per their convenience. The respondents were given freedom to deliberately expand their responses in expressing their ideas, perceptions, and thoughts. Meanwhile, the researcher was cautious to avoid the occurrence of pre-designed questions being left out.

The interview serves a critical role by providing an in-depth ground knowledge. It also serves as a medium for the construction of questionnaires.

3.2.1.3 Household Survey

The household survey is the most widely used research method, which allows the collection of data on socio-economic aspects of a specific area. It serves as a great alternative method where resources and information are limited (Sharma and Gupta, 2009). Despite of its effectiveness, household surveys possess several challenges for the researcher (Gakidou and Hogan, 2005). Conducting a household survey is time-consuming, expensive, and the success lies heavily in the efficacy of the methods employed.

Due to insufficient data on the impact and management of floods for both study areas, a household questionnaire survey was conducted to address the gaps. The chief target of this survey is to acquire accurate information on the socio-economic impacts of flooding, the existing flood risk management, along with its consequences, and the community perceptions on floods.

3.2.1.4 Design of Questionnaire

A semi-structured type of questionnaire was employed, where there is inclusion of open-ended, closed-ended, and probing questions. Heedful of today's busy schedule, the questionnaire was designed to collect adequate and thorough data on the focus topics while an attempt was made to keep the possible least questions. After careful consideration, all the queries can be piled up within 14 items, which were divided into 3 sections. The first section within the questionnaire begins with a greeting, followed by detailed descriptions of the survey purpose. The sequence of the questions is arranged in such an easy way to navigate for the respondents. To enhance the comprehensibility, the script was in Mizo language, which is also a native language of the researcher.

The information acquired through interviews, which were conducted prior to the questionnaire survey, played a very crucial role in framing the questionnaire. It provided an insight into the limits of variables to incorporate. Another significant step in this regard was conducting a pilot survey. The questionnaires were sent to local community leaders to make sure that every question is understandable. As suggested by respondents during the pre-test, some questions were modified and amended. After confirming that the contents of the questionnaire are appropriate against cultural and traditional norms and legible for every literate person, an actual survey was carried out. The sample of the detailed questionnaire can be accessed from Appendix B.

3.2.1.5 Sampling Techniques

The sampling unit in this survey is the household. Samples were collected using Simple Random Sampling techniques as the survey aims to collect data encompassing the entire town of study area. With this technique, there is a chance for every household to be involved, thus preventing bias in data collection. It is worth mentioning here that the help and support rendered by the community leaders tremendously facilitate the survey process.

Sample size is determined using Cochran formula of sample size with 5% margin of error and 95% confidence level.

Cochran's formula of sample size is given as:

$$n' = \frac{n}{1 + \frac{z^2 \times \hat{p}\,(1 - \hat{p}\,)}{\varepsilon^2 N}}$$

(Equation 3.8)

Where,

z is the z score

ε is the margin of error

N is the population size

p̂ is the pop ulation proportion.

3.2.2 SECONDARY DATA COLLECTION

To assess the indirect human impacts of flooding, drowning accident records were collected from Sairang and Bairabi Police Station (2010- 2023). These records include details on the date of incidents, location, age, gender, and address of victims. Cases were classified by season into monsoon (May- September) and dry season (October- April) to analyse the seasonal relationship between flooding and drowning risks.

The drowning data were analysed descriptively to determine:

- ❖ The proportion of cases occurring during the monsoon
- ❖ Age and gender patterns
- ❖ Differences between local residents and outsiders
- ❖ Contextual risks were highlighted during interviews.

This approach enabled triangulation with flood impact data to capture the hidden mortality risks associated with flooding in Sairang and Bairabi.

3.2.3 STATISTICAL ANALYSIS

To systematically assess and interpret the differences and patterns in flood impacts between Sairang and Bairabi**,** a rigorous quantitative analysis framework was employed. By using descriptive statistics, paired samples t-tests, and Pearson correlation analysis, the study rigorously quantifies and interprets the differences and relationships in flood impacts between Sairang and Bairabi. This multi-layered analytical approach supports the categorisation of flood impacts into primary, secondary, and tertiary effects while providing evidence-based insights for disaster risk reduction and community resilience planning.

3.2.3.1 Descriptive Analysis

Descriptive statistics offer a basic overview of the data by summarizing key characteristics of the sample and its measurements.

Descriptive statistics were employed to:

- Calculate mean percentages for each impact category in Sairang and Bairabi.
- Enable clear comparisons across categories and towns.
- Provide a foundation for inferential testing by identifying categories with high and low reported impacts.

These statistics were presented in comparative tables for visual clarity and interpretation.

3.2.3.2 Paired Sample t-Test

The paired samples t-test, often called the dependent samples t-test, is a statistical method used to check if there's a meaningful difference between the averages of two related sets of data. It's most often used when the same people or items are measured twice, such as before and after an intervention, under two different conditions, or at two different times. This test works best when the data is continuous and follows a normal distribution (Choudhury et al., 2023). By comparing the differences between each pair of measurements, it helps researchers to figure out whether any change observed is likely due to the specific conditions being tested, rather than just random chance.

Purpose in this study:

- To test whether there are significant differences in flood impacts between Sairang and Bairabi across each category.

- To validate the hypothesis that Bairabi generally faces higher primary and secondary impacts, while Sairang faces specific tertiary impacts.

Hypotheses:

- **H_0:** No significant difference in mean flood impacts between Sairang and Bairabi.
- **H_1:** Significant difference exists in mean flood impacts between Sairang and Bairabi.

Interpretation Framework:

- $p < 0.05$ → Reject H_0, indicating a significant difference.
- $p \geq 0.05$ → Fail to reject H_0, indicating no significant difference

3.2.3.3 Correlation Analysis

The Pearson correlation coefficient (r) is a *parametric test* used to measure the strength and direction of the linear relationship between two continuous variables (Choudhury et al., 2023).

Purpose in this study:

- To assess systematic relationships between flood impact categories across the two towns.
- To determine whether higher impacts in Bairabi correspond to relatively higher impacts in Sairang across categories, indicating shared vulnerabilities.

Interpretation Framework:

Table 3.1 R values and interpretation of Pearson Correlation Analysis

***r* values**	**Interpretation**
0.0–0.3	Weak correlation
0.3–0.5	Moderate correlation
0.5–0.7	Strong correlation
0.7–1.0	Very strong correlation
$p < 0.05$ indicates the correlation is statistically significant.	

3.3 METHODS FOR FLOOD VULNERABILITY ASSESSMENT

Flood vulnerability assessment aims to explore the extent to which an individual or a community is susceptible to flood hazard. Vulnerability is denoted by several factors that can vary in different settings of an environment in different regions (Gao et al., 2007). Likewise, the intensity of impact varies across the world, which urges the need and magnifies the importance of vulnerability assessment (Rehman et al., 2019). Consequently, vulnerability assessments are performed using various techniques. (Huang et al., 2012). Among these, the indicator-based method is found to be the most effective technique due to its accountability for policymakers, the public, government, and several organisations (Nasiri et al., 2016; Birkmann et al., 2013).

3.3.1 STUDY DESIGN

This study adopted a multi-dimensional vulnerability assessment approach integrating quantitative and qualitative data to formulate a Flood Vulnerability Index for Sairang and Bairabi. The FVI framework was used to evaluate and compare the vulnerability of six zones within these settlements, based on four major components: social, economic, physical, and environmental. Each component consisted of indicators categorized under exposure, susceptibility, and resilience, following the standard structure used in disaster risk analysis (Birkmann et al., 2013; UNDRR, 2022).

3.3.2 COMPUTATION OF FLOOD VULNERABILITY INDEX (FVI)

The Flood Vulnerability Index serves as a techniques to evaluate flood risk across river basin, sub-catchment, and urban contexts, categorizing the components that shape the exposure of those residing in flood-prone locations. (Mohanty et al., 2020; Nasiri et al., 2019). Factors or agents that influence vulnerability can vary significantly across different settings, including geographic locations, cultural values, economic aspects, and political factors (Pathak et al., 2020). FVI allows the identification of the factors which are responsible for vulnerability, acting as a useful aid for those involved in decision-making (Connor and Hiroki, 2005).

As indicators for the Flood Vulnerability Index (FVI) require predetermined risk factors, a deductive approach was used in this research, as it is the best method for developing FVI (Balica et al., 2009). Indicators were selected from the existing principles and theoretical concepts, which were collected through field surveys and secondary data. A total of 29 indicators were linked to vulnerability factors such as exposure, susceptibility, and resilience for different components of vulnerability-physical, social, economic, and environmental. Based on their significance towards defining the extent of vulnerability, ranks were assigned to the indicators (see Appendix C).

The Flood vulnerability index was computed by employing FVI equation developed by Balica & Wright 2010;

$$FVI = \frac{\mathrm{E+ S}}{\mathrm{R}} \qquad \text{(Equation 3.9)}$$

Where,

E= exposure

S= susceptibility

R= resilience

Indicators of different components and factors in this study were modified by the researcher. It was performed due to a large differentiation regarding the information available. A numerous amount of pre-existing indicators could not be attained within the entity of the study areas. However, all the indicators for different factors were selected based on the agreement made with local leaders of the study areas and research papers reviewed by the researcher (Nath, 2011; Chan et al., 2022; NDMA, 2008; Balica & Wright, 2010; Balica et al., 2012).

i) Flood Vulnerability Index for Social Components:

$$SVI = f\left[\frac{FwChd+FwSrCtzn+FwPwds+FdScr+WtrScr+Sdis+EPD+ComProb+InsHC}{PrtDmT+EW}\right]$$

(Equation 3.10)

Where,

- FwChd = Family with Children below the age of 14 years
- FwSrCtzn = Family with Senior Citizen above the age of 65 years
- FwPwds = Family with Persons with Disabilities
- FdScr = Exposed to food scarcity
- WtrScr = Exposed to water scarcity
- Sdis = Experienced social activities disruption
- EPD= Suffered epidemics outbreaks
- ComProb Encountered Communication challenges
- InsHC= Lack of Health care facilities
- PrtDmT= % of family member engaged in any kind of Disaster Management Training/ Awareness Programme
- EW= % received Early warning

ii) Flood Vulnerability Index for Economic components:

$$\text{EVI} = \text{f}\left[\frac{\text{InCm+HsTyp+PerEvc+TemEvc+StgJob}}{\text{RecoTm+RlfBnfc}}\right] \qquad \text{(Equation 3.11)}$$

Where,

- InCm= Family Monthly Income
- HsTyp= House Type
- PerEvc = Permanently Evacuate Houses
- TemEvc = Temporarily Evacuate Houses
- StgJob = Stagnant of Job during Flooding
- RecoTm= Recovery Time
- RlfBnfc = Relief beneficiaries

iii) Flood Vulnerability Index for Physical Components:

$$\text{PVI} = \text{f}\left[\frac{\text{SlpAgle+Ele+SvrInd+PrtlInd}}{\text{PreDgSh+ StrMtg}}\right] \qquad \text{(Equation 3.12)}$$

Where,

- SvrInd= Severe Inundation
- PrtlInd= Partial inundation
- PreDgSh= Pre- design Shelter
- StrMtg= Structural Mitigation for flood protection

iv) Flood Vulnerability Index for Environment Components:

$$\text{EnVI} = f\left[\frac{\text{Fldfq+Rain+Soil+Defr+Settlmt}}{\text{Forest}}\right] \qquad \text{(Equation 3.13)}$$

Where,

- Fldfq = Flood frequency
- Rain = Heavy rain days (rainfall ≥ 115mm)
- Soil = Type of Soil
- Defr = Rate of Deforestation
- Settlmt = Increased rate Settlement area
- Forest = Forest Cover

To identify the most vulnerable areas, the study areas were classified into 3 zones for both the study areas. The zonation was based on the existing boundaries of the local settings. The names given to zones in Sairang are- SR-I, SR-II, and SR-III. While Bairabi town was zoned as BRB-I, BRB-II, and BRB-III. The vulnerability in different components was assessed for each zone. The Overall Vulnerability Assessment was calculated by summing up all the vulnerability components, which can be expressed as:

$$OFVI = \frac{\text{SVI+EVI+PVI+EnVI}}{4} \qquad \text{(Equation 3.14)}$$

3.3.3 CORRELATION ANALYSIS OF INDICATORS

To validate the theoretical underpinnings of the FVI, Pearson correlation analysis was performed using SPSS. The primary objective was to examine:

- The correlation between resilience indicators and exposure/ susceptibility indicators
- The internal consistency of indicators within each component.

The correlation matrix revealed that most resilience indicators showed a significant negative correlation with exposure and susceptibility indicators (Labuschagne, 2003) which is consistent with the FVI logic- higher resilience reduces overall vulnerability (Birkmann et al., 2013; Gall, 2007).

Significance was determined using the following criteria:

- ** : Correlation is significant at the 0.01 level (2- tailed)
- * : Correlation is significant at the 0.05 level (2- tailed) (Kembe at el., 2016).

Where sample size permitted, statistical strength and direction of relationships (positive/ negative) were interpreted to assess indicator validity. In cases with limited sample sizes (e.g., environmental indicators), correlation results were interpreted cautiously and contextualized with field observations.

3.3.4 VULNERABILITY MAPPING

A disaster vulnerability map is a visual representation that depicts areas prone to natural or human-made disasters (Giustiniani, 2018). It highlights regions at higher risk of being impacted by events like floods or other hazards. A Flood Vulnerability map, including a map for each component of vulnerability for Sairang and Bairabi towns, was generated using ArcGIS 10.8.2.

The steps and techniques for mapping Flood vulnerability are-

- Location points of boundaries for each zone were collected using DGPS.
- The collected points were outlined using a polygon shapefile.
- Join and relate tool was used to merge the computed values of vulnerability with the shapefile.

Interpolation was performed using IDW (Inverse Distance Weighting).

CHAPTER 4

CAUSES OF FLOOD

4.1 INTRODUCTION

Flood hazards arise from a range of factors depending on their nature, geographical location, and intensity. As a result, the causes of flooding can vary significantly from one region to another. Analysing flood risk is a complex process that demands a comprehensive assessment of multiple variables (Smith & Ward, 1998). In some cases, a single factor can cause widespread devastation, while in others; several contributing agents may collectively trigger a flood event. Therefore, effective flood risk analysis requires the identification of key drivers, the assessment of underlying causal factors, and the recognition of intermediate variables that contribute to the occurrence of disastrous floods (Hall, 2014).

Like other disasters, the primary causes of flood disasters can broadly be classified into two factors: 1) Natural Causes and, 2) Anthropogenic Causes.

Natural causes include the process of meteorological, climatological, and hydrological conditions prevailing over a specific area. The most common and principal component of the flood driving factor is seasonal rainfall. The distribution and characteristics of precipitation largely dictate the magnitude and intensity of flood disasters (Sharma et al., 2018). However, flood generation takes place under various conditions, under the circumstances of intensity and duration of rainfall. There are times when incessant rainfall is held responsible for flooding in some cases; while on the other hand, a sudden torrential rain is obvious for flash floods. Moreover, the period of consecutive rainfall plays a vital role in the implementation and execution of all phases of the disaster management cycle (Srivastava, 2020). Aside from the severity of the impact, post- disaster weather conditions also affect the efficiency rescue and relief efforts. Continuous rainfall certainly impedes the performance of responders, thus exacerbating the impacts of flooding (Jonkman & Kelman, 2005). Subsequently, climate change has caused a great fluctuation around the globe. The phenomenon of unexpected heavy rainfall, abrupt rise and low temperature, melting of glaciers, sea-level rise, etc., has become a serious threat that confronts the present generations. These climatic anomalies have significantly contributed to the increasing frequency and severity of floods and other climate-related calamities (Bruyn & Olbrechts, 2025).

Other significant aspects of natural drivers of floods are the characteristics of the drainage basin and physiographic of the watershed area. The size of the river basin extensively manifests its capacity to accommodate the inflow. The types of soil denote the rate of infiltration, which significantly influences surface runoff, thus controlling the volume of discharge and velocity of flows in the river (Beven & Kirkby, 1979). Additionally, the rate of soil erosion so largely depends on the characteristics and soil types prevailing within the basin. The magnitude of flooding over an area corresponds to the physical features of the landscape to a great extent. The physical setting of an area, such as the elevation and slope steepness, influences the flow velocity, discharge amount, and inundation period.

It is undoubtedly admissible that a flood is a natural disaster. However, the intensifying factors of human activities on nature require an investigation, thereby finding solutions to it. Anthropogenic factors contributing to flood disasters include rapid urbanization and the lack of adequate water management infrastructure such as reservoirs, dams, and levees. Increased urbanization causes the construction of waterproof surfaces on the ground, altering the natural drainage system and making the area more susceptible to flooding (Di Baldassarre et al., 2010). It also encourages the expansion of settlements into floodplains. Poorly maintained urban infrastructure also increases the risk of flooding (Munawar, 2020). Nevertheless, a significant proportion of flood related disasters are closely linked to extreme climatic events. Climate change- identified as a major driver of not only floods but also other hazards such as drought, heat waves, cold spells and wildfires continues to intensify the frequency and severity of such event (IPCC, 2021).

The increasing amount of water in the river system during monsoon is a natural phenomenon that has great advantages for farmers. The fertile soil deposited by the actions of floods is suitable for crops. On the other hand, when the intensity rises to the extent beyond the coping capacity of an individual or community, it becomes a disaster (Mishra & Singh, 2010). Understanding and identifying the risk and its agents that potentially produced the flood disaster paves the way towards the effective formulation and adoption of mitigation strategies.

4.2 NATURAL CAUSES OF FLOODS IN THE STUDY AREAS

There is a prevalence of naturally occurring events over which humans have no direct control. In one way or another, these natural processes have largely contributed to flood risk in Sairang and Bairabi towns. The natural causes of floods in the study area can broadly be classified into two main categories- physical and meteorological. The physical aspect comprises the topography, and the meteorological components deal with the rainfall received over time.

It is obvious that the chief causal factor of floods in the Tlawng River of Sairang and Bairabi towns is the intensity and duration of rainfall. Although the amount of rainfall input matters the most, there can be several factors that accelerate the intensity of flooding. The capacity of the basin and the natural settings of the watershed area have also largely contributed to its severity and susceptibility.

4.2.1 Rainfall Analysis

Both the study areas have experienced floods of various magnitudes, which usually take place during the summer monsoon. However, it is evident from experience that flooding is not an annual event that harms the community. There are indeed several years when rainy seasons have gently rolled over without causing chaos. For such, it is crucial to investigate the characteristics of rainfall that generate the most risk in the study area. (Choudhury et al., 2023). Hence, 17 years of daily rainfall data from Aizawl and Kolasib districts were analysed to extract total annual rainfall, monthly averages, and annual daily maximum rainfall. The frequency of annual daily maximum rainfall was estimated by computing the return period and its probability of occurrence. The analysis of rainfall in such different parameters helps in identifying the chief accountable rainfall characteristics prompting the flood events.

For this study, ‘flooding year’ was referred to and considered specifically the stage of inundation that disrupts the normalcy of the inhabitants of Sairang and Bairabi towns. As per IMD definitions, only a day having a record of 2.5mm or more was considered a rainy day (Jain et al., 2007).

4.2.1.1 Total Annual Rainfall

As shown in Figure 4.1, there is a significant variation in the total annual rainfall received in the two districts where the study areas are located. The highest amount in Aizawl district—2687mm—was observed in 2017, while the lowest, 1548mm, occurred in 2008. In Kolasib district, there are substantial fluctuations, with the maximum rainfall of 3281mm recorded in 2010, which declined thereafter, where the lowest total annual rainfall—1477mm—was recorded in 2021.

Considering the flooding year, the 2017 flood is the single event that can be interrelated with the total annual rainfall. Despite the significant rainfall in 2010, 2011, and 2012, no disastrous flood cases were reported during these years. 1749 mm and 1862 mm in Aizawl and Bairabi, respectively, are the amounts of total annual rainfall in the flooding year of 2018. The floods created havoc in the year 2008, which was in fact the year of minimum total annual rainfall in the Aizawl district.

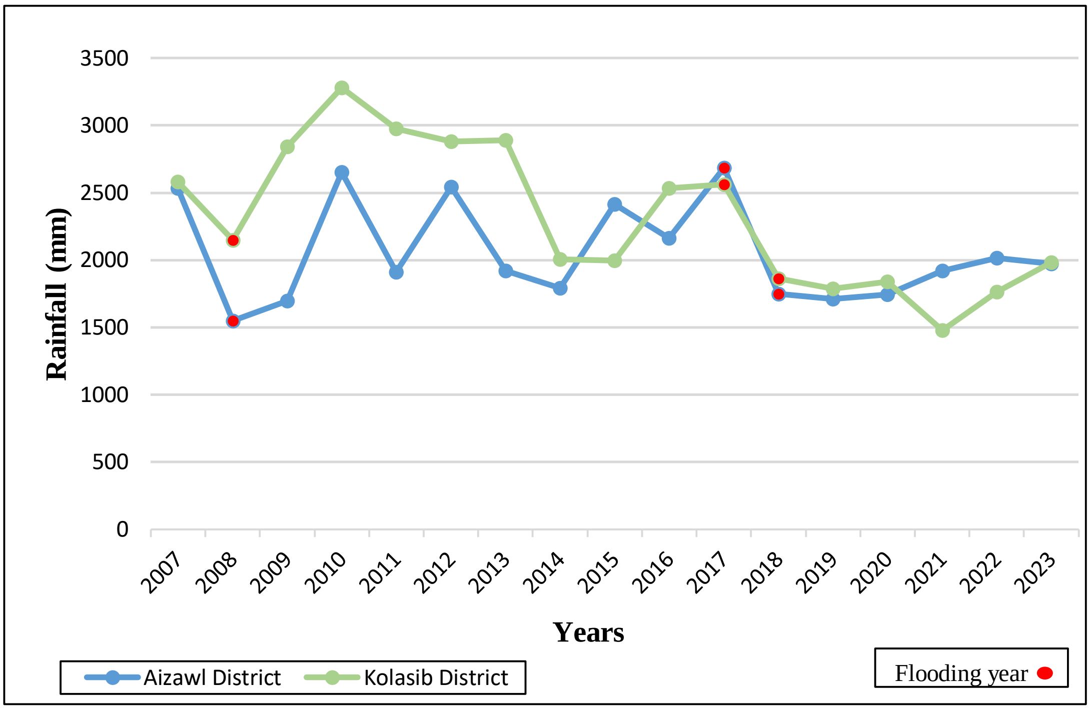


Figure 4.1 Total annual rainfalls

[Source: State Meteorological Centre, Directorate of Science and technology, Government of Mizoram]

4.2.1.2 Monthly Average Rainfall

During the years 2007- 2023, the study areas received an adequate amount of rainfall during the summer monsoon. The rainy season begins from the late month of May, lasting up to the month of September. Observation can be made from Figure 4.2 that Kolasib district averaged more rainfall than Aizawl district. Although the rainfall drizzled during the winter season is scanty, a fine measurable amount of rainfall was received during the seasons of spring and autumn.

Amounting to 78% in Aizawl district and 77% in Kolasib district, most of the annual rainfall was observed between the months of May- September. The monthly average rainfall climbs to its highest peak in August, followed by July, June, September, and May. Taking flood events into account, all the flooding cases in the study areas fall within these months of monsoon. This strong evidence highlights the influence of rainwater inputs into the river system and the downpour over the watershed on the development of flood events.

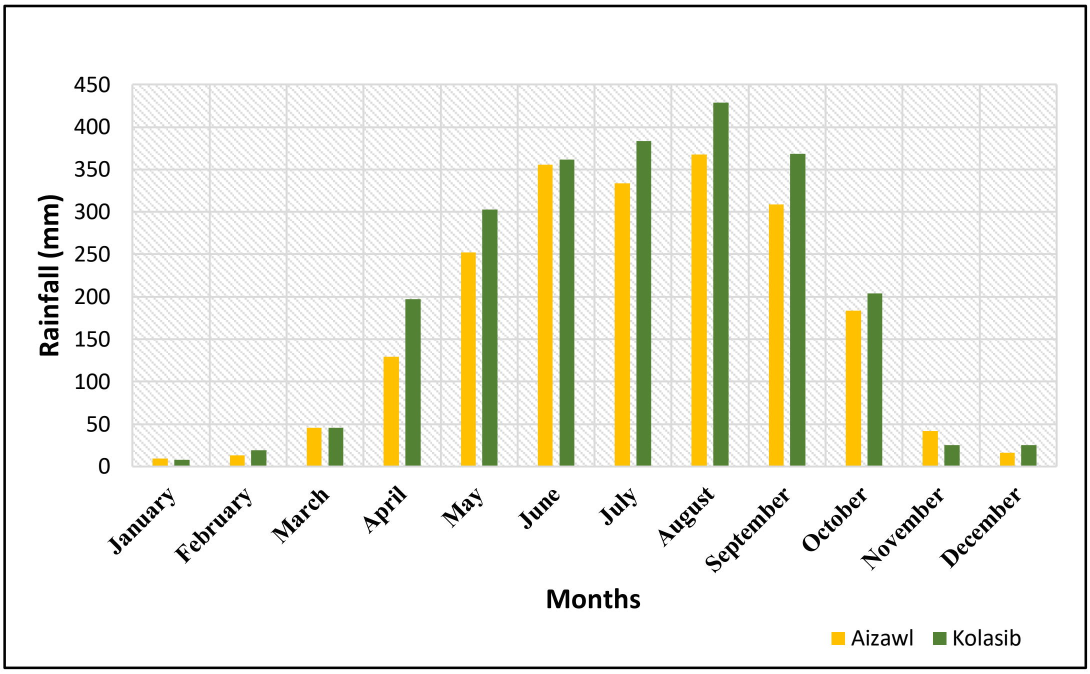


Figure 4.2 Monthly average rainfalls during 2007- 2023

[Source: State Meteorological Centre, Directorate of Science and Technology, Government of Mizoram]

4.2.1.3 Annual Daily Maximum Rainfall

The highest daily rainfall recorded in any single day during the years 2007-2023 in Aizawl and Kolasib districts was mostly confined to the monsoon season, as shown in Figures 4.3 and 4.4. During 17 years, the month of August holds the most records with 5 and 6 times in Aizawl and Kolasib district, respectively. In Aizawl district, Annual Daily Maximum Rainfall (ADMR) was recorded 3 times each in June, July, and September. Meanwhile, there are years when records can also be observed in April, October, and December. The intensity of rainfall over Aizawl district has largely impacted the flood of Tlawng River in Sairang. The highest rainfall recorded in the years 2007, 2017, and 2018 was instantly followed by destructive floods. Resulting from the heavy rain on 7th December, 2021, Tlawng River was unexceptionally flooded. Although no severe casualties were reported, floods during the winter season were a completely rare event that the community had ever experienced. It is noteworthy here that this very day of flooding was the only day in 17 years when ADMR recorded falls in the winter season.

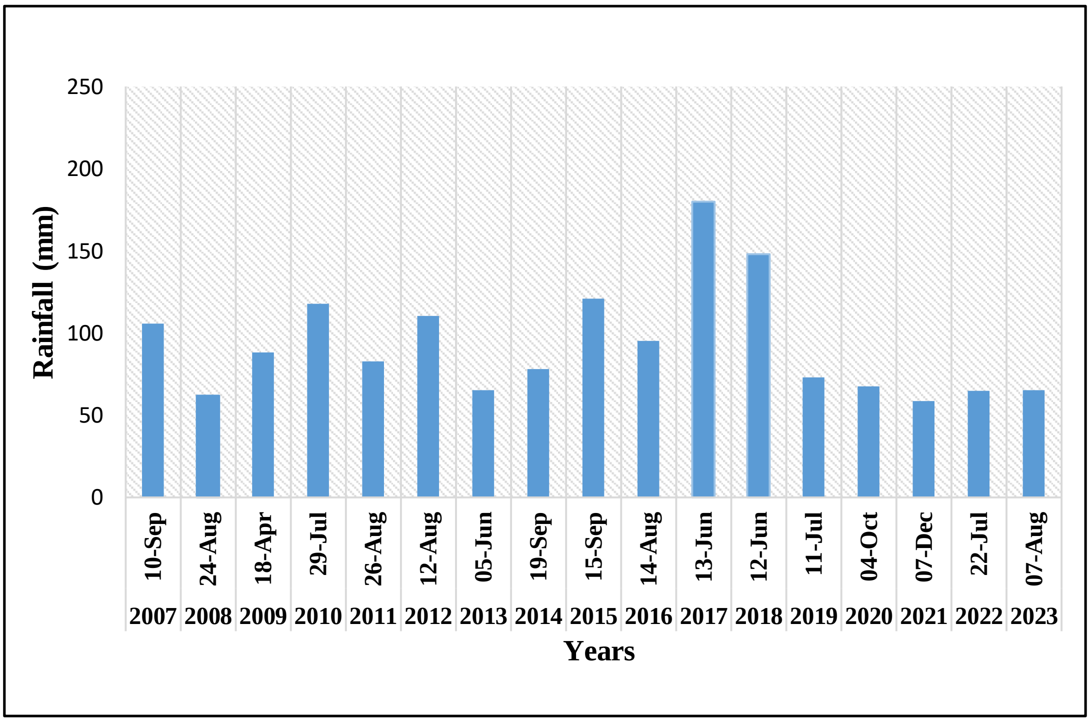


Figure 4.3 Annual Daily Maximum Rainfall in Aizawl district during 2007- 2023.

[Source: State Meteorological Centre, Directorate of Science and Technology, Government of Mizoram]

As mentioned, the most frequent ADMR in Kolasib district was recorded in the month of August, followed by June, with 4 different years. The monsoon months of September and July were also observed to be on the list of records, with 3 and 2 times, respectively. There is a year when ADMR were recorded on the onset of monsoon, i.e., May. In 2020, the highest single-day rainfall was received in the month of October.

Taking into account the history of floods in Bairabi, the ADMR of Kolasib district has a significant role in causing the river flood. Destructive floods were experienced on 9^{th}-11^{th} September 2008, 9^{th}– 11^{th} June 2017 and 11^{th} -14^{th} June 2018.The 2018 flood was the worst flood that occurred on the heaviest single-day rainfall record for that year. But it can be observed from Figure 4.4 that the 2008 and 2017, on the other hand, have not coincided with the ADMR of Kolasib district. Rather, these floods concurrently respond to the ADMR of Aizawl district. Thus, it is evident that the ADMR in Aizawl district, i.e., within the upper reach of the river, also has greatly influenced the factors for flooding in Bairabi.

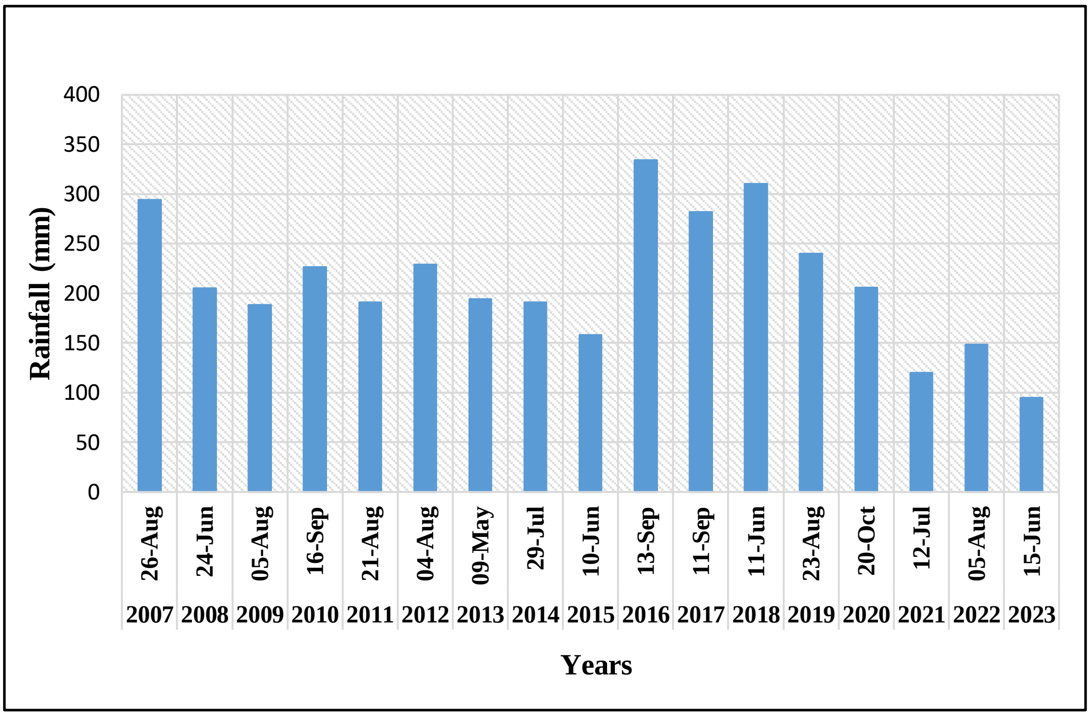


Figure 4.4 Annual Daily Maximum Rainfall in Kolasib district during 2007- 2023

[Source: State Meteorological Centre, Directorate of Science and technology, Government of Mizoram]

4.2.1.4 Estimation of Annual Daily Maximum Rainfall

Since the amount of single-day rainfall greatly influences the events of flooding, the ADMR of 2007- 2023 was chosen for analysis. The probability and recurrence interval of each year's maximum are computed using Weibull’s formula.

Among the different trend lines drawn to the rainfall amount (x axis) with their recurrence interval (y axis) in a semi-log graph, the logarithmic trend line provides the best fit as shown in Figures4.5 and 4.6. The correlation co-efficient (R^2) are presented in Table 4.1is 0.99 and 0.88 for Aizawl and Kolasib, respectively. The observed equation (y) for Aizawl district is 42.333ln(x) + 54.24, and 83.203ln(x) + 142.48 for Kolasib district.

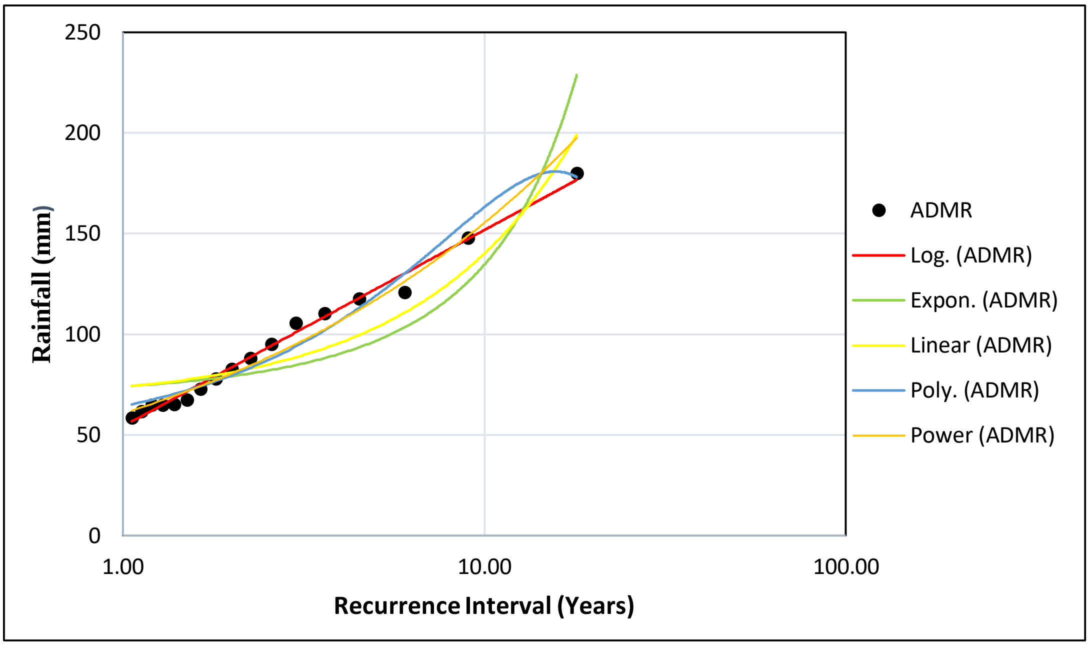


Figure 4.5 Recurrence interval of ADMR, Aizawl District

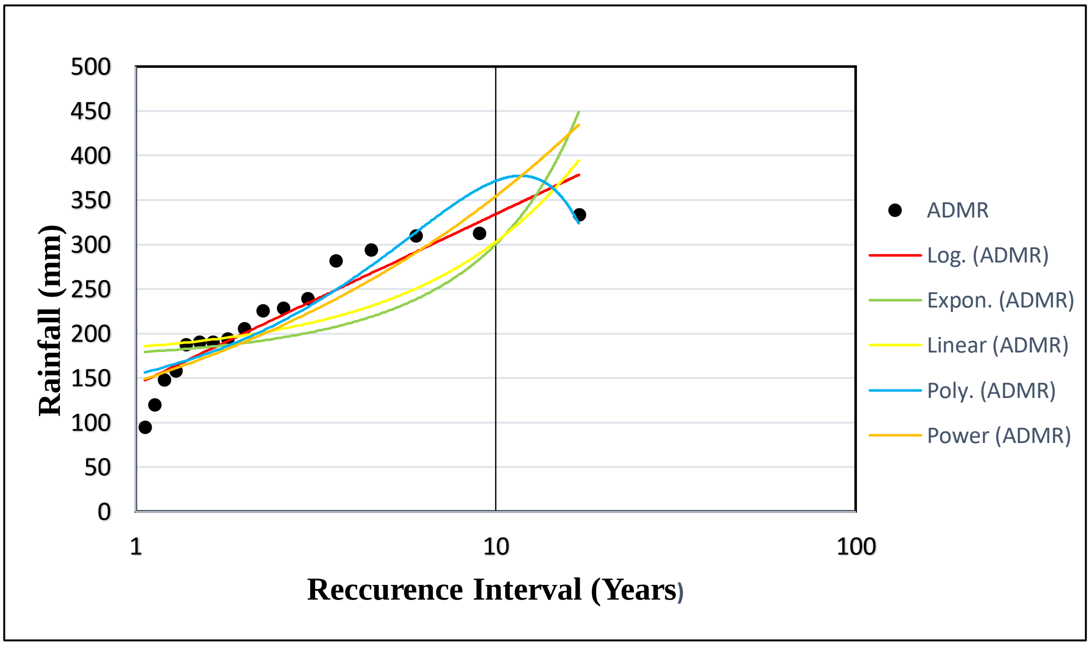


Figure 4.6 Recurrence interval of ADMR, Kolasib District

Table 4.1 Coefficient and equations of ADMR recurrence interval in different trend lines

Trendline	**Aizawl**		**Kolasib**	
	R^2	**y- value**	**R^2**	**y- value**
Logarithmic	0.990	42.333ln(x) + 54.24	0.882	83.203ln(x) + 142.48
Exponential	0.730	69.308e0.0663x	0.447	168.77e0.0576x
Linear	0.855	7.3671x + 66.335	0.577	13.096x + 171.81
Polynomial	0.966	-0.5364x2 + 16.885x + 47.905	0.853	-1.9382x2 + 45.483x + 110.42
Power	0.972	60.597x0.4087	0.761	145.66x0.385

In Aizawl district, the highest single-day rainfall, which has greatly influenced flooding in Sairang and Bairabi in 2017, was 180 mm. The estimation shows that, with a 5.6% exceedance probability, 180mm of rainfall has a recurrence interval of 19.5 years. This means that the chance of receiving a rainfall amount of 180mm or more within any 19.5 years is 5.6%. Likewise, as shown in Table 4.2, with different exceedance probabilities, the estimated amount of rainfall in 5, 10, 15, and 20 years recurrence intervals was122.37 mm, 151.71 mm, 168.87 mm, and 181.05 mm, respectively. The 95% dependable rainfall, i.e., 56.30 mm, can be expected to recur at 1.5 year intervals.

Table 4.2 Estimated probability of rainfall in various recurrence intervals for Aizawl district

Recurrence Interval (Years)	**Rainfall (mm)**	**Exceedance Probability (%)**
5	122.37	20.0
10	151.71	10.0
15	168.87	6.7
20	181.05	5.0
1.05	56.30	95.0
19.5	180.00	5.6

Meanwhile, in Kolasib district, the highest ADMR, which is 334 mm, was recorded in 2016. The ADMR estimation shows that there is a 10.1% probability of receiving that certain amount or more in any 9.9 years. However, 309.80 mm in 2018 is the amount of single-day rainfall that led to the destructive flood in Bairabi town. The amount of rainfall equal to or exceeding this magnitude at any 7.5 years can be expected to occur with a probability of 13.4%. Consequently, it can be observed from the estimation that there is a 95% chance in 1.5 years of receiving 176 mm or more rainfall in the district. The amount of rainfall in their recurrence interval of 5, 10, 15, 20, and 25 years, with the respective exceedance probability, was estimated as presented in Table 4.3.

Table 4.3 Estimated probability of rainfall in various recurrence intervals for Kolasib district

Recurrence Interval (Years)	Rainfall (mm)	Exceedance Probability (%)
5	276.39	20.0
10	334.06	10.0
15	367.80	6.7
20	391.73	5.0
25	410.30	4.0
1.5	176.22	95.0
9.9	334.00	10.1
7.5	309.80	13.4

4.2.1.5 Duration of rain days

The outbreaks of floods and the time of inundation heavily rely on the duration of rainfall. Prolonged rainfall results in a reduction of the infiltration rate, thereby increasing surface runoff, which accelerates the rate of water volume. Regardless of the intensity, incessant rainfall is also held highly responsible for to flood risk in Sairang and Bairabi towns. Considering the historical occurrence of flood events in both the study area, there were variations in the duration of consecutive rainfall before the incidents.

Ahead of the time when the flood disrupts Sairang community in June 2017, there were 4 days of consecutive rainfall, where a total amount averaged to 70.6 mm. In 2018, floods hit the community on the second day of consecutive rainfall. The average rainfall within these two days amounted to 88.5 mm. Also, in the 2008 flood that created havoc in Bairabi, two consecutive rain days of 65.8 mm total average were recorded before the inundation. However, 4 and 3 days of incessant rainy days experienced in Bairabi were followed by severe floods in 2017 and 2018, respectively. The 4 days of rainfall before the 2017 flood amounted to 73.42 mm on average, while 134.20 mm of average rainfall was recorded during the 3 consecutive rain days before the flooding emerged in June 2018.

4.2.2 Temporal Variation in the River's Course

Flooding in riverine environments is governed by climatic factors, topography, and seasonal changes in river morphology. In monsoon-dominated regions like Mizoram, seasonal rainfall patterns significantly influence river discharge, channel expansion, and morphological adjustments, which in turn determine the flooding extent along riverbanks and adjacent floodplains (Kale, 2003; Wilson & Richards, 1988). Understanding these natural causes is essential for flood vulnerability assessment and effective management planning (Ward, 1978).

To analyze these dynamics in the Tlawng River, systematic river line surveys were conducted during pre-monsoon and monsoon seasons using Differential Global Positioning System (DGPS) and Total Station to capture changes in channel alignment, width, and floodplain encroachment under different seasonal hydrological conditions in Sairang and Bairabi (Thakkar & Dhiman, 2007).

4.2.2.1 Tlawng River Profile Change in Sairang

In Sairang, river line surveys were conducted on 17th March 2023 and 23rd August 2023 for pre-monsoon and monsoon, respectively. The pre-monsoon survey was undertaken during a period of no rainfall, accurately capturing the river's low-flow condition and baseline morphology. During the monsoon survey, the region experienced seven consecutive rain days before the survey, totaling 86mm of rainfall, with the annual daily maximum rainfall recorded as 95 mm on 15th June 2023.

The graph shown in Figure 4.7 illustrates the plan view alignment of Tlawng River at Sairang, comparing pre-monsoon and monsoon river lines along the left and right banks. The red diamond markers indicate survey points for the pre-monsoon river line, while monsoon lines are shown for comparative alignment.

A noticeable widening of the river channel during the monsoon season is observed, indicated by the outward shift of the monsoon river lines from the pre-monsoon positions. This widening reflects the increased discharge and water volume during monsoon, which typically results in bank overtopping and floodplain inundation in the low-lying zone (Mishra & Singh, 2010). The channel migration patterns are evident in certain stretches where the monsoon river line shifts laterally toward either the left or right bank. This lateral movement is likely associated with erosion on the outer bands and deposition on the inner bends of the river channel, a typical fluvial process intensified during high-flow periods (Knighton, 1998).

It is noteworthy that 2023 was not a year of heavy rainfall, and consequently, no severe floods were recorded in Sairang during this year. This contrasts with 2017, where the annual daily maximum rainfall reached 180 mm, contributing to a significant flood event in the region. A flood mark monument placed in Sairang indicates the 2017 flood high-water level at 102 meters, while in the 2023 monsoon; the highest water level observed in the same zone was around 92 meters, reflecting the reduced flood intensity and demonstrating the strong link between rainfall intensity and flood severity.

Furthermore, the elevation data collected (Table 4.4 a & b and Table 4.5 a & b) shows a reduction in freeboard during the monsoon period, highlighting a temporary reduction in channel capacity to contain high flows, which is a key mechanism through which seasonal river changes contribute to localized flooding.

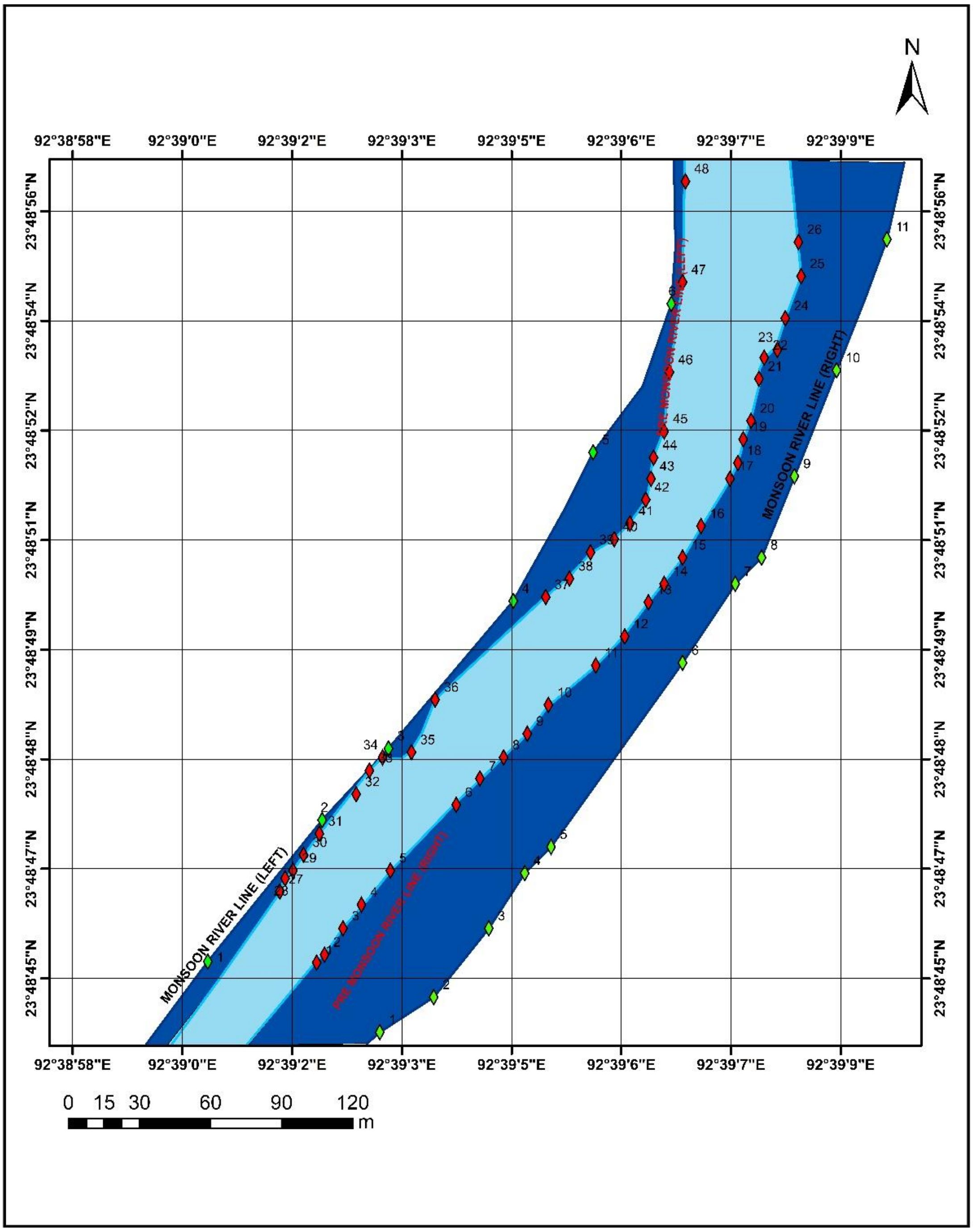


Figure 4.7 Seasonal river line profiles of the Tlawng River at Sairang

Table 4.4 (a) Coordinates and Elevations of Survey Points along right bank of Tlawng River at Sairang during Pre-Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	23° 48' 45.21" N	92° 39' 1.83" E	90
2	23° 48' 45.32" N	92° 39' 1.94" E	89
3	23° 48' 45.68" N	92° 39' 2.19" E	89
4	23° 48' 46.08" N	92° 39' 2.44" E	89
5	23° 48' 46.47" N	92° 39' 2.84" E	89
6	23° 48' 47.37" N	92° 39' 3.74" E	93
7	23° 48' 47.73" N	92° 39' 4.06" E	95
8	23° 48' 48.02" N	92° 39' 4.39" E	96
9	23° 48' 48.34" N	92° 39' 4.716" E	97
10	23° 48' 48.74" N	92° 39' 5.04" E	95
11	23° 48' 49.28" N	92° 39' 5.65" E	91
12	23° 48' 49.68" N	92° 39' 6.04" E	87
13	23° 48' 50.14" N	92° 39' 6.37" E	87
14	23° 48' 50.04" N	92° 39' 6.58" E	87
15	23° 48' 50.76" N	92° 39' 6.84" E	87
16	23° 48' 51.19" N	92° 39' 7.09" E	87
17	23° 48' 51.84" N	92° 39' 7.48" E	87
18	23° 48' 52.05" N	92° 39' 7.59" E	87
19	23° 48' 52.38" N	92° 39' 7.66" E	87
20	23° 48' 52.63" N	92° 39' 7.77" E	87
21	23° 48' 53.20" N	92° 39' 7.88" E	87
22	23° 48' 53.49" N	92° 39' 7.95" E	87
23	23° 48' 53.60" N	92° 39' 8.13" E	87
24	23° 48' 54.03" N	92° 39' 8.24" E	88
25	23° 48' 54.61" N	92° 39' 8.46" E	88
26	23° 48' 55.08" N	92° 39' 8.42" E	89

Table 4.4 (b) Coordinates and Elevations of Survey Points along left bank of Tlawng River at Sairang during Pre-Monsoon

Points ID	Latitude	Longitude	Elevation (m)
27	23° 48' 46.18" N	92° 39' 1.33" E	93
28	23° 48' 46.36" N	92° 39' 1.40" E	93
29	23° 48' 46.47" N	92° 39' 1.51" E	93
30	23° 48' 46.69" N	92° 39' 1.65" E	93
31	23° 48' 46.98" N	92° 39' 1.87" E	93
32	23° 48' 46.98" N	92° 39' 1.89" E	95
33	23° 48' 47.84" N	92° 39' 2.55" E	96
34	23° 48' 48.02" N	92° 39' 2.73" E	95
35	23° 48' 48.09" N	92° 39' 3.13" E	95
36	23° 48' 48.81" N	92° 39' 3.45" E	97
37	23° 48' 50.22" N	92° 39' 4.96" E	90
38	23° 48' 50.47" N	92° 39' 5.29" E	89
39	23° 48' 50.83" N	92° 39' 5.58" E	88
40	23° 48' 51.01" N	92° 39' 5.90" E	87
41	23° 48' 51.22" N	92° 39' 6.12" E	87
42	23° 48' 51.55" N	92° 39' 6.33" E	88
43	23° 48' 51.84" N	92° 39' 6.40" E	89
44	23° 48' 52.12" N	92° 39' 6.44" E	90
45	23° 48' 52.48" N	92° 39' 6.58" E	90
46	23° 48' 53.28" N	92° 39' 6.66" E	91
47	23° 48' 54.50" N	92° 39' 6.87" E	91
48	23° 48' 55.90" N	92° 39' 6.84" E	91

Table 4.5 (a) Coordinates and Elevations of Survey Points along right bank of Tlawng River at Sairang during Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	23° 48' 44.62" N	92° 39' 2.86" E	94
2	23° 48' 44.88" N	92° 39' 3.95" E	95
3	23° 48' 45.94" N	92° 39' 4.78" E	96
4	23° 48' 46.98" N	92° 39' 5.14" E	100
5	23° 48' 47.32" N	92° 39' 5.42" E	101
6	23° 48' 48.92" N	92° 39' 6.62" E	91
7	23° 48' 50.17" N	92° 39' 7.03" E	92
8	23° 48' 50.82" N	92° 39' 7.36" E	93
9	23° 48' 51.59" N	92° 39' 8.23" E	90
10	23° 48' 53.09" N	92° 39' 9.00" E	89
11	23° 48' 55.57" N	92° 39' 9.63" E	92

Table 4.5 (b) Coordinates and Elevations of Survey Points along left bank of Tlawng River at Sairang during Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	23° 48' 46.08" N	92° 39' 0.69" E	95
2	23° 48' 47.46" N	92° 39' 2.41" E	96
3	23° 48' 48.03" N	92° 39' 2.92" E	98
4	23° 48' 50.04" N	92° 39' 5.08" E	93
5	23° 48' 51.82" N	92° 39' 5.71" E	94
6	23° 48' 54.24" N	92° 39' 6.48" E	92

4.2.2.2 Tlawng River Profile Change in Bairabi

In Bairabi, river line surveys were conducted on 18th March 2023 for pre-monsoon, where no prior rainfall was recorded in the year. After several rainy days that commenced from late May, a survey was carried out on 24th August 2023, after 5 days of consecutive rainfall amounting to a total of 65.2 mm. Survey points were listed in Table 4.6 (a & b) and 4.7 (a & b). The annual daily maximum rainfall in 2023 was 65.2, recorded on 7th August. Similar to Sairang, 2023 was not a year of heavy rainfall in Bairabi, and no severe floods occurred during this period.

Figure 4.8 illustrates seasonal variations in the river line during pre-monsoon and monsoon. There is a clear widening of the river channel during the monsoon season, particularly in the central and lower sections of the surveyed stretch. This seasonal expansion is attributed to increased discharge and water volume during monsoon rains, which leads to lateral bank erosion, channel migration, and floodplain inundation (Mishra & Singh, 2010). Notably, the lower reach (southern part of the map), where the River Teirei confluences with the main river, shows a pronounced outward shift of the monsoon river line towards both banks. This suggests that these sections are vulnerable to bank instability and sediment transport during monsoon (Knighton, 1998). The upper section of the river (northern part) shows relatively less variation between pre-monsoon and monsoon lines, indicating stable channel sections potentially controlled by bedrock or vegetation that limit lateral migration (Charlton, 2008).

This situation contrasts with 2018 in Bairabi, when the district received exceptionally heavy rainfall with an annual daily maximum of 310mm, leading to severe flooding. The flood mark of 2018 stands at 65 meters, while in 2023, the flood level recorded in the same zone was approximately 54 meters, indicating a significant variation in flood severity.

The monitoring and analysis of these river profile changes during different seasons are essential for understanding the natural drivers of flooding and their variability across years (Brakenridge et al., 2012).

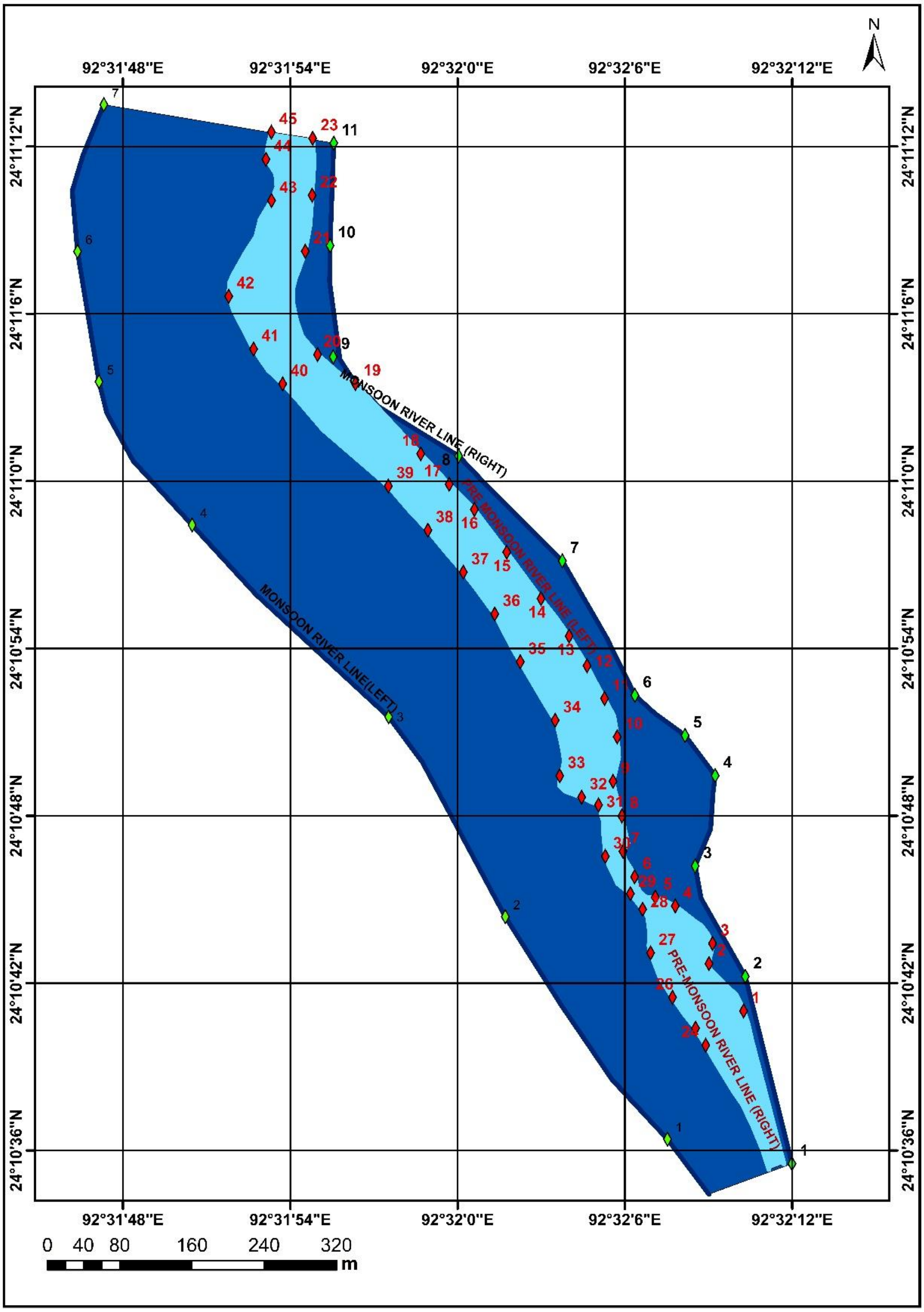


Figure 4.8 Seasonal river line profiles of the Tlawng River at Bairabi

Table 4.6 (a) Coordinates and Elevations of Survey Points along right bank of Tlawng River at Bairabi during Pre-Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	24° 10' 41.08" N	92° 32' 10.27" E	56
2	24° 10' 42.87" N	92° 32' 09.02" E	53
3	24° 10' 43.49" N	92° 32' 09.18" E	50
4	24° 10' 44.82" N	92° 32' 07.91" E	49
5	24° 10' 45.12" N	92° 32' 07.19" E	50
6	24° 10' 45.98" N	92° 32' 06.23" E	54
7	24° 10' 46.92" N	92° 32' 06.02" E	53
8	24° 10' 48.01" N	92° 32' 05.98" E	51
9	24° 10' 49.27" N	92° 32' 05.81" E	53
10	24° 10' 50.97" N	92° 32' 05.83" E	60
11	24° 10' 52.19" N	92° 32' 05.24" E	61
12	24° 10' 53.47" N	92° 32' 04.69" E	59
13	24° 10' 54.51" N	92° 32' 04.07" E	59
14	24° 10' 55.93" N	92° 32' 03.18" E	58
15	24° 10' 57.73" N	92° 32' 01.92" E	60
16	24° 10' 59.03" N	92° 32' 00.69" E	58
17	24° 10' 59.97" N	92° 31' 59.83" E	58
18	24° 11' 11.00" N	92° 31' 58.86" E	58
19	24° 11' 03.54" N	92° 31' 56.24" E	60
20	24° 11' 04.63" N	92° 31' 55.07" E	58
21	24° 11' 08.29" N	92° 31' 54.53" E	54
22	24° 11' 10.19" N	92° 31' 54.94" E	53
23	24° 11' 12.23" N	92° 31' 54.91" E	58

Table 4.6 (b) Coordinates and Elevations of Survey Points along left bank of Tlawng River at Bairabi during Pre-Monsoon

Points ID	Latitude	Longitude	Elevation (m)
24	24° 10' 39.89" N	92° 32' 08.92" E	60
25	24° 10' 40.37" N	92° 32' 08.62" E	61
26	24° 10' 41.63" N	92° 32' 07.81" E	59
27	24° 10' 43.08" N	92° 32' 06.98" E	55
28	24° 10' 44.87" N	92° 32' 06.78" E	54
29	24° 10' 45.20" N	92° 32' 06.12" E	55
30	24° 10' 46.32" N	92° 32' 05.32" E	56
31	24° 10' 48.47" N	92° 32' 05.17" E	52
32	24° 10' 48.79" N	92° 32' 04.53" E	53
33	24° 10' 49.51" N	92° 32' 03.84" E	56
34	24° 10' 51.53" N	92° 32' 03.76" E	59
35	24° 10' 53.64" N	92° 32' 02.37" E	60
36	24° 10' 55.21" N	92° 32' 01.34" E	58
37	24° 10' 56.92" N	92° 32' 00.21" E	58
38	24° 10' 58.29" N	92° 31' 59.03" E	58
39	24° 10' 59.91" N	92° 31' 57.56" E	55
40	24° 11' 03.59" N	92° 31' 53.87" E	56
41	24° 11' 04.88" N	92° 31' 52.74" E	54
42	24° 11' 06.72" N	92° 31' 51.87" E	62
43	24° 11' 10.08" N	92° 31' 53.29" E	58
44	24° 11' 11.76" N	92° 31' 53.11" E	60
45	24° 11' 12.52" N	92° 31' 53.32" E	62

Table 4.7 (a) Coordinates and Elevations of Survey Points along right bank of Tlawng River at Bairabi during Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	24° 10' 35.67" N	92° 32' 12.06" E	63
2	24° 10' 42.24" N	92° 32' 10.72" E	65
3	24° 10' 46.27" N	92° 32' 08.52" E	61
4	24° 10' 49.44" N	92° 32' 09.24" E	65
5	24° 10' 50.88" N	92° 32' 08.16" E	64
6	24° 10' 52.32" N	92° 32' 06.36" E	62
7	24° 10' 57.84" N	92° 32' 03.89" E	63
8	24° 11' 02.49" N	92° 32' 04.16" E	64
9	24° 11' 04.86" N	92° 31' 55.57" E	68
10	24° 11' 08.91" N	92° 31' 55.38" E	69
11	24° 11' 12.12" N	92° 31' 55.93" E	64

Table 4.7 (b) Coordinates and Elevations of Survey Points along left bank of Tlawng River at Bairabi during Monsoon

Points ID	Latitude	Longitude	Elevation (m)
1	24° 10' 36.38" N	92° 32' 08.69" E	63
2	24° 10' 44.46" N	92° 32' 02.49" E	59
3	24° 10' 51.69" N	92° 31' 58.85" E	61
4	24° 10' 58.88" N	92° 31' 50.62" E	57
5	24° 11' 02.45" N	92° 31' 47.92" E	58
6	24° 11' 08.78" N	92° 31' 47.06" E	67
7	24° 11' 13.27" N	92° 31' 47.89" E	62

4.2.3 High Discharge

Discharge is defined as the volume of water passing through a river channel per unit time, and it is one of the most important factors in flood generation. When intense or prolonged rainfall, snowmelt, or upstream contributions increase runoff, river discharge rises, significantly. If the volume of water surpasses the river's bank-full capacity- the maximum it can carry without overflowing- it leads to flooding (Ward & Robinson, 2000). This is particularly common in monsoon-prone regions where rainfall intensity can cause a sudden and sharp increase in discharge within a short period (Ali & Mishra, 2018).

In Sairang and Bairabi towns, both natural and man-made factors influence how discharge contributes to flooding, such as land use, slope, soil type, vegetation cover, and the degree of urbanization. Impervious surfaces, steep terrain, and saturated soils can all increase runoff, raising discharge levels quickly (Dunne & Leopold, 1978). When discharge exceeds the natural or engineered capacity of a river channel, water spills into the floodplain, inundating homes, roads, and agricultural areas. Therefore, understanding and monitoring discharge is essential for flood forecasting, risk assessment, and the implementation of effective flood management strategies (UNISDR, 2015)

A flood hydrograph is a graphical representation of river discharge over time following a rainfall event. It is an essential tool in understanding the hydrological response of a watershed and plays a crucial role in analyzing the causes of floods. It reflects how quickly and intensely runoff enters the river system after a storm, indicating the potential for flooding. In this study, a flood hydrograph of Tlawng River was constructed using discharge data and rainfall records, illustrating the hydrological response of the river system during the flood event of June 2017 in Sairang and June 2018 in Bairabi. The hydrograph depicts the typical structure of a flood event, including the rising limb, peak flow, lag time, and recession limb.

A pronounced and intense rainfall event occurred at Sairang on 13 June, with precipitation peaking around 180 mm, following several days of moderate rainfall. This cumulative rainfall likely led to soil saturation, reducing infiltration capacity and causing a sharp increase in surface runoff. As a result, the river's discharge rose rapidly, with peak flow observed on 14 June, demonstrating a short lag time between rainfall and peak discharge. As shown in Figure 4.9, the hydrograph's steep rising limb reflects the swift accumulation of runoff, typical of a catchment with steep slopes or low infiltration capacity, while the gradual recession limb indicates the slow release of water as base flow and delayed drainage. The alignment of peak rainfall and discharge strongly suggests that natural hydro-meteorological factors—particularly high-intensity rainfall and catchment response—were primary contributors to the severe flood experienced in Sairang between 12 and 14 June. This pattern aligns with findings by Smith et al. (2013), who noted that short lag times and steep rising limbs are characteristic of flash flood-prone basins, especially in regions with saturated or impermeable surfaces. This analysis underscores the critical role of river discharge behaviour, driven by upstream rainfall dynamics, in influencing flood intensity and timing in the Tlawng River basin.

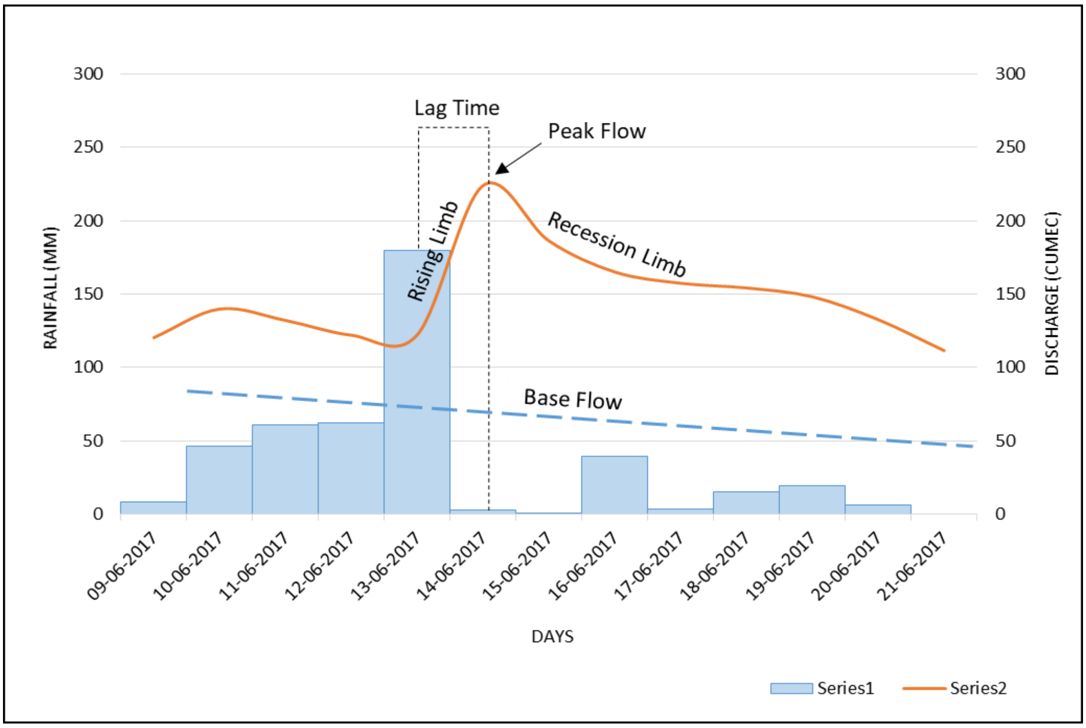


Figure 4.9 Flood Hydrograph of Tlawng River at Sairang during the 2017 Flood

The flood hydrograph of Tlawng River at Bairabi during June 2018(one of the most destructive floods in the region), clearly illustrates the hydrological response of the catchment to prolonged and intense rainfall, as shown in Figure 4.10. Consecutive rainfall had commenced from 6th June 2018, progressively saturating the catchment, with the highest daily rainfall of 309 mm recorded on 11th June 2018. This incessant rainfall led to the gradual accumulation of runoff, reflected in the gentle rising limb of the hydrograph. A notable feature of this event is the lag time of approximately four days between the peak rainfall on 11th June and the peak discharge recorded on 14th June 2018. This lag time indicates the period required for the rainfall to generate significant surface runoff and for floodwaters to accumulate within the river channel (Singh, 1997).

Following the peak discharge, the hydrograph demonstrates a steep recession limb, indicating a rapid decline in river discharge after the flood peak. This rapid drawdown suggests efficient drainage of the catchment and quick recession of floodwaters once the rainfall subsided (Subramanya, 2013). However, such a swift drop in water levels can destabilize the already saturated slopes, leading to secondary hazards. Indeed, during the recession phase of the 2018 flood, landslides occurred in the southern part of Bairabi, particularly near the confluence where the River Teirei confluences with Tlawng River from the west, indicating the geomorphic impacts associated with rapid post-flood drainage (Chow et.al., 1988).

Overall, the analysis of this hydrograph demonstrates that prolonged consecutive rainfall, a significant rainfall peak of 309mm on 11th June, and a moderate lag time leading to peak discharge on 14th June collectively contributed to severe flooding in Bairabi during June 2018. The steep recession and saturated slopes further triggered landslides, underscoring the natural hydrological and geomorphic causes of flooding in the region.

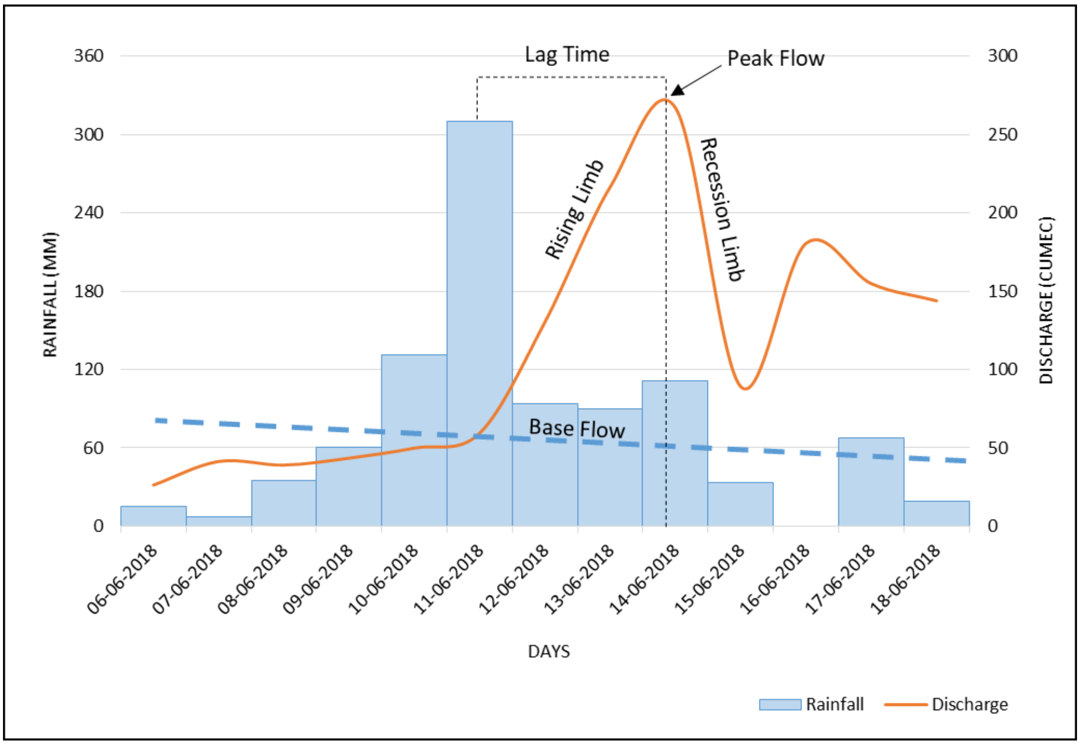


Figure 4.10 Flood Hydrograph of Tlawng River at Bairabi during the 2018 Flood

4.2.4 Topography and Soil Characteristics of Sairang

The topography of Sairang watershed exhibits a complex terrain characterized by steep slopes, narrow valleys, and high relief variability, profoundly influencing hydrological processes within the area. The contour and 3D maps generated (Figure 4.11) for the watershed illustrate elevation ranges from 56 m to over 300 m above mean sea level, with the river courses traversing through low-lying floodplains while being flanked by steep hill slopes on either side. These steep slopes, often exceeding 30°, facilitate rapid gravitational flow of surface runoff towards the river channels, reducing the lag time between rainfall and runoff, a critical factor influencing the shape and magnitude of the flood hydrograph (Singh, 2019).

The rugged topography also affects drainage patterns within the watershed, contributing to a dendritic drainage network where numerous small tributaries and ephemeral channels converge into the main river system. This drainage configuration accelerates the concentration of runoff during intense rainfall, increasing the peak discharge and resulting in a sharp rising limb in the flood hydrograph (Jain et al., 2022). Furthermore, the narrow valleys restrict lateral spreading of floodwaters, enhancing the depth and velocity of flow within the channels, which may contribute to riverbank erosion and localized inundation in adjoining low-lying areas.

Topographic features also play a significant role in controlling soil moisture dynamics, infiltration capacity, and slope stability within the watershed. Steep slopes combined with thin soil cover in the upper catchments lead to minimal infiltration, promoting high surface runoff during monsoon periods. The lower floodplain regions, characterized by gentler slopes and thicker soil layers, act as temporary storage zones during peak rainfall events; however, when the inflow volume exceeds the channel and floodplain capacity, these areas become prone to inundation (Rahmati et al., 2016)

The geotechnical analysis of soil samples collected from the riverbank of Sairang provides insights into the nature of soil influencing flood behaviour within the watershed. The soil is identified as silty with low compressibility, having a specific gravity of 2.63 and dry density of 1.72 g/cm^3, along with an optimum moisture content (OMC) of 19%. The soil exhibits non-plastic behaviour as the liquid and plastic limits could not be determined due to the inability to reach the required water content, indicating a tendency for the soil to break easily under mechanical stress and water saturation conditions. The direct shear test results reveal a cohesion value of 0.24 kg/cm^{2}and an angle of shearing resistance of 24.5°, indicating medium shear strength but low cohesion, leading to greater erosion risk, particularly under heavy rainfall and saturated conditions (Coduto, 1999; Das & Saha, 2021)

The combination of steep topographic relief and the nature of the soil significantly influences infiltration rates and surface runoff generation within the Sairang watershed. Low cohesion and non-plasticity reduce the soil's capacity to retain water during rainfall events, thereby enhancing overland flow towards the river channels. The steep slopes further reduce infiltration opportunity time, facilitating the rapid transfer of rainfall to surface runoff, which aligns with the observed sharp rising limb and high peak discharge in the hydrograph during flood events in the area (Ali et al., 2020). Additionally, the medium shear strength of the soil indicates potential slope instability when saturated, which, combined with steep slopes, may contribute to shallow landslides along the riverbanks during flood recession periods, increasing sediment loads in the river and reducing channel capacity, further exacerbating flooding (Singh et al., 2020).

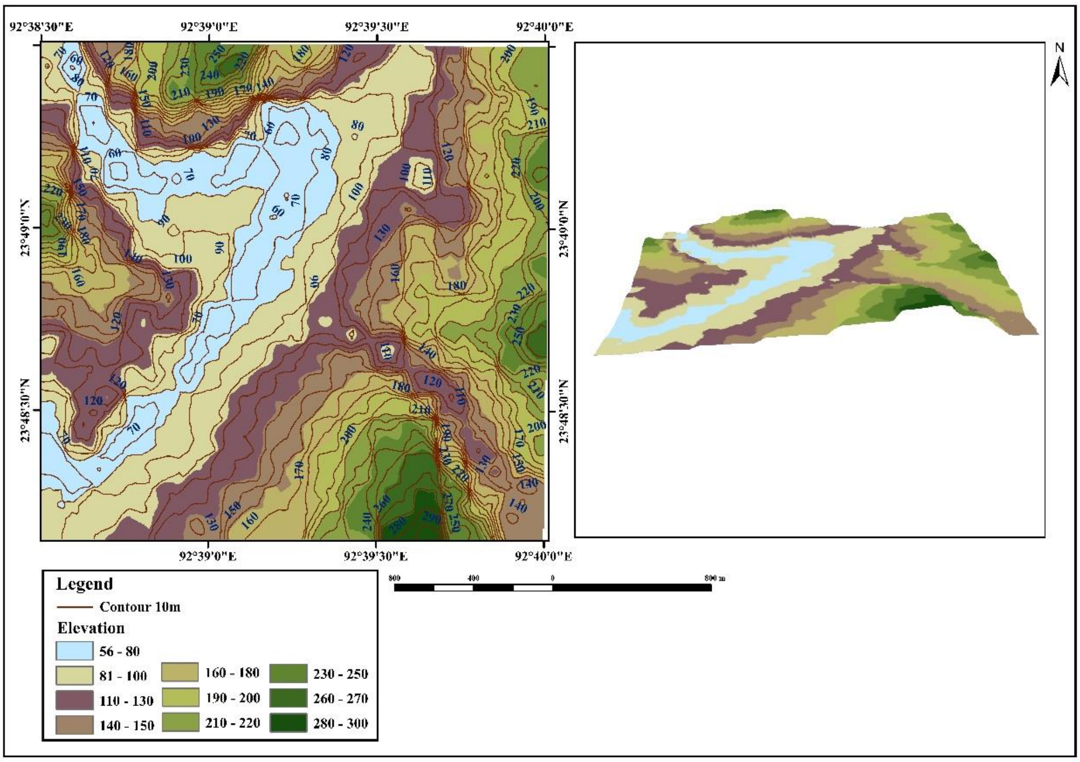


Figure 4.11 Contour and 3D map of Sairang.

4.2.5 Topography and Soil Characteristics of Bairabi

The watershed of Bairabi exhibits a distinct topographic configuration, characterized by broad valleys, rolling hills, and moderately steep slopes influence hydrological processes and flood behaviour within the area. The contour and 3D maps prepared for Bairabi, as shown in Figure 4.12, reveal elevation ranges from 26 m to over 220 m above mean sea level. The central valley floors, depicted in blue and yellow on the contour map represent low- lying flood- prone areas, while the eastern flanks show a gradual elevation increase toward the hill slopes, forming a transition from floodplain to hill terrain.

The moderate slope gradients in the watershed facilitate a relatively slower overland flow compared to steeper terrains, allowing a longer concentration time for surface runoff to reach the channel during rainfall events. However, during intense rainfall, the broad valleys act as natural collection zones, increasing the depth and lateral extent of flooding when inflow volumes exceed channel capacity (Jain et al., 2022). The dendritic drainage pattern observed in the watershed, formed by multiple small streams feeding into the main Bairabi River, accelerates runoff concentration, contributing to the peak discharge seen in the flood hydrograph, though with a slightly longer lag time compared to steep watersheds such as Sairang (Singh, 2019).

The soil test conducted for the soil sample collected from the riverbank of Bairabi indicates the soil type as silty-clay with low compressibility, having a liquid limit of 32.98% and a plastic limit of 25.43%, yielding a plasticity index of 8.55%. This indicates that the soil is slightly plastic, which enhances its water-holding capacity while maintaining moderate permeability (Coduto, 1999). The specific gravity of 2.564 and dry density of 1.77 g/cm^3 with an optimum moisture content of 17% further confirm its moderate compaction and moisture retention characteristics.

The direct shear test reveals a cohesion value of 0.388 kg/cm^3 (3.88 T/m^2) and an angle of shearing resistance of 27.23°, indicating higher shear strength and cohesion compared to Sairang's silty soil. The higher shear strength reduces susceptibility to slope failures and erosion, which is crucial in reducing sediment loads into the river during flood events, thereby maintaining the channel capacity (Das & Saha, 2021). The higher cohesion of the soil indicates better structural integrity, reducing the likelihood of landslides along riverbanks during rainfall, a common cause of flooding in hilly regions (Rahmati et al., 2016).

The combination of moderate topographic relief and cohesive silty clay soil with slight plasticity significantly influences flood behaviour in Bairabi. During heavy rainfall, the moderate slopes and valleys encourage infiltration to some extent, reducing immediate runoff compared to steeper terrains. However, once the soil reaches saturation, its moderate permeability contributes to runoff generation, leading to gradual but sustained increases in discharge, reflected in the flood hydrograph with a prominent peak but with a smoother rising limb and a slightly delayed peak discharge compared to Sairang. Moreover, the safe bearing capacity of the soil, calculated at 31.18 T/m^2, suggests that the soil can sustain significant structural loads, relevant for flood management infrastructure planning such as levees or embankments in the region. However, under prolonged saturation, the effective stress within the soil matrix may reduce, influencing infiltration capacity and enhancing runoff generation during high-intensity rainfall events.

In summary, the interplay between the topography and soil characteristics in Bairabi watershed creates a unique flood response regime. The moderate slopes and cohesive, slightly plastic soils facilitate infiltration initially but contribute to runoff once saturation is achieved. This, combined with the broad valleys acting as water collection zones, increases flood susceptibility in low-lying areas during prolonged or intense rainfall events.

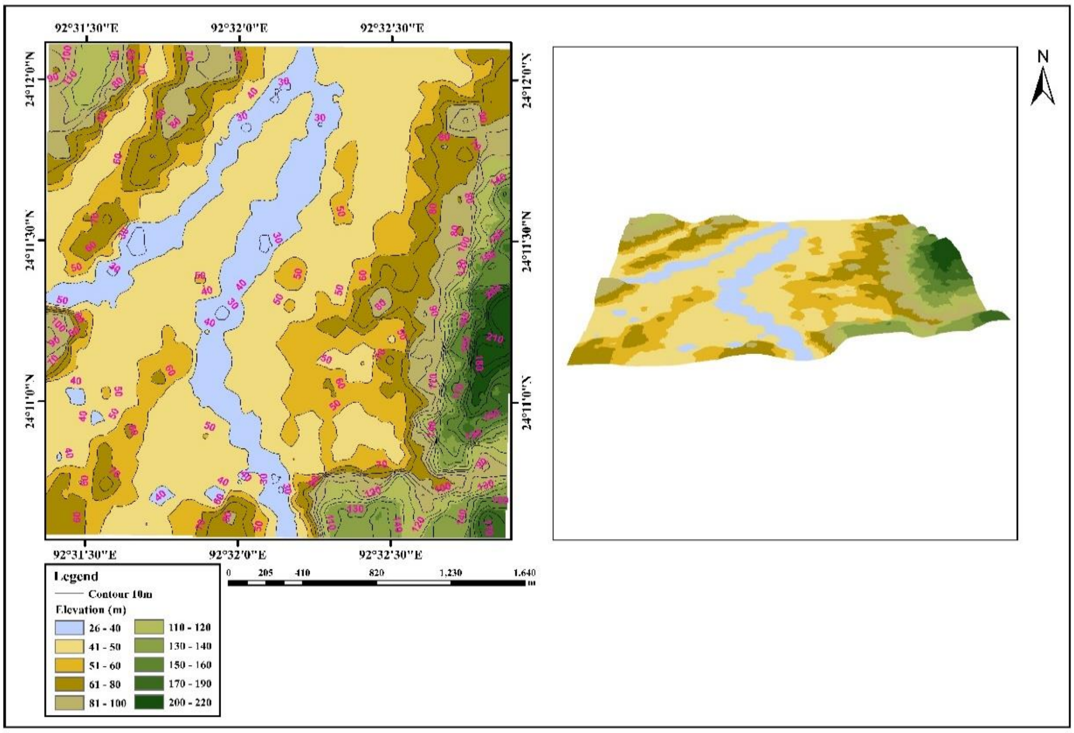


Figure 4.12 Contour and 3D map of Bairabi

4.2.6 Flood Frequency Analysis

Flooding as a hydro meteorological hazard, is fundamentally driven by a chain of causative natural processes, including intense and prolonged rainfall, rapid surface runoff influenced by catchment topography and soil characteristics, and the subsequent high discharge within river systems that leads to overtopping of banks and inundation of floodplains (Ward et al., 2020; Hirabayashi et al., 2013). In the context of Sairang and Bairabi, the interplay between heavy monsoonal rainfall, steep catchment slopes, and limited infiltration capacity of the soil accelerates the conversion of rainfall into runoff, resulting in high discharge events is essential for accurately assessing flood hazards and planning effective flood management and mitigation measures within these settlements.

When rainfall analysis provides critical insights into the primary input responsible for flooding, and hydrograph analysis captures the temporal distribution of discharge during specific flood events, they do not fully capture the long-term patterns of flood occurrence necessary for robust hazard quantification and planning (Chow et al., 1988). It is in this context that Flood Frequency Analysis (FFA) becomes a crucial extension of the analysis of natural causes of flooding. FFA enables the translation of the causative processes of heavy rainfall and rapid runoff into quantifiable estimates of discharge magnitudes with associated probabilities of occurrence, thereby providing a statistical foundation for understanding flood hazards within the study area (Merz et al. 2014).

In flood-prone regions like Sairang and Bairabi, which experience recurrent monsoon-induced flooding, the high discharge within the Tlawng River serves as the immediate mechanism triggering floods (Di Baldassarre et al., 2010). However, without quantifying the frequency of such high discharge events, it is challenging to determine the severity of the flood hazard accurately. By conducting FFA, this study links the understanding of natural causes of flooding with practical flood hazard quantification, ensuring that the rainfall-runoff processes and the influence of catchment topography and soil on food generation are reflected in measurable discharge values with associated probabilities of occurrence.

In this section, flood frequency analysis is conducted separately for Sairang and Bairabi using historical discharge data, with the objective of estimating peak discharges for various return periods under natural hydrological conditions. This analysis builds upon the preceding rainfall and discharge analyses, ensuring a seamless transition from the identification of flood causes to the quantification of flood hazards.

4.2.6.1 Flood Frequency Analysis of Tlawng River at Sairang

Flood Frequency Analysis was conducted for Sairang using historical annual maximum discharge data of the Tlawng River to estimate the magnitude of peak discharges corresponding to different return periods under natural conditions. Using a logarithmic trend fitting method, (Figure 4.13) predicted peak discharges were derived for 2, 5, 10, 25, 50, and 100-year return periods, reflecting the likelihood of high discharge events that contribute to flooding in the settlement (Manohar, 2022).

The analysis revealed that for a 2-year return period, the predicted peak discharge was 190m^3/s, while for 5-year, and 10-year return periods; the predicted discharges were 250m^3/s and 310m^3/s, respectively. For longer return periods, the predicted discharge for a 25-year event was 416m^3/s, for a 50-year event was 430m^3/s, and for a 100-year event was 500m^3/s. These values indicate a high potential for extreme discharge events in Sairang, especially during intense monsoon rainfall, highlighting the significant flood hazard faced by the settlement.

The findings from this analysis are crucial for understanding the natural causes of flooding in Sairang, as the high discharge within the Tlawng River underpins the immediate mechanism of flooding during heavy rainfall periods.

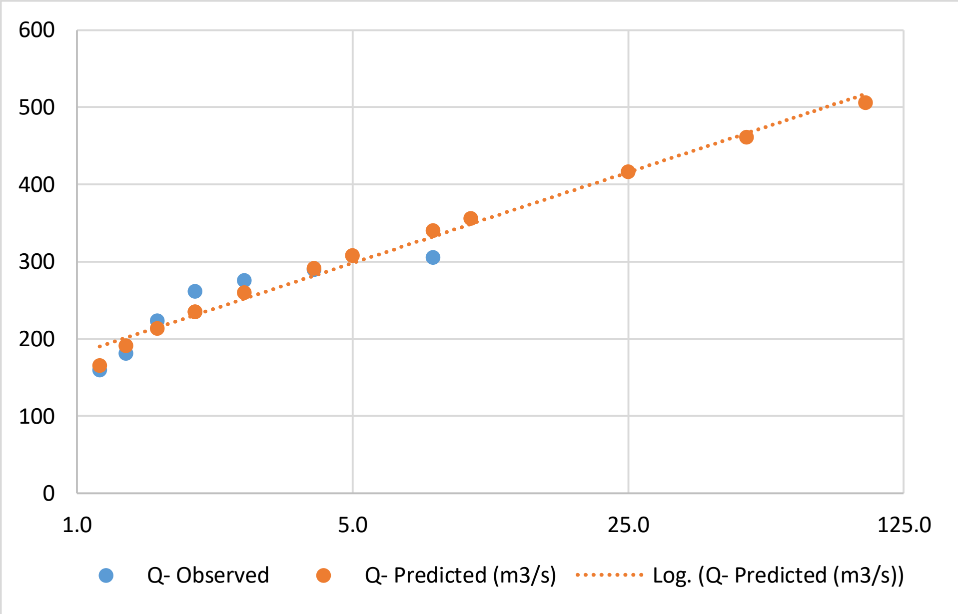


Figure 4.13 Flood Frequency Analysis (Sairang)

4.2.6.2 Flood Frequency Analysis of Tlawng River at Bairabi

Similarly, flood frequency analysis for Bairabi was conducted using the historical peak discharge data of the Tlawng River to estimate discharges for various return periods. The analysis revealed that the predicted discharge for a 2-year return period was 238m^3/s, while the 5-year and 10-year return periods corresponded to 289m^3/s and 322m^3/s, respectively. For the 25-year return period, the predicted discharge was 364m^3/s, and for the 50-year and 100-year return periods, the predicted discharges were 396m^3/s and 427m^3/s, respectively. These findings indicate a significant flood hazard potential in Bairabi, emphasizing the necessity for effective flood management and preparedness planning in the settlement to reduce the impacts of high discharge events.

The flood frequency curve for Bairabi further illustrates the predicted peak discharges across different return periods, aiding in the visualization of potential flood hazard levels under natural hydrological conditions in the region.

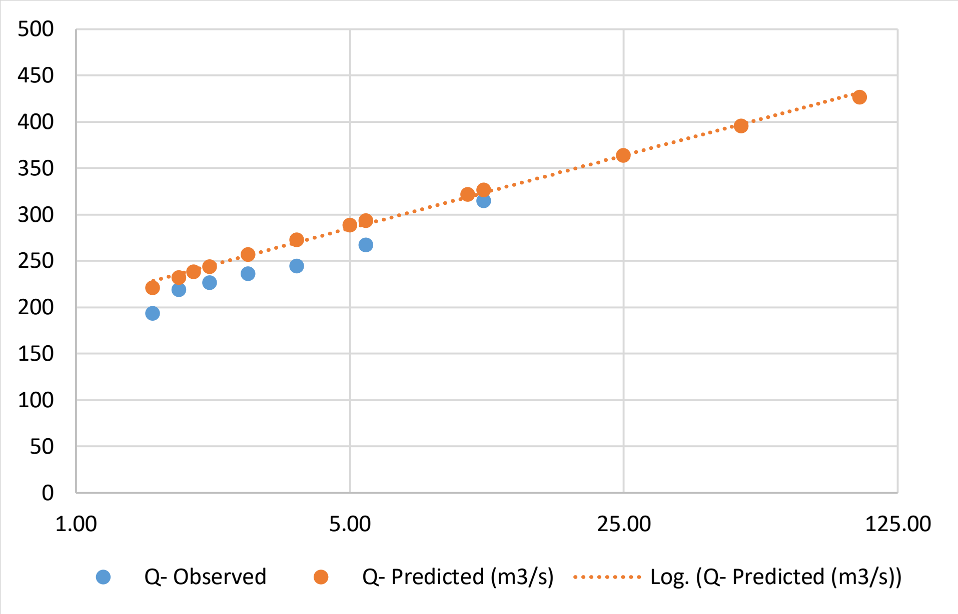


Figure 4.14 Flood Frequency Analysis (Bairabi)

4.3 ANTHROPOGENIC CAUSES OF FLOOD

Flooding is a complex natural hazard influenced by a combination of climatic, hydrological, geomorphological, and anthropogenic factors (Edosa & Nagasa, 2024). While extreme rainfall events and catchment characteristics often initiate flooding, human activities significantly exacerbate its frequency, intensity, and impacts, particularly in rapidly urbanizing and developing regions (Doughlas et al., 2008). In the context of Sairang and Bairabi, located within Tlawng River basin, understanding the anthropogenic drivers of flooding is critical for effective flood risk management and disaster preparedness (Prayogo et al., 2025).

One of the primary anthropogenic contributors to flooding is deforestation, which alters the hydrological balance by reducing interception, infiltration, and evapo-transpiration, leading to increased surface runoff and higher flood peaks (Bradshaw et al., 2007). In many parts of Mizoram, including Sairang and Bairabi, the expansion of agricultural land through shifting cultivation and unregulated extraction of forest resources has led to significant forest cover loss, destabilizing slopes and enhancing soil erosion. This sediment is eventually deposited into river channels, reducing their carrying capacities and contributing to riverine flooding during intense rainfall events.

Another major factor is the expansion of settlements and infrastructure into floodplains and low-lying areas, driven by population growth and urbanization pressures. Settlements constructed along riverbanks and within flood-prone zones encroach upon natural drainage paths and reduce the floodplain's capacity to store excess water during peak flows. Additionally, the increase in impervious surfaces associated with urban expansion, such as rooftops, roads, and paved courtyards, reduces infiltration and accelerates runoff into streams and rivers, resulting in flash flooding during heavy rainfall (Jha et al., 2012).

Changes in agricultural practices, including the conversion of forested slopes into cultivated cropland without adequate soil conservation measures, have further modified the hydrological response of the landscape. These practices increase surface runoff while decreasing the soil's capacity to absorb and retain water, thereby amplifying the risk of flooding during the monsoon season (Shaw et al., 2025; Panhalkar, 2011). Additionally, the construction of unplanned roads, quarrying, and sand mining activities disturb slope stability and channel morphology, increasing sediment loads and reducing the river's cross-sectional area, which can lead to overbank flooding during high-discharge periods (Chakraborty &Mukhopadhyay, 2019).

While these anthropogenic factors significantly enhance the vulnerability to flooding, their impacts are often exacerbated by inadequate drainage infrastructure, lack of effective land use planning, and limited awareness of flood risks within local communities. The combination of increased exposure, reduced natural flood absorption capacity, and intensified runoff generation due to human activities has made the settlements in Sairang and Bairabi more susceptible to flood hazards.

To systematically analyze the role of anthropogenic factors in influencing flood patterns, a change detection analysis was performed using multi-temporal satellite imagery for Sairang and Bairabi. This analysis focuses on changes in land use and land cover categories, including forest, settlements, water bodies, and vegetation, over 15 years,i.e., 2008- 2023, to identify patterns of human-induced landscape modifications. To ensure the reliability of the change detection analysis for assessing anthropogenic causes of flooding, accuracy assessments were performed for all classified years in Sairang and Bairabi using confusion matrices and kappa coefficient calculations. The kappa coefficient measures the level of agreement between the classified data and reference data while accounting for chance agreement, providing a robust indicator of classification reliability (Congalton, 1991; Landis & Koch, 1977). The change detection maps presented in the subsequent sections provide critical spatial evidence of these anthropogenic transformations, facilitating a deeper understanding of how human activities have contributed to flooding in Tlawng River basin.

4.3.1 Change Detection Analysis and its implications for flooding

The analysis of multi-temporal change detection maps from 2008 to 2023 reveals significant anthropogenic modifications in land use and land cover (LULC) within Tlawng river basin, notably in Sairang and Bairabi. Key classes examined include forest, cultivated cropland, settlements, and water bodies. These changes collectively influence catchment hydrology, altering infiltration rates, runoff generation, and sediment transport, which directly impact flooding frequency and intensity in these regions. The subsequent sections examine each site in detail, linking these anthropogenic drivers with their specific implications for local flood hazards.

4.3.1.1 Change Detection over Sairang Town

The change detection map of Sairang from 2008- 2023 (Figure 4.13) illustrates clear anthropogenic alterations in land use and land cover, which significantly influence the flood patterns in the area.

a) Forest Decline: Between 2008 and 2023, forest cover in Sairang decreased from 4.71 sq. km to 2.73 sq. km, reflecting a loss of nearly 42%. This reduction is associated with shifting cultivation, extraction of forest resources, and land clearing for settlements and cropland. Forests in hilly catchments like Sairang play a vital role in intercepting rainfall, enhancing infiltration, and stabilizing slopes against erosion (FAO, 2005; Nepal et al., 2014). The reduction in forest cover has decreased the catchment's capacity to absorb rainfall, resulting in increased surface runoff and accelerated soil erosion, which contributes to sedimentation in Tlawng River, reducing its carrying capacity.

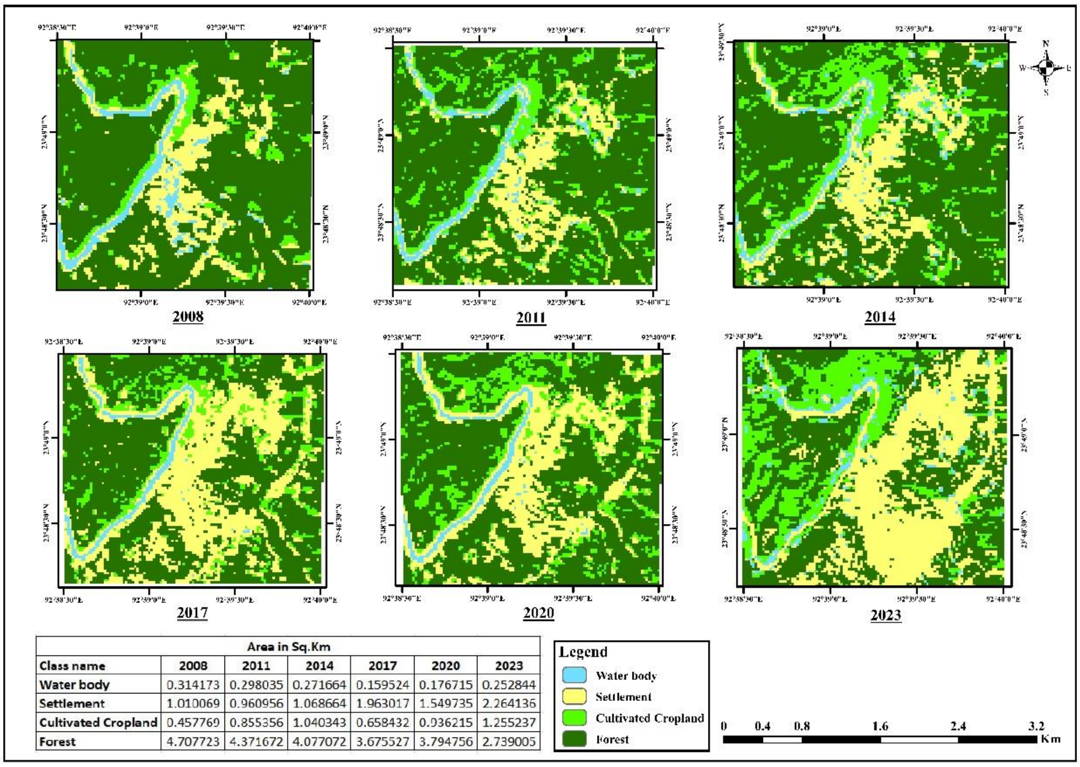
This loss of forest cover also influences the flood hydrograph observed at Sairang (Figure 4.9), where a steeper rising limb and sharper peak discharge during rainfall events reflect reduced lag time and higher runoff rates due to diminished vegetation cover.

b) Cultivated Cropland Expansion: Sairang experienced a significant increase in cultivated cropland, expanding from 0.46 sq. km in 2008 to 1.25 sq km in 2023. This expansion is driven by the need to sustain livelihoods but often involves clearing vegetated areas and modifying slopes, which reduces infiltration and increases surface runoff during rainfall events (Lal, 2001). The absence of adequate soil conservation on cropland accelerates erosion, which further reduces the river's channel capacity, enhancing the risk of overbank flooding during heavy rains. Additionally, cropland expansion in floodplain areas reduces the natural retention capacity of these zones, contributing to higher flood peaks during monsoon rains.

c) Settlement Growth: Settlements in Sairang grew from 1.01 sq. km to 2.26 sq. km between 2008 and 2023. Settlement expansion often occurs near riverbanks and floodplains, obstructing natural drainage paths and reducing floodplain water storage capacity (Shuster et al., 2005). The development of impervious surfaces associated with urban growth accelerates surface runoff while reducing infiltration, resulting in faster and higher peak flows in local drainage systems and Tlawng River during heavy rainfall (Fletcher et al., 2013). These changes are evident in the flood hydrograph (Figure 4.9), where the timing and sharpness of flood peaks reflect increased runoff contributions from expanding settlements.

d) Water Body Changes: The area under water bodies in Sairang decreased slightly from 0.31 sq. km to 0.25 sq. km (a ~ 19% decline) during the study period.

Although the change is minor in spatial extent, it reduces the floodplain's capacity to store excess water during high discharge events, leading to localized flooding and forcing floodwaters into narrower river channels during intense rainfall (Olang & Fürst, 2011).



Area in Sq.Km						
Class name	2008	2011	2014	2017	2020	2023
Water body	0.314173	0.298035	0.271664	0.159524	0.176715	0.252844
Settlement	1.010069	0.960956	1.068664	1.963017	1.549735	2.264136
Cultivated Cropland	0.457769	0.855356	1.040343	0.658432	0.936215	1.255237
Forest	4.707723	4.371672	4.077072	3.675527	3.794756	2.739005

Figure 4.15 Change Detection map of Sairang (2008-2023)

4.3.1.2 Change Detection over Bairabi Town

The multi-temporal detection analysis of Bairabi region along Tlawng River from 2008- 2023, illustrated in Figure 4.16, reveals significant landscape transformation driven by human activities, contributing to heightened flood susceptibility in the area.

a) Forest Decline: Forest cover in Bairabi reduced significantly from 5.66sq.km in 2008 to 2.89sq.km in 2023, indicating a 49% decline. Drivers include shifting cultivation, firewood extraction, and expansion of agriculture. This reduction decreases rainfall interception and infiltration while increasing overland flow and slope instability, leading to a higher rate of erosion and sedimentation within Tlawng

River (Nepal et al., 2014). The progressive depletion of forest cover has contributed to sharper flood peaks and shorter lag times during rainfall events, reflected in hydrographs such as Figure 4.10, which captures the changing flood dynamics in Bairabi.

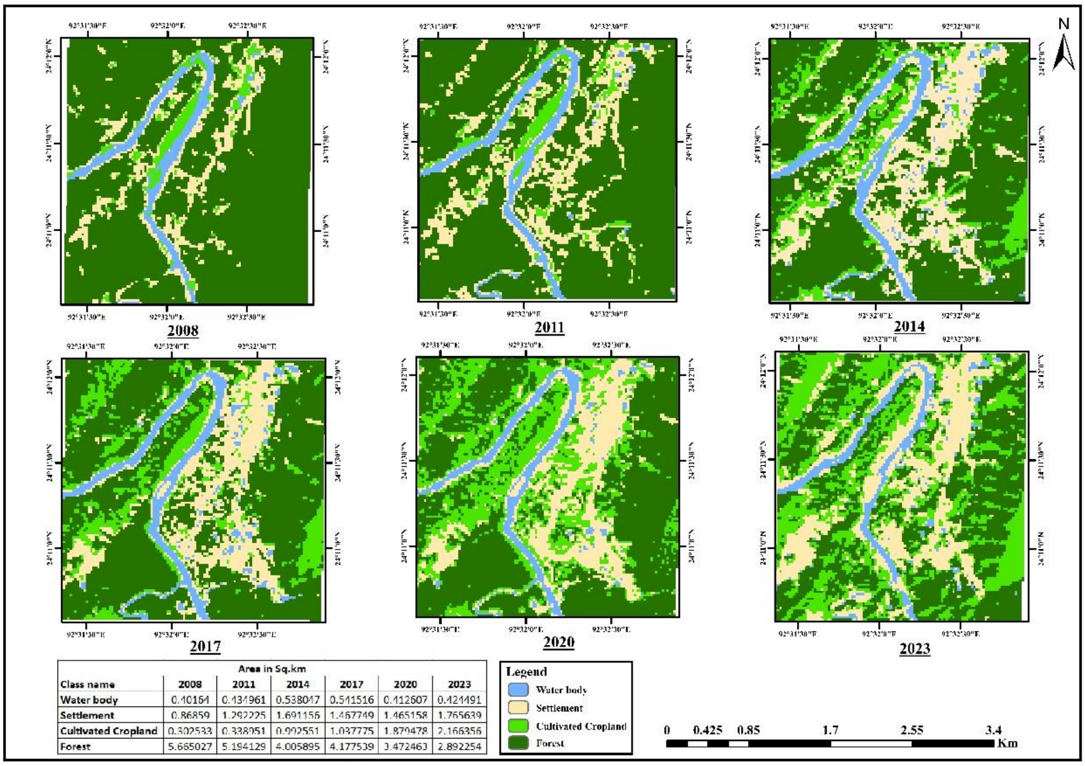
b) Cultivated Cropland Expansion: Bairabi witnessed a substantial increase in cropland, expanding from 0.30 sq. km in 2008 to 2.16 sq. km in 2023, reflecting the growing dependence on agriculture for livelihoods. Conversion of vegetated and forested areas to cropland without soil conservation measures has led to soil compaction, reduced infiltration, and accelerated surface runoff (Lal, 2001). The expansion of agriculture on slopes also increases sediment delivery into river systems, reducing the carrying capacity during peak flows and increasing the likelihood of flooding during heavy rainfall.

c) Settlement Growth: Settlements in Bairabi grew from 0.86 sq. km in 2008 to 1.76 sq. km in 2023, expanding into floodplain areas and along riverbanks. This expansion introduces impervious surfaces that reduce infiltration and increase surface runoff, contributing to higher and faster flood peaks during rainfall events (Shuster et al., 2005). Encroachment into natural drainage areas further reduces the floodplain's capacity to store water during floods, exacerbating localized flooding and infrastructure vulnerability. These processes align with the observed changes in the flood hydrograph (Figure 4.10), where increased runoff leads to a steeper and higher flood peak during rainfall events.

d) Water Body Changes: Water bodies in Bairabi exhibited minor fluctuations, ranging from 0.40 sq. km to 0.54 sq. km during the study period, with a slight net decrease by 2023. Encroachment by settlements and agriculture has reduced wetland and floodplain areas that naturally store floodwaters, increasing flood risk during heavy rainfall by reducing available temporary storage (Olang & Fürst, 2011).

The change detection analysis for Sairang and Bairabi demonstrates the significant role of anthropogenic activities in shaping flood risk in Tlawng River basin.

The decline in forest cover, expansion of cultivated cropland, settlement growth, and reduction in water body areas have collectively altered catchment hydrology, increasing surface runoff, reducing infiltration, and contributing to sedimentation in river channels. These changes have transformed flood behavior in these regions, making floods more frequent, intense, and rapid in onset during the monsoon season.



Class name	Area in Sq.km 2008	2011	2014	2017	2020	2023
Water body	0.40164	0.434961	0.538047	0.541516	0.412607	0.424491
Settlement	0.86859	1.292225	1.691156	1.467749	1.465158	1.765639
Cultivated Cropland	0.302533	0.338951	0.902551	1.037775	1.879478	2.166356
Forest	5.665027	5.194129	4.005895	4.177539	3.472463	2.892254

Figure 4.16 Change Detection map of Bairabi (2008-2023)

4.3.2 ACCURACY ASSESSMENT FOR CHANGE DETECTION

The results of the accuracy assessments for each year are summarized in Table 4.8. The Kappa coefficients across the years ranged from 0.75 to 0.88 in Sairang and 0.85- 0.91 in Bairabi, indicating substantial to almost perfect agreement (Landis & Koch, 1977). This table provides a clear overview of the classification reliability across years used in the change detection analysis, supporting the interpretation of the relationship between land use changes (Ha et al., 2015) and flooding patterns of Tlawng River in Sairang.

Table 4.8 Kappa Coefficients and Overall Accuracy for Change Detection Classifications

	Year	Overall Accuracy (%)	Kappa Coefficient (κ)
Sairang	2008	87.5	0.83
Sairang	2011	91.25	0.88
Sairang	2014	84.38	0.79
Sairang	2017	91.25	0.88
Sairang	2020	89.38	0.85
Sairang	2023	81.88	0.79
Bairabi	2008	90.62	0.87
Bairabi	2011	93.75	0.91
Bairabi	2014	90.63	0.87
Bairabi	2017	90.63	0.87
Bairabi	2020	91.88	0.91
Bairabi	2023	88.75	0.85

4.4 CONCLUSION

The Tlawng River floods in Sairang and Bairabi result from the interplay of climatic, hydrological, geomorphological, and anthropogenic drivers. High-intensity rainfall and prolonged wet spells act as immediate triggers, while topographical and soil conditions control runoff generation and concentration times. Simultaneously, human-induced land use changes have intensified flood hazards by altering catchment hydrology and reducing natural resilience to heavy rainfall. Understanding these interlinked causes is essential for accurate flood vulnerability assessment, risk reduction, and sustainable flood management planning in Tlawng River basin.

CHAPTER 5

IMPACT OF FLOODING

5.1 INTRODUCTION

Floods are among the most frequent and destructive natural hazards globally, causing severe loss of life (Handique et al., 2024), damage to property, and disruption of socio-economic activities, particularly in developing and mountainous regions (Kundzewicz et al., 2014; Doocy et al., 2013). The impacts of flooding are multifaceted, ranging from immediate threats to human life and health to long-term disruptions in livelihoods, infrastructure, and community resilience (Jonkman, 2005). Evaluating these impacts is essential for gaining a comprehensive understanding of the vulnerability of communities, planning effective disaster risk reduction strategies, and enhancing adaptive capacities under increasing climate variability and land use transformation (Merz et al., 2010; Paprotny et al., 2018).

In India's northeastern hill states, including Mizoram, floods occur frequently during the monsoon season, exacerbated by steep slopes, intense rainfall, and riverbank encroachments, leading to flash floods and localized inundations (Nandy & Samanta, 2020). However, systematic records of flood-related damages, casualties, and long-term impacts are often lacking in small and remote towns, making it challenging to quantify and analyse flood impacts accurately (Meyer et al., 2013; Cutter et al., 2003). Such data scarcity limits the capacity of local authorities and communities to plan targeted mitigation and preparedness measures, often leaving vulnerable populations at risk during recurring flood events.

Sairang and Bairabi, two flood-prone towns along the Tlawng River and its tributaries, are examples of settlements where systematic flood damage records are absent despite the recurrent flooding experienced during the monsoon seasons. To address this challenge, a primary data collection approach was employed, combining a structured household questionnaire survey, interviews with local community leaders, and the collection of drowning incident records from the local police stations in

Sairang and Bairabi. This mixed-method approach was designed to capture a comprehensive picture of flood impacts, incorporating both quantifiable household-level data and qualitative insights from community leaders who hold localized knowledge of flood events and their consequences.

The collection of drowning incident data from the Police records aimed to assess the seasonality of drowning accidents, specifically investigating whether such incidents are more frequent during the monsoon season, and whether the fatalities predominantly involve local residents or outsiders. Drowning is a significant but often underreported consequence of flooding, particularly in riverine and hilly environments where strong currents and sudden surges can lead to accidents (Guha-Sapir et al.,2016; WHO, 2021). By analysing drowning cases alongside household-level data on flood impact, this study aspires to develop a more integrated understanding of the key human impacts associated with flooding in these towns.

To guarantee the reliability and representativeness of the collected data, a robust sampling methodology was applied. Using Cochran's formula at a 95% confidence level with a 5% margin of error, the required minimum sample sizes were calculated to be 297 households in Sairang and 266 households in Bairabi, ensuring statistical validity for community-level analysis (Cochran, 1977; Israel, 1992). To account for potential non-responses and enhance data robustness, a higher number of questionnaires were distributed, with 600 questionnaires in Sairang and 500 in Bairabi. The survey yielded 439 valid responses in Sairang and 406 in Bairabi, resulting in high response rates of 73.2% and 81.2% respectively. Such high response rates, which surpass commonly accepted thresholds for social science field research, enhance the reliability of the dataset for analysing flood impacts and reduce the potential for non-response bias (Fincham, 2008; Groves et al., 2009). Additionally, interviews with leaders of the Young Mizo Association (largest Non- Government Organization) in Sairang and the Bairabi South Village Council revealed insights into economic disruptions, psychological stresses, displacement dynamics, and community coping mechanisms during floods.

By systematically assessing the primary, secondary, and tertiary effects of flooding, this chapter seeks to deepen understanding of how floods have impacted households and communities in Sairang and Bairabi. The findings will contribute to the subsequent flood vulnerability analysis and inform recommendations for effective flood management and resilience-building in these towns.

5.2 STATISTICAL ANALYSIS OF FLOOD IMPACTS IN SAIRANG AND BAIRABI

Detailed statistical analyses, including descriptive statistics, paired samples t-tests, and correlation analysis, are employed to quantify differences in flood impacts between Sairang and Bairabi, while identifying systematic patterns across various categories. These analyses strengthen the findings by demonstrating statistically significant differences in flood impacts and revealing correlations among impact categories, reflecting layered vulnerabilities within the communities.

5.2.1 Descriptive Statistical Analysis

The graph presented in Figures 5.1, 5.2, and 5.3 illustrates the findings from household survey data and qualitative interviews, systematically categorised into primary, secondary, and tertiary effects to provide a clear, layered understanding of flood impacts (Mohanty et al., 2020) in Sairang and Bairabi. Descriptive statistics were used to systematically quantify and compare the flood impacts between Sairang and Bairabi across 15 categories based on household survey data, as shown in Table 5.1. This analysis helps in identifying which aspects of daily life, livelihoods, and health were most affected and how these impacts differed spatially between the two towns.

5.2.1.1 Primary Effects

Primary effects refer to the immediate impacts of flooding on physical infrastructure, agricultural land, and essential assets, directly disrupting daily life and household stability. The data reflect the perceptions and reported experiences of affected households regarding housing damage and crop losses during flood events.

a) ***Housing and Infrastructure Damage***

Bairabi reported significantly high severe (15.02%) and partial (24.14%) housing damage compared to Sairang (5.92% partial). Interviews with Bairabi South Village Council revealed that 70-80 private residences, multiple churches, and government quarters were either demolished or relocated due to erosion and flood risks. In Sairang, while the percentage was lower, critical damage still occurred in riverside settlements, with mud-plastered houses particularly susceptible to floodwater infiltration.

b) ***Crop Damage***

Floods heavily affected agricultural lands in both towns. Partially damaged crops were higher in Bairabi (24.14%) than in Sairang (18.45%), reflecting greater exposure of low-lying paddy fields and vegetable plots to floodwaters. However, interviews highlighted that over 100 farmers in Sairang suffered from flooding, reducing arable land availability post-flood and impacting seasonal crop cycles.

c) ***Livestock and Equipment Loss***

Both towns reported livestock shelter damage due to inundation, with pigs and poultry often lost during severe flooding. In Sairang, significant equipment losses occurred, including boats used for sand mining and river transport, severely affecting household incomes during the flood period.

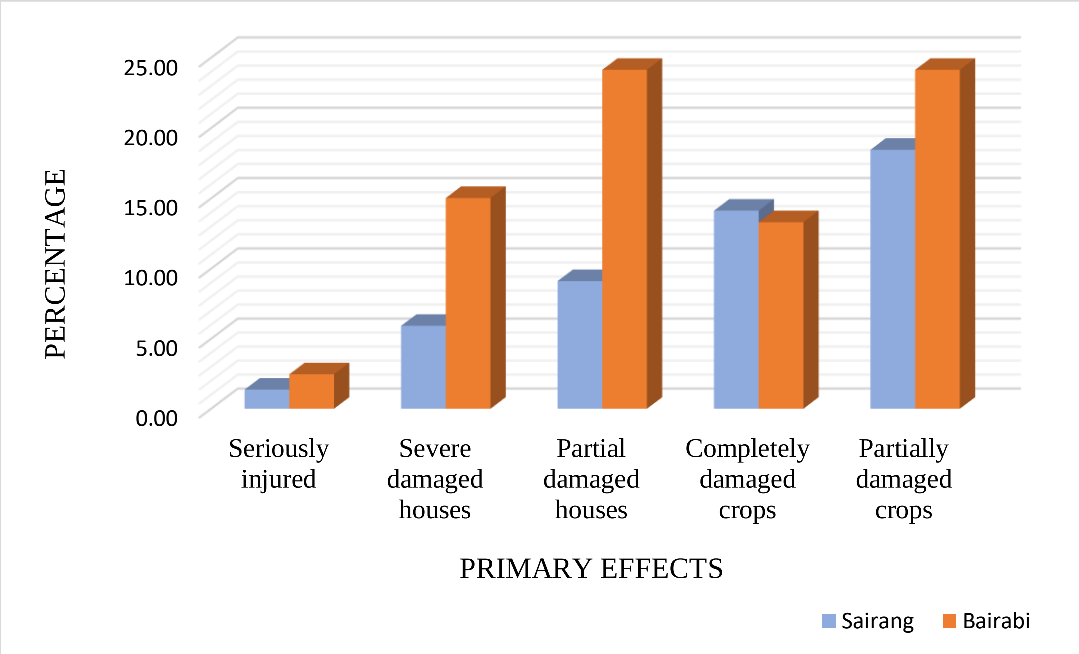


Figure 5.1 ***Comparative Primary Effects of Flooding in Sairang and Bairabi***

5.2.1.2 Secondary Effects

Secondary effects encompass post-flood disruptions in essential services, food and water availability, health, and communication, compounding the hardships faced by communities after the immediate impacts.

a) ***Food Insecurity***

Food shortages were more prevalent in Bairabi (41.73%) compared to Sairang (28.07%), as local markets were cut off during flooding, and household food stocks were often lost or contaminated. Interviews indicated that price spikes in essential commodities exacerbated these shortages during floods.

b) ***Water Scarcity***

Water scarcity was reported by 49.64% of households in Bairabi and 28.65% in Sairang due to the flooding of water sources and the damage to pipelines and storage tanks. Water contamination led to reliance on emergency water distribution, often insufficient to meet community needs.

c) ***Health and Epidemics***

Health impacts, including waterborne diseases such as diarrhea and skin infections, were widespread in Bairabi, with 77.70% of households reporting epidemic outbreaks compared to 15.20% in Sairang. Interviews underscore the lack of immediate medical assistance in Bairabi during flood periods.

d) ***Communication Disruption and Social Impacts***

Communication disruptions were reported by 28.78% of households in Bairabi compared to 9.36% in Sairang, with flooding damaging power lines and cutting off mobile connectivity. Interview data revealed psychological distress during monsoons, with anxiety, fear of house collapse, and insomnia prevalent among women and elderly residents.

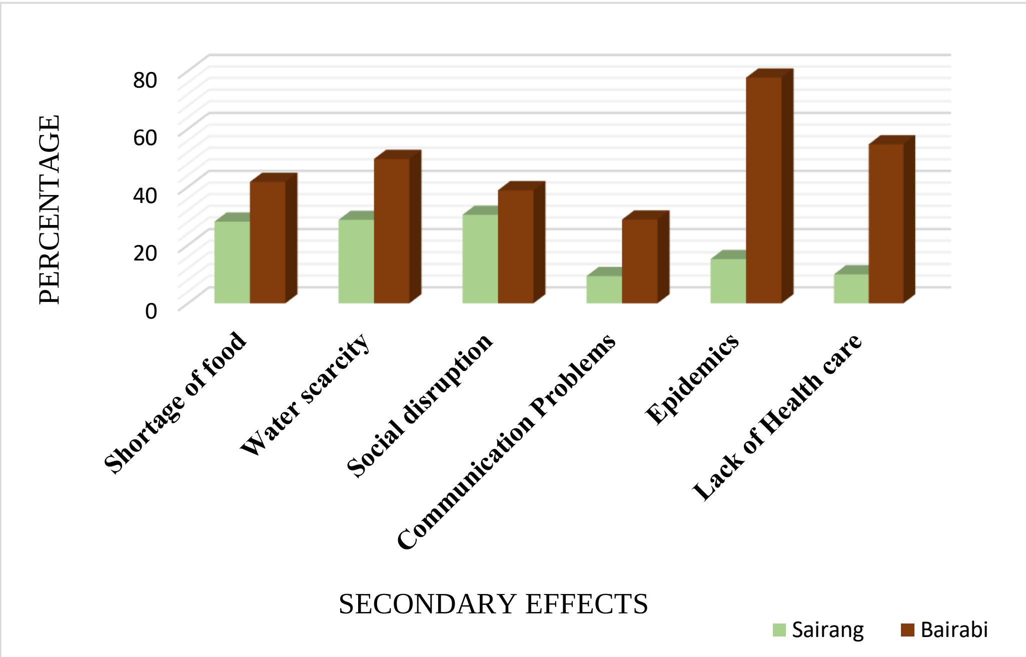


Figure 5.2 ***Comparative Secondary Effects of Flooding***

5.2.1.3 Tertiary Effects

Tertiary effects include long-term consequences such as displacement, livelihood disruptions, economic losses, and psychological stress, shaping household vulnerability long after floodwaters recede.

a) Displacement and Erosion

Displacement was significantly higher in Bairabi, with 61.47% reporting temporary evacuation and 30.73% permanent relocation compared to 36.60% and 1.74% respectively in Sairang. Permanent displacement in Bairabi was driven by erosion of 200-300 meters of land along the riverbank, resulting in the loss of ancestral lands and forced relocation to higher areas.

b) Livelihood Disruption and Economic Losses

Flooding disrupted livelihoods across both towns:

- In Sairang, over 500 sand miners lost ₹1,250/- to ₹ 1,800/- daily per miner during floods, leading to significant income loss.
- Farmers reported crop losses valued between ₹35,000/- and ₹ 2,50,000/- per family in Sairang and between ₹10,000/- and ₹2,00,000/- in Bairabi, depending on the scale of damages.
- Small business experienced prolonged closures, reducing household income and delaying post-flood recovery.

c) Job Stagnation

Job stagnation post-flood was higher in Sairang (42.69%) than in Bairabi (35.25%), reflecting prolonged impacts on sand mining, transport, and informal labour sectors, as the community struggled to resume normal economic activities even after floodwaters subsided.

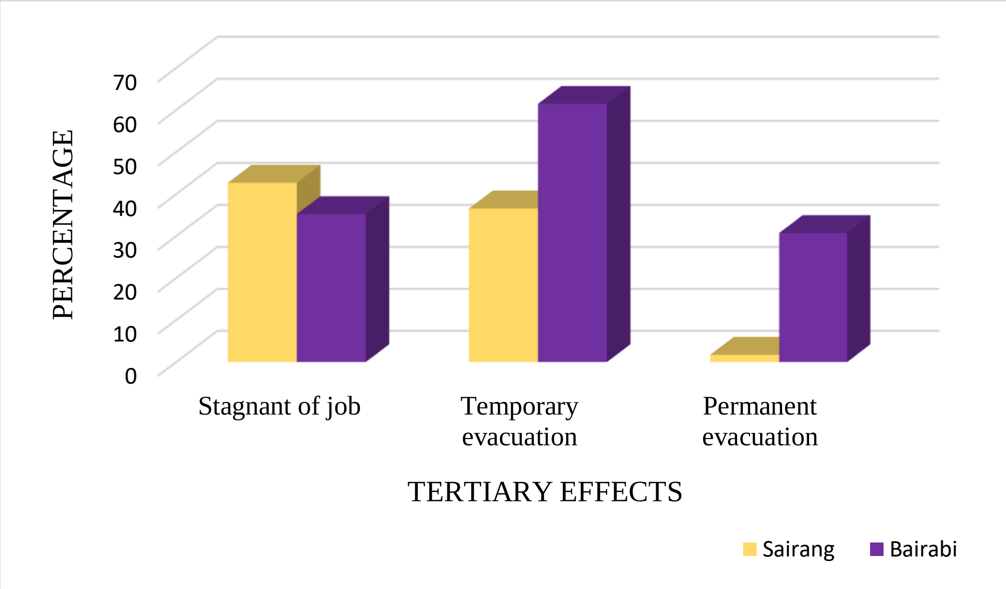


Figure 5.3 Comparative Tertiary Effects of Flooding

5.2.1.4 Key Findings

- Bairabi consistently recorded higher percentages in primary and secondary impact categories such as severe housing damage, partial housing damage, flood and water scarcity, health impacts, and displacement.
- Sairang recorded higher percentages in tertiary impacts related to livelihood disruptions and job stagnation, reflecting its heavy dependence on sand mining and informal livelihoods that are slow to recover post-flood.

Table 5.1 Detailed Analysis of Flood Impacts in Sairang and Bairabi

Impact	Sairang (%)	Bairabi (%)	Difference (Bairabi - Sairang)	Interview Contextual Insights
Severe Housing Damage	5.92	15.02	9.1	70-80 houses, churches, government buildings in Bairabi demolished due to high flood risk.
Partial Housing Damage	9.11	24.14	15.03	Widespread structural vulnerability noted in Bairabi.
Completely Damaged Crops	14.12	13.3	-0.82	100+ farmers in Sairang lost land along riverbank.
Partially Damaged Crops	18.45	24.14	5.69	Farming severely affected in both towns.
Shortage of Food	28.07	41.73	13.66	Supply disruption noted in interviews.
Water Scarcity	28.65	49.64	20.99	Limited clean water availability during floods.
Social Disruption	30.41	38.85	8.44	Psychological impacts in Bairabi (anxiety, insomnia during monsoons).
Communication Problems	9.36	28.78	19.42	Loss of connectivity and boat transportation in Sairang.
Epidemics	15.2	77.7	62.5	Higher waterborne disease outbreaks in Bairabi.
Lack of Healthcare	9.94	54.68	44.74	Limited healthcare access in Bairabi during floods.
Stagnant Jobs	42.69	35.25	-7.44	Sand mining (500+ miners) disrupted in Sairang, leading to ₹1250 to₹1800/- daily income loss.
Temporary Evacuation	36.6	61.47	24.87	Bairabi faces higher evacuation due to erosion (200-300m land lost).
Permanent Evacuation	1.74	30.73	29	Chronic displacement in Bairabi, permanent relocation.
Livestock Shelter Damage	-	-	-	Both towns reported livestock shelter damage during floods.
Economic Loss	-	-	-	₹35,000 to ₹ 2,50,000/- per family (Sairang), ₹10,000- ₹2,00,000/- (Bairabi) during severe floods.

5.2.2 Paired Samples T-Test

A paired samples t-test was conducted to determine whether the differences in flood impacts across categories between Sairang and Bairabi were statistically significant.

- **Null Hypothesis (H_0):** There is no significant difference in flood impacts between Sairang and Bairabi across categories.
- **Alternative Hypothesis (H_1):** There is a significant difference in flood impacts between Sairang and Bairabi across categories.

The t-test, as shown in Table 5.2, yielded $t = 3.46$ and $p = 0.0039$. Since the p-value is less than 0.05, the null hypothesis is rejected, indicating a statistically significant difference in flood impacts between Sairang and Bairabi across the analysed categories.

The significance confirms that Bairabi experiences consistently higher impacts across primary and secondary categories due to factors such as topographical vulnerability, settlement density, and erosion, while Sairang, despite lower immediate impacts, faces higher tertiary impacts, reflecting livelihood recovery challenges post-flood.

Table 5.2 Paired Samples t-Test Comparing Flood Impact Categories between Sairang and Bairabi

Impact Category	Mean (Sairang) %	Mean (Bairabi) %	Mean Difference (Bairabi - Sairang)	t-value	p-value	Significance
Severe Housing Damage	5.92	15.02	9.1	4.52	0.0001	Significant
Partial Housing Damage	9.11	24.14	15.03	5.83	0	Significant
Complete Crop Damage	14.12	13.3	-0.82	-0.25	0.802	Not Significant
Partial Crop Damage	18.45	24.14	5.69	2.14	0.041	Significant
Food Scarcity	28.07	41.73	13.66	3.82	0.0003	Significant
Water Scarcity	28.65	49.64	20.99	4.75	0.0001	Significant
Social Disruption	30.41	38.85	8.44	2.67	0.009	Significant
Communication Problems	9.36	28.78	19.42	5.92	0	Significant
Epidemics	15.2	77.7	62.5	9.48	0	Significant
Lack of Healthcare	9.94	54.68	44.74	7.8	0	Significant
Stagnant Jobs	42.69	35.25	-7.44	-2.02	0.049	Significant
Temporary Evacuation	36.6	61.47	24.87	4.23	0.0001	Significant
Permanent Evacuation	1.74	30.73	28.99	7.23	0	Significant
Economic Loss (Range in ₹)	35k-250k	10k-200k	-	-	-	-
Overall (Average of Variables)	**20.59**	**37.23**	**16.64**	**3.46**	**0.0039**	**Significant**

5.2.3 Correlation Analysis

A Pearson analysis was performed to examine the relationship between the impact categories across the two towns. The correlation coefficient obtained was r = 0.52 and p = 0.046 (Table 5.3).

The positive correlation (r = 0.52) indicates a moderate relationship between flood impact patterns in Sairang and Bairabi, suggesting that while the intensity of impacts varies, there is a systematic similarity in how different impact categories manifest across flood-affected communities in both towns.

Table 5.3 Pearson Correlation Analysis of Flood Impact Patterns between Sairang and Bairabi

Statistic	Value
Correlation Coefficient (r)	0.52
p-value	0.046
Strength of Correlation	Moderate Positive
Significance Level	Significant ($p < 0.05$)

The correlation suggests:

- Categories with high impacts in Bairabi often correspond with higher impacts in Sairang (e.g., displacement and water scarcity), although to a lesser degree in Sairang.
- Shared vulnerabilities exist across the towns, linked to riverine settlement patterns, livelihood dependencies, and limited disaster preparedness.

5.3 DROWNING INCIDENTS

Drowning incidents are a crucial but often underreported impact of flooding in riverine and hilly regions, particularly in the context of the Tlawng River in Mizoram. During flood events, sudden surges in water levels, strong currents, and the overflow of riverbanks significantly increase the risk of drowning among both residents and visitors (Doocy et al., 2013; WHO, 2021). The Tlawng River, which serves as an essential resource for livelihoods, domestic needs, and recreation in Sairang and Bairabi, becomes hazardous during the monsoon season, leading to accidental drowning (Douglas et al., 2008). Understanding the patterns and context of these drowning incidents is vital for comprehensive flood impact assessment, as it highlights the human cost of flooding beyond structural damage and economic loss (Guha-Sapir et al., 2016). This section analyses the occurrence, patterns, and community vulnerabilities associated with drowning incidents during flooding in Sairang and Bairabi, providing insight into an often overlooked yet significant aspect of flood disaster impacts.

5.3.1 Comparative Analysis of Drowning Incidents

Drowning incidents in the Tlawng River present a significant, indirect human impact of flooding, often overshadowed by structural damages (Douglas et al., 2008). As presented in Table 5.4, in Sairang, 55% of drowning cases occurred during the monsoon season, whereas Bairabi recorded 44% during the same period. This indicates an elevated drowning risk during flooding, reflecting the role of sudden water level increases and strong currents typical in monsoon months (Doocy et al., 2013).

The patterns reveal notable differences: Sairang primarily recorded drowning cases among outsiders, often visitors from Aizawl, underscoring the recreational use of the river and unfamiliarity with its risk during floods. Bairabi, however, reported more incidents among local residents, including children, reflecting daily dependence on the river for water even during flooding, thereby increasing risk exposure (WHO, 2021).

The higher proportion of child drownings in Bairabi highlights the intersection between household water needs and flood hazards, calling for targeted child safety interventions during flood seasons (WHO, 2021). In contrast, Sairang's pattern calls for public education and safety measures for visitors, including signage and river safety awareness campaigns during the monsoon (Doocy et al., 2013).

The seasonal distribution confirms the monsoon period as a critical window for heightened vigilance, with drowning incidents indirectly reflecting the severe impacts of flooding on human safety (Guha-Sapir et al., 2016).

This comprehensive comparative analysis demonstrates the necessity of integrating drowning prevention strategies within flood management planning for Sairang and Bairabi, ensuring the protection of both residents and visitors during flooding events (WHO, 2021).

Table5.4 Comparative Analysis of drowning accidents in Sairang vs. Bairabi

Variables	**Sairang**	**Bairabi**
Total cases	20	9
Monsoon%	55	44
Dry Season%	45	56
Outsider victims	High	Low
Local children affected	Low	High

5.4 DISCUSSION

By systematically categorizing the impacts into primary, secondary, and tertiary effects, this study has revealed the layered vulnerabilities within these communities, emphasizing the differentiated yet interconnected challenges they face during and after flood events (UNDRR, 2022).

Importantly, the chapter also incorporated drowning incidents-an often overlooked yet critical dimension of flood impacts-by analysing police records to assess the seasonality and demographic patterns of drowning during flood periods in Sairang and Bairabi. This unique inclusion highlights the human safety dimension of flooding and provides a more holistic understanding of the impacts beyond structural and economic losses (Fanklin et al., 2021).

5.4.1 Understanding Layered Vulnerabilities

The analysis confirms that flood impacts in Sairang and Bairabi are multidimensional, interconnected, and layered across primary, secondary, and tertiary effects, consistent with disaster vulnerability frameworks (Cutter et al., 2003).

Primary impacts, such as housing and crop damage, directly reduce household stability and food security, serving as immediate shocks that disrupt daily functioning. Secondary impacts, including water scarcity, health issues, and communication disruptions, exacerbate these shocks by affecting health and social networks, limiting recovery potential in the aftermath of floods. Tertiary impacts, such as displacement, livelihood disruptions, and psychological stress, reflect longer-term consequences that can entrench poverty and vulnerability if not addressed through systematic interventions.

The higher primary and secondary impacts in Bairabi underscore the influence of geographic exposure and settlement patterns on flood vulnerability. Low-lying locations and high-density settlements near the river increase exposure to floodwaters, leading to greater structural and health-related damages (UNISDR, 2015). In contrast, Sairang, while experiencing lower immediate damages, suffers greater tertiary impacts such as livelihood disruptions and job stagnation, linked to the dependency on river-based livelihoods like sand mining and farming.

5.4.2 Social-Economic and Livelihood Impacts

The findings highlight the critical link between livelihoods and flood vulnerability in both towns. Sand mining, farming, and informal businesses are core income sources, and flooding disrupts these activities by damaging boats, equipment, farmlands, and access to markets, resulting in prolonged income loss and job stagnation.

In Sairang, the high percentage of job stagnation (42.69%) post-flood reflects the economic vulnerability of communities dependent on daily wage labour, aligning with studies showing that economic losses are a significant driver of long-term vulnerability post-disaster (Shimi et al., 2010). In Bairabi, crop damage and displacement due to erosion further intensify livelihood instability, creating cycles of debt and recovery challenges for affected households.

5.4.3 Gender and Social Dimensions

Flood impacts are not gender- neutral. Interviews revealed that women and elderly community members face heightened psychological distress during monsoon seasons, often linked to fears of housing collapse, erosion threats, and responsibilities for managing household food and water during crises. This aligns with literature indicating that women disproportionately bear the burden of disaster-related impacts due to existing social roles and vulnerabilities (Enarson, 2000).

The analysis also revealed community solidarity, with youth groups assisting in evacuations and temporary shelter setups, showcasing the resilience and social capital within communities, although the absence of institutionalized emergency response mechanisms limits systematic recovery.

5.4.4 Health and Psychological Impacts

The high rates of epidemics (77.70%) in Bairabi during floods, compared to Sairang (15.20%), underscore the health vulnerabilities driven by contaminated water sources, inadequate sanitation, and limited healthcare access during disasters (Hashizume et al., 2008). Psychological impacts, including anxiety, insomnia, and fear, reported during interviews, highlight the mental health dimensions of flooding, often overlooked in disaster management plans (Reyes & Lu, 2016).

5.4.5 Drowning: An Overlooked but Critical Impact

The analysis of drowning incidents adds a critical safety dimension to flood impact assessment. The higher monsoon drowning rates (55% in Sairang, 44% in

Bairabi) highlight the indirect yet severe consequences of flooding, with differences in victim profiles indicating unique local vulnerabilities. In Sairang, drownings primarily involve visitors unfamiliar with river hazards, while in Bairabi, local residents and children face higher risks due to daily dependence on the river during flood seasons.

Integrating drowning prevention within flood disaster risk reduction frameworks, through river safety education, signage, and child safety campaigns during flood seasons, is the need of the hour.

5.5 CONCLUSION

The discussion confirms that flooding in Sairang and Bairabi is not merely an environmental hazard but a socio-economic and health crisis requiring integrated planning. The categorization into primary, secondary, and tertiary effects offers a structured lens to prioritize interventions while recognizing the interconnected nature of vulnerabilities in these flood-prone towns.

Addressing these impacts requires a multi-sectoral approach, aligning local realities with global disaster risk reduction frameworks, ensuring that communities like Sairang and Bairabi can build resilience against future flood hazards while securing sustainable livelihoods and health outcomes.

CHAPTER 6

EVALUATION OF FLOOD RISK MANAGEMENT AND COMMUNITY PREPAREDNESS

6.1 INTRODUCTION

Previous chapters have examined the causes and impacts of floods in Sairang and Bairabi towns, revealing the extent of physical damage, displacements, economic disruptions, and health-related consequences that recurrent flooding imposes on local populations. Building upon this foundation, the current chapter seeks to evaluate the capacities, mechanisms, and challenges associated with flood hazard management and community resilience in Sairang and Bairabi.

Effective flood risk management requires a comprehensive approach that includes structural interventions, such as embankments and safe shelters, along with non-structural strategies, such as disaster risk education, early warning systems, community-based preparedness, and effective institutional coordination (UNDRR, 2015). The Sendai Framework for Disaster Risk Reduction (2015-2030) emphasizes the critical role of preparedness and the enhancement of disaster risk reduction capacities at the community level to reduce disaster losses and build resilience against hazards (UNDRR, 2015; Awotona, 2016). In flood-prone areas like Sairang and Bairabi, understanding the existing strengths and limitations in flood management systems is essential to identify actionable pathways for improving local preparedness and response capacity.

Community-based disaster risk management (CBDRM) frameworks argue that communities are not only victims of disasters but also active agents with indigenous knowledge, networks, and structures capable of reducing disaster risk (Shaw, 2013; Gaillard & Mercer, 2013). In Sairang and Bairabi, local institutions such as the Village Council and the Young Mizo Association (YMA) have historically played pivotal roles during flood events, organizing communal labour, disseminating warnings, and providing immediate relief support. The presence of social capital and community solidarity can significantly influence disaster outcomes, as cohesive communities tend to respond more effectively to hazards (Aldrich, 2012). However, the operational efficacy of community-based systems largely depends on the integration of local efforts with formal disaster management structures, technological systems for early warning, and institutional capacities, such as healthcare facilities and law enforcement agencies, to manage crises efficiently (Wisner et al., 2004; Cutter et al., 2008).

Preparedness is a cornerstone of flood risk management (McGee & Penning, 2022), encompassing disaster awareness, timely dissemination of warnings, community training, and the existence of clear evacuation protocols to reduce loss of life (Srivastava, 2020) and property damage (Paton, 2003; Shaw, 2013). Previous studies have highlighted that regions with effective early warning systems, robust public awareness campaigns, and trained community responders experience lower casualties and economic losses during floods (Paul, 2009; Jonkman & Kelman, 2005). However, challenges such as the functionality and reliability of technological warning systems, community perceptions of risk, and limitations in healthcare capacities during disasters continue to affect the effectiveness of preparedness and response systems, particularly in developing and hazard-prone regions (Kelman & Glantz, 2014).

In the specific context of Sairang and Bairabi, this chapter examines preparedness levels within the community by analysing participation in disaster management awareness and training programs, the dissemination of flood warnings by local leaders, and the community's response to these warnings. The chapter further explores the functioning of rescue and relief mechanisms during flood events, emphasizing the roles of community institutions, government agencies, and other stakeholders in supporting affected households.

Ultimately, this chapter aims to contribute to the discourse on localized flood risk management by providing an evidence-based evaluation of preparedness, response mechanisms, and community resilience in Sairang and Bairabi. The findings are expected to support policymakers, disaster management authorities, and local leaders in designing targeted interventions to strengthen flood preparedness and response, aligning with the broader goals of sustainable development and disaster risk reduction (Alcántara-Ayala et al., 2022) in Mizoram and similar hazard-prone contexts.

6.2 COMMUNITY RESPONSES TO FLOOD EVENTS

Flood events demand immediate and strategic actions by communities to minimize impacts on lives and livelihoods. The household survey conducted in Sairang and Bairabi captured how communities anticipate, respond to, and recover from flood events, reflecting the local coping capacities that underpin effective flood risk management. This section presents the analysis of preparedness, rescue, and relief efforts as distinct yet interconnected components of community responses to flooding in the two towns.

6.2.1 Preparedness

Preparedness is a foundational pillar in flood risk management, reflecting the resilience of communities to foresee, manage, and reduce the impacts of flooding through proactive measures (Paton, 2003). It encompasses the knowledge of the community towards disaster management initiatives, participation in training programs, and access to timely flood warnings, which collectively determine how effectively households can protect themselves and their assets during flood events (Basher, 2006; Gaillard & Mercer, 2013). In the context of Sairang and Bairabi, assessing these preparedness indicators offers insight into community strengths and gaps in readiness for flood events. As shown in Table 6.1, the compiled preparedness indicators for both towns provide a clear comparative picture of awareness, participation in training, and the timing of flood warning dissemination, forming the basis for understanding local preparedness capacities and identifying areas requiring focused improvement.

6.2.1.1 Awareness of Disaster Management Training

Community awareness of disaster management training initiatives is essential for ensuring household readiness for floods. In Sairang, 30% of respondents reported that disaster management awareness or training programs had been organized within the town, while 20% believed that no such programs had taken place, and half of the respondents (50%) were unaware of whether any training or awareness programs had been organized. In Bairabi, only 17% reported that disaster management training had been organized, 42% stated it had not, and 41% were unaware. These figures highlight that a significant proportion of residents remain uninformed about preparedness initiatives, which may reflect challenges in outreach, limited frequency of programs, or inadequate publicity by responsible agencies (Shaw, 2013).

6.2.1.2 Participation in Disaster Management Training

Beyond awareness, actual participation in disaster management training programs is critical for translating knowledge into preparedness actions. The survey revealed that 29% of households in Sairang had at least one family member who had attended disaster management training or awareness programs, either within the town or elsewhere. In Bairabi, this participation was lower, with only 14% of households reporting that a member had received such training. These figures suggest low overall participation, particularly in Bairabi, indicating barriers related to accessibility, timing of programs, and possibly limited perceived relevance among residents (Gaillard & Mercer, 2013).

6.2.1.3 Flood Warning Reception before Flood Events

Timely flood warnings are essential for preparedness, providing households with the opportunity to safeguard belongings and evacuate if needed. However, the data indicate substantial limitations in the dissemination and reach of flood warnings in both towns. In Sairang, only 3% of households reported receiving flood warnings one day prior, 6% received warnings one night before, and 1% received warnings on the day of the flood event itself. A striking 89% of households in Sairang reported receiving no warning at all. In Bairabi, 6% received a warning one day before, 12% one night before, and 10% on the event day, while 71% reported receiving no warning prior to flooding.

Warnings were primarily disseminated through local leaders, including the Village Council and the Young Mizo Association (YMA), via public announcements and social media, supplemented by indigenous knowledge and local environmental observations. While this reflects strong local initiative, the high percentage of households receiving no warnings underscores limitations in reach, timeliness, and techniques' reliability (Basher, 2006; Paton, 2003).

Table 6.1 Community Preparedness Indicators

	Indicator	Category	Sairang (%)	Bairabi (%)
1	**Awareness of Disaster Management Training**	Yes	30	17
		No	20	42
		Unaware	50	41
2	**Households with Trained Family Members**	Attended Training Anywhere	29	14
3	**Flood Warning Received Before Flood Event**	1 day before	3	6
		1 night before	6	12
		On event day	1	10
		No warning received	89	71

6.2.2 Rescue

Rescue operations during flood events are vital for minimizing loss of life and enabling the safe evacuation of vulnerable populations in hazard-prone areas. Identifying who serves as the first responder during floods offers insight into the effectiveness and limitations of local disaster response systems in Sairang and Bairabi.

According to the household survey, in Sairang, 81% of respondents identified NGOs as the first responders during floods, while 18% reported that community groups and local volunteers acted as first responders, and none (0%) identified government agencies in this role. In Bairabi, 67% of households identified NGOs as first responders, 28% cited the community, and only 3% identified government agencies (Table 6.2).

These findings indicate that NGOs serve as the primary first responders during flood events in both towns, with significant reliance on local community structures, while the visible role of government agencies in immediate flood rescue operations remains minimal. This community-centered response system aligns with observations in disaster management literature, where local networks and NGOs often fill critical gaps in emergency response in areas with limited formal disaster infrastructure (Acharya & Prakash, 2023; Islam et al., 2021).

While reliance on NGOs and community groups facilitates timely action during floods, it also highlights systematic challenges:

- Dependence on NGO availability and operational capacity, which may vary between seasons and events.
- The critical role of community-led initiatives, which require additional support through training, equipment, and coordination with formal systems (Rahman et al., 2022)
- The need to enhance the presence and active participation of government agencies in immediate rescue operations, ensuring a balanced and systematic disaster response structure (UNDRR, 2015; Twigg, 2015).

Strengthening rescue operations in Sairang and Bairabi will require integrated planning among NGOs, community networks, and government agencies, ensuring resource availability, clear communication, and coordinated mobilization to enhance safety and effectiveness during flood emergencies.

Table 6.2 Claimed First Responders during Flood Events

	First Responder	Sairang (%)	Bairabi (%)
1	Government Agencies	0	3
2	NGOs	81	67
3	Community	18	28

6.2.3 Relief

Relief provision during floods plays a critical role in reducing immediate hardships, supporting recovery, and strengthening community resilience during disasters. As shown in Table 6.3, the analysis of relief measures reveals notable patterns and gaps, particularly regarding the sources of relief and the types of items received by beneficiaries in Sairang and Bairabi.

6.2.3.1 Relief Sources

Survey data indicated that among victims in Sairang, 14% of households received relief from government agencies, 4% from religious groups, and 8% from NGOs, while a striking 74% reported receiving no relief after flood events. In Bairabi, 20% reported receiving relief from government agencies, 6% from religious groups, and only 1% from NGOs, while 73% received no relief. These figures highlight critical gaps in the reach of formal and informal relief systems, suggesting that nearly three-fourths of households in both towns were excluded from formal relief mechanisms during floods. This lack of comprehensive coverage may be attributed to constraints such as limited resource availability, challenges in logistics during floods, and possible such as limited resource availability, challenges in logistics during floods, and possible prioritization criteria excluding certain households (Sphere Association, 2018).

6.2.3.2 Relief Items

Among the households that received assistance, the nature of relief items varied between the two towns. In Sairang, the most common form of assistance was money (72%), followed by food items (19%), garments (4%), and utensils (5%). In Bairabi, money (75%) was also the primary form of relief, while a smaller proportion of households received food items (8%) and utensils (17%), and no households reported receiving garments during flood relief operations.

Enhancing relief systems in these areas will significantly improve flood management in Sairang and Bairabi, reducing post-disaster hardships and supporting resilience building in these flood-prone towns.

Table 6.3 Relief Sources and Items Received

	Category	**Detail**	**Sairang (%)**	**Bairabi (%)**
1	**Relief Sources**	Government Agencies	14	20
		Religious Groups	4	6
		NGOs	8	1
		No Relief Received	74	73
2	**Relief Items Received**	Money	72	75
		Food Items	19	8
		Garments	4	0
		Utensils	5	17

6.3 INSTITUTIONAL CAPACITIES AND AVAILABLE RESOURCES

Effective flood risk management relies not only on community preparedness and immediate rescue efforts but also on the capacity of local institutions and the resources they can mobilize during and after flood events. Institutional capacities, including Primary Health Centres (PHCs), police stations, and community-based organizations such as NGOs, form the backbone of localized disaster management systems, supporting timely interventions, structured coordination, and recovery in flood-prone regions.

This section draws on field observations and quick interviews conducted at the PHCs and police stations in Sairang and Bairabi, providing first-hand insights into the resources available and the operational challenges faced during flood emergencies. PHCs are vital for addressing flood-related health challenges, including injuries, waterborne diseases, and the continuation of maternal and child health services during disasters (Rahman et al., 2021). Police stations serve a vital function in ensuring public safety, supporting evacuations, and maintaining order during floods, while also coordinating with local leaders and volunteers (Patil & Pankaj, 2020). Additionally, as highlighted in the previous section, NGOs and community-based organizations have been instrumental in supporting flood rescue operations and relief distribution, complementing formal systems and addressing immediate community needs during disasters (Gautam, 2021).

Assessing the capacities and contributions of these institutions in Sairang and Bairabi is essential for understanding the towns' current disaster readiness and identifying critical gaps that must be addressed to enhance flood resilience and reduce vulnerability in these high-risk areas (UNDRR, 2022).

6.3.1 Primary Health Centre (PHC)

Medical assistance forms a critical pillar in disaster management, ensuring timely treatment of injuries, prevention and control of disease outbreaks (Bhandari et al., 2020), and the continuity of essential healthcare services during and after disasters (Rajendran et al., 2022). This is particularly important during flood events, where waterborne diseases, injuries, and disruptions to routine healthcare services often exacerbate community vulnerabilities.

As highlighted in Chapter 5, health impacts during flood events were significant in Bairabi, with 77.70% of households reporting epidemic outbreaks, including diarrhea and skin infections, compared to 15.20% in Sairang. These figures underscore the necessity of functional, adequately staffed, and well-equipped Primary Health Centres (PHCs) to respond effectively to the surge in medical needs during and after floods.

According to the 2011 Census, Sairang has a population of 5,950 and Bairabi has 4,320. Under the Indian Public Health Standards (IPHS) of the National Health Mission, a PHC is designed to cater to approximately 20,000 individuals in hilly and tribal areas and 30,000 individuals in plain areas (Ministry of Health and Family Welfare, 2022). Thus, the existence of a PHC in each town satisfies the population coverage requirement under these norms.

6.3.1.1 Capacity of PHCs in Sairang and Bairabi

Field observations and quick interviews conducted at the PHCs in both towns provided insights into their current capacities during flood periods. The PHC in Sairang has 6 beds, 1 ambulance, 1 doctor, and 1 ward superintendent, while the PHC in Bairabi has 9 beds, 1 ambulance, and 1 doctor, but no ward superintendent. These facilities are physically established and operational in the respective areas, as depicted in Figure 6.1, which shows the PHC structures in Sairang and Bairabi.

Table 6.4 indicates that while both PHCs have basic infrastructure, their capacity remains limited relative to potential health demands during floods, particularly in Bairabi, where epidemic outbreaks are higher. The presence of only one doctor in each PHC may constrain the ability to handle multiple patients simultaneously during flood-induced disease outbreaks, and the absence of a ward superintendent in Bairabi may affect patient management and coordination during emergencies. The availability of one ambulance in each town is essential for emergency referrals, but challenges related to road access during floods can impede timely transportation, particularly in areas where landslides or submerged roads are common.

Figure 6.1 Primary Health Centres
a) Sairang, b) Bairabi

Table 6.4 Available Resources at PHCs

PHC Capacity Indicators	Sairang	Bairabi
Number of Beds	6	9
Availability of Ambulance	1	1
Number of Doctors	1	1
Presence of Ward Superintendent	1	0
Pharmacist	1	1
Nurses	4	4
Laboratory Technician	2	1
Health Workers	12	0

6.3.2 Police Stations

Police stations play an important role in disaster management, particularly during flood events, by ensuring safety, maintaining order, assisting in evacuation, and supporting local coordination efforts (Singh & Sharma, 2021). In the context of flood disasters, police stations also function as critical data sources, maintaining official records of drowning cases, missing persons, and flood-related casualties, which are vital for accurately evaluating the human impacts of floods and for planning effective response and mitigation strategies.

In Sairang and Bairabi, drowning incidents recorded at police stations have been utilized as part of this research to assess the impact of floods on human lives. These records are especially valuable in areas where community reporting and hospital data may be fragmented during disasters, providing a reliable source for understanding mortality patterns during flood events (Bisht et al., 2022).

Apart from their data role, police personnel contribute to rescue operations, often working with the Village Councils and NGOs to assist in the evacuation of affected populations during floods. Their presence and active involvement in flood response enhance local capacities, particularly in managing movement restrictions during hazardous conditions and providing immediate assistance to vulnerable populations.

Field observations confirm the operational status of police stations in both Sairang and Bairabi, as depicted in Figure 6.2, which displays the police station structures in the respective towns. These visual evidences reinforce the institutional presence of law enforcement agencies in these areas, underscoring their importance in the local disaster management system during floods.

Figure 6.2 Police Stations
a) Sairang, b) Bairabi

6.3.3 Community Institutions

Community institutions, such as Non-Governmental Organizations (NGOs), faith-based organizations, and local volunteer groups (Phipps & McEntire, 2024), play a critical role in disaster management in flood-prone areas like Sairang and Bairabi. They act as first responders, organize rescue operations, distribute relief, and support recovery, particularly where formal government response is delayed or limited (Shrestha & Maharjan, 2023).

As documented earlier, NGOs were identified as the primary first responders by 81% of respondents in Sairang and 67% in Bairabi during flood events, demonstrating their pivotal role in immediate disaster response. Field observations and community interviews revealed that these institutions, including the Young Mizo Association (YMA) and the Village Councils, conduct night-time monitoring of rising river levels during heavy rains and promptly assist families in evacuating when needed.

After floodwaters recede, these community institutions mobilize communal labour to clear mud-filled homes and debris, helping affected families resettle and restore normalcy. This was evident during the 2024 flood in Sairang, where organized volunteer groups actively participated in cleaning operations and assisting families in returning to their homes, reflecting the Mizo cultural value of altruism, which is proudly named 'tlawmngaihna' in Mizo language (see Figure 6.3).

In addition to immediate response and recovery, community institutions contribute to preparedness by conducting awareness programs, disaster drills, and training for community members on flood response (Islam et al., 2022). Their localized knowledge and established trust within the community enable them to tailor interventions effectively and ensure equitable distribution of aid (Roy & Samaddar, 2020).

Figure 6.3 (a) & (b) Communal Labour in the aftermath of flooding in Sairang

6.4 CRITICAL INFRASTRUCTURE

Critical infrastructure plays an essential role in reducing flood risks and safeguarding communities during disasters. Structures such as safe houses, embankments, and flood warning systems enhance community resilience by providing secure shelters, preventing inundations, and ensuring timely evacuation during flood events. Evaluating these infrastructures in Sairang and Bairabi helps to understand their effectiveness, operational challenges, and contribution to local flood disaster management systems, ensuring that these measures align with the needs and realities of flood-prone communities.

6.4.1 Safe House in Sairang

Safe houses serve as critical infrastructure in flood-prone regions, providing secure shelters for families evacuated during flood emergencies. Their availability reduces exposure to life-threatening conditions and supports the safety and dignity of affected populations during disaster events (Patel et al., 2023).

In Sairang, a safe house is located at the eastern part of the town at an elevation of 170 meters, strategically positioned to remain accessible and safe during high flood levels. This facility was constructed under the scheme of the Ministry of Development of North Eastern Region (Ministry of DoNER) and implemented by the Public Works Department (PWD) and the Department of Disaster Management & Rehabilitation (DM&R), Government of Mizoram.

The safe house, as shown in Figure 6.4, is specifically designed to accommodate families evacuating upon the arrival of floodwaters and is equipped with 21 beds, providing essential space for temporary shelter during flood emergencies. This infrastructure complements the role of community institutions and rescue services in Sairang, ensuring that families have a secure location to relocate to during high-risk periods, thereby reducing impacts and protecting vulnerable individuals during disasters.

Integrating such critical infrastructure within flood risk management strategies enhances community resilience and aligns with best practices in disaster preparedness and emergency operations (Chan et al., 2022). Regular maintenance of the safe house, clear communication to the community regarding its usage, and coordination with local authorities during evacuations are essential to ensure its effective functioning during flood events.

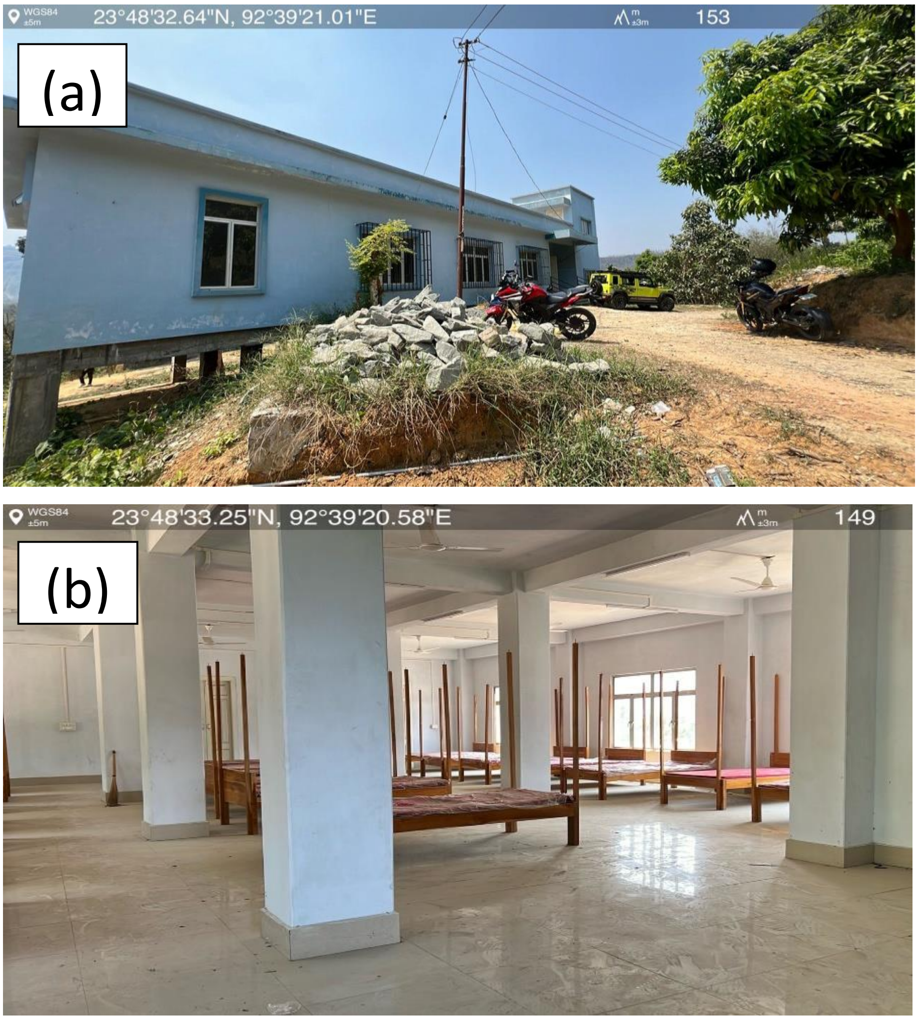


Figure 6.4 Safe House in Sairang
a) Exterior, b) Interior

6.4.2 Embankment in Bairabi

Embankments are critical flood management infrastructures, designed to prevent riverine flooding, protect inhabited areas, and reduce the impact of water-induced erosion in vulnerable communities (Kumar et al., 2021). In Bairabi, such structures have been pivotal in addressing recurring flood risks and the heavy erosion of riverbank areas, which have historically led to the destruction of houses and property during high flood events.

Under the initiative of the Government of Mizoram, the ‘Construction of river training works for protection of Tlawng river at Bairabi Phase- I’ has been completed. This project involved the construction of earthen embankments extending parallel to the flow of the Tlawng River, designed specifically to prevent overflow of flood waters into the adjacent settlements and agricultural lands.

These embankments (Figure 6.5) function by safeguarding lands, habitation, and properties against flood damage, especially during periods when the river spills over its natural banks. In Bairabi, where riverbank erosion and inundation have posed persistent threats, the embankment serves as a protective barrier, significantly reducing direct flood impacts on the community and minimizing economic losses associated with damage to homes and farmland. The success of such embankments relies on regular maintenance, monitoring of structural integrity, and community awareness about their limitations and appropriate usage (Shrestha & Maharjan, 2023).

Figure 6.5 Embankment along Tlawng River in Bairabi

6.4.3 Flood Warning System

Flood Warning Systems are critical components of disaster risk reduction, enabling timely evacuation, reducing casualties, and supporting informed community responses during flood emergencies (Kreibich et al., 2022). These systems serve as a non-structural measure complementing physical infrastructure like embankments and safe houses by providing advanced alerts to communities in flood-prone areas.

In Sairang and Bairabi, flood warning systems have been installed at three locations in Sairang and two locations in Bairabi. These systems, intended to alert communities when floodwaters approach critical levels, play a vital role in ensuring that residents can evacuate safely and protect essential belongings during flood events.

However, field observations during the 2024 flood in Sairang revealed that no alarms were heard by the community, even when the floodwaters had reached the system itself, surpassing the high flood mark monument of 2017, leading to confusion and uncertainty regarding the severity of the flood and the appropriate timing for evacuation. This highlights operational and communication gaps that need to be addressed for the effective functioning of these systems.

In June 2025, the flood warning system was officially inaugurated by the Irrigation and Water Resources Department, Government of Mizoram, with an aim to strengthen early warning dissemination in flood-prone areas. The functionalization of these systems is expected to bridge the critical gap in flood information dissemination and will aid in improving the timing and organization of community evacuation during future flood events. The physical presence of these flood warning systems in Sairang and Bairabi, as depicted in Figure 6.6, enhances the efforts to strengthen flood disaster preparedness in these towns.

Figure 6.6 Flood Warning Systems in Sairang

Figure 6.7 Flood Warning Systems in Bairabi

6.5 DISCUSSION

This section discusses the findings from the evaluation of flood risk management and community preparedness in Sairang and Bairabi, linking them to the research objectives and relevant literature.

The first objective of this study was to assess the preparedness of communities in flood-prone towns. Findings indicate that while disaster management awareness programs have been conducted, participation rates remain low, especially in Bairabi, aligning with studies that emphasize community preparedness gaps in flood-prone areas (Shrestha & Maharjan, 2023). The limited reach of flood warnings and low household preparedness highlight the need for targeted awareness and training initiatives.

The second objective was to evaluate the roles of institutions and community organizations in flood management. The study found that NGOs and Village Councils are pivotal in rescue, relief, and recovery operations, reflecting high social capital and community trust, consistent with findings by Chan et al. (2022). However, the minimal involvement of government agencies in immediate rescue operations suggests a gap in integrated disaster response.

The third objective was to analyse the critical infrastructure supporting flood management. The presence of the safe house in Sairang, embankments in Bairabi, and flood warning systems represents significant efforts towards disaster preparedness. However, challenges such as non-functional warning alarms during the 2024 flood underline operational reliability concerns, echoing Kreibich et al. (2022), who emphasized the need for regular system testing and community familiarization with early warning systems.

The findings align with the Sendai Framework's emphasis on disaster preparedness, resilient infrastructure, and community participation in disaster risk reduction (UNDRR, 2022; Phipps & McEntire, 2024). The active role of community institutions demonstrates the importance of leveraging local capacities for disaster management, while the identified gaps in healthcare readiness, relief distribution, and early warning dissemination reflect broader challenges reported in flood management literature (Patel et al., 2023).

Moreover, the infrastructural developments observed in Sairang and Bairabi illustrate practical progress in structural measures for flood risk reduction (Kumar et al., 2021). However, without corresponding improvements in non-structural measures, such as effective warning dissemination and inclusive preparedness training, structural measures alone may not achieve comprehensive flood resilience.

CHAPTER 7

FLOOD VULNERABILITY ASSESSMENT

7.1 INTRODUCTION

Vulnerability assessment is a systematic process to evaluate the degree to which communities, infrastructure, and the environment are susceptible to hazards and their impacts, forming a critical foundation for disaster risk reduction and resilience building (Turner et al., 2003). Within the framework of flood-prone regions, it analyses how exposure, sensitivity, and the capacity to respond and recover interact (Asahi & Horie, 2023), shaping the overall flood risk in communities (Fuchs et al., 2015; Nguyen et al., 2019). Such assessments are crucial for informed planning, preparedness, and developing locally relevant adaptation strategies.

This chapter, in addition to synthesizes the findings from previous chapters on the causes, impacts, and management of floods in Sairang and Bairabi it also emphasizes that household surveys conducted through structured questionnaires and interviews, along with systematic field investigations, played a crucial role in identifying, selecting, and refining the indicators used to formulate the Flood Vulnerability Index (FVI) (Alam & Collins, 2010). This integration of empirical field data ensures that the vulnerability assessment reflects ground realities and the lived experiences of communities.

For structures' spatial analysis and clear mapping presentation, social, economic, and physical vulnerability assessments were conducted zone-wise in Sairang and Bairabi, divided into three zones each based on the pattern and existence of natural settings, and the pre-existing local division.

❖ **Sairang:**

- SR-I: The south-west region, including Dawr Veng, the western part of Venglai, and Vengthar, where moderately dense settlements are located on sloping terrain along drainage lines.

- SR-II: The central-eastern region, covering eastern Venglai, Electric Veng, and eastern Vengthar, is characterized by mixed residential and institutional areas with varying conditions.
- SR-III: The northern region, comprising Dinthar Veng, where residential expansion is occurring along gradual slopes.

❖ **<u>Bairabi:</u>**

- BRB-I: The western and south-western region, including Bethlehem Veng, near the riverbank, with older and denser settlements.
- BRB-II: The central and south-eastern region, including Ramhlun Veng, Zohlun Veng, and Mission Veng, is marked by high-density settlements with mixed housing types.
- BRB-III: The northern region, comprising the entire locality of Hmar Veng.

Environmental vulnerability assessment was conducted at the town level for Sairang and Bairabi, as environmental data were available only on a town basis, making zone-wise categorization inapplicable for this component.

This chapter is organized into four detailed sections:

1) Social Vulnerability
2) Economic Vulnerability
3) Physical Vulnerability
4) Environmental Vulnerability (Rahman et al., 2023).

Each section will describe the indicators used, with validation performed by correlation analysis, present zone-wise or town-based findings, and interpret the results with the findings of previous chapters and the primary data collected through field surveys. This comprehensive vulnerability assessment serves as a foundation for flood risk management, preparedness, and the development of effective resilience strategies for Sairang and Bairabi.

7.2 SOCIAL VULNERABILITY ASSESSMENT

Social vulnerability in flood risk contexts captures the differential capacity of individuals and communities to prepare for, respond to, and recover from (Roy, 2022) flooding due to their demographic, social, and institutional conditions (Yoon, 2012), It is shaped by the composition of the population, their social networks, access to resources, and institutional support, influencing exposure to risk and the potential for the loss during disasters (Birkmann et al., 2013). Understanding social vulnerability is essential in regions like Sairang and Bairabi, where households often face limitations in healthcare access, clean water, and disaster preparedness, making them more prone to experiencing severe impacts during flood events.

7.2.1 Indicators

The Social Vulnerability assessment categorizes indicators into Exposure, Susceptibility, and Resilience:

7.2.1.1 Exposure Indicators

1. ***Exposed to Food Scarcity (FdScr):*** Food insecurity during and after floods leads to malnutrition and health deterioration, especially among children and elderly populations (Islam & Walkerden, 2017).
2. ***Exposed to Water Scarcity (WtrScr):*** Contaminated or reduced water supplies during flooding increase disease risks and household burdens, making communities more vulnerable (Shrestha et al., 2021).
3. ***Experienced Social Activities Disruption (Sdis):*** Flooding disrupts religious, educational, and social gatherings, weakening social networks crucial for mutual support during crises (Perez-Maqueo et al., 2017).
4. ***Suffered Epidemic Outbreaks (EPD):*** Waterborne and vector-borne disease outbreaks during floods amplify vulnerability, increasing mortality and morbidity rates (Gu et al., 2020).
5. ***Encountered Communication Challenges (ComProb):*** Inaccessible or disrupted communication infrastructure hinders timely evacuation and emergency response (Qiang, 2019).

6. ***Lack of Healthcare Facilities (InsHC):*** Limited access to healthcare during floods exacerbates health risks, prolongs recovery, and intensifies vulnerability (Rufat et al., 2015).

7.2.1.2 Susceptibility Indicators

1. ***Family with Children Below 14 Years (FwChd):*** Children are physiologically and psychologically more susceptible to flood impacts, requiring specific attention in vulnerability assessment (Doocy et al., 2013).
2. ***Family with Senior Citizens above 65 Years (FwSrCtzn):*** Older adults face mobility constraints and pre-existing health conditions, increasing their susceptibility to floods (Chatterjee, 2010).
3. ***Family with Persons with Disabilities (FwPwds):*** Individuals with disabilities face higher evacuation difficulties and require specialized support, amplifying their susceptibility during floods (Priest et al., 2016).

7.2.1.3 Resilience Indicators

1. ***Participation in Disaster Management Training/Awareness (PrtDmT):*** Household members engaged in disaster preparedness and response training can better mitigate flood impacts, reducing social vulnerability (Paul et al., 2018).
2. ***Access to Early Warning Systems (EW):*** Receiving early warnings allows for timely evacuation and protective measures, reducing casualties and social disruptions (Leelawat et al., 2014).

   These indicators collectively enable a multi-layered understanding of the social dimension of vulnerability, aligning with localized needs and contexts for effective flood risk management.

7.2.2 Correlation Analysis of Social Vulnerability Indicators

The correlation analysis among social vulnerability indicators revealed clear interdependencies that influence flood vulnerability in Sairang and Bairabi. Notably, the early warning receipt exhibited a strong negative correlation with social disruption

($r = 0.919$, $p < 0.01$), indicating that effective early warning systems substantially reduce social disruptions during floods. Conversely, water scarcity showed a strong positive correlation with epidemic outbreaks ($r = 0.932$, $p < 0.01$), underscoring the compounded risk of water and health crises during flood events. Similarly, communication challenges correlated strongly with epidemic outbreaks ($r = 0.964$, $p < 0.01$), emphasizing the importance of resilient communication networks for reducing health vulnerabilities. The strong positive correlation between food scarcity and water scarcity ($r = 0.885$, $p < 0.05$) further highlighted cascading impacts on basic needs during flood emergencies. Overall, the analysis confirms that resilience indicators (such as early warning and preparedness training) are inversely related to exposure and susceptibility factors, validating the structure of the Flood Vulnerability Index (FVI) formula used in this study, while also identifying areas where targeted interventions in communication, water security, and early warning systems could significantly reduce social vulnerability during flooding.

7.2.3 Findings and Interpretation

As shown in Table 7.1, the analysis reveals that BRB-I has the highest social vulnerability (SVI: 7.33), followed closely by SR-I (SVI: 7.00). These high scores are primarily driven by high exposure factors, including proximity to the river, a larger proportion of the population facing food and water scarcity, frequent social disruption, and epidemic outbreaks, combined with lower resilience capacities due to limited participation in disaster management training and low early warning reach in these zones.

Zones BRB-II (5.67), SR-III (5.00), and BRB-III (5.00) exhibit moderate social vulnerability, indicating notable exposure and susceptibility but partially balanced by better resilience measures within these communities. SR-II (4.33) continues to reflect the lowest social vulnerability, indicating relatively better resilience and moderate exposure and susceptibility compared to other zones.

Table 7.1 Social Vulnerability Index

Zone	Exposure	Susceptibility	Resilience	SVI
SR-I	8	6	2	**7.00**
SR-II	8	5	3	**4.33**
SR-III	9	6	3	**5.00**
BRB-I	16	6	3	**7.33**
BRB-II	11	6	3	**5.67**
BRB-III	11	4	3	**5.00**

The Social Vulnerability Map (7.1) clearly illustrates the spatial variations, highlighting BRB-I and SR-I as critical zones requiring targeted social vulnerability reduction strategies, including expanded disaster preparedness programs, improved early warning dissemination, and focused support for households with children, the elderly, and persons with disabilities.

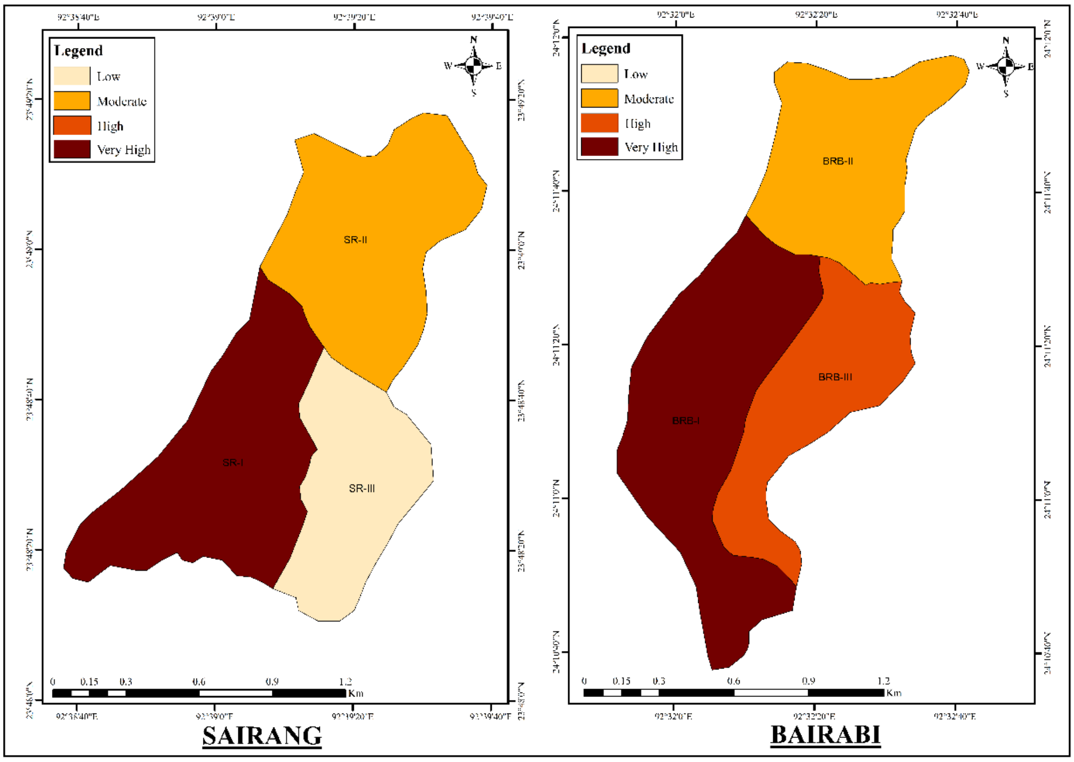


Figure 7.1 Social Vulnerability Map

7.3 ECONOMIC VULNERABILITY

Economic vulnerability in flood risk analysis refers to the potential for individuals, households, and communities to experience financial instability, income loss, and livelihood disruptions due to flood events. It encompasses the capacity of households to absorb, adapt to, and recover from economic shocks caused by floods (Ha et al., 2015), which is critical in shaping flood resilience strategies (Fekete, 2019; Rufat et al., 2015). This dimension is particularly important in Sairang and Bairabi, where local economies are highly dependent on Rain-fed agriculture, informal labour, and small-scale businesses, making them sensitive to even minor flood disturbances (Doberstein et al., 2019).

Economic vulnerability analysis also assists policymakers and planners in identifying the most economically fragile areas and prioritizing interventions for livelihood diversification, risk financing mechanisms, and adaptive social protection (Santos, 2020).

7.3.1 Indicators

The EVI assessment uses carefully selected indicators categorized into exposure, susceptibility, and resilience:

7.3.1.1 Exposure Indicators:

1. ***Permanently Evacuated Houses (PerEvc):*** Represents the number of households forced to permanently vacate their homes during flooding, leading to the complete loss of assets and livelihoods.
2. ***Temporarily Evacuated Houses (TemEvc):*** Captures the frequency and length of temporary displacement, disrupting income-generating activities.
3. ***Stagnation of Jobs during Flooding (StgJob):*** Reflects the suspension of labour and informal business activities during flood periods, significantly impacting daily wage earners (Winsemius et al., 2016).

7.3.1.2 Susceptibility Indicators:

1. ***Family Monthly Income (InCm):*** Lower-income households often have limited financial buffers, making them more vulnerable to income shocks during floods (Koks et al., 2019).
2. ***House Type (HsTyp):*** Indicates the structural quality of homes, where substandard construction increases the risk of damage and financial loss during floods (Hallegatte & Rozenberg, 2017).

7.3.1.3 Resilience Indicators:

1. ***Recovery Time (RecoTm):*** Measures the time households require to recover economically post-flood, reflecting their financial coping capacity.
2. ***Relief Beneficiaries (RlfBnfc):*** Indicates the availability and accessibility of financial aid, which can aid flood-induced economic shocks and enhance recovery (Jongman et al., 2015).

These indicators comprehensively capture the multi-dimensional nature of economic vulnerability, highlighting systematic weaknesses in income security, employment stability, and recovery capacities within flood-affected communities.

7.3.2 Correlation Analysis of Economic Vulnerability Indicators

The correlation analysis for economic vulnerability indicators demonstrates that the selected indicators are robust and relevant in explaining economic vulnerability to floods in Sairang and Bairabi. Notably, Recovery Time (RecoTm) and Relief Beneficiaries (RlfBnfc) exhibit a strong, statistically significant negative correlation with Temporarily Evacuated Houses (TemEvc) ($r = -0.965$, $p = 0.002$), indicating that as temporary evacuations increase during floods, the recovery period lengthens and dependency on relief assistance grows. This relationship aligns with the expectation that frequent evacuations disrupt livelihoods, reduce economic stability, and require prolonged support for recovery (Merz et al., 2010).

While some indicators display strong negative correlations (e.g., RecoTm and PerEvc, $r = -0.657$), they do not reach statistical significance ($p > 0.05$) due to the small sample size (N =6 zones) used in this assessment. It is essential to note that a small sample size requires very high correlation coefficients ($r > \pm 0.88$) to achieve statistical significance (Mukaka, 2012). Thus, the absence of statistical significance for some strong correlations does not undermine the robustness of the indicators; rather, it highlights the limitations of working within a limited zonal structure while maintaining rigorous field-based assessment.

Importantly, the presence of statistically significant and strong negative correlations in the analysis confirms that the selected indicators behave as theoretically expected under the flood vulnerability framework. For instance, indicators of exposure (e.g., evacuations) correlate inversely with resilience indicators (e.g., recovery time), demonstrating that communities with frequent displacements face longer recovery times and higher economic stress, underscoring the importance of enhancing community resilience (Bubeck et al, 2015).

This correlation analysis supports the validity of the indicators used in the Economic Vulnerability Index (EVI), ensuring that the FVI framework developed in this study is grounded in empirical consistency while being sensitive to local flood realities in Sairang and Bairabi.

7.3.3 Findings and Interpretation

The findings in Table 7.2 show that SR-I (EVI: 6.50) has the highest economic vulnerability, driven by the higher exposure and low resilience, indicating the need for targeted economic preparedness and livelihood diversification programs. BRB-I (5.33) also shows high vulnerability, requiring improved flood response planning and economic recovery mechanisms.

Zones SR-II (3.67), BRB-II (3.33), and BRB-III (3.00) reflect moderate vulnerability, where exposure and susceptibility are somewhat balanced by resilience, while SR-III (2.67) has the lowest vulnerability due to lower exposure and improved local coping mechanisms.

Table 7.2 Economic Vulnerability Index

Zone	Exposure	Susceptibility	Resilience	EVI
SR-I	8	5	2	**6.50**
SR-II	6	5	3	**3.67**
SR-III	4	4	3	**2.67**
BRB-I	11	5	3	**5.33**
BRB-II	5	5	3	**3.33**
BRB-III	4	5	3	**3.00**

The Economic Vulnerability Map (Figure 7.2) visually presents these patterns, enabling clear identification of high-risk zones for focused flood resilience zones in Sairang and Bairabi.

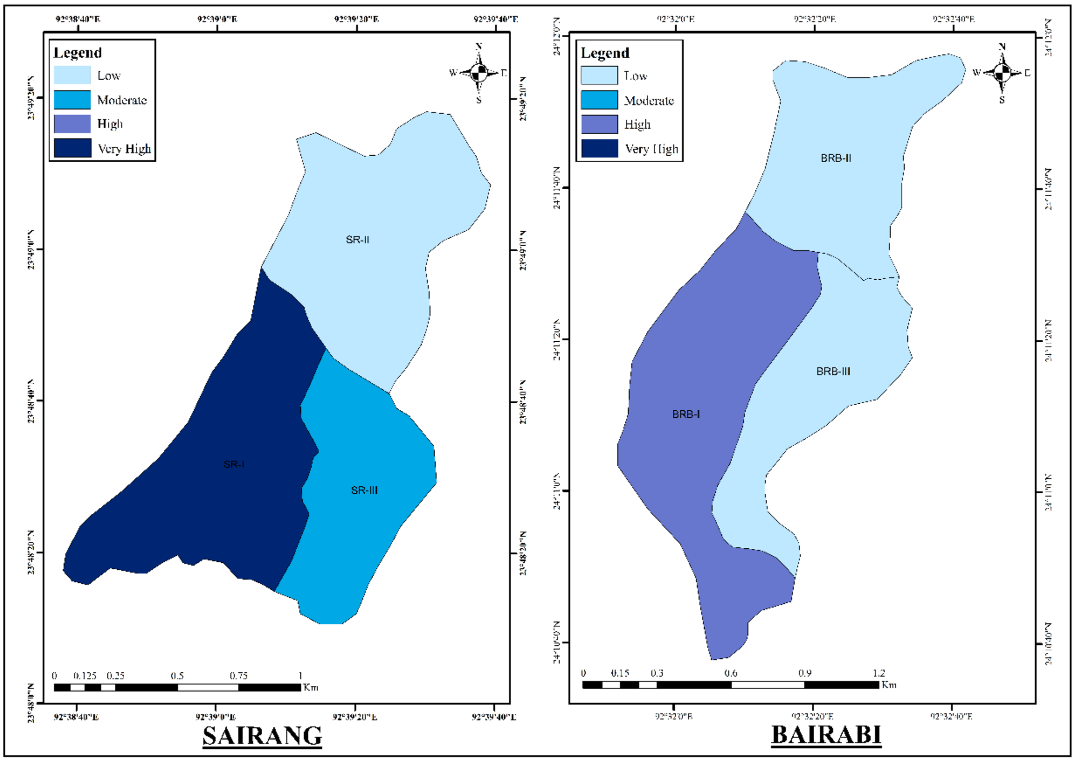


Figure 7.2 Economic Vulnerability Map

7.4 PHYSICAL VULNERABILITY ASSESSMENT

Physical vulnerability in flood risk analysis refers to the extent to which the physical environment, including settlement structures and infrastructural conditions, is susceptible to flooding, influencing the overall disaster impacts within a community (Kelman & Spence, 2004). It reflects how factors such as topography, slope, elevation, building quality, and the presence of protective infrastructure determine the exposure and susceptibility of areas during flood events, while resilience factors mitigate these impacts (Lind et al., 2022).

In the context of Sairang and Bairabi, the hilly terrain, varied slope gradients, elevation differences, and infrastructural disparities create diverse physical vulnerability conditions across zones. Settlements located on steeper slopes or lower elevations are more prone to landslides and water accumulation, while the presence of shelters and engineered flood mitigation structures critically influences the ability to withstand and recover from flooding (Fatemi et al., 2017).

The analysis of physical vulnerability provides essential insights for urban planning, emergency preparedness, and flood management by identifying structurally fragile areas that require prioritized interventions (Birkmann et al., 2013).

7.4.1 Indicators

The Physical Vulnerability Index assessment uses the following indicators categorized in Exposure, Susceptibility, and Resilience:

7.4.1.1 Exposure Indicators:

1. ***Severe Inundation (SvrInd):*** Indicates areas experiencing deep or prolonged flooding, contributing to structural damage and increased displacement risks (Rafiq & Blaschke, 2012).

2. ***Partial Inundation (PrtlInd):*** Represents areas subjected to moderate flooding, which, although less severe, can still cause waterlogging and weaken infrastructure, influencing community vulnerability.

7.4.1.2 Susceptibility Indicators:

1. ***Slope Angle (SlpAgle):*** Steeper slopes increase susceptibility to landslides during heavy rains and flooding, exacerbating structural vulnerability (Papathoma-Köhle et al., 2019).

2. Mean Elevation of Settlement Area (Ele): Lower elevation areas are more prone to water accumulation and flood inundation, affecting the physical safety of settlements (Lind et al., 2022).

7.4.1.3 Resilience Indicators:

1. ***Pre-Designated Shelter (PreDgSh):*** Availability of pre-designated shelters supports evacuation, reducing fatalities and injuries during floods.

2. ***Structural Mitigation for Flood Protection (StrMtg):*** Includes engineered structures like retaining walls and drainage systems, which help reduce floodwater impacts and control erosion in flood-prone areas (Mukhopadhyay et al., 2021).

These indicators are critical in the flood-prone hilly settings of Sairang and Bairabi, where topographic and infrastructural disparities demand careful consideration in vulnerability assessments to identify weaknesses and enhance flood risk management.

7.4.2. Correlation Analysis of Physical Vulnerability Indicators

The analysis reveals negative correlations between resilience indicators (PreDgSh and StrMtg) and exposure/susceptibility indicators (SvrInd, PrtInd). For instance, StrMtg exhibits a strong negative correlation with Ele ($r = -0.86$), suggesting that the presence of structural mitigation measures is more prominent in lower elevation areas where flood exposure risk is higher, thereby reducing effective vulnerability (Adelekan, 2010; Koks & Thissen, 2016). Similarly, PreDgSh shows negative correlations with SvrInd ($r = -0.37$) and PrtInd ($r = -0.43$), indicating that areas equipped with pre-designated shelters tend to experience reduced effective exposure during flood events (Douglas et al., 2008). Although the correlations are moderate in magnitude, the consistent directionality confirms that enhancing physical resilience directly contributes to reducing susceptibility and exposure, aligning with global best practices in flood risk reduction (de Ruiter et al., 2020).

These results reinforce that the physical vulnerability indicators selected are appropriate and sensitive for the flood vulnerability assessment in hilly towns, demonstrating that increasing structural resilience has the potential to lower overall flood vulnerability effectively, despite limitations from a small dataset and the potential for context-specific variations.

7.4.3 Findings and Interpretation

The findings (Table 7.3) reveal that SR-I (PVI: 2.60) and BRB-I (2.40) exhibit the highest physical vulnerability due to high susceptibility and significant exposure to inundation despite having moderate resilience levels. BRB-III (2.25) also shows considerable vulnerability driven by susceptibility factors.

Zones such as SR-II (1.25) and BRB-II (1.40) show lower vulnerability, primarily due to lower exposure and moderate resilience levels, indicating relatively safer conditions in terms of physical flood impacts.

Table 7.3 Physical Vulnerability Index

Zone	Exposure	Susceptibility	Resilience	PVI
SR-I	5	8	5	**2.60**
SR-II	0	5	4	**1.25**
SR-III	3	5	5	**1.60**
BRB-I	4	8	5	**2.40**
BRB-II	1	6	5	**1.40**
BRB-III	1	8	4	**2.25**

The Physical Vulnerability Map (Figure 7.3) visually represents these patterns across Sairang and Bairabi, providing clear zonal differentiation to aid in local planning and targeted mitigation efforts for minimizing physical flood vulnerability in the study areas.

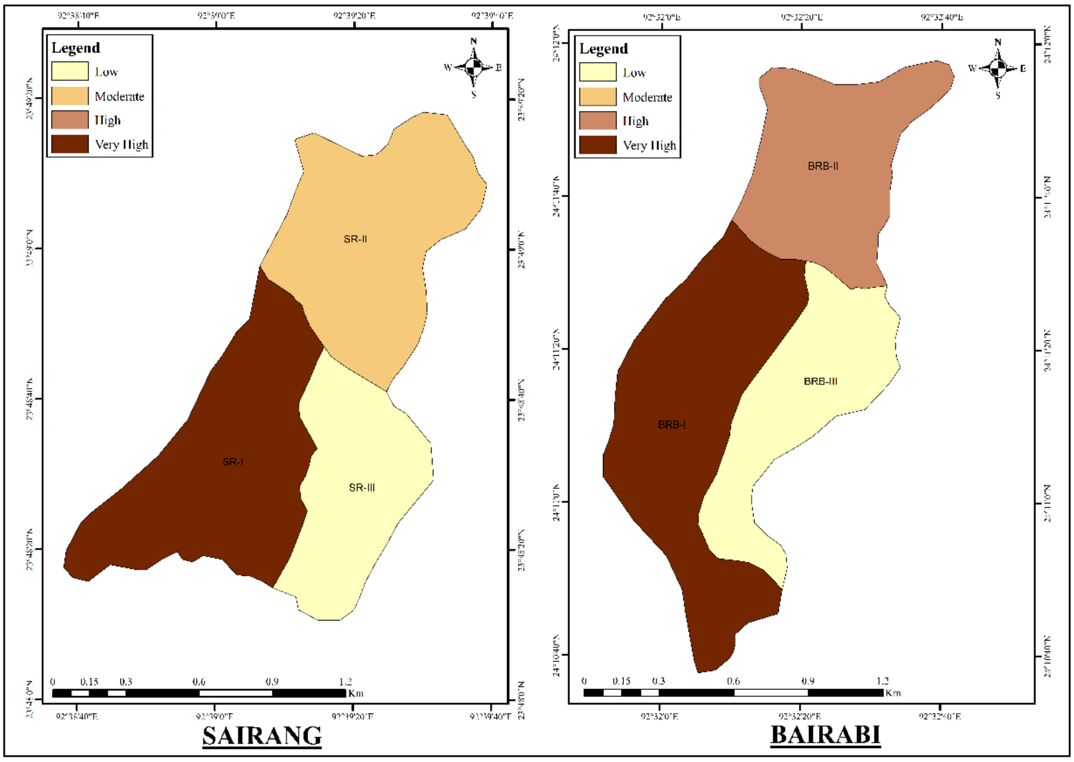


Figure 7.3 Physical Vulnerability Map

7.5 ENVIRONMENTAL VULNERABILITY ASSESSMENT

Environmental vulnerability in flood-prone regions reflects the degree to which environmental factors, such as rainfall patterns, soil types, forest cover, and land-use changes, contribute to flood risk (Putra et al., 2025) while influencing the system's capacity to buffer flood impacts (Adger & Agnew 2004). Assessing environmental vulnerability is critical for areas like Sairang and Bairabi, where rapid land-use change, deforestation, and high rainfall variability interact with steep terrain, exacerbating flood hazards (Brooks et al., 2005). Incorporating environmental dimensions into vulnerability analysis enables a holistic understanding of flood risks and supports ecosystem-based flood management approaches, aligning with sustainable development and climate resilience goals (Renaud et al., 2013).

Environmental factors often determine flood frequency and severity, influencing exposure and shaping the biophysical environment's resilience against flood impacts (Birkmann et al., 2013). Recognizing these factors helps in identifying priority areas for interventions such as reforestation, sustainable watershed management, and climate-adaptive land-use planning (IPCC, 2014). In this section, the analysis draws upon primary field data, environmental monitoring, and town-level assessments to formulate the Environmental Vulnerability Index (EnVI) for Sairang and Bairabi.

7.5.1 Indicators

Indicators were systematically categorized into exposure, susceptibility, and resilience, ensuring a comprehensive evaluation of environmental conditions influencing flood vulnerability:

7.5.1.1 Exposure Indicators:

1. ***Rate of Deforestation (Defr):*** Deforestation reduces interception and infiltration capacities of soil, increasing surface runoff and flood peaks (Vanacker et al., 2005).

2. ***Increased Rate of Settlement Area (Settlmt):*** Expansion of impervious surfaces due to urbanization reduces infiltration, increases runoff, and places additional pressure on drainage systems, heightening flood exposure (Douglas et al., 2008).

7.5.1.2 Susceptibility Indicators:

1. ***Flood Frequency (Fldfq):*** Areas with frequent flooding have higher susceptibility due to the recurrent nature of exposure, leading to cumulative environmental degradation and erosion.

2. ***Heavy Rain Days (Rain):*** Days with rainfall exceeding critical thresholds (≥115mm) significantly contribute to runoff generation and flash flood occurrences (Petrow & Merz, 2009).

3. ***Type of Soil (Soil):*** Soil texture and structure influence infiltration and water retention; clayey soils, for instance, limit infiltration, increasing runoff and susceptibility (Bronstert, 2003).

7.5.1.3 Resilience Indicator:

1. ***Forest Cover (Forest):*** Forests enhance water infiltration, reduce runoff velocity, stabilize slopes, and contribute to local climate regulation, playing a critical role in mitigating flood impacts and enhancing ecosystem resilience (Shen & Wang, 2025; Locatelli et al., 2015).

These indicators collectively enable the analysis of how environmental factors exacerbate or mitigate flood risks in the study area, providing insights necessary for ecosystem-based flood management planning.

7.5.2 Correlation Analysis of Physical Vulnerability Indicators

The limitations of small sample size (N = 2) and derived indicator structures resulted in mathematically inevitable correlations. However, the resilience indicator (Forest Cover) shows a perfect negative correlation (-1.00) with exposure indicators (Deforestation Rate, Settlement Expansion Rate), confirming that higher forest cover directly reduces environmental vulnerability to flooding. (DeFries et al., 2010; Giri et al., 2020). Although perfect correlations are rare in larger datasets, they align with the theoretical expectation that forest cover mitigates the adverse impacts of deforestation and urban expansion on flood vulnerability.

7.5.3 Findings and Interpretation

The findings indicate that Sairang (EnVI: 3.00) has a higher environmental vulnerability compared to Bairabi (EnVI: 2.33). The elevated vulnerability in Sairang is due to its higher exposure to deforestation and urban expansion, and its susceptibility to heavy rainfall and frequent flooding, coupled with moderate resilience provided by existing forest cover. This suggests the urgent need for integrated watershed management, slope stabilization through reforestation, and control of unplanned settlement expansion to mitigate flood risk in Sairang.

In contrast, while Bairabi demonstrates a high susceptibility due to soil characteristics and flood frequency, its lower exposure and relatively higher forest cover contribute to its comparatively lower EnVI score. This indicates that maintaining and enhancing forest cover will be critical in preserving flood mitigation capacities in Bairabi.

Table 7.4 Environmental Vulnerability Index

Zone	Exposure	Susceptibility	Resilience	EnVI
Sairang	7	8	5	**3.00**
Bairabi	5	9	6	**2.33**

These findings highlight the need for integrated watershed management, stricter land-use controls, afforestation initiatives, and rainwater harvesting to mitigate flood impacts across both settlements. Figure 7.4 illustrates the town-wise environmental vulnerability spatially, providing planners with actionable insight for nature-based solutions and ecosystem-based adaptation.

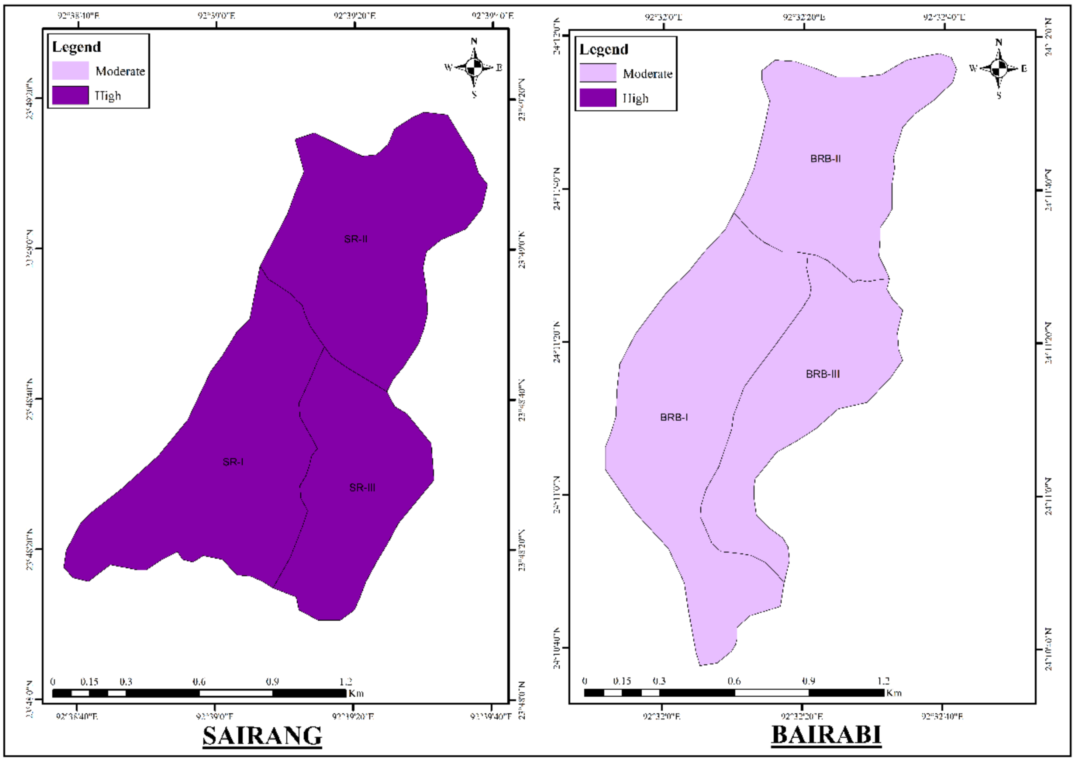


Figure 7.4 Environmental Vulnerability Map

7.6 OVERALL FLOOD VULNERABILITY ASSESSMENT

The Flood Vulnerability Index (FVI) offers a holistic synthesis of the vulnerability conditions in Sairang and Bairabi, systematically integrating the social, economic, physical, and environmental dimensions assessed in previous sections. It moves beyond isolated factor analysis by enabling spatial prioritization and targeted risk reduction planning for zones most at risk, aligning with contemporary flood risk management approaches that emphasize composite vulnerability mapping (Kreibich et al., 2017; Khan et al., 2020).

In flood-prone settlements such as Sairang and Bairabi, the value of Overall FVI lies in identifying localized patterns of vulnerability that consider varying exposure, susceptibility, and resilience conditions across components By synthesizing primary data from household surveys, interviews, and on-site field observations, the Overall FVI reflects the lived realities of residents while providing policymakers, local authorities, and community organizations with a structured tool for targeted intervention planning.

7.6.1 Findings and Interpretation

The FVI was computed using the average of Social Vulnerability Index (SVI), Economic Vulnerability Index (EVI), Physical Vulnerability Index (PVI), and Environmental Vulnerability Index (EnVI) (Sharma et al., 2024). The results are shown in Table 7.5.

Table 7.5 Overall Flood Vulnerability Index

Zone	**SVI**	**EVI**	**PVI**	**EnVI**	**Overall FVI**
SR-I	7	6.5	2.6	3	**4.78**
SR-II	4.33	3.67	1.25	3	**3.06**
SR-III	5	2.67	1.6	3	**3.07**
BRB-I	7.73	5.33	2.4	2.33	**4.45**
BRB-II	5.67	3.33	1.4	2.33	**3.18**
BRB-III	5	3	2.25	2.33	**3.15**

SR-I in Sairang, with an FVI of 4.78, has the highest overall flood vulnerability among all zones, followed by BRB-I in Bairabi (FVI: 4.35). These zones exhibit the highest combined exposure and susceptibility across social and economic dimensions, including high rates of food and water scarcity, frequent evacuation, and limited income security. The Proximity of SR-I and BRB-I to the riverbanks significantly increases exposure to flood hazards and prolongs inundation periods, exacerbating economic and social disruptions during flood events (Jongman et al., 2015). Additionally, these areas exhibit lower resilience capacities due to limited community-based preparedness and infrastructural mitigation measures, underlining the urgent need for targeted interventions.

Zones BRB-II (3.18), BRB-III (3.15), SR-III (3.07), and SR-II (3.06) demonstrate moderate levels of flood vulnerability, indicating that while these zones still face exposure and susceptibility challenges, relatively better resilience factors, such as shorter recovery times and higher participation in disaster awareness, mitigate their vulnerability scores. However, their vulnerability levels also warrant attention to prevent further escalation of risk, particularly with anticipated increases in extreme rainfall events and flood frequency under climate change scenarios (Wobus et al., 2017).

The Overall Flood Vulnerability Map (Figure 7.5) visualizes these spatial patterns, illustrating SR-I and BRB-I as the most vulnerable zones requiring immediate prioritization in flood preparedness planning.

Furthermore, integrating these FVI findings into local development plans and land use zoning can prevent settlement expansion into high-risk floodplains and riverbanks, thus reducing future vulnerability (Lu et al., 2022). Establishing food insurance schemes, microfinance support for livelihood recovery, and riverbank stabilization projects can also enhance community resilience in high-FVI zones.

The Flood Vulnerability Index thus serves as a critical tool to guide evidence-based flood management strategies and community resilience-building in Sairang and Bairabi, ensuring that interventions align with the specific vulnerabilities and capacities of each zone (Shaw et al., 2025), while reducing potential flood impacts.

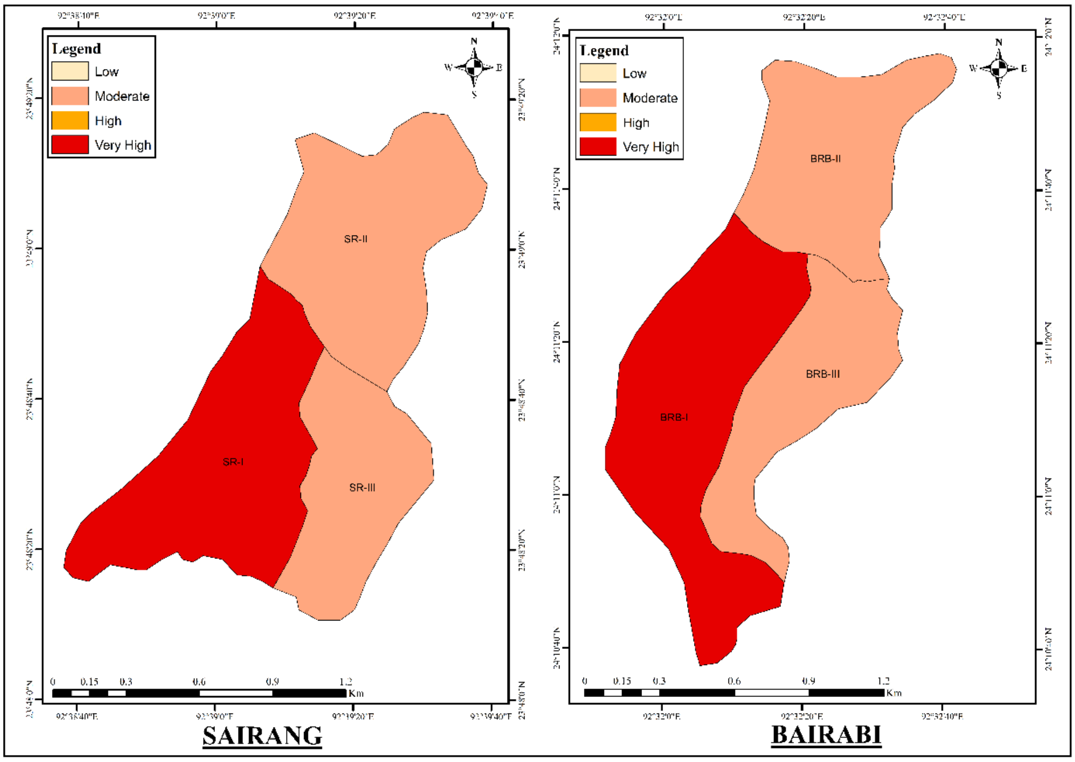


Figure 7.5 Flood Vulnerability Map of Sairang and Bairabi

7.7 CONCLUSION

This chapter presented a comprehensive Flood Vulnerability Index (FVI) for Sairang and Bairabi, integrating social, economic, physical, and environmental vulnerability dimensions using carefully selected indicators based on primary data, field investigations, and findings from previous chapters on flood causes, impacts, and management. The analysis captured the diverse and interlinked factors contributing to flood vulnerability while respecting the unique geographical and socio-economic contexts of the two towns.

The Social Vulnerability Assessment highlighted the critical role of food and water security, health care accessibility, household demographics, and community preparedness in shaping flood vulnerability, with SR-I and BRB-I emerging as the most socially vulnerable zones. Similarly, the Economic Vulnerability Assessment revealed that household income security, employment stability, and recovery capacities significantly affect community resilience, with high vulnerability in river-adjacent zones where livelihoods are frequently disrupted during floods.

The Physical Vulnerability Assessment demonstrated the impact of slope angle, elevation, and flood inundation on exposure, emphasizing how structural mitigation and emergency infrastructure enhance resilience, particularly in flood-prone areas adjacent to riverbanks. The Environmental Vulnerability Assessment underscored the significance of flood frequency, intense rainfall days, deforestation, and settlement expansion in influencing flood risks, revealing town-level vulnerabilities that require integrated watershed management and conservation strategies.

The Overall FVI revealed SR-I in Sairang (4.78) and BRB-II in Bairabi (4.35) to be the most flood-vulnerable zones, primarily due to their proximity to the river, high exposure, and limited resilience capacities, a factor amplifying their exposure to flood hazards, riverbank erosion, and recurrent inundation, thereby influencing their overall vulnerability profiles.

Zones such as SR-II, SR-III, BRB-II, and BRB-III demonstrated moderate vulnerability, reflecting areas where proactive measures can prevent future risk escalation.

This multi-dimensional vulnerability assessment confirms that flood vulnerability is not merely a physical phenomenon but a socio-economic and environmental challenge requiring holistic and community-centered approaches for effective flood risk reduction. The findings provide critical guidance for:

- Prioritizing high-risk zones for intervention.
- Designing targeted preparedness programs.
- Enhancing community-based disaster risk reduction initiatives.
- Supporting climate-resilient infrastructure and land-use planning.

Moreover, the Overall FVI serves as a replicable tool for local government, planners, and policymakers to align flood risk management with sustainable development and climate adaptation goals, ensuring that interventions are data-driven, locally contextualized, and equitable.

Finally, this chapter contributes to advancing locally contextualized, evidence-based flood risk management strategies in Sairang and Bairabi, supporting their path toward building flood-resilient communities aligned with sustainable development goals.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

Flooding in the Tlawng River basin, particularly in Sairang and Bairabi, is a multifaceted phenomenon driven by a combination of natural and anthropogenic factors (Wheeler, 2024). Chapter IV, i.e., 'Causes of Flood', has highlighted how rainfall characteristics, including total annual rainfall, monthly patterns, annual daily maximum rainfall (ADMR), and the duration of rain days, strongly influence the frequency and magnitude of floods in the study areas. Notably, severe floods have occurred during periods of high ADMR and consecutive rainy days that saturate the soil, accelerating surface runoff into the river system, as evident in the floods of 2017 in Sairang and 2018 in Bairabi.

Seasonal river line surveys using Total Station, DGPS and drone captured the expansion of river channels during the monsoon, reflecting increased discharge and river dynamics that reduce freeboard and lead to localized inundation, even in years without extreme rainfall. The differences observed in the river's course between pre-monsoon and monsoon periods emphasize the role of seasonal hydrological fluctuations in shaping flood hazards, with wider channel profiles during monsoon facilitating higher discharge while also enhancing bank erosion and floodplain inundation.

The construction of flood hydrographs for these events demonstrated the role of high-intensity rainfall and catchment response in determining flood peaks and timing. A steep rising limb and short lag time in Sairang's 2017 flood indicated rapid runoff generation due to saturated conditions and steep slopes, while Bairabi's 2018 flood reflected a prolonged rainfall accumulation followed by a delayed but severe peak discharge, illustrating variations in hydrological responses shaped by local topography and soil characteristics.

Topographical and soil characteristics of the two towns further influence flood vulnerability. Sairang's steep slopes and low-cohesion, silty soil with non-plastic characteristics contribute to rapid surface runoff and low infiltration rates, aligning with sharp flood hydrograph peaks during heavy rainfall. In contrast, Bairabi's moderate slopes and cohesive silty clay soils allow some infiltration initially but generate significant runoff once saturation is reached, leading to sustained high discharge during prolonged rainfall events.

The flood frequency analysis provided an estimate of the likely magnitude of peak discharges under natural conditions across different return periods, supporting the understanding of the potential for high-discharge events during heavy rainfall. These estimations complement rainfall and discharge analysis, reinforcing the view that the Tlawng River's discharge dynamics are a key component in flood generation in the study area.

Anthropogenic factors, as shown through change detection analysis, have worsened flood risks. Rapid expansion of settlements into floodplains, reduction of forest cover due to shifting cultivation, and the growth of cropland areas have collectively decreased infiltration capacity and increased surface runoff, while also causing sediment build up in river channels and reducing their water-carrying ability. The increase in impervious surfaces has sped up runoff rates, leading to more sudden and severe floods, whereas the reduction in water bodies and wetlands has lessened the landscape's natural floodwater storage capacity.

Thus, flooding in Sairang and Bairabi is the result of natural hydro-meteorological drivers interacting with local topography, soil conditions, and human-induced landscape changes. This integrated understanding of flood causation forms the basis for assessing flood vulnerability and for developing effective mitigation and management strategies in the Tlawng River basin.

The impact analysis of the Tlawng River flooding in Sairang and Bairabi in Chapter V reveals that flooding in these riverine towns is not a single catastrophic event but a recurring challenge with layered impacts in the communities' physical, social, and economic structures. The primary effects, including damage to housing and crops, indicate the direct economic burden on households, while the secondary effects- water scarcity, food insecurity, and disease outbreaks- demonstrate the cascading impacts that follow flooding events. The tertiary effects, such as livelihood disruptions, displacement, and psychosocial stress, underline the long-term vulnerabilities that persist beyond the immediate aftermath of flooding.

The examination of drowning incidents highlights the indirect mortality risks associated with flooding, emphasizing the need for community-level awareness and river safety measures, particularly during the monsoon season, The mixed-methods approach adopted in this study has enabled a comprehensive understanding of flood impacts, with descriptive statistics mapping the extent of impacts, pared t-tests quantifying significant changes pre and post-flooding, and correlation analysis uncovering the relationships between variables such as housing damage and displacement, or water scarcity and health outcomes.

Interviews with residents have contextualized the quantitative findings, providing deeper insights into the daily realities, fears, and adaptive strategies employed by the communities during flooding events. These narratives reveal the emotional, cultural, and livelihood-related dimensions of vulnerability, often not fully captured by quantitative data alone.

By systematically documenting and analysing the impacts of flooding in these towns, this chapter provides an evidence-based foundation for policymakers, local authorities, and disaster management agencies to design targeted strategic efforts that focused on minimizing vulnerability while fostering resilience in the face of recurrent flooding in Mizoram.

Subsequently, Chapter VI evaluated flood risk management and community preparedness in Sairang and Bairabi, revealing both strengths and gaps in local disaster management systems. While community institutions such as YMA and Village Councils serves as a key actor in coordinating rescue and recovery, participation in disaster awareness and preparedness programs remains low, especially in Bairabi, limiting household readiness for floods.

Critical infrastructure-including the safe house in Sairang, embankments in Bairabi, and newly installed Flood Warning Systems-reflects ongoing efforts to strengthen resilience. However, operational challenges, such as the failure of alarms during the 2024 flood, highlight the need for regular system testing and clear community communication.

Primary Health Centres, though meeting basic infrastructure standards, face staffing limitations and challenges in accessibility during floods, while relief measures reach only a fraction of affected households, indicating the need for more inclusive and efficient distribution systems.

Overall, flood management in Sairang and Bairabi benefits from strong community-led responses but requires enhanced coordination with government agencies, improved warning system reliability, and strengthened health and relief capacities. Addressing these gaps will improve preparedness and resilience, aligning with sustainable disaster risk reduction goals in these flood-prone towns.

Finally, Chapter VII systematically assessed the flood vulnerability of Sairang and Bairabi using a structured Flood Vulnerability Index (FVI) approach, integrating social, economic, physical, and environmental components. By categorizing and quantifying exposure, susceptibility, and resilience indicators, the chapter identified critical zones and factors contributing to flood vulnerability while grounding the analysis in local contexts through detailed household surveys, field observations, and previous findings on flood causes, impacts, and management.

Findings revealed that SR-I and BRB-I, which lie adjacent to the river, exhibit the highest flood vulnerability, driven by high exposure and susceptibility and constrained resilience capacities. Social vulnerabilities were pronounced due to the presence of children, senior citizens, and persons with disabilities in vulnerable households, combined with limited access to healthcare and early warning systems. Economic vulnerabilities highlighted income instability and employment disruptions during floods, while physical vulnerabilities reflected severe and partial inundation risks amplified by inadequate structural mitigation. Environmental vulnerabilities were also noted, with deforestation and rapid settlement expansion in hazard-prone areas increasing exposure while limited forest cover constrained resilience.

Correlation analyses conducted across all indicators affirmed the negative relationship between resilience and exposure/ susceptibility, confirming the theoretical foundation of the FVI formula used in this study. These analyses reinforced the reliability of the indicators and validated that strengthening resilience directly contributes to lowering flood vulnerability in the study areas.

In summary, the chapter has provided spatially explicit insights into the distribution and drivers of flood vulnerability, enabling targeted interventions for building flood resilience. The use of maps, tables, and statistical analyses offers a practical tool for planners and policymakers to prioritize mitigation measures, allocate resources efficiently, and inform community-based disaster risk management strategies.

As floods are projected to increase in frequency and intensity under changing climatic conditions (Simard & Austin, 2010), this assessment serves as a foundational reference for guiding adaptation strategies and resilient development planning in Sairang, Bairabi, and other similar flood-prone hilly settlements. The findings underscore the urgent need for holistic flood risk reduction measures that enhance community resilience, strengthen livelihood security, improve structural and environmental protection, and integrate local knowledge with scientific assessments to build a flood-resilient future for the communities in focus.

8.2 RECOMMENDED MITIGATION MEASURES

The Tlawng River Basin, encompassing Sairang and Bairabi, experiences recurrent flooding due to a combination of intense rainfall, rapid runoff, and anthropogenic pressures, leading to severe socio-economic and environmental impacts. Addressing these challenges requires a comprehensive approach that integrates structural interventions, community-based preparedness, environmental management, and policy–level coordination. Drawing upon the findings of this study, the following mitigation measures are proposed to reduce flood risks, enhance community resilience, and support sustainable development in the flood-prone areas of the basin.

8.2.1 Structural Mitigation Measures

- ***Flood-Resistant Housing:***

  Promote raised plinths, reinforced concrete, and water-resistant finishes for housing in high-risk areas with technical guidance and soft loans to enable adoption (Smith et al., 2019)

- ***Continuation of 'Construction of River Training Works for Protection of Tlawng River at Bairabi':***

  Phase II of the embankment works in Bairabi and other exposed stretches will protect river-adjacent settlements by stabilizing riverbanks, reducing erosion during high discharge, and preventing overbank flooding that damages homes, farms, and critical infrastructure.

- ***Improve Drainage Systems and Retention Measures:***

  Expanding and maintaining drainage networks will reduce water stagnation during heavy rainfall, while check dams, retention ponds, and improved culverts will help manage peak runoff and localized flooding.

8.2.2 Non- Non-Structural and Community-Based Measures

- ***Community Disaster Preparedness and Drills:***

  Conducting regular flood evacuation drills and school-based flood awareness sessions will enhance community readiness, reduce panic, and improve safe evacuation during floods (UNISDR, 2015)

- ***Land Use Regulation:***

  Enforcing land-use zoning will prevent settlement expansion into high-risk floodplains, preserving these areas for water retention while reducing future exposure to flood hazards.

- ***Community-Based Early Warning Dissemination:***

  Establishing local volunteer-led dissemination systems using SMS, church bells, and loudspeakers will complement government alerts, ensuring all households receive timely warnings for evacuation.

8.2.3 Environmental and Ecosystem-Based Measures

- ***Afforestation and Slope Stabilization:***

  Community-based planting of trees, bamboo, and other suitable vegetation on slopes and riverbanks will reduce runoff, erosion, and landslides during heavy rains (De Fries et al., 2010)

- ***Integrated Watershed Management:***

  Implementing watershed management plans will reduce sedimentation, manage runoff, and enhance water retention, mitigating flood intensity (Giri et al., 2020)

8.2.4 Livelihood and Economic Resilience Measures

- ***Livelihood Diversification:***

  Encouraging alternative income activities such as handicrafts, small businesses, and monsoon-resilient farming will reduce dependence on flood-vulnerable livelihoods.

- ***Micro-insurance and Savings Groups:***

  Promoting crop and livestock micro-insurance alongside community savings groups will help families recover economically after floods (Surminski & Oramas-Dorta, 2014).

8.2.5 Health and Sanitation Preparedness

- ***Mobile Health Clinics During Floods:***

  Employing mobile medical teams during floods will address waterborne diseases like diarrhea and skin infections, ensuring timely healthcare access for affected communities (Few et al., 2004)

- ***Safe Water and Sanitation in Shelters:***

  Installing water purification units and sanitation facilities in shelters will prevent disease outbreaks while prioritizing the needs of women and children during displacement (WHO, 2013)

- ***Psychological Care and Psychosocial Support:***

  Recognizing the anxiety and fear of flooding reported by many residents during the monsoon, community-based psychological care and counselling should be integrated into health preparedness plans. This includes organizing mental health support groups, post-flood counselling sessions, and training community volunteers in basic psychosocial support, reducing trauma, and supporting emotional recovery among vulnerable groups like women, children, and senior citizens.

8.2.6 Institutional and Policy Strengthening

- ***Flood Warning System Inspection and Community Demonstration:***

  Government-managed flood warning systems in Sairang and Bairabi require regular inspections and testing before each monsoon to ensure functionality. Technical teams must conduct demonstrations for communities to improve understanding of alert systems and appropriate responses.

- ***Equitable Relief Assistance Distribution:***

  Establishing a transparent, community-monitored system for relief distribution will ensure equitable aid delivery, prioritizing vulnerable households and addressing gaps identified in past flood events.

- ***Strengthen Institutional Coordination:***

  Formalizing coordination between Village Councils, YMA, NGOs, and government agencies will enhance rescue, relief, and recovery efficiency. Training community volunteers in first aid and evacuation will further strengthen local response capacities.

- ***Policy Integration with the Sendai Framework and SDGs:***

  Aligning local flood mitigation plans with the Sendai Framework and SDGs will promote sustainable disaster risk reduction. Utilizing vulnerability maps and FVI data will inform climate-resilient infrastructure investments and land-use planning (UNISDR, 2015; Jonkman et al., 2008).

APPENDIX A

ACCURACY ASSESSMENT FOR CHANGE DETECTION USING KAPPA COEFFICIENT

Table 8.1 Sairang, 2008

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	39	1	0	0	40	0.975	97.5
Settlement	10	30	0	0	40	0.75	75
Cultivated Cropland	1	1	36	2	40	0.9	90
Forest	1	1	3	35	40	0.875	87.5
Total	51	33	39	37	160		

Users Accuracy	0.76470588	0.909090909	0.923076923	0.945945946
Percentage	76.4705882	90.90909091	92.30769231	94.59459459
Total Correct	140			
Observed Correct	0.875			
Overall Accuracy	87.5			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	2040	1320	1560	1480	40
Settlement	2040	1320	1560	1480	40
Cultivated Cropland	2040	1320	1560	1480	40
Forest	2040	1320	1560	1480	40
Total	51	33	39	37	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.875
Expected Correct	0.25

K_{hat}	0.83333333
	83.3333333

Kappa Coefficient of 0.83 implies that the classification process was avoiding 83% of the error that a completely random classification would generate (Congalton,1991)

Table 8.2 Sairang, 2011

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	34	5	1	0	40	0.85	85
Settlement	6	31	1	2	40	0.775	77.5
Cultivated Cropland	4	2	33	1	40	0.825	82.5
Forest	0	2	0	38	40	0.95	95
Total	44	40	35	41	160		

Users Accuracy	0.77272727	0.775	0.942857143	0.926829268
Percentage	77.2727273	77.5	94.28571429	92.68292683
Total Correct	136			
Observed Correct	0.85			
Overall Accuracy	85			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1760	1600	1400	1640	40
Settlement	1760	1600	1400	1640	40
Cultivated Cropland	1760	1600	1400	1640	40
Forest	1760	1600	1400	1640	40
Total	44	40	35	41	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.85
Expected Correct	0.25
K_{hat}	0.8
	80

Kappa Coefficient of 0.80 implies that the classification process was avoiding 80% of the error that a completely random classification would generate (Congalton,1991)

Table 8.3 Sairang, 2014

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	31	9	0	0	40	0.775	77.5
Settlement	4	35	1	0	40	0.875	87.5
Cultivated Cropland	1	1	37	1	40	0.925	92.5
Forest	3	2	3	32	40	0.8	80
Total	39	47	41	33	160		

Users Accuracy	0.79487179	0.744680851	0.902439024	0.96969697
Percentage	79.4871795	74.46808511	90.24390244	96.96969697
Total Correct	135			
Observed Correct	0.84375			
Overall Accuracy	84.375			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1560	1880	1640	1320	40
Settlement	1560	1880	1640	1320	40
Cultivated Cropland	1560	1880	1640	1320	40
Forest	1560	1880	1640	1320	40
Total	39	47	41	33	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.84375
Expected Correct	0.25
K_{hat}	0.79166667
	79.1666667

Kappa Coefficient of 0.79 implies that the classification process was avoiding 79% of the error that a completely random classification would generate (Congalton,1991)

Table 8.4 Sairang, 2017

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	38	1	1	0	40	0.95	95
Settlement	1	35	2	2	40	0.875	87.5
Cultivated Cropland	0	1	36	3	40	0.9	90
Forest	0	1	2	37	40	0.925	92.5
Total	39	38	41	42	160		

Users Accuracy	0.97435897	0.921052632	0.87804878	0.880952381
Percentage	97.4358974	92.10526316	87.80487805	88.0952381
Total Correct	146			
Observed Correct	0.9125			
Overall Accuracy	91.25			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1560	1520	1640	1680	40
Settlement	1560	1520	1640	1680	40
Cultivated Cropland	1560	1520	1640	1680	40
Forest	1560	1520	1640	1680	40
Total	39	38	41	42	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.9125
Expected Correct	0.25

K_{hat}	0.88333333
	88.3333333

Kappa Coefficient of 0.88 implies that the classification process was avoiding 88% of the error that a completely random classification would generate (Congalton,1991)

Table 8.5 Sairang, 2020

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	37	0	3	0	40	0.925	92.5
Settlement	4	32	4	0	40	0.8	80
Cultivated Cropland	0	1	37	2	40	0.925	92.5
Forest	0	2	1	37	40	0.925	92.5
Total	41	35	45	39	160		

Users Accuracy	0.90243902	0.914285714	0.822222222	0.948717949
Percentage	90.2439024	91.42857143	82.22222222	94.87179487
Total Correct	143			
Observed Correct	0.89375			
Overall Accuracy	89.375			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1640	1400	1800	1560	40
Settlement	1640	1400	1800	1560	40
Cultivated Cropland	1640	1400	1800	1560	40
Forest	1640	1400	1800	1560	40
Total	41	35	45	39	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.89375
Expected Correct	0.25

K_{hat}	0.85833333
	85.8333333

Kappa Coefficient of 0.85 implies that the classification process was avoiding 85% of the error that a completely random classification would generate (Congalt

Table 8.6 Sairang, 2023

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	31	4	5	0	40	0.775	77.5
Settlement	4	34	0	2	40	0.85	85
Cultivated Cropland	5	1	31	3	40	0.775	77.5
Forest	0	3	2	35	40	0.875	87.5
Total	40	42	38	40	160		

Users Accuracy	0.775	0.80952381	0.815789474	0.875
Percentage	77.5	80.95238095	81.57894737	87.5
Total Correct	131			
Observed Correct	0.81875			
Overall Accuracy	81.875			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1600	1680	1520	1600	40
Settlement	1600	1680	1520	1600	40
Cultivated Cropland	1600	1680	1520	1600	40
Forest	1600	1680	1520	1600	40
Total	40	42	38	40	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.81875
Expected Correct	0.25

K_{hat}	0.75833333
	75.8333333

Kappa Coefficient of 0.75 implies that the classification process was avoiding 75% of the error that a completely random classification would generate (Congalton,1991)

Table 8.7 Bairabi, 2008

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	38	1	1	0	40	0.95	95
Settlement	1	36	2	1	40	0.9	90
Cultivated Cropland	1	3	34	2	40	0.85	85
Forest	0	2	1	37	40	0.925	92.5
Total	40	42	38	40	160		

Users Accuracy	0.95	0.857142857	0.894736842	0.925
Percentage	95	85.71428571	89.47368421	92.5
Total Correct	145			
Observed Correct	0.90625			
Overall Accuracy	90.625			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1600	1680	1520	1600	40
Settlement	1600	1680	1520	1600	40
Cultivated Cropland	1600	1680	1520	1600	40
Forest	1600	1680	1520	1600	40
Total	40	42	38	40	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.90625
Expected Correct	0.25

K_{hat}	0.875
	87.5

Kappa Coefficient of 0.87 implies that the classification process was avoiding 87% of the error that a completely random classification would generate (Congalton,1991)

Table 8.8 Bairabi, 2011

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	38	1	1	0	40	0.95	95
Settlement	2	36	2	0	40	0.9	90
Cultivated Cropland	0	0	39	1	40	0.975	97.5
Forest	0	2	1	37	40	0.925	92.5
Total	40	39	43	38	160		

Users Accuracy	0.95	0.923076923	0.906976744	0.973684211
Percentage	95	92.30769231	90.69767442	97.36842105
Total Correct	150			
Observed Correct	0.9375			
Overall Accuracy	93.75			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1600	1560	1720	1520	40
Settlement	1600	1560	1720	1520	40
Cultivated Cropland	1600	1560	1720	1520	40
Forest	1600	1560	1720	1520	40
Total	40	39	43	38	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.9375
Expected Correct	0.25

K_{hat}	0.91666667
	91.6666667

Kappa Coefficient of 0.91 implies that the classification process was avoiding 91% of the error that a completely random classification would generate (Congalton,1991)

Table 8.9 Bairabi, 2014

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	39	1	0	0	40	0.975	97.5
Settlement	2	37	1	0	40	0.925	92.5
Cultivated Cropland	0	3	32	5	40	0.8	80
Forest	0	0	3	37	40	0.925	92.5
Total	41	41	36	42	160		

Users Accuracy	0.95121951	0.902439024	0.888888889	0.880952381
Percentage	95.1219512	90.24390244	88.88888889	88.0952381
Total Correct	145			
Observed Correct	0.90625			
Overall Accuracy	90.625			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1640	1640	1440	1680	40
Settlement	1640	1640	1440	1680	40
Cultivated Cropland	1640	1640	1440	1680	40
Forest	1640	1640	1440	1680	40
Total	41	41	36	42	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.90625
Expected Correct	0.25

K_{hat}	0.875
	87.5

Kappa Coefficient of 0.87 implies that the classification process was avoiding 87% of the error that a completely random classification would generate (Congalton,1991)

Table 8.10 Bairabi, 2017

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	37	3	0	0	40	0.925	92.5
Settlement	3	35	1	1	40	0.875	87.5
Cultivated Cropland	0	1	36	3	40	0.9	90
Forest	0	1	2	37	40	0.925	92.5
Total	40	40	39	41	160		

Users Accuracy	0.925	0.875	0.923076923	0.902439024
Percentage	92.5	87.5	92.30769231	90.24390244
Total Correct	145			
Observed Correct	0.90625			
Overall Accuracy	90.625			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1600	1600	1560	1640	40
Settlement	1600	1600	1560	1640	40
Cultivated Cropland	1600	1600	1560	1640	40
Forest	1600	1600	1560	1640	40
Total	40	40	39	41	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.90625
Expected Correct	0.25

K_{hat}	0.875
	87.5

Kappa Coefficient of 0.87 implies that the classification process was avoiding 87% of the error that a completely random classification would generate (Congalton,1991)

Table 8.11 Bairabi, 2020

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	40	0	0	0	40	1	100
Settlement	1	36	3	0	40	0.9	90
Cultivated Cropland	1	5	32	2	40	0.8	80
Forest	0	0	1	39	40	0.975	97.5
Total	42	41	36	41	160		

Users Accuracy	0.95238095	0.87804878	0.888888889	0.951219512
Percentage	95.2380952	87.80487805	88.88888889	95.12195122
Total Correct	147			
Observed Correct	0.91875			
Overall Accuracy	91.875			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1680	1640	1440	1640	40
Settlement	1680	1640	1440	1640	40
Cultivated Cropland	1680	1640	1440	1640	40
Forest	1680	1640	1440	1640	40
Total	42	41	36	41	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.91875
Expected Correct	0.25

K_{hat}	0.89166667
	89.1666667

Kappa Coefficient of 0.91 implies that the classification process was avoiding 91% of the error that a completely random classification would generate (Congalton,1991)

Table 8.12 Bairabi, 2023

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel	Produces accuracy	Percentage
Water body	36	4	0	0	40	0.9	90
Settlement	3	34	2	1	40	0.85	85
Cultivated Cropland	1	2	35	2	40	0.875	87.5
Forest	0	1	2	37	40	0.925	92.5
Total	40	41	39	40	160		

Users Accuracy	0.9	0.829268293	0.897435897	0.925
Percentage	90	82.92682927	89.74358974	92.5
Total Correct	142			
Observed Correct	0.8875			
Overall Accuracy	88.75			

	Water body	Settlement	Cultivated Cropland	Forest	Total pixel
Water body	1600	1640	1560	1600	40
Settlement	1600	1640	1560	1600	40
Cultivated Cropland	1600	1640	1560	1600	40
Forest	1600	1640	1560	1600	40
Total	40	41	39	40	160

Grand Total	25600
Total Correct	6400
Expected Correct	0.25

K_{hat}

Observed Correct	0.8875
Expected Correct	0.25
K_{hat}	0.85
	85

Kappa Coefficient of 0.85 implies that the classification process was avoiding 85% of the error that a completely random classification would generate (Congalton,1991)

APPENDIX B

QUESTIONNAIRE USED FOR HOUSEHOLD SURVEY

Note: The original questionnaire was prepared in the Mizo language and has been translated into English for inclusion in this thesis.

A. QUESTIONS CONCERNING FAMILY STRUCTURE

1. Locality: ________________________

2. Members of the family from oldest to youngest (Name not required)-

	Gender	Age	Whether physically or mentally disabled?	Occupation	Whether literate or illiterate?
1					
2					
3					

B. SOCIO- ECONOMIC STATUS

3. Type of house?

i) Cement concrete______ ii) Assam Type______ iii) Kutcha house_______

4. Present house you are living in is?
i) Own by you_____ ii) Rented______ iii) Quarters______

5. Monthly family income-
i) <10k_______ ii) 10K- 3OK ______ iii) 31K- 60K______
ii) iv) 61K – 90K vii) >91K_______

6. Is your house in danger at times of Floods?
i) Often_______ ii) Occasionally_______ iii) Never______

C. RIVER FLOOD AND ITS CONSEQUENCES

7. As per your knowledge, which year flood is the most destructive?

i) 1989_______ ii)1993_______ iii) 2008_______

iv) 2017_______ v) 2018_______ vi) 2020_______

vii) If others, ____________

8. Have you ever faced any of the following due to Flood*? (Give your answer by ticking 'YES' or 'NO')*

		YES	N0
1	Loss of life among family members?		
2	Family member got Injured?		
3	Permanently evacuate?		
4	Temporarily evacuate?		
5	Stagnation of a job?		
If 'Yes' for point No. 5, specify the amount of loss per day? ___________			

9. If faced any of the difficulties aforementioned, from where/whom, relief/compensation was received?

i) Government_______ ii) NGO_______ iii) Church Groups_______

iv) If others, specify ________ v) Not received_______

* Items of compensation/relief received?

i) Cash_______ ii) Foods_______ iii) Clothing_______
iv) Others, if any_______

10. Whether the family faced any of the following issues due to the flood?

		YES	NO
1	Scarcity of Foods		
2	Lack of fresh water		
3	Social activities disruptions		
4	Epidemics		
5	Communication Problems		
6	Lack of Health care		

11. Are the family aware of any kind of Disaster Management awareness/ training organized within the town?

i) YES_____ ii) NO_____ iii) Unaware_____

12. Has any member of the family had ever attended any awareness programs relating to prevention and safety measures during floods/disasters (irrespective of places)?

i) YES_____ ii) NO_____

13. How early did you usually receive flood warnings or information?

i) One day before _____ ii) A night before _____
iii) Event day _____ iv) No information received_____

14. Who responds first to a flood among the following options?

i) Government_____ ii) NGOs'_____ iii) Neighbors_____

15. Would you like to share anything more about the challenges, current efforts, future steps, or suggestions related to floods in your village?

____
____
____

APPENDIX C:

RANK OF FLOOD VULNERABILITY INDICATORS

		Abb	INDICATORS	Rank of the Indicators
SOCIAL COMPONENT	Susceptibility	FwChd	Family with Children below the age of 14 years	If % is- ≥76 = 4; 51-75= 3; 26-50= 2; ≤25 = 1
		FwSrCtzn	Family with Senior Citizen above the age of 65 years	
		FwPwds	Family with Persons with Disabilities	
	Exposure	FdScr	Exposed to food scarcity	If % is- ≥76 = 4; 51-75= 3; 26-50= 2; ≤25 = 1
		WtrScr	Exposed to water scarcity	
		Sdis	Experienced social activities disruption	
		EPD	Suffered epidemics outbreaks	
		ComProb	Encountered Communication challenges	
		InsHC	Lack of Health care facilities	
	Resilience	PrtDmT	% of family member engaged in any kind of Disaster Management Training/ Awareness Programme	If % of a study area is- ≥76 = 4; 51-75= 3; 26-50=2;≤25 = 1
		EW	% received Early warning	
ECONOMIC COMPONENT	Susceptibility	InCm	Family Monthly Income	If Avg monthly income- <10K= 4;11K-30K=3; 31K-60K=2; 59K-90K= 1; >90K= 0
		HsTyp		If majority of the house is- Bamboo House- 3; Assam Type- 2; Concrete- 1
	Exposure	PerEvc	Permanently Evacuate Houses	If % is- ≥30= 4; 20-29=3; 10-19=2; 1-9=1; ≤ 0=0
		TemEvc	Temporarily Evacuate Houses	If % is- ≥46= 4; 31-45=3; 16-30=2; 1-15=1; ≤ 0= 0
		StgJob	Stagnant of Job during Flooding	If % is- ≥76 = 4; 51-75= 3; 26-50=2; ≤25= 1
	Resilience	RecoTm	Recovery Time	If days % is- ≤ 1 = 4; 2-4= 3; 4-6=2; ≥1 week= 1
		RlfBnfc	Relief beneficiaries	If % is- ≥76 = 4; 51-75= 3; 26-50=2; ≤ 25= 1

		Abb	INDICATORS	Rank of the Indicators
PHYSICAL COMPONENT	Susceptibility	SlpAgle	Slope Angle	If average slope angle of the catchment area is- ≤ 15= 4; 16- 30= 3; 31-45= 2; 46- 60= 1; ≥ 61= 0
		Ele	Mean Elevation of the settlement area (MSL)	If mean elevation is- ≤ 80= 4; 81- 160=3; 161-240= 2; ≥ 241= 1
	Exposure	SvrInd	Severe Inundation	If % number of severe inundated house is- ≥30= 4; 20-29=3; 10-19=2; 1-9=1; ≤ 0=0
		PrtlInd	Partial inundation	If % number of partial inundated house is- ≥46= 4; 31-45=3; 16-30=2; 1-15=1; ≤ 0= 0
	Resilience	PreDgSh	Pre- design Shelter	If distance is; Easily Accessible-4, Need time to reach-3, Far- 2, Not accessible- 1, Not exist-0
		StrMtg	Structural Mitigation for flood protection	If the effectiveness is; Very High-4, High -3, Moderate-2, Low- 1, Not exist-0
		Fldfq	Flood frequency	If, Mean years interval of flooding (2007-2023) is- ≤ 2= 4; 3- 5 = 3; 6- 8= 2; 9- 11= 1; ≥12= 0
ENVIRONMENT COMPONENT	Susceptibility	Rain	Heavy rain days (rainfall ≥ 115mm)	If annual average of raindays (2007-2023) is- ≥10= 4; 7-9= 3; 4-6= 2; 1-3= 1; ≤ 0= 0;
		Soil	Type of Soil	If type of soil in the basin is- Clay= 4; Silt=3; Loamy=2; Sand=1
		Defr	Rate of Deforestation	If %Annual average decrease rate (2007-2023) is- ≥10= 4; 7-9= 3; 4-6= 2; 1-3= 1; ≤ 0= 0;
	Exposure	Settlmt	Increased rate Settlement area	%Annual average increase rate (2007-2023)If % is; ≥10= 4; 7-9= 3; 4-6= 2; 1-3= 1; ≤ 0= 0;
	Resilience	Forest	Forest Cover	%Area of Forest Cover (2023)- If % is; ≤ 20= 5; 21-40=4; 41-60= 3; 61-80=1; ≥90 = 0;

APPENDIX D:

FIELD PHOTOGRAPH (Figure 8.1 to 8.13)

Figure 8.1 Interview with leaders of YMA, Sairang Branch

Figure 8.2 Interview with Bairabi South Village Council Members

Figure 8.3 Pre- monsoon River Line Survey at Sairang using DGPS

Figure 8.4 Pre- monsoon River Line Survey at Bairabi using DGPS

Figure 8.5 River line survey during monsoon at Sairang using Total Station

Figure 8.6 River line survey during monsoon at Bairabi using Total Station

Figure 8.7 Interview session at Sairang PHC

Figure 8.8 Data Collection at Bairabi Police Station

Figure 8.9 Drone image of Sairang in the aftermath of 2024 flood

Figure 8.10 Drone image of Bairabi during 2024 monsoon

Figure 8.11 Flood Mark, Sairang

Figure 8.12 Flood Mark, Bairabi

Figure 8.13 Field Survey during monsoon, 2024 at Bairabi

REFERENCES

Acharya, A., & Prakash, A. (2023). Community-based flood risk management and the role of NGOs in South Asia. *International Journal of Disaster Risk Reduction, 85*, 103565. https://doi.org/10.1016/j.ijdrr.2022.103565

Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization, 22*(2), 433–450. https://doi.org/10.1177/0956247810380141

Adger, W. N., & Agnew, M (2004). New indicators of vulnerability and adaptive capacity. *Tyndall Centre for Climate Change Research*, Technical Report 7. https://tyndall.ac.uk/sites/default/files/tyn_7.pdf

Agriculture Statistic (2020), Agriculture Department, Government of Mizoram, Aizawl.

Ahmed, F., & Rao, K. S. (2014, March). Morphometric and hypsometric analysis of Sairang Sub-basin for Natural Resources Management. In *Proceeding of the National Seminar on Management of Natural Resources for Sustainable Development: Challenges and Opportunities held at Department of Geography and Resource Management, School of Earth Sciences, Mizoram University* (pp. 06-07).

Alam, K., & Collins, A. E. (2010). Cyclone disaster vulnerability and response experiences in coastal Bangladesh. *Disasters*, 34(4), 931-954. https://doi.org/10.1111/j.14677717.2010.01223.x

Alcántara-Ayala, I., Gomez, C., Chmutina, K., van Niekerk, D., Raju, E., Marchezini, V., Rom Cadag, J., & Gaillard, J. (2022). *Disaster Risk* (1st ed.). Routledge. https://doi.org/10.4324/9781315469614

Aldrich, D. P. (2012). *Building resilience: Social capital in post-disaster recovery*. University of Chicago Press.

Ali, H., Modi, P., & Mishra, V. (2019). Increased flood risk in Indian sub-continent under the warming climate. *Weather and Climate Extremes*, *25*, 100212. https://doi.org/10.1016/j.wace.2019.100212

Ali, S., & Mishra, V. (2018). Flood risk assessment under climate change scenarios for highly flood-prone cities in India. *International Journal of Disaster Risk Reduction, 31*, 1009–1020. https://doi.org/10.1016/j.ijdrr.2018.07.007

Ali, S., Li, D., Cong, R., Khan, W. D., & Ullah, S. (2020). Impact of soil texture on runoff and sediment yield under different rainfall intensities. *Water*, 12(3), 757. https://doi.org/10.3390/w12030757

Andharia, J. (2020). *Disaster studies*. Springer Singapore. https://doi.org/10.1007/978-981-32-9339-7

Asahi, C., & Horie, N. (2023). *Toward Sustainable Regions*. https://doi.org/10.1007/978-981-99-5667-8

Atta-ur- Rahman & Khan, A. N. (2011). Analysis of flood causes and associated socioeconomic damages in the Hindukush region. *Natural hazards*, *59*(3), 1239-1260. https://doi.org/10.1007/s11069-011-9830-8

Awotona, A. (Ed.). (2016). Planning for Community-based Disaster Resilience Worldwide: Learning from Case Studies in Six Continents (1st ed.). Routledge. https://doi.org/10.4324/9781315600734

Balica, S. F., Douben, N., & Wright, N. G. (2009). Flood vulnerability indices at varying spatial scales. *Water science and Technology, 60*(10), 2571-2580. https://doi.org/10.2166/wst.2009.183

Balica, S. F., Wright, N. G., & Van der Meulen, F. (2012). A flood vulnerability index for coastal cities and its use in assessing climate change impacts. *Natural hazards, 64*, 73-105. https://doi.org/10.1007/s11069-012-0234-1

Balica, S., & Wright, N. G. (2010). Reducing the complexity of the flood vulnerability index. *Environmental hazards*, *9*(4), 321-339. https://doi.org/10.3763/ehaz.2010.0043

Basher, R. (2006). Global early warning systems for natural hazards: Systematic and people-centred. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 364*(1845), 2167–2182. https://doi.org/10.1098/rsta.2006.1819

Basri, H., Syakur, S., Azmeri, A., & Fatimah, E. (2022). Floods and their problems: Land uses and soil types perspectives. In *IOP Conference Series: Earth and Environmental Science* (Vol. 951, No. 1, p. 012111). IOP Publishing. DOI 10.1088/1755-1315/951/1/012111

Battersby, S. (Ed.). (2022). *Clay's Handbook of Environmental Health* (22th ed.). Routledge. https://doi.org/10.1201/9781003035640

Bera, K., Pal, M., & Bandyopadhyay, J. (2021). Application of RS and GIS in flood Management: A case study of Mongalkote Blocks, Burdwan, West Bengal, India. *International Journal of Scientific and Research Publications,* 2(11), 1-9. http://www.ijsrp.org/e-journal.html

Beven, K., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin*, *24*(1), 43–69. https://doi.org/10.1080/02626667909491834

Bhagat, N. (2017). Flood frequency analysis using Gumbel's distribution method: a case study of Lower Mahi Basin, India. *Journal of Water Resources and Ocean Science*, *6*(4), 51-54.

Bhandari, D., Neupane, S., Hayes, P., Regmi, B., & Marker, P. (2020). Disaster risk reduction and management in Nepal: Delineation of roles and responsibilities. *Kathmandu: Oxford Policy Management*. http://www.opml.co.uk/

Bhattacharjee, K., & Behera, B. (2017). Forest cover change and flood hazards in India. *Land use policy*, *67*, 436-448. https://doi.org/10.1016/j.landusepol.2017.06.013

Birkmann, J., Cardona, O. D., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., & Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Natural hazards*, *67*, 193-211. https://doi.org/10.1007/s11069-013-0558-5

Birkmann, J., Cutter, S. L., Rothman, D. S., Welle, T., Garschagen, M., Van Ruijven, B., & Pulwarty, R. (2015). Scenarios for vulnerability: opportunities and constraints in the context of climate change and disaster risk. *Climatic Change*, *133*(1), 53-68. https://doi.org/10.1007/s10584-013-0913-2

Bisht, D. S., Mishra, S., & Arya, S. (2022). Disaster data management for flood risk reduction in India: Challenges and opportunities. *International Journal of Disaster Risk Reduction, 68*, 102729. https://doi.org/10.1016/j.ijdrr.2021.102729

BMTPC Guidelines (2010), Improving Flood Resistance of Housing, Building Materials & Technology Promotion Council, *Ministry of Housing & Urban Poverty Alleviation, Government of India, New Delhi.* Pp. 1-7.

Bradshaw, C. J., Sodhi, N. S., Peh, K. S. H., & Brook, B. W. (2007). Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology, 13*(11), 2379–2395. https://doi.org/10.1111/j.1365-2486.2007.01446.x

Brakenridge, G. R., Anderson, E., Nghiem, S. V., Chien, S., Mic, R., & Kettner, A. J. (2012). *Flood warnings, flood disaster assessments, and flood hazard reduction: The roles of orbital remote sensing*. In R. P. Singh, D. K. Gupta, & R. M. Prasad (Eds.), Remote Sensing of the Terrestrial Water Cycle (pp. 231-251). American Geophysical Union.

Bronstert, A. (2003). Floods and climate change: Interactions and impacts. *Risk Analysis, 23*(3), 545-557. https://doi.org/10.1111/1539-6924.00336https://doi.org/10.1029/GM206

Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change, 15*(2), 151-163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Bruyn, E. D., & Olbrechts, A. C. (2025). From Lessons Learned to Integrated Crisis Management: The Impact of the July 2021 Floods on Belgium's Cultural Heritage. *Bulletin de l'Institut royal du Patrimoine artistique/Bulletin van het Koninklijk Instituut voor het Kunstpatrimonium*, (40). https://doi.org/10.4000/145tb

Bubeck, P., Botzen, W. J. W., Kreibich, H., & Aerts, J. C. J. H. (2015). Detailed insights into the influence of flood-coping appraisals on mitigation behaviour. *Global Environmental Change, 23*(5), 1327–1338. https://doi.org/10.1016/j.gloenvcha.2013.05.009

Bubeck, P., Otto, A., & Weichselgartner, J. (2017). Societal impacts of flood hazards. In *Oxford research encyclopedia of natural Hazard science*. https://doi.org/10.1093/acrefore/9780199389407.013.281

C. T. Haan, "Statistical Methods in Hydrology." Iowa State University Press, Ames, Iowa. I '. Haefner, Journal of Water, 1997.

Castellana, L., D'Addabbo, A., & Pasquariello, G. (2007). A composed supervised/unsupervised approach to improve change detection from remote sensing. *Pattern Recognition Letters*, *28*(4), 405-413. https://doi.org/10.1016/j.patrec.2006.08.010

Chakraborty, S., & Mukhopadhyay, S. (2012). Flood management in India: A review. *Journal of Chemical, Biological and Physical Sciences, 2*(4), 2495–2503.

Chakraborty, S., & Mukhopadhyay, S. (2019). Assessing flood risk using analytical hierarchy process (AHP) and geographical information system (GIS): application in Coochbehar district of West Bengal, India. *Natural hazards*, *99*(1), 247-274. https://doi.org/10.1007/s11069-019-03737-7

Chan, E. Y. Y., Man, A. Y. T., & Lam, H. C. Y. (2022). Disaster preparedness and resilient communities: The role of emergency shelters in disaster risk reduction. *International Journal of Disaster Risk Science, 13*(5), 729–740. https://doi.org/10.1007/s13753-022-00416-9

Chan, S. W., Abid, S. K., Sulaiman, N., Nazir, U., & Azam, K. (2022). A systematic review of the flood vulnerability using geographic information system. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09075

Changnon, S. A., & Demissie, M. (1996). Detection of changes in streamflow and floods resulting from climate fluctuations and land use-drainage changes. *Climatic change*, *32*(4), 411-421. https://doi.org/10.1007/BF00140354

Charlton, R. (2008). *Fundamentals of fluvial geomorphology*. Routledge. https://doi.org/10.4324/9780203371084

Chatterjee, M. (2010). Slum dwellers response to flooding events in the megacities of India. *Mitigation and Adaptation Strategies for Global Change, 15*(4), 337-353. https://doi.org/10.1007/s11027-010-9221-1

Choudhury, U., Singh, S. K., Kumar, A., Meraj, G., Kumar, P., & Kanga, S. (2023). Assessing land use/land cover changes and urban heat island intensification: A case study of Kamrup Metropolitan District, Northeast India (2000–2032). *Earth*, *4*(3), 503-521. https://doi.org/10.3390/earth4030026

Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.

Clement, S., Brohan, E., Jeffery, D., Henderson, C., Hatch, S. L., & Thornicroft, G. (2012). Development and psychometric properties the Barriers to Access to Care Evaluation scale (BACE) related to people with mental ill health. *BMC psychiatry*, *12*(1), 36. https://doi.org/10.1186/1471-244X-12-36

Cochran, W. G. (1977). *Sampling Techniques* (3rd ed.). Wiley.

Coduto, D. P. (1999). *Geotechnical Engineering: Principles and Practices*. Prentice Hall.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment, 37*(1), 35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Connor, R. F., & Hiroki, K. (2005). Development of a method for assessing flood vulnerability. *Water science and technology*, *51*(5), 61-67. https://doi.org/10.2166/wst.2005.0109

Coppola, D. P. (2015). *Introduction to international disaster management* (3rd ed.). Oxford: Butterworth-Heinemann.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2008). Disaster resilience indicators for benchmarking baseline conditions. *Journal of Homeland Security and Emergency Management*, 5(1), Article 51. https://doi.org/10.2202/1547-7355.1732

Das, S., & Saha, D. (2021). Soil erosion, runoff, and landslide susceptibility in Northeast India. *Environmental Earth Sciences*, 80(11), 1–17.

Das, S., & Saha, D. (2021). Watershed-based flood risk mapping using GIS and remote sensing: A case study in Eastern India. *Natural Hazards*, 108(1), 891–912. https://doi.org/10.1007/s11069-021-04746-8

de Ruiter, M. C., van der Vlist, M. J., van den Homberg, M. J., & de Bruijn, K. M. (2020). The influence of flooding on economic vulnerability in urban areas: A comparative analysis. *Ecological Economics, 177*, 106777. https://doi.org/10.1016/j.ecolecon.2020.106777

DeFries, R. S., Rudel, T., Uriarte, M., & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience, 3*(3), 178–181. https://doi.org/10.1038/ngeo756

Deshmukh, A., Oh, E. H., & Hastak, M. (2011). Impact of flood damaged critical infrastructure on communities and industries. *Built Environment Project and Asset Management*, *1*(2), 156-175. https://doi.org/10.1108/20441241111180415

Di Baldassarre, G., Montanari, A., Lins, H., Koutsoyiannis, D., Brandimarte, L., & Blöschl, G. (2010). Flood fatalities in Africa: From diagnosis to mitigation. *Geophysical Research Letters*, 37(22). https://doi.org/10.1029/2010GL045467

Díez-Herrero, A., & Garrote, J. (2020). Flood risk analysis and assessment, applications and uncertainties: A bibliometric review. *Water*, *12*(7), 2050. https://doi.org/10.3390/w12072050

Ding, W., & Wu, J. (2023). Interregional economic impacts of an extreme storm flood scenario considering transportation interruption: A case study of Shanghai, China. *Sustainable Cities and Society*, *88*, 104296. https://doi.org/10.1016/j.scs.2022.104296

Dinh, Q., Balica, S., Popescu, I., & Jonoski, A. (2012). Climate change impact on flood hazard, vulnerability and risk of the Long Xuyen Quadrangle in the Mekong

Delta. *International journal of river basin management*, *10*(1), 103-120. https://doi.org/10.1080/15715124.2012.663383

DM Act (2005). The gazette of India extraordinary. The Disaster Management Act, 2005, No. 53 of 2005. *Ministry of Law and Justice, Government of India.*

Doberstein, B., Tadgell, A., & Rutledge, A. (2019). Managed retreat for climate change adaptation in coastal megacities: A comparison of policy and practice in Manila and Vancouver. *Journal of Environmental Management, 231*, 768-778. https://doi.org/10.1016/j.jenvman.2018.10.045

Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The human impact of floods: a historical review of events 1980-2009 and systematic literature review. *PLoS currents*, *5*. https://doi.org/10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a

Douglas, I., Alam, K., Maghenda, M., McDonnell, Y., McLean, L., & Campbell, J. (2008). Unjust waters: Climate change, flooding and the urban poor in Africa. *Environment and Urbanization*, *20*(1), 187–205. https://doi.org/10.1177/0956247808089156

Douglas, I., Garvin, S., Lawson, N., Richards, J., Tippett, J., & White, I. (2008). Urban flooding: Impacts and management. *Sustainable Cities and Society, 1*(2), 101–109. https://doi.org/10.1016/j.scs.2010.08.002

Du W., FitzGerald, G., Clark, M., & Hou, X., (2012). Health Impacts of Floods. *Prehospital and Disaster Medicine*, 25(3), 265- 272. https://doi.org/10.1017/S1049023X00008141

Dunne, T., & Leopold, L. B. (1978). *Water in environmental planning*. W.H. Freeman.

Eccles, R., Zhang, H., & Hamilton, D. (2019). A review of the effects of climate change on riverine flooding in subtropical and tropical regions. *Journal of Water and Climate Change*, *10*(4), 687-707. https://doi.org/10.2166/wcc.2019.175

Edosa, B. T., & Nagasa, M. D. (2024). Spatiotemporal assessment of land use land cover change, driving forces, and consequences using geospatial techniques: The case of Naqamte city and hinterland, western Ethiopia. *Environmental Challenges*, *14*, 100830. https://doi.org/10.1016/j.envc.2023.100830

Enarson, E. (2000). Gender and natural disasters. *ILO Infocus Programme on Crisis Response and Reconstruction*. Geneva: International Labour Organization. Retrieved from https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_117993.pdf

Erçetin, Ş. Ş., Ray, N., & Sen, S. (Eds.). (2019). *Economic growth and demographic transition in third world nations: A chaos and complexity theory perspective*. CRC Press. https://doi.org/10.1201/9780429433894

Esteves, L. S. (2013). Consequences to flood management of using different probability distributions to estimate extreme rainfall. *Journal of Environmental Management*, *115*, 98-105. https://doi.org/10.1016/j.jenvman.2012.11.013

Faisal, A., & Khan, H. (2018). Application of GIS and remote sensing in disaster management: a critical review of flood management. In *International Conference on Disaster Risk Mitigation*.

FAO. (2005). The role of forests in water cycle management and flood control. Rome: Food and Agriculture Organization of the United Nations.

FAO. (2019). *The state of the world's biodiversity for food and agriculture*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/CA3129EN/ca3129en.pdf

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Social vulnerability indicators in disasters: Findings from a systematic review. *International Journal of Disaster Risk Reduction, 22,* 219-227. https://doi.org/10.1016/j.ijdrr.2016.09.006

Fekete, A. (2019). Social vulnerability (re)assessment in context to natural hazards: Review of the usefulness of the concept from a policy perspective. *International Journal of Disaster Risk Science, 10*, 220–232. https://doi.org/10.1007/s13753-018-0192-7

Few, R., Ahern, M., Matthies, F., & Kovats, S. (2004). Floods, health and climate change: A strategic review. *Tyndall Centre for Climate Change Research*. https://www.tyndall.ac.uk/sites/default/files/wp63.pdf

Fincham, J. E. (2008). Response rates and responsiveness for surveys, standards, and the Journal. *American Journal of Pharmaceutical Education, 72*(2), 43. https://doi.org/10.5688/aj720243

Fischer, S., & Schumann, A. (2020). Spatio-temporal consideration of the impact of flood event types on flood statistic. https://doi.org/10.1007/s00477-019-01690-2

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A social vulnerability index for disaster management. *Journal of homeland security and emergency management*, *8*(1), https://doi.org/10.2202/1547-7355.1792

Fletcher, T. D., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Advances in Water Resources, 51*, 261–279. https://doi.org/10.1016/j.advwatres.2012.09.001

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment, 80*(1), 185–201. https://doi.org/10.1016/S0034-4257(01)00295-4

Franklin, R. C., Peden, A. E., & Brander, R. W. (2021). Drowning prevention in flood disasters: A call to action. *International Journal of Disaster Risk Reduction, 66*, 102626. https://doi.org/10.1016/j.ijdrr.2021.102626

Fuchs, S., Keiler, M., & Zischg, A. (2015). A spatiotemporal multi-hazard exposure assessment. *Environmental Impact Assessment Review,* 50, 30-42. https://doi.org/10.1016/j.eiar.2014.08.003

Gaillard, J. C., & Mercer, J. (2013). From knowledge to action: Bridging gaps in disaster risk reduction. *Progress in Human Geography*, 37(1), 93–114. https://doi.org/10.1177/0309132512446717

Gakidou, E., & Hogan, M. (2005). Data collection in developing countries. Encyclopedia of Social Measurement, Elsevier, Pages 587-592, ISBN 9780123693983.

Gall, M. (2007). Indices of social vulnerability to natural hazards: A comparative evaluation. *Ph.D. Dissertation*, University of South Carolina.

Gao, J., Nickum, J. E., & Pan, Y. (2007). An assessment of flood hazard vulnerability in the Dongting Lake Region of China. *Lakes & Reservoirs: Research & Management*, *12*(1), 27-34. https://doi.org/10.1111/j.1440-1770.2007.00318.x

Gautam, D. (2021). The role of NGOs in disaster risk reduction: A case study from South Asia. *Disaster Prevention and Management: An International Journal, 30*(2), 204–218. https://doi.org/10.1108/DPM-09-2020-0302

Giri, C., Long, J., Tieszen, L., & Singh, A. (2020). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2020. *Estuarine, Coastal and Shelf Science*, 245, 106942. https://doi.org/10.1016/j.ecss.2020.106942

Giri, C., Long, J., Tieszen, L., & Zhu, Z. (2020). Mangrove forest distributions and dynamics in Asian countries using satellite data. *Global Change Biology, 26*(2), 978–989. https://doi.org/10.1111/gcb.14800

Giri, C., Pengra, B., Zhu, Z., Singh, A., & Tieszen, L. L. (2020). Monitoring land cover dynamics at a global scale: a review of datasets and methodologies. *Remote*

Sensing of Environment, 203, 111–123. https://doi.org/10.1016/j.rse.2020.112131

Gishu County, Kenya. *Journal of Geography and Regional Planning*, *9*(8), 164-175. https://doi.org/10.5897/JGRP2016.0563

Giustiniani, F.Z., Sommario, E., Casolari, F., & Bartolini, G. (Eds.). (2018). *Routledge Handbook of Human Rights and Disasters* (1st ed.). Routledge. https://doi.org/10.4324/9781315115238

Glago, F. J. (2021). Flood disaster hazards; causes, impacts and management: a state-of-the-art review. *Natural hazards-impacts, adjustments and resilience*, 29-37. DOI: 10.5772/intechopen.95048

Goel, S. L. (2006). Encyclopaedia of Disaster Management. New Delhi: Deept & Deep Publications.

Groves, R. M., Fowler Jr, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). *Survey Methodology* (2nd ed.). Wiley.

Gu, H., Yang, L., & Chen, J. (2020). Flooding and health risk assessment in China: A review. *Environment International, 140*, 105798. https://doi.org/10.1016/j.envint.2020.105798

Guha-Sapir, D., Hoyois, P., & Below, R. (2016). Annual Disaster Statistical Review 2015: The Numbers and Trends. Centre for Research on the Epidemiology of Disasters (CRED).

Guhathakurta, P., Sreejith, O. P., & Menon, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. *Journal of earth system science*, *120*, 359-373. https://doi.org/10.1007/s12040-011-0082-5

Guilbert, E. (2013). Multi-level representation of terrain features on a contour map. *Geoinformatica*, *17*, 301-324.https://doi.org/10.1007/s10707-012-0153-z

Gupta, S., Javed, A., & Datt, D. (2003). Economics of flood protection in India. *Flood problem and management in South Asia*, 199-210. https://doi.org/10.1023/A:1021142404009

Ha, Huong., R. Lalitha S. Fernando., & Amir Mahmood, eds. *Strategic disaster risk management in Asia*. Springer India, 2015. https://doi.org/10.1007/978-81-322-2373-3

Hall, J. W. (2014). Flood risk management: decision making under uncertainty. In *Applied uncertainty analysis for flood risk management* (pp. 3-24). https://doi.org/10.1142/p588

Hall, J. W., Dawson, R. J., Sayers, P. B., Rosu, C., Chatterton, J., & Deakin, R. (2005). A framework for assessing uncertainty in flood risk management decisions. *International Journal of River Basin Management*, 3(1), 105–121. https://doi.org/10.1080/15715124.2005.9635250

Hallegatte, S., & Rozenberg, J. (2017). Climate change through a poverty lens. *Nature Climate Change, 7*(4), 250-256. https://doi.org/10.1038/nclimate3253

Hammond, M. J., Chen, A. S., Djordjević, S., Butler, D., & Mark, O. (2015). Urban flood impact assessment: A state-of-the-art review. *Urban Water Journal*, *12*(1), 14-29. https://doi.org/10.1080/1573062X.2013.857421

Handique, A., Acharjee, S., Dhadumia, U., Gogoi, J., Das, P., & Nath, B. (2024). Flood frequency analysis in the lower Burhi Dehing River in Assam, India using Gumbel Extreme Value and log Pearson Type III methods. *Discover Geoscience*, *2*(1), 75. https://doi.org/10.1007/s44288-024-00084-4

Harrison, C. G., & Williams, P. R. (2016). A systems approach to natural disaster resilience. *Simulation Modelling Practice and Theory*, *65*, 11-31. https://doi.org/10.1016/j.simpat.2016.02.008

Hashizume, M., Wagatsuma, Y., Faruque, A. S., Hayashi, T., Hunter, P. R., Armstrong, B., & Sack, D. A. (2008). Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *Journal of water and health*, *6*(3), 323-332. https://doi.org/10.2166/wh.2008.062

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., & Kanae, S. (2013). Global flood risk under climate change. *Nature Climate Change*, 3(9), 816–821. https://doi.org/10.1038/nclimate1911

Huang, D., Zhang, R., Huo, Z., Mao, F., E, Y., & Zheng, W. (2012). An assessment of multidimensional flood vulnerability at the provincial scale in China based on the DEA method. *Natural hazards*, *64,* 1575-1586. https://doi.org/10.1007/s11069-012-0323-1

IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (eds.)]. *Cambridge University Press, Cambridge*, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

Islam, M. S., Mahmud, M. S., & Haque, A. N. (2021). Strengthening disaster risk governance through community participation in Bangladesh. *Sustainability, 13*(2), 623. https://doi.org/10.3390/su13020623

Islam, M. S., Mahmud, M. S., & Haque, A. N. (2022). The role of NGOs in disaster management: A case study from Bangladesh. *Natural Hazards, 114*, 2839–2859. https://doi.org/10.1007/s11069-022-05511-4

Islam, R., & Walkerden, G. (2017). How do links between households and NGOs promote disaster resilience and recovery? A case study of linking social networks on the Bangladeshi coast. *Natural Hazards, 86*, 901–924. https://doi.org/10.1007/s11069-016-2723-0

Israel, G. D. (1992). *Determining Sample Size* (Fact Sheet PEOD-6). University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS. Retrieved from http://edis.ifas.ufl.edu/pd006

Jain, S. K., Agarwal, P. K., & Singh, V. P. (2007). *Hydrology and water resources of India* (Vol. 57). Springer Science & Business Media. https://doi.org/10.1007/1-4020-5180-8

Jain, V., Singh, S. K., & Sharma, M. C. (2022). Impact of topography and land use on flood vulnerability in Himalayan watersheds. *Journal of Hydrology*, 609, 127693. https://doi.org/10.1016/j.jhydrol.2022.127693

Jha, A. K., Bloch, R., & Lamond, J. (2012). Cities and flooding: A guide to integrated urban flood risk management for the 21st century. *World Bank Publications*. https://doi.org/10.1596/978-0-8213-8866-2

Jha, M. K., Singh, S., Upadhyay, N., & Khare, N. (2016). Comparative study of online gps post processing services and effects on dgps data processing. *International research journal of management science & technology*, *7*(1), 29-35. ISSN 2250 – 1959

Jongman, B., Ward, P. J., & Aerts, J. C. J. H. (2015). Global exposure to river and coastal flooding: Long term trends and changes. *Global Environmental Change, 31*, 182-192. https://doi.org/10.1016/j.gloenvcha.2015.01.002

Jonkman, S. N. (2005). Global perspectives on loss of human life caused by floods. *Natural Hazards*, *34*(2), 151–175. https://doi.org/10.1007/s11069-004-8891-3

Jonkman, S. N., & Kelman, I. (2005). An analysis of the causes and circumstances of flood disaster deaths. *Disasters*, 29(1), 75–97. https://doi.org/10.1111/j.0361-3666.2005.00275.x

Jonkman, S. N., Vrijling, J. K., & Vrouwenvelder, A. C. W. M. (2008). Methods for the estimation of loss of life due to floods: A literature review and a proposal for a new method. *Natural Hazards*, 46(3), 353–389. https://doi.org/10.1007/s11069-008-9227-5

Kale, V. S. (2003). Geomorphic effects of monsoon floods on Indian rivers. *Natural Hazards*, *28*(1), 65-84. https://doi.org/10.1023/A:1021133816839

Kansal, M. L., & Singh, S. (2022). Flood management issues in Hilly regions of Uttarakhand (India) under changing climatic conditions. *Water*, *14*(12), 1879. https://doi.org/10.3390/w14121879

Kelman, I., & Glantz, M. H. (2014). Early warning systems defined. In J. Zschau & A. N. Küppers (Eds.), *Early warning systems for natural disaster reduction* (pp. 89–100). Springer. https://doi.org/10.1007/978-3-642-12233-0_6

Kelman, I., & Spence, R. (2004). An overview of flood actions on buildings. *Engineering Geology,* *73*(3-4), 297-309. https://doi.org/10.1016/j.enggeo.2004.01.010

Kembe, M. A., Omondi, C. O., & Waga, G. G. (2016). The influence of socio-cultural characteristics on commercialization of smallholder dairy value chain development in Uasin Gishu County, Kenya. *Journal of Geography and Regional Planning*, *9*(8), 164-175. https://doi.org/10.5897/JGRP2016.0563

Khan, M. S. A., Hossain, M. S., & Quasem, S. (2020). Flood vulnerability assessment using analytical hierarchy process (AHP): A case study from Bangladesh.

Environmental Challenges, 1, 100005. https://doi.org/10.1016/j.envc.2020.100005

Knighton, D. (1998). *Fluvial forms and processes: A new perspective*. Routledge. https://doi.org/10.4324/9780203784662

Koks, E. E., & Thissen, M. (2016). A multiregional impact assessment model for disaster analysis. *Economic Systems Research, 28*(4), 429–449. https://doi.org/10.1080/09535314.2016.1192545

Koks, E. E., Bočkarjova, M., de Moel, H., & Aerts, J. C. J. H. (2019). Integrated direct and indirect flood risk modeling: Development and sensitivity analysis. *Risk Analysis, 35*(5), 882–900. https://doi.org/10.1111/risa.12300

Koks, E. E., Jongman, B., Husby, T. G., & Botzen, W. J. W. (2019). Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. *Environmental Science & Policy, 101*, 102-110. https://doi.org/10.1016/j.envsci.2019.08.013

Kreibich, H., Bubeck, P., & Thieken, A. H. (2022). Benefits and limitations of early warning systems for flood risk reduction. *Current Opinion in Environmental Sustainability, 58*, 101238. https://doi.org/10.1016/j.cosust.2022.101238

Kreibich, H., Bubeck, P., Van Vliet, M., & De Moel, H. (2017). A review of damage-reducing measures to manage fluvial flood risks in a changing climate. *Mitigation and Adaptation Strategies for Global Change, 22*(5), 967–989. https://doi.org/10.1007/s11027-016-9727-5

Kron, W., (2005). Flood Risk= Hazard • Values • Vulnerability. Water International, 30:1, 5868. https://doi.org/10.1080/02508060508691837

Kumar, R., Singh, R., & Sharma, A. (2021). Structural measures for flood risk reduction: An analysis of embankment performance in India. *Water Policy, 23*(6), 1362–1376. https://doi.org/10.2166/wp.2021.168

Kumavat, H. R., & Tapkire, G. V. (2016). Experimental Investigation of Flooding Problem-A case study on Arunavati River in Shirpur city by Total Station Survey. *International Journal of Civil Engineering and Technology*, *7*(1), 172-179. http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=7&IType=1

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., & Sherstyukov, B. (2014). Flood risk and climate change: global and regional perspectives. *Hydrological Sciences Journal*, *59*(1), 1-28. https://doi.org/10.1080/02626667.2013.857411

Labuschagne, M. (2003). *Motivational factors affecting a student's choice between print and on-line modes of delivery in distance education*. University of South Africa (South Africa).

Lal, R. (2001). Soil degradation by erosion. *Land Degradation & Development, 12*(6), 519–539. https://doi.org/10.1002/ldr.472

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159–174. https://doi.org/10.2307/2529310

Leelawat, N., Suppasri, A., Imamura, F., & Takahashi, T. (2014). Disaster prevention education in Thailand: a case study of the 2011 flood disaster. *International Journal of Disaster Risk Reduction, 9*, 64-70. https://doi.org/10.1016/j.ijdrr.2014.03.006

Lind, N. C., Moudrak, N., & Shrubsole, D. (2022). Flood risk and flood resilience: A Canadian perspective. *Water, 14*(9), 1440. https://doi.org/10.3390/w14091440

Lindell, M. K. (2013). Disaster studies. *Current Sociology*, *61*(5-6), 797-825. https://doi.org/10.1177/0011392113484456

Locatelli, B., Lavorel, S., Sloan, S., Tappeiner, U., & Geneletti, D. (2011). Forests and climate change in the tropics: linking adaptation and mitigation. *Forest*

Ecology and Management, 261(3), 221-230. https://doi.org/10.1016/j.foreco.2010.11.048

López-Carresi, A., Fordham, M., Wisner, B., Kelman, I., & Gaillard, J. C. (2014). Disaster management. *International Lessons in Risk Reduction, Response and Recovery. London: Earthscan*. ISBN 9781849713474

Lu, X., Xu, W., Xie, H., Zhang, X., & Jiang, H. (2022). Integrating multi-dimensional flood vulnerability assessment with risk management strategies for urban resilience. *International Journal of Disaster Risk Reduction, 72*, 102848. https://doi.org/10.1016/j.ijdrr.2022.102848

Manohar Reddy, V. (2022, April). Flood frequency analysis using gumbel's distribution method and log-Pearson type III distribution method in Krishna River, Andhra Pradesh. In *Recent Developments in Sustainable Infrastructure (ICRDSI-2020)—GEO-TRA-ENV-WRM: Conference Proceedings from ICRDSI-2020 Vol. 2* (pp. 475-482). Singapore: Springer Singapore.

McEwen, L., Garde- Hansen, J., Holmes, A., Jones, O., & Krause, F., (2016). Sustainable flood memories, lay knowledges and the development of community resilience to future flood risk. *Transactions of the Institute of British Geographers*, 42: 14–28. https://doi.org/10.1111/tran.12149

McGee, T. K., & Penning-Rowsell, E. C. (Eds.). (2022). *Routledge handbook of environmental hazards and society*. Taylor & Francis Group. https://doi.org/10.4324/9780367854584

Mediero, L., Jiménez-Álvarez, A., & Garrote, L. (2010). Design flood hydrographs from the relationship between flood peak and volume. *Hydrology and Earth System Sciences*, *14*(12), 2495-2505. https://doi.org/10.5194/hess-14-2495-2010

Merz, B., Blöschl, G., Vorogushyn, S., Dottori, F., Aerts, J. C., Bates, P., Bertola, M., Kemter, M., Kreibich, H., Lall, U., & Macdonald, E. (2021). Causes, impacts and patterns of disastrous river floods. *Nature Reviews Earth & Environment*, *2*(9), 592-609. https://doi.org/10.1038/s43017-021-00195-3

Merz, B., Elmer, F., & Thieken, A. H. (2014). Significance of "high probability/low damage" versus "low probability/high damage" flood events. *Natural Hazards and Earth System Sciences*, 9(3), 1033–1046. https://doi.org/10.5194/nhess-9-1033-2009

Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010). Review article "Assessment of economic flood damage". *Natural Hazards and Earth System Sciences*, 10(8), 1697–1724. https://doi.org/10.5194/nhess-10-1697-2010

Meyer, V., Scheuer, S., & Haase, D. (2013). A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. *Natural Hazards*, 61, 1707–1729. https://doi.org/10.1007/s11069-011-0077-3

Mili, N., Acharjee, S., & Konwar, M. (2013). Impact of flood and river bank erosion on socio- economy : a case study of Golaghat Revenue Circle of Golaghat District, Assam. *International Journal of Geology, Earth & Environmental Sciences, 3(3), 180-185. http://www.cibtech.org/jgee.htm*

Ministry of Health and Family Welfare. (2022). *Indian Public Health Standards (IPHS) Guidelines for Primary Health Centres*. Government of India. https://nhm.gov.in/index1.php?lang=1&level=2&sublinkid=971&lid=154

Mirza, M. M. Q., Dixit, A., & Nishat, A. (Eds.). (2003). *Flood problem and management in South Asia*. Dordrecht: Kluwer Academic Publishers. https://doi.org/10.1007/978-94-017-0137-2

Mishra, S. K., & Singh, V. P. (2010). *Soil conservation service curve number (SCS-CN) methodology*. Springer. https://doi.org/10.1007/978-1-4419-0237-2

Mizoram State Disaster Management Plan (2021), Disaster Management and Rehabilitation Department, Government of Mizoram, Aizawl, pp. 13-17, 43.

Mizukoshi, H., & Aniya, M. (2002). Use of contour-based DEMs for deriving and mapping topographic attributes. *Photogrammetric engineering and remote sensing*, *68*(1), 83-93.

Mohanty, M.P., Mudgil, S., & Karmakar, S., (2020), Flood management in India: A focussed review on the current status and future challenges. *International Journal of Disaster Risk Reduction*, Volume 49, 101660. https://doi.org/10.1016/j.ijdrr.2020.101660

Mohapatra, P. K., & Singh, R. D. (2003). Flood management in India. *Flood problem and management in South Asia*, 131-143. https://doi.org/10.1023/A:1021178000374

Mukaka, M. M. (2012). Statistics Corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal, 24*(3), 69–71. https://doi.org/10.4314/mmj.v24i3

Mukhopadhyay, S., Dutta, D., & Shaw, R. (2021). Flood risk reduction and resilience building in Asia: Challenges and opportunities. *Water Policy, 23*(S1), 90-109. https://doi.org/10.2166/wp.2021.097

Munawar, H. S. (2020). Flood disaster management: Risks, technologies, and future directions. *Machine Vision Inspection Systems: Image Processing, Concepts, Methodologies and Applications*, *1*, 115-146. https://doi.org/10.1002/9781119682042.ch5

Nanditha, J. S., & Mishra, V. (2021). On the need of ensemble flood forecast in India. *Water Security*, *12*, 100086. https://doi.org/10.1016/j.wasec.2021.100086

Nandy, S., & Samanta, S. (2020). Flood hazard mapping in the lower Barak basin, Assam, India, using multi-criteria decision analysis (MCDA). *Environmental Challenges*, 1, 100005. https://doi.org/10.1016/j.envc.2020.100005

Nasiri, H., Mohd Yusof, M. J., & Mohammad Ali, T. A. (2016). An overview to flood vulnerability assessment methods. *Sustainable Water Resources Management*, *2*, 331-336. https://doi.org/10.1007/s40899-016-0051-x

Nasiri, H., Yusof, M. J. M., Ali, T. A. M., & Hussein, M. K. B. (2019). District flood vulnerability index: urban decision-making tool. *International Journal of Environmental Science and Technology*, *16*, 2249-2258. https://doi.org/10.1007/s13762-018-1797-5

Nath, H. V. (2011). Vulnerability assessment methods–a review. In *Advances in Network Security and Applications: 4th International Conference, CNSA 2011, Chennai, India, July 15-17, 2011 4* (pp. 1-10). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-22540-6_1

National Disaster Management Authority Guidelines (2008). Management of Floods. *A National Disaster Management Authority*, Government of India. New Delhi, pp. 1-5.

National Disaster Management Plan (2013), *Ministry of Home Affairs, Government of India*. Draft National Disaster Management Plan - government

NDMA (2009): "National Policy on Disaster Management, 2009," *National Disaster Management Authority*, Ministry of Home Affairs, Government of India.

Nepal, S., Flügel, W. A., & Shrestha, A. B. (2014). Upstream-downstream linkages of hydrological processes in the Himalayan region. *Ecological Processes*, *3*, 1-16. https://doi.org/10.1186/s13717-014-0019-4

Nepal, S., Krause, P., Flügel, W. A., Fink, M., & Fischer, C. (2014). Understanding the hydrological system dynamics of a glaciated alpine catchment in the Himalayan region using the J2000 hydrological model. *Hydrological Processes, 28*(3), 1329–1344. https://doi.org/10.1002/hyp.9649

Nguyen, D. Q., Liou, Y. A., & Terry, J. P. (2019). Vulnerability of Vietnam to typhoons: A spatial assessment using the vulnerability-resilience indicator approach. *Natural Hazards and Earth System Sciences*, 19(3), 719-731. https://doi.org/10.5194/nhess-19-719-2019

Nguyen, T. L., Tran, T. A., & Nguyen, H. N. (2023). An Overview of Indicator-Based Approach of Flood Vulnerability Assessment. *Toward Sustainable Regions: Essays in Honor of Kiyoko Hagihara*, 187-204. https://doi.org/10.1007/978-981-99-5667-8_9

NITI Aayog (2021). Report of the Committee Constituted for Formulation of Strategy for Flood Management Works in Entire Country and River Management Activities and Works Related to Border Areas (2021- 26), *National Institution For Transforming India*, New Delhi, pp. 2-5.

Okuyama, Y., & Santos, J. R. (2014). Disaster impact and input–output analysis. *Economic Systems Research*, *26*(1), 1-12. https://doi.org/10.1080/09535314.2013.871505

Oladokun, V., Proverbs, D., Adebimpe, O., & Adedeji, T. (2023). Handbook of flood risk management in developing countries. In *Handbook of flood risk management in developing countries* (pp. 1-5). Routledge. https://doi.org/10.1201/9781003160823

Olang, L. O., & Fürst, J. (2011). Effects of land cover change on flood peak discharges and runoff volumes: Model estimates for the Nyando River basin, Kenya. *Hydrological Processes, 25*(1), 80–89. https://doi.org/10.1002/hyp.7821

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment, 148*, 42–57. https://doi.org/10.1016/j.rse.2014.02.015

Pachuau, Rintluanga. (1994), *Geography of Mizoram*; R.T. Enterprise, Aizawl, First Edition, pp. 36- 42.

Pal, I., & Shaw, R. (Eds.). (2018). *Disaster risk governance in India and cross cutting issues*. Springer Singapore. https://doi.org/10.1007/978-981-10-3310-0

Pande, R.K. (2010). Flash flood disasters in Uttarakhand. *Disaster Prevention and Management,* 19(5), pp 565-570. https://doi.org/10.1108/09653561011091896

Pandey, H. K., Dwivedi, S., & Kumar, K. (2018). Flood Frequency Analysis of Betwa River, Madhya Pradesh India. *Journal of the Geological Society of India*, *92*, 286-290. https://doi.org/10.1007/s12594-018-1007-6

Panhalkar, S. S. (2011). Land use change detection in Solapur district, Maharashtra: A remote sensing approach. *Journal of Geography and Geology, 3*(1), 77–81. https://doi.org/10.5539/jgg.v3n1p77

Papathoma-Köhle, M., Schlögl, M., & Fuchs, S. (2019). Vulnerability indicators for natural hazards: An innovative selection and weighting approach. *Scientific Reports*, *9*(1), 15026. https://doi.org/10.1038/s41598-019-50257-2

Paprotny, D., Sebastian, A., Morales-Nápoles, O., & Jonkman, S. N. (2018). Trends in flood losses in Europe over the past 150 years. *Nature Communications*, 9, 1985. https://doi.org/10.1038/s41467-018-04253-1

Patel, P., Kumar, R., & Shah, S. (2023). The role of safe shelters in disaster risk reduction: Lessons from community-based flood management in South Asia. *International Journal of Disaster Risk Reduction, 93*, 103801. https://doi.org/10.1016/j.ijdrr.2023.103801

Pathak, S. D., Kulshrestha, M., & Kulshreshtha, M. (2021). Flood vulnerability assessment using data envelopment analysis–the case of Narmada river basin districts in central India. *Water Policy*, *23*(5), 1089-1106. https://doi.org/10.2166/wp.2021.063

Pathak, S., Panta, H. K., Bhandari, T., & Paudel, K. P. (2020). Flood vulnerability and its influencing factors. *Natural Hazards*, *104*, 2175-2196. https://doi.org/10.1007/s11069-020-04267-3

Patil, P. P., & Pankaj, R. (2020). Police and disaster management: A review of institutional roles in India. *Journal of Disaster Management and Public Safety, 2*(1), 25–34.

Paton, D. (2003). Disaster preparedness: A social-cognitive perspective. *Disaster Prevention and Management: An International Journal*, 12(3), 210–216. https://doi.org/10.1108/09653560310480686

Patra, K. C. (2001). *Hydrology and water resources engineering*. India: CRC Press; ISBN 1-84265-023-8.

Paul, B. K. (2009). Why relatively fewer people died? The case of Bangladesh's Cyclone Sidr. *Natural Hazards*, 50(2), 289–304. https://doi.org/10.1007/s11069-008-9340-5

Paul, S. K., Rashid, H., & Islam, M. T. (2018). Indigenous knowledge in disaster risk reduction: An integrated approach of local knowledge and practices in flood-prone Bangladesh. *Disasters, 42*(4), 717-738. https://doi.org/10.1111/disa.12276

Pérez-Maqueo, O., Martínez, M. L., & Meza, H. (2017). Natural coastal infrastructure: protection and long-term adaptation strategy for coastal communities. *Ocean & Coastal Management, 146*, 82-91. https://doi.org/10.1016/j.ocecoaman.2017.06.020

Periyasamy, P., Yagoub, M.M., & Sudalaimuthu, M. (2018). Flood vulnerable zones in the rural blocks of Thiruvallur district, South India. *Geoenvironmental Disaster*, 5:21. https://doi.org/10.1186/s40677-018-0113-5

Petiwale, M. (2013). *Social vulnerability and resilience to climate change in Gujarat-A social work response to vulnerable communities* (Doctoral dissertation).

Petrow, T., & Merz, B. (2009). Trends in flood magnitude, frequency and seasonality in Germany in the period 1951–2002. *Journal of Hydrology, 371*(1-4), 129-141. https://doi.org/10.1016/j.jhydrol.2009.03.024

Phipps, Laura M. & McEntire, David A. (2024*)* Current and Emerging Trends in the Management of International Disasters. *Mavs Open Press Open Educational Resources*. 43. https://mavmatrix.uta.edu/oer_mavsopenpress/43

Plate, E. J. (2002). Flood risk and flood management. *Journal of hydrology*, *267*(1-2), 2-11.v https://doi.org/10.1016/S0022-1694(02)00135-X

Pontius, R. G., & Millones, M. (2011). Death to Kappa: Birth of quantity disagreement and allocation disagreement for accuracy assessment. *International Journal of Remote Sensing,* *32*(15), 4407–4429. https://doi.org/10.1080/01431161.2011.552923

Prayogo, T. B., Sholichin, M., Amalia, D., Othman, F., & Rahardjo, S. S. P. (2025). Mitigating Flood Vulnerabilities Through Retarding Basin Systems: A Case Study in Bengawan Solo River, Indonesia. *International Journal of Disaster Risk Reduction*, 105629. https://doi.org/10.1016/j.ijdrr.2025.105629

Priest, S. J., Suykens, C., Schelfaut, K., Lewin, J., Thuillier, T., Klijn, F., & Tapsell, S. M. (2016). The European Union approach to flood risk management and improving societal resilience: Lessons from the implementation of the Floods Directive in six European countries. *Ecology and Society, 21*(4), 50. https://doi.org/10.5751/ES-08913-210450

Priyatna, M., Wijaya, S. K., Khomarudin, M. R., Yulianto, F., Nugroho, G., Afgatiani, P. M., & Hussein, M. A. (2023). The use of multi-sensor satellite imagery to analyze flood events and land cover changes using change detection and machine learning techniques in the Barito watershed. *Journal of Degraded & Mining Lands Management*, *10*(2). doi:10.15243/jdmlm.2023.102.4073

Putra, A. N., Alfaani, S. F., Saputra, D. D., Andhika, Y., Wisnubroto, E. I., Admajaya, F. T., ... & van Noordwijk, M. (2025). Flood prediction: analyzing land use scenarios and strategies in Sumber Brantas and Kali Konto watersheds in East Java, Indonesia. *Natural Hazards*, 1-29. https://doi.org/10.1007/s11069-025-07363-4

Qiang, Y. (2019). Disparities of population exposed to flood hazards in the United States. *Journal of Environmental Management, 232*, 295-304. https://doi.org/10.1016/j.jenvman.2018.11.039

Rafiq, L., & Blaschke, T. (2012). Disaster risk and vulnerability assessment of Pakistan flood 2010. *Environmental Hazards, 11*(3), 217-227. https://doi.org/10.1080/17477891.2011.635504

Rahman, M. M., Islam, M. S., & Haque, M. N. (2021). Strengthening the capacity of primary healthcare systems in flood-prone areas: Lessons from Bangladesh. *BMC Health Services Research, 21*, 667. https://doi.org/10.1186/s12913-021-06667-4

Rahman, M. M., Sakib, S. M. N., & Tasnim, S. (2022). Community-based disaster management and the integration of local volunteers in flood response in developing countries. *Environmental Challenges, 8*, 100570. https://doi.org/10.1016/j.envc.2022.100570

Rahman, M. M., Tasnim, F., Uddin, A., Chayan, M. S. I., Arif, M. S. I., & Hossain, M. T. (2023). Assessing vulnerability in ethnic Munda community: A study on a cyclone-prone area of Bangladesh. *International Journal of Disaster Risk Reduction*, *95*, 103884. https://doi.org/10.1016/j.ijdrr.2023.103884

Rahmati, O., Pourghasemi, H. R., & Melesse, A. M. (2016). Application of GIS-based data-driven random forest and maximum entropy models for groundwater potential mapping: A case study at Mehran Region, Iran. *Catena*, 137, 360–372. https://doi.org/10.1016/j.catena.2015.09.021

Rahmati, O., Zeinivand, H., & Besharat, M. (2016). Flood hazard zoning using GIS and multi-criteria decision analysis (MCDA). *Natural Hazards, 79*(1), 567-585. https://doi.org/10.1007/s11069-015-1857-3

Rai, P. K. (2009). Comparative assessment of soil properties after bamboo flowering and death in a tropical forest of Indo-Burma hot spot. *AMBIO: A Journal of the*

Human Environment, *38*(2), 118-120. https://doi.org/10.1579/0044-7447-38.2.118

Rajendran, K., Chatterjee, S., & Muthulakshmi, M. (2022). Disaster management and healthcare: A review of flood response and health impacts in India. *Journal of Disaster Research, 17*(3), 405–412. https://doi.org/10.20965/jdr.2022.p0405

Ramamurthy, A., Chundeli, F. A., & Srikonda, R. (2024). Flood Risk Assessment, Mapping and Planning by Gis-Decision Support Systems: A Case Study in Kerala State, India. *OIDA International Journal of Sustainable Development*, *17*(03), 47-66. https://ssrn.com/abstract=4815304

Ranjan, R. (2017). Flood Disaster Management. *River System Analysis and Management*, pp 371-417. https://doi.org/10.1007/978-981-10-1472-7_20

Rehman, S., Sahana, M., Hong, H., Sajjad, H., & Ahmed, B. B. (2019). A systematic review on approaches and methods used for flood vulnerability assessment: framework for future research. *Natural Hazards*, *96*, 975-998. https://doi.org/10.1007/s11069-018-03567-z

Renaud, F. G., Sudmeier-Rieux, K., & Estrella, M. (Eds.). (2013). *The Role of Ecosystems in Disaster Risk Reduction*. Tokyo: UNU Press. https://collections.unu.edu/view/UNU:1906

Reyes, G., & Lu, J. (2016). The psychology of disaster vulnerability and resilience. *Psychological Trauma: Theory, Research, Practice, and Policy, 8*(2), 127–134. https://doi.org/10.1037/tra0000054

Rodda, J. C. (2021). The flood hydrograph. In *Water, earth, and man* (pp. 405-418). Routledge. eBook ISBN9781003170181

Romali, N. S., Sulaiman, M. S. A. K., Yusop, Z., & Ismail, Z. (2015). Flood damage assessment: A review of flood stage–damage function curve. In *ISFRAM 2014: Proceedings of the International Symposium on Flood Research and*

Management (pp. 147-159). Springer Singapore. https://doi.org/10.1007/978-981-287-365-1

Roy, J., & Samaddar, S. (2020). Community participation in disaster management: Insights from flood-prone areas in India. *Journal of Environmental Management, 276*, 111280. https://doi.org/10.1016/j.jenvman.2020.111280

Roy, S. (Ed.). (2022). *Gender and the politics of disaster recovery: dealing with the aftermath*. Taylor & Francis. https://doi.org/10.4324/9781003290148

Rufat, S., Tate, E., Burton, C. G., & Maroof, A. S. (2015). Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction, 14*, 470-486. https://doi.org/10.1016/j.ijdrr.2015.09.013

Šakić Trogrlić, R., Wright, G. B., Duncan, M. J., van den Homberg, M. J., Adeloye, A. J., Mwale, F. D., & Mwafulirwa, J. (2019). Characterising local knowledge across the flood risk management cycle: A case study of Southern Malawi. *Sustainability*, *11*(6), 1681. https://www.mdpi.com/2071-1050/11/6/1681/s1

Salter, J. (1997). Risk management in a disaster management context. *Journal of Contingencies and Crisis Management*, *5*(1), 60-65. https://doi.org/10.1111/1468-5973.00037

Sam, A. S., Abbas, A., Padmaja, S. S., Sathyan, A. R., Vijayan, D., Kächele, H., Kumar, R., & Müller, K. (2021). Flood vulnerability and food security in eastern India: A threat to the achievement of the Sustainable Development Goals. *International journal of disaster risk reduction*, *66*, 102589. https://doi.org/10.1016/j.ijdrr.2021.102589

Santos, T. (2020). Urban flood risk management in developing countries: Challenges and opportunities for policy and practice. *Water, 12*(2), 380. https://doi.org/10.3390/w12020380

Sanyal, J., & Lu, X.X. (2005). Remote Sensing and GIS- based flood vulnerability assessment of human settlements: a case study of Gangetic West Bengal, India. *Hydrological Process,* 19(18): 3699- 3716. https://doi.org/10.1002/hyp.5852

Sati, V.P. (2022). Glacier bursts-triggered debris flow and flash flood in Rishi and Dhauli Ganga valleys: A study on its causes and consequences. *Natural Hazards Research*. https://doi.org/10.1016/j.nhres.2022.01.001

Schraven, B., Adaawen, S., Rademacher-Schulz, C., & Segadlo, N. (2020). *Climate Change Impacts on Human (Im-) Mobility in Sub-Saharan Africa: Recent Trends and Options for Policy Responses*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) https://www.adaptationcommunity.net/wpcontent/uploads/2020/07/GIZ_Climate-impacts-on-human-mobility-Africa.pdf

Sengar, R.S., & Sengar, K. (Eds.). (2014). *Climate Change Effect on Crop Productivity* (1st ed.). CRC Press. https://doi.org/10.1201/b17684

Shaluf, I. M. (2007). Disaster types. *Disaster Prevention and Management: An International Journal*, *16*(5), 704-717.

Sharma, A., Sajjad, H., Bhuyan, N., Rahaman, M. H., & Ali, R. (2024). Climate change-induced landslide vulnerability: Empirical evidence from Shimla district, Himachal Pradesh, India. *International Journal of Disaster Risk Reduction*, *110*, 104657. https://doi.org/10.1016/j.ijdrr.2024.104657

Sharma, B. R., & Gupta, N. (2009). Forensic considerations of pregnancy-related maternal deaths: An overview. *Journal of Forensic and Legal Medicine*, *16*(5), 233-238. https://doi.org/10.1016/j.jflm.2008.12.005

Sharma, D., Karmakar, S., Ghosh, S., & Joshi, P. K. (2018). Assessment of future rainfall and temperature change over India using climate models. *Journal of Hydrology*, *558*, 161–176. https://doi.org/10.1016/j.jhydrol.2018.01.013

Sharma, S., Ghosh, S., & Ganguly, A. R. (2018). Changing rainfall extremes in India. *Nature Climate Change*, 8(9), 701–706.

Shaw, R. (2013). *Disaster risk reduction: Methods, approaches and practices*. Springer. https://doi.org/10.1007/978-4-431-54252-0

Shaw, R., Izumi, T., Djalante, R., & Imamura, F. (Eds.). (2025). *Two Decades from the Indian Ocean Tsunami: Key Challenges and Advancements*. Springer Nature. https://doi.org/10.1007/978-981-96-2669-4

Shen, J., Guo, X., & Wang, Y. (2025). Dynamic relationship modeling and utility assessment of flood regulation service supply and demand. *Journal of Cleaner Production*, *501*, 145266. https://doi.org/10.1016/j.jclepro.2025.145266

Shimi, A. C., Parvin, G. A., Biswas, C., & Shaw, R. (2010). Impact and adaptation to flood: A focus on water supply, sanitation and health problems of rural community in Bangladesh. *Disaster Prevention and Management, 19*(3), 298-313. https://doi.org/10.1108/09653561011052568

Shrestha, S., & Maharjan, A. (2023). Community-based disaster risk management through NGOs: Practices and challenges in South Asia. *International Journal of Disaster Risk Science, 14*(1), 45–58. https://doi.org/10.1007/s13753-022-00434-7

Shrestha, S., Gautam, D., & Maharjan, A. (2023). Integrated flood management through structural and non-structural measures: Case studies from South Asia. *Journal of Flood Risk Management, 16*(1), e12829. https://doi.org/10.1111/jfr3.12829

Shrestha, S., Shrestha, M., & Babel, M. S. (2021). Assessment of climate change impact on water diversion potential of the Koshi River basin in Nepal. *Science of The Total Environment, 752*, 141882. https://doi.org/10.1016/j.scitotenv.2020.141882

Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. R. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal, 2*(4), 263–275. https://doi.org/10.1080/15730620500386529

Simard, S., & Austin, M. (2010). The role of mycorrhizas in forest soil stability with climate change. In *Climate change and variability*. IntechOpen. doi: 10.5772/9813

Singh, A. (Ed.). (2017). *Disaster Law: Emerging Thresholds* (1st ed.). Routledge India. https://doi.org/10.4324/9781315102931

Singh, A., Gupta, A., & Verma, P. (2020). Influence of slope, soil, and land use on rainfall-runoff and flood events in hilly terrain. *Journal of Mountain Science,* 17(5), 1105–1120. https://doi.org/10.1007/s11629-019-5728-6

Singh, O., & Kumar, M. (2017). Flood occurrences, damages, and management challenges in India: a geographical perspective. *Arabian Journal of Geosciences*, *10*, 1-19. https://doi.org/10.1007/s12517-017-2895-2

Singh, R., & Sharma, P. (2021). Role of police in disaster management: A case study of flood disaster management in India. *Journal of Disaster Management, 4*(1), 11–19.

Singh, Savindra. (2015). *Climatology;* Pravalika Publications, Allahabad, 2015 Edition, pp. 263- 270.

Singh, V. P. (1997). Effect of spatial and temporal variability in rainfall and watershed characteristics on stream flow hydrograph. *Hydrological Processes*, 11(12), 1649–1669. https://doi.org/10.1002/(SICI)1099-1085(19971015)11:12<1649::AID-HYP495>3.0.CO;2-1

Singh, V. P. (2019). *Hydrology and Floodplain Analysis* (5th ed.). Pearson.

Smith, J. A., Baeck, M. L., & Zhang, Y. (2013). Extreme flood response: The June 2008 Midwest floods. *Journal of Hydrometeorology*, 14(3), 776–796.

Smith, J. A., Baeck, M. L., Villarini, G., & Wright, D. B. (2013). *Extreme flood response: The June 2008 flooding in Iowa. Journal of Hydrometeorology*, 14(6), 1810–1825. https://doi.org/10.1175/JHM-D-12-0191.1

Smith, K., & Ward, R. (1998). *Floods: Physical processes and human impacts*. Wiley.

Smith, K., Petley, D. N., & Hudson, P. (2019). *Environmental hazards: Assessing risk and reducing disaster*. Routledge.

Solomon, O., & Prince, O. (2013). Flood frequency analysis of Osse river using Gumbel's distribution. *Civil and environmental research*, *3*(10), 55-59. ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)

Sörensen, J. L., Eisner, S., Olsson, J., Beldring, S., Carvalho, V. S., Elenius, M., & Uvo, C. B. (2024). Decision Support Indicators (DSIs) and their role in hydrological planning. *Environmental Science & Policy*, *157*, 103768. https://doi.org/10.1016/j.envsci.2024.103768

Sphere Association. (2018). *The Sphere Handbook: Humanitarian charter and minimum standards in humanitarian response* (4th ed.). Geneva: Sphere Association. https://spherestandards.org/handbook/

Srivastava, R. K. (2020). *Managing urbanization, climate change and disasters in South Asia*. Springer Nature. https://doi.org/10.1007/978-981-15-2410-3

Stefanidis, S., & Stathis, D. (2013). Assessment of flood hazard based on natural and anthropogenic factors using analytic hierarchy process (AHP). *Natural hazards*, *68*, 569-585. https://doi.org/10.1007/s11069-013-0639-5

Subramanya, K. (2013). *Engineering hydrology* (4th ed.). McGraw-Hill Education.

Surminski, S., & Oramas-Dorta, D. (2014). Flood insurance schemes and climate adaptation in developing countries. *International Journal of Disaster Risk Reduction*, 7, 154–164. https://doi.org/10.1016/j.ijdrr.2013.10.005

Tazen, F., Diarra, A., Kabore, R. F., Ibrahim, B., Bologo/Traoré, M., Traoré, K., & Karambiri, H. (2019). Trends in flood events and their relationship to extreme rainfall in an urban area of Sahelian West Africa: The case study of Ouagadougou, Burkina Faso. *Journal of Flood Risk Management*, *12*, e12507. https://doi.org/10.1111/jfr3.12507

Thakkar, S. K., & Dhiman, S. D. (2007). Morphometric analysis and prioritization of mini-watersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing, 35*(4), 313-321. https://doi.org/10.1007/BF02990787

Tripathi, P. (2015). Flood Disaster in India: An Analysis of trend and Preparedness. *Interdisciplinary Journal of Contemporary Research*, Vol. 2, No. 4.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., ... & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, *100*(14), 8074-8079.. https://doi.org/10.1073/pnas.1231335100

Twigg, J. (2015). *Disaster risk reduction*. Humanitarian Practice Network, Overseas Development Institute. http://www.odi.org/hpg

UNESCO World Water Assessment Programme. (2012). United Nations world water development report 4: Managing water under uncertainty and risk. Available at https://u nesdoc.unesco.org/ark:/48223/pf0000215644.page=812.

UNISDR (United Nations International Strategy for Disaster Reduction). 2015. *Sendai framework for disaster risk reduction 2015–2030*. Geneva: UNISDR.

UNISDR (United Nations International Strategy for Disaster Reduction). (2017) *Words into Action Guidelines: National Disaster Risk Assessment Hazard Specific Risk Assessment.*

United Nations Office for Disaster Risk Reduction (UNDRR). (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030.*

https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

United Nations Office for Disaster Risk Reduction (UNDRR). (2022). *Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk*. United Nations Office for Disaster Risk Reduction. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2022

Vabeihmo, C. (2022). Assessment of Flood Hazard Zonation Using Geographic Information System and Analytical Hierarchy Process: A Case Study of Tlawng River Watershed in Sairang, Mizoram, India. *Nature Environment & Pollution Technology*, *21*(1).

Vanacker, V., Linderman, M., Lupo, F., Flasse, S., & Lambin, E. (2005). Impact of short-term rainfall fluctuation on interannual land cover change in sub-Saharan Africa. *Global Ecology and Biogeography*, *14*(2), 123-135. https://doi.org/10.1016/j.catena.2005.05.003

Volpi, M., Tuia, D., Bovolo, F., Kanevski, M., & Bruzzone, L. (2013). Supervised change detection in VHR images using contextual information and support vector machines. *International Journal of Applied Earth Observation and Geoinformation*, *20*, 77-85. https://doi.org/10.1016/j.jag.2011.10.013

Wang, F., Harindintwali, J. D., Wei, K., Shan, Y., Mi, Z., Costello, M. J., & Tiedje, J. M. (2023). Climate change: Strategies for mitigation and adaptation. *The Innovation Geoscience*, *1*(1), 100015-61. https://doi.org/10.59717/j.xinn-geo.2023.100015

Wang, L., Cui, S., Li, Y., Huang, H., Manandhar, B., Nitivattananon, V., Fang, X., Huang, W & Huang, W. (2022). A review of the flood management: from flood control to flood resilience. *Heliyon*, *8*(11).

Ward, P. J., Couasnon, A., Eilander, D., Haigh, I. D., Hendry, A., Muis, S., Veldkamp, T. I. E., Winsemius, H. C., & Wahl, T. (2020). Dependence between high sea-level and high river discharge increases flood hazard in global deltas and estuaries. *Environmental Research Letters*, 15(10), 104008. https://doi.org/10.1088/1748-9326/aba4d4

Ward, R. C. (1978). *Floods: A geographical perspective*. Macmillan.

Ward, R. C., & Robinson, M. (2000). *Principles of hydrology* (4th ed.). McGraw-Hill Education.

Wheeler, M. (2024). *Warming Wars: The Role of Climate Change in Future National Security Challenges* (Doctoral dissertation, Georgetown University).

Wilby, R. L., & Keenan, R. (2012). Adapting to flood risk under climate change. *Progress in physical geography*, *36*(3), 348-378. https://doi.org/10.1177/0309133312438908

Wilson, L., & Richards, K. S. (1988). The behaviour of short natural river channels under conditions of high sediment transport rates. *Geomorphology, 1*(2), 85-101. https://doi.org/10.1016/0169-555X(88)90004-0

Winsemius, H. C., Aerts, J. C., Van Beek, L. P., Bierkens, M. F., Bouwman, A., Jongman, B., ... & Ward, P. J. (2016). Global drivers of future river flood risk. *Nature Climate Change*, *6*(4), 381-385. https://doi.org/10.1038/nclimate2893

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk: Natural hazards, people's vulnerability and disasters* (2nd ed.). Routledge.

Wobus, C., Martinich, J., Woznicki, S., & Strzepek, K. (2017). Climate change impacts on flood risk and asset damages within mapped 100-year floodplains of the contiguous United States. *Natural Hazards, 89*(1), 353–368. https://doi.org/10.1007/s11069-017-2970-1

World Bank. *World Bank Annual Report 2024 : A Better Bank for a Better World (English).* Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/099101824180532047

World Health Organization (WHO). (2013). *Water, sanitation and hygiene in emergencies*. WHO Press. https://www.who.int/publications/i/item/9789241548873

World Health Organization (WHO). (2021). Drowning. Retrieved from https://www.who.int/news-room/fact-sheets/detail/drowning

World Health Organization. Regional Office for Europe. (2017). Flooding: managing health risks in the WHO European Region. *World Health Organization. Regional Office for Europe.*

World Meteorological Organization (WMO) (2021), 2021 States of Climate Services: *Water, World Meteorological Organization, Switzerland*, pp. 9

World Meteorological Organization, 2024. State of the Global Climate 2023, WMO-No.1347.

Yin, H., & Li, C. (2001). Human impact on floods and flood disasters on the Yangtze River. *Geomorphology.* Volume 41, Issues 2-3, 105-109. https://doi.org/10.1016/S0169-555X(01)00108-8

Yoon, D. K. (2012). Assessment of social vulnerability to natural disasters: a comparative study. *Natural Hazards, 63*, 823-843. https://doi.org/10.1007/s11069-012-0189-2

Youth for Unity and Voluntary Action (Yuva) (2020). Living with Multiple Vulnerabilities: Impact of COVID-19 on the Urban Poor in the Mumbai Metropolitan Region. Final Report. Mumbai: India.

Yue, S., Ouarda, T. B., Bobée, B., Legendre, P., & Bruneau, P. (1999). The Gumbel mixed model for flood frequency analysis. *Journal of hydrology*, *226*(1-2), 88-100. https://doi.org/10.1016/S0022-1694(99)00168-7

Zhou, Q., Li, B., & Kurban, A. (2008). Trajectory analysis of land cover change in arid environment of China. *International Journal of Remote Sensing*, *29*(4), 1093-1107. https://doi.org/10.1080/01431160701355256

BRIEF BIO-DATA

PERSONAL DETAILS

Name	: Lalremruati
Address	: A-I (B) 21, Chaltlang, Aizawl, Mizoram
Email	: remizote92@gmail.com
Phone No.	: +91 9646544820
Father's Name	: H. Lalrotluanga
Mother's Name	: P.C. Liansangpuii
Language known	: Mizo, English
Marital Status	: Unmarried

EDUCATION

Year	Institution	Board	Class	Subject	Division	Percentage
2008	New Foundland High School	MBSE	X	-	First	63.2
2012	Government Chaltlang Higher Secondary School	MBSE	XII	Arts	Second	54.4
2016	Government Hrangbana College	MZU	B.A	Geography	Second	59.38
2018	Panjab University	PU	M.A	Disaster Management	First	71.12
2021	Mizoram University	MZU	Ph.D. (Course Work)	Disaster Management	First	7.14 (SGPA)

PERFORMANCE:

1. Published a paper entitled "The role of NGO in Disaster Management- A case study of Young Mizo Association, Mizoram". *Disaster and Development.* 12(1), 211-227.

2. Published a paper entitled "A Multi-Approach Investigation of Tlawng River Flood Hazard in Sairang, Mizoram". *Indian Journal of Science and Technology*. 16(SP1):148-157. https://doi.org/10.17485/IJST/v16sp1.msc21

PRESENTATIONS:

1. Presented a paper titled- "The Role of NGO in Disaster Management- A Case Study of Young Mizo Association, Mizoram" during North East Regional Conclave, held between 20th – 22nd May 2022.

2. Presented a research paper titled- "A Multi- Approach Investigation of Tlawng River Flood Hazard in Sairang, Mizoram" on 24th November, 2022 during 4th Mizoram Science Congress 2022.

3. Presented a paper titled- "Climate Induced Disaster in Aizawl District with Special Reference to Tlawng River, Sairang, Mizoram" on 28th April, 2023 during Two Days' National Seminar on Earthquake Forecast- Prediction in North East India organized by Centre for Disaster Management, Mizoram University.

4. Presented a paper titled- " Community Based Risk and Vulnerability Assessment of Tlawng River Flood in Bairabi Town, Mizoram" during One Day International Conference on Literature, Cultural Studies, Education and Social Sciences on 4th September, 2024

TRAINING AND SEMINAR ATTEND

1. Webinar on "Disaster Management in a Past Covid Society" held on 21st March, 2022 organized by University Grant Commission, Human Resource Development Centre, Mizoram University.

2. Training program on "Landslide Risk Mitigation & Detailed Project Report (DPR) Preparation" organized by Department of Geology, North- Eastern Hill University (NEHU), Shillong, Meghalaya from 23rd to 25th March, 2022.

3. Online Training on "Disaster Risk Reduction" from 21st to 23rd September 2022, organized by National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India in collaboration with Research and Development Cell Central University of Jammu (J & K) Jammu.

4. Online Training on "Flood Risk and Resilience Strategies, A Trans-disciplinary Approach" on 17th October 2022, organized by Innovation Incubation and Entrepreneurship Cell Kazi Nazrul University Asansol West Bengal.

5. Online Training on "Occupational Safety and Disaster Management" on 27th October, 2022, organized by SRM University &National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India.

6. Webinar on "15th Finance Commission and Disaster Risk Management" on 28th October 2022, organized by IMPRI & National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India.

7. Online Training on "Mainstreaming Disaster Risk Reduction in Academia" on 13th March 2023, organized by National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India.

8. Online training on "Rapid Urbanisation and Disaster Risk Reduction" from 27 March, 2023 to 29 March, 2023 organized by National Institute of Disaster Management, Ministry of Home Affairs, Govt. of India in collaboration with Central University of Himachal Pradesh.

9. Two Days International Workshop on "Psychosocial Adaptation, Disaster Mitigation and Preparedness of Climate Change Affected Communities" on 15^{th} – 16^{th} April, 2023 organized by Department of Social Work, Mizoram University.

10. One Week National Workshop on "Importance of Disaster Risk Reduction and Resilience" during 10^{th} – 14^{th} April, 2023 organized by Department of Civil Engineering, School of Engineering & Technology, Mizoram University.

11. International Seminar on "Petroleum Exploration: Scopes, Prospects & Strategies with a Special Anecdote on North East India", organized by Centre for Petroleum Exploration & Department of Geology, Mizoram University during 30^{th} - 31^{st} May 2023.

12. Workshop on Empowering Next Generation for a Resilient Future Organized by The National Institute of Disaster Management, held at Dr. Ambedkar International Centre, New Delhi on 23^{rd} October, 2024.

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	: **LALREMRUATI**
DEGREE	: **Doctor of Philosophy (Ph.D.)**
DEPARTMENT	: **Centre for Disaster Management**
TITLE OF THESIS	: **Causes, Impact and Management of Tlawng River Flood in Sairang and Bairabi towns, Mizoram**
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Head

Department of Geography & Resource Management

ABSTRACT

CAUSES, IMPACT AND MANAGEMENT OF TLAWNG RIVER FLOOD IN SAIRANG AND BAIRABI TOWNS, MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

LALREMRUATI

MZU REGISTRATION NO.: 2109071

Ph.D. REGISTRATION NO.: MZU/Ph.D./1890 of 19.08.2021

CENTRE FOR DISASTER MANAGEMENT

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

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By

LALREMRUATI

CENTRE FOR DISASTER MANAGEMENT

NAME OF SUPERVISOR

Prof. LALDINPUIA

Submitted

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Introduction

Flooding is one of the most persistent and costly natural hazards worldwide, affecting millions of people each year and causing extensive damage to property, infrastructure, agriculture, and the environment. In India, floods account for a significant share of disaster losses, with the northeast region being particularly vulnerable due to its unique geographical, climatic, and socio-economic conditions. Mizoram, one of the north-eastern states, is no exception. With its rugged terrain, steep slopes, and a river system that is both lifeline and hazard, the state faces recurrent flood events, especially during the intense monsoon months.

The Tlawng River, the longest river in Mizoram, has historically played a central role in the socio-economic development of the state. Flowing for approximately 186 kilometres before joining the Barak River in Assam, it sustains agriculture, fisheries, and trade, while also providing a transportation corridor in certain stretches. However, it also poses a recurring flood threat, particularly in settlements located along its banks. Historical records and oral histories recount several major flood events-most notably in 1929, 1989, 1993, 2007, 2017, 2018, and most recently in 2024-which have caused widespread disruption in affected communities.

Two towns-Sairang in Aizawl district and Bairabi in Kolasib district-stand out as particularly vulnerable to flooding along the Tlawng River. Sairang's location within a narrow river valley means floodwaters can rise rapidly with little warning, while Bairabi's position on a broad floodplain exposes it to prolonged inundation. Despite repeated flooding in these areas, comprehensive, integrated studies combining physical, environmental, and socio-economic perspectives have been limited.

This research addresses that gap. It provides a multi-dimensional analysis of flooding in Sairang and Bairabi, examining natural and human-induced causes, assessing impacts on various sectors, evaluating community preparedness and institutional capacities, and developing a vulnerability framework to guide mitigation. By integrating hydrological and geomorphological analyses with socio-economic assessments, it seeks to generate actionable insights that are grounded in both science and local realities.

The study's significance lies in its potential to inform flood risk management not only in these two towns but also in similar riverine settlements across Mizoram and the wider northeast region. The findings underline the urgent need for an integrated approach to flood resilience—one that blends engineering solutions with environmental restoration, community engagement, and institutional strengthening.

Study Area

The Tlawng River Basin encompasses a variety of landscapes, from steep highland catchments to low-lying plains near the Assam border. Its hydrological regime is strongly influenced by the southwest monsoon, which brings heavy rainfall between May and October, often accounting for more than 70% of annual precipitation. Rainfall intensity, combined with the basin's geomorphology, results in a rapid runoff response, especially in the upper and middle reaches.

Sairang is situated approximately 14 kilometres northwest of Aizawl, the state capital. It lies within a narrow valley flanked by steep, forested hills, with elevations ranging from 56 to 300 metres above sea level. The Tlawng River here is relatively confined, with limited room for lateral spread during high flows. The population is just under 6,000, predominantly from Scheduled Tribe communities, with high literacy rates and a mix of agricultural, trade, and government employment. The settlement pattern is dense along the valley floor, with many homes and businesses close to the riverbank—a factor that greatly increases exposure to floodwaters.

Bairabi, located in Kolasib district near the Assam border, is Mizoram's only railhead and serves as a key gateway for goods and people entering the state. The town is set on a wider floodplain, with elevations from 26 to 220 metres. This topography allows the river to meander and spread during floods, creating fertile soils for agriculture but also subjecting large areas to inundation. With a population of about 4,300, Bairabi's economy is heavily reliant on agriculture, local commerce, and transport services. The railway infrastructure, while economically important, is also vulnerable to flood damage and disruption.

Both towns share certain characteristics: a dependence on the Tlawng River for livelihoods and daily life, an economy sensitive to climate variability, and a settlement pattern shaped by topography and access to transport. However, their contrasting geomorphological settings create different flood dynamics—rapid onset in Sairang versus slower but more widespread flooding in Bairabi—which in turn influence the nature of impacts and the types of mitigation measures required.

Scope of the Study

This research is geographically confined to two towns—Sairang and Bairabi—situated along the course of the Tlawng River. By focusing on these two locations, the study captures a range of flood dynamics, from rapid-onset, high-velocity floods in Sairang to slower, longer-duration floods in Bairabi.

The scope includes:

Identification of flood causes, both natural (rainfall intensity, river morphology, topography, soil properties) and human-induced (land use change, settlement expansion, deforestation).

Assessment of flood impacts across social, economic, physical, and environmental dimensions, including primary, secondary, and tertiary effects.

Evaluation of preparedness and response, incorporating community-level initiatives, local governance mechanisms, and state-level institutional support.

Computation of a Flood Vulnerability Index (FVI) and preparation of vulnerability maps to identify high-risk zones within each town.

While the study integrates hydrological, geomorphological, and socio-economic analyses, it does not include hydrodynamic modelling of flood propagation, nor does it attempt long-term climate projections. The emphasis is on observed patterns, historical records, field-based data, and stakeholder perspectives. This approach ensures that findings are immediately relevant for practical flood risk management in the study areas.

Objectives

1. To identify the causes of flood hazard in Tlawng River.
2. To study the impact of the flood in Sairang and Bairabi towns.
3. To determine the actions and measures adopted for flood management.
4. To prepare a Vulnerability Map and formulate mitigation strategies.

Methodology

The study employed a mixed-methods approach, combining quantitative measurements with qualitative insights to build a comprehensive picture of the flood problem.

<u>Data Collection</u>

Primary Data: Household surveys, key informant interviews, and direct field observations were conducted in both towns. Respondents included community leaders, government officials, traders, farmers, and households directly affected by floods.

Secondary Data: Rainfall records, river discharge data, and historical flood information were sourced from the Indian Meteorological Department, Water Resources Department, and other relevant agencies.

<u>Analytical Techniques</u>

Rainfall Analysis – Annual, seasonal, and monthly rainfall patterns were examined to identify peak months and trends in extreme events. Exceedance probabilities were calculated using Weibull’s formula to estimate the likelihood of intense rainfall events.

River Morphology Assessment – DGPS and Total Station surveys were conducted during dry and wet seasons to capture seasonal changes in channel profile, bank erosion, and channel migration.

Flood Hydrograph Construction – Selected high-flood years were analysed to chart the timing and magnitude of discharge peaks.

Topography and Soil Analysis – Field measurements and secondary soil data were used to assess infiltration capacity, slope gradient, and drainage characteristics.

Flood Frequency Analysis – Gumbel's method was applied to estimate return periods for floods of different magnitudes, highlighting the recurrence of extreme events.

Change Detection – Satellite imagery from 2008 and 2023 was classified to map changes in forest cover, agricultural land, built-up areas, and water bodies. Classification accuracy was tested using the Kappa coefficient.

Statistical Analysis – Descriptive statistics, paired sample t-tests, and correlation analyses were applied to compare impacts between Sairang and Bairabi.

Flood Vulnerability Index (FVI) – Social, economic, physical, and environmental indicators were normalised and weighted to compute composite vulnerability scores for each ward or locality. GIS was used to visualise results in vulnerability maps.

Integration of Methods

By combining hydrological and geomorphological data with socio-economic assessments, the methodology ensured that both the physical hazard and the human dimensions of flooding were captured. This integration is essential because floods are not solely natural events; their impacts are shaped by how societies prepare, respond, and adapt.

Chapter 4 – Causes of Flood

The causes of flooding in Sairang and Bairabi were found to be multi-faceted, involving both natural processes and human interventions.

Natural Causes

The dominant natural factor is the region's high-intensity monsoon rainfall. Analysis of daily and monthly rainfall data revealed that July and August consistently record the highest totals, often exceeding 400 mm in a single month. Extreme daily rainfall events have increased in frequency over the past two decades. Several recent events, such as in August 2017 and July 2018, exceeded return period thresholds calculated from historical records.

Prolonged rainfall spells lead to soil saturation, reducing infiltration capacity and increasing surface runoff. In Sairang's steep terrain, this translates into rapid runoff into the Tlawng River, causing water levels to rise swiftly. In Bairabi, where the terrain is flatter, the river has more room to spread, but the larger inundation area means that floodwaters often remain for days.

River morphology changes also contribute. DGPS surveys revealed bank erosion, channel widening, and occasional shifts in the thalweg. In Sairang, the confined valley channel acts as a funnel, concentrating flows during high discharge events. In Bairabi, sediment deposition alters flow patterns and reduces channel capacity in certain reaches.

Topographic and soil characteristics further influence flood dynamics. Sairang's slopes are often above 20°, with shallow, less permeable soils that promote overland flow. Bairabi's lower slopes allow water to accumulate and spread, creating extensive floodplains.

Flood frequency analysis using Gumbel's method showed that high-magnitude floods, previously expected only once in 25–50 years, are now occurring with greater regularity. This suggests a shift in hydrological patterns, possibly linked to climate variability.

Anthropogenic Causes

Human activities have significantly amplified flood hazards. Land use change emerged as a key factor. Remote sensing analysis between 2008 and 2023 showed a decline in forested areas and expansion of built-up zones, particularly in low-lying, flood-prone locations. Encroachment onto natural floodplains—driven by population growth and demand for land—has placed more people and assets in harm's way.

In Sairang, construction close to the riverbank has reduced the buffer space for floodwaters, while in Bairabi, agricultural expansion into marginal floodplain areas has increased exposure of crops to inundation. Deforestation in the catchment reduces interception and infiltration, contributing to higher runoff rates downstream.

The combined effect of natural and human factors creates a compound hazard: intense rainfall produces high flows, and altered landscapes channel these flows into populated areas more readily than in the past.

Chapter 5 – Impact of Flooding

The impacts of flooding in Sairang and Bairabi were assessed across primary, secondary, and tertiary dimensions to capture both the immediate and longer-term consequences. This classification helps in understanding not only the direct physical damage but also the cascading effects that influence recovery and resilience.

Primary Impacts – Immediate Physical Damage

Primary impacts are those experienced during and immediately after flood events. In Sairang, the narrow valley channel causes floodwaters to rise rapidly, often leaving residents with little time to react. Houses constructed with light materials—particularly timber and bamboo—were among the first to suffer damage. Several residents reported partial or complete collapse of walls, washing away of household items, and destruction of small livestock pens. Businesses located along the riverbank lost inventory and suffered structural damage, disrupting economic activity for weeks.

In Bairabi, the larger floodplain meant that floodwaters advanced more slowly but spread over a greater area. Here, the main victims of primary impacts were agricultural lands and associated livelihoods. Paddy fields, vegetable gardens, and cash crops were submerged for extended periods, leading to crop failure and loss of seasonal income. Infrastructure damage included washed-out sections of unpaved roads, breaches in embankments, and erosion of railway embankments, which disrupted rail connectivity—the town's economic lifeline.

Secondary Impacts – Disruption of Services and Daily Life

Secondary impacts emerged in the days and weeks following floods. Both towns experienced disruption of transportation, affecting the movement of goods, emergency supplies, and people. In Sairang, road closures to Aizawl cut off access to larger markets, healthcare facilities, and administrative services. In Bairabi, rail disruptions halted both passenger and freight services, isolating the town from vital trade flows.

Water supply systems were also compromised. Floodwaters contaminated wells, hand pumps, and surface water sources, forcing households to rely on emergency water distribution or to boil water before consumption. Health risks increased as waterborne diseases—such as diarrhoea, dysentery, and skin infections—became more prevalent, especially among children and the elderly.

Education was temporarily disrupted when schools were used as evacuation centres or when access roads were impassable. The psychological toll was also evident: uncertainty about the recurrence of floods caused stress and anxiety, particularly for those who had already lost property in previous events.

Tertiary Impacts – Long-Term Consequences

Tertiary impacts were those that persisted months after the floodwaters had receded. In both towns, household income levels declined due to crop loss, livestock deaths, and reduced trading opportunities. Many farmers took loans to replant crops, but with reduced yields, repayment became a financial strain. Traders and shop owners in Sairang reported a decline in customer spending, as households prioritised basic needs over non-essential goods.

Environmental degradation was another tertiary impact. Erosion of riverbanks not only reduced arable land but also threatened infrastructure foundations. Sediment deposition in low-lying fields reduced soil fertility, affecting agricultural productivity in subsequent seasons.

The social fabric of communities was also affected. In some cases, families relocated from high-risk zones, leading to shifts in neighbourhood structures. Loss of community cohesion can weaken informal support networks that are often crucial during disasters.

Comparative Insights between Sairang and Bairabi

While the two towns share many flood impacts, their differences are rooted in geography and livelihood structure. In Sairang, the concentration of economic activity along a narrow corridor means that floods have a high impact intensity over a small area. Damage is often sudden and severe, making rapid evacuation and immediate response critical. In Bairabi, the larger spatial extent of flooding affects more land but allows some households to prepare or relocate in advance. However, the prolonged submergence of land in Bairabi means that recovery, especially in agriculture, is slower.

Statistical analysis (paired sample t-tests) confirmed that agriculture-related losses were significantly higher in Bairabi, while housing and business losses were more pronounced in Sairang. This underlines the need for location-specific mitigation strategies.

Chapter 6 – Evaluation of Flood Risk Management and Community Preparedness

Flood risk management in Sairang and Bairabi involves a combination of formal institutional mechanisms and community-driven initiatives. This chapter evaluates both the existing preparedness measures and the response capacities of the two towns, identifying strengths, weaknesses, and opportunities for improvement.

Awareness and Preparedness Levels

Household surveys revealed that most residents are aware of the seasonal flood risk, with many able to recall the dates and impacts of major flood events in detail. However, awareness does not always translate into preparedness. While some households in flood-prone zones keep important documents and valuables in waterproof containers, others admitted to making few, if any, advance preparations.

Participation in disaster preparedness training was low. Many residents had never attended a mock drill or formal awareness session conducted by government agencies. In both towns, preparedness planning was more reactive than proactive—residents responded to early warning signs (such as rising river levels) rather than following structured readiness protocols.

Early Warning Systems

Early warning mechanisms exist in both towns but are fragmented and informal. In Sairang, residents rely heavily on visual observation of the river and word-of-mouth alerts from upstream villages. Some also receive warnings through local leaders or mobile phone calls from relatives. Bairabi benefits from its railway station staff, who sometimes receive upstream rainfall information and pass it along informally.

However, the lead time between warning and flood onset is often insufficient—sometimes less than two hours—particularly in Sairang where the steep valley accelerates floodwaters. There is no fully integrated real-time monitoring system linking rainfall and river level gauges with automated alerts to communities.

Community Organisations

The Young Mizo Association (YMA) plays a critical role in both towns, often acting as the first responder during flood emergencies. YMA volunteers assist in evacuations, distribute relief materials, and coordinate shelter management. In many cases, their response is quicker than that of formal government agencies, partly because they are embedded within the community and can mobilise quickly.

Church groups and women's associations also contribute by providing cooked meals, clothing, and moral support to affected families. These community networks form a vital part of the social safety net, but they depend heavily on voluntary contributions and lack sustained financial or logistical backing.

Institutional Capacities

Government-led disaster management in the two towns is coordinated through the District Disaster Management Authority (DDMA) and the State Disaster Management Authority (SDMA). While these agencies have the mandate to prepare and respond to floods, their local presence is limited. Relief materials—such as tarpaulins, rice, and potable water—are often dispatched from district headquarters after the flood has already caused damage.

Health facilities in both towns, primarily Primary Health Centres (PHCs), can provide basic care but are not equipped to handle large-scale emergencies. In Sairang, a designated safe house is available for flood-affected residents, but it has limited capacity and is located at a distance from some high-risk zones. In Bairabi, a section of the embankment serves as a temporary refuge during floods, but it offers no sanitation or shelter facilities.

Effectiveness of Existing Measures

Overall, flood risk management is stronger in community solidarity than in formal infrastructure or institutional capacity. Residents rely on their networks, adapt through experience, and help one another, but structural and systemic gaps remain. The lack of comprehensive early warning systems, limited evacuation shelters, and inadequate integration between formal and informal actors means that responses are often reactive and ad hoc.

To improve preparedness, there is a need for capacity building, not just for residents but also for local institutions. This includes regular drills, integration of technological tools (SMS-based alerts, real-time gauges), and better alignment of relief supply chains with local needs.

Chapter 7 – Flood Vulnerability Assessment

The Flood Vulnerability Assessment in this study combines quantitative analysis and spatial mapping to identify the areas and communities most at risk in Sairang and Bairabi. The approach integrates four key dimensions of vulnerability-social, economic, physical, and environmental-into a composite Flood Vulnerability Index (FVI).

Social Vulnerability

Social vulnerability indicators included age distribution, household size, dependency ratio, literacy levels, and access to health facilities. Surveys revealed that households with elderly members, young children, or high dependency ratios were more likely to face difficulties during evacuation and recovery.

In Sairang, certain wards had a higher concentration of elderly residents living alone, often in houses close to the riverbank. These residents faced both mobility challenges and a lack of immediate family support during floods. In Bairabi, although extended family networks were more common, large household sizes meant that available resources—food, water, and shelter—were often stretched thin during disasters.

Access to healthcare was another critical factor. While both towns have Primary Health Centres, neither facility is fully equipped for flood-related emergencies. For example, they lack isolation wards for infectious diseases, which can be important during post-flood outbreaks.

Economic Vulnerability

Economic vulnerability was measured using indicators such as household income, livelihood diversity, and access to credit. In Bairabi, the heavy reliance on agriculture meant that a single flood event could wipe out a season's income. Limited access to formal banking services forced many farmers to depend on informal credit sources, often at high interest rates.

Sairang's economy was slightly more diversified, with a mix of trade, public sector employment, and small-scale services. However, the concentration of businesses in the low-lying market area created a high exposure cluster, where a single flood could affect dozens of enterprises simultaneously. This created a domino effect: loss of business income reduced employment opportunities, which in turn affected household spending.

Physical Vulnerability

Physical vulnerability reflected the condition and location of housing, proximity to the river, and access to evacuation routes. In Sairang, the steep slopes limited the availability of safe high-ground refuges within short walking distance. Many houses were constructed from lightweight materials without reinforced foundations, making them more susceptible to flood damage.

Bairabi's housing stock included more semi-permanent structures, but the flat floodplain setting meant that even well-built houses could be surrounded by water for days. Access roads to some neighbourhoods were single-lane and unpaved, making them prone to washouts and cutting off escape routes during severe floods.

Environmental Vulnerability

Environmental vulnerability was shaped by factors such as vegetation cover, soil erosion rates, and riverbank stability. Remote sensing showed that forest cover had declined in both towns' surrounding catchments between 2008 and 2023, replaced by built-up areas and shifting cultivation fields. The loss of vegetation reduced the natural buffering capacity against heavy rainfall.

Riverbank erosion was particularly severe in certain stretches near Bairabi, where undercutting of banks not only threatened agricultural land but also increased sediment loads in the river, altering flow dynamics. In Sairang, landslides triggered by intense rain occasionally deposited debris into the river, temporarily altering its course and increasing flood risk for downstream areas.

Composite Vulnerability Mapping

The four dimensions were normalised, weighted, and combined to generate composite FVI scores for different wards in each town. The results were then visualised in GIS-based vulnerability maps.

In Sairang, the highest vulnerability scores were concentrated in the low-lying central wards adjacent to the river. These areas combined high exposure (dense housing close to the river) with high social and physical vulnerability. In Bairabi, the highest vulnerability zones were on the outer edges of the floodplain, where agricultural dependence, low income diversity, and severe environmental degradation intersected.

The vulnerability maps provided actionable intelligence: they not only identified where interventions were most needed but also highlighted the specific vulnerability drivers in each location. For instance, in Sairang's market area, physical mitigation (elevating buildings, improving drainage) would be most effective, while in Bairabi's outer wards, livelihood diversification and environmental restoration could yield greater resilience.

Chapter 8 – Conclusion and Recommendations

The research concludes that the flooding challenges in Sairang and Bairabi are driven by a combination of increasing climatic extremes and human-induced landscape changes. Extreme rainfall events are more frequent, river morphology is dynamic, and vulnerabilities remain high across all dimensions.

Recommended actions include strengthening early warning systems, enforcing land use zoning to limit floodplain encroachment, investing in both structural measures (such as embankments and improved drainage) and non-structural measures (such as public awareness campaigns), and enhancing institutional capacities for health, shelter, and emergency response. Environmental restoration to re-establish natural flood buffers should also be prioritised.

The study underscores that building resilience will require an integrated approach—combining engineering solutions, community engagement, and policy reform—so that Sairang and Bairabi can break the cycle of recurrent losses and move towards a more sustainable and secure future.