South Asia
Bioregionalism
Working Group

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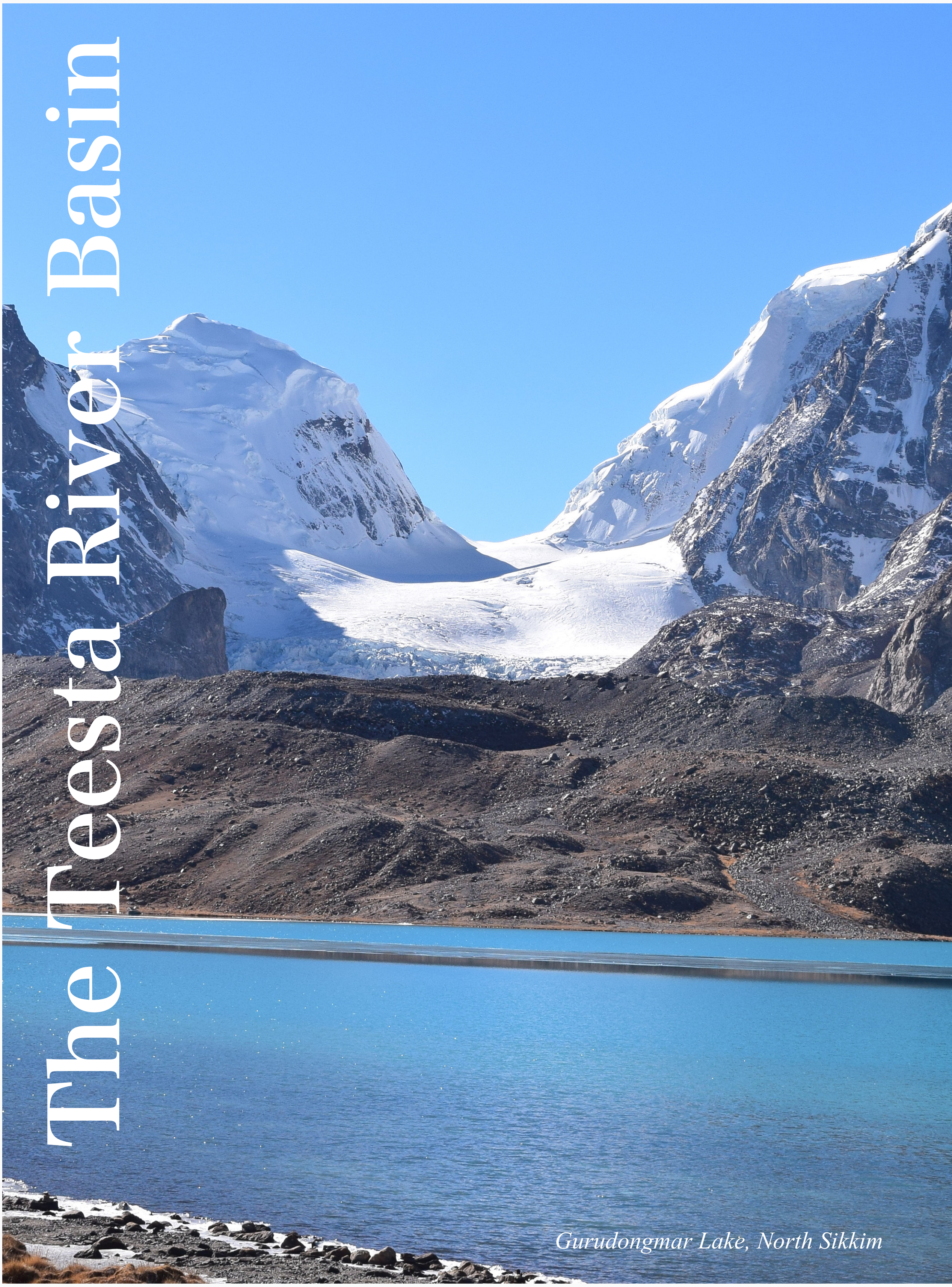
Multi-hazard Mapping of
The Teesta River Basin



Gurudongmar Lake, North Sikkim

2023 South Asia Bioregionalism Working Group

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1. Introduction

Sebu Tso: Head waters of Lachung chhu; a tributary of Teesta in North Sikkim

When an area is impacted by more than one hazard, is known as a multi-hazard. A multi-hazard map (MHM) helps policymakers and planners to analyze all-natural hazards occurring in an area or a region for vulnerability and risk assessment and ultimately for the decision-making process. The MHM can play a vital role in the planning of new development projects as well as the incorporation of hazard reduction techniques into existing developments (Anonymous 2021)[1].

The main purpose of MHM is to collect together in one map the different hazard-related information for a study area to convey a composite picture of the natural hazards of varying magnitude, frequency, and affected areas (Anonymous 2021)[1]. A MHM may also be referred to as a 'composite,' 'synthesized,' and 'overlay' hazard map (Anonymous 2021)[1]. One area may suffer from many individuals or inter-related natural hazards. Using individual maps to depict information on each hazard may be clumsy and confusing for planners and decision-makers because of their varying frequency, magnitude, and affected areas (Anonymous 2021)[1]. In the Teesta River basin, we can find different elevations and climatic zones. Therefore, the basin is frequently affected by different types of natural hazards. Every year, thousands of people and millions of dollars are lost due to many natural disasters in the basin. On average, flood-induced damage to crops, houses and public utilities is about INR. 2.8 million in Sikkim (CWC 2019)[2].

2. Study Area

The Teesta River is a tributary of the mighty Brahmaputra River. It originates in Chitamu Lake in the Sikkim Himalayas (7200 m, amsl) and enters first into the Darjeeling plain and then to the Duars plain of West Bengal in India (Banglapedia 2014)[3]. It enters Bangladesh at the Kharibari border of Nilphamari district (Banglapedia 2014)[3]. The Teesta is a perennial, rain- and snow-fed river (Prasai and Surie 2013)[4]. The discharge of water through the Teesta varies significantly between dry and wet spells. This basin extends from 87° 57′ 45.024′′ E to 89° 40′ 39.427′′ E longitudes and from 25° 29′ 25.73′′ N to 28° 8′ 27.883′′N latitudes (**Fig. 1**). Teesta River basin covers an area of 11,888 km^2 and drains India and Bangladesh. About 16% of the basin area is in Bangladesh and the remaining 84% area is lying in India. The description of the administrative boundaries of the basin is given in **Table 1**.

Due to high rainfall, rainfall and earthquake-induced landslides, and forest fires; the sediment yield from the basin is highest in the Indian Himalayan region. The piedmont and plain zone of the basin (elevation range 21-250 m) are prone to flooding and extensively used for cultivation. Hilly regions (251-3500 m) are prone to landslides, earthquakes, and flash flooding and are extensively covered by different types of virgin forest cover. The alpine meadows, scrublands, and pro-glacial lakes are found between 3501 and 5200 m altitude. Pro-glacial lakes (e.g., south Lhonak Lake) in this zone have a high potential for glacial lake outburst floods (GLOFS) (**Table 2** and **Fig.2**).

Rainfall is relatively intense in Sikkim and Darjeeling Himalaya. Owing to the location of the Rajmahal hills location to the west and the Meghalaya plateau, a copious amount of moisture-laden monsoonal wind from the Bay of Bengal is directed to the Teesta valley, Thus, leading to considerable precipitation in the area **Table No.1.**

S.No	**District/State**	**Mean Annual Temp (Centigrade#)**	**Mean Annual Rainfall (mm)**	**Average number of rainy days**
1	Darjeeling (West Bengal)	13.40	3608	126
2	Sikkim	19.50##	2376	161
3	East Sikkim	15.75	2438	-
4	West Sikkim	23.35	2022	-
5	North Sikkim	20.35	3007	-
6	South Sikkim	18.55	2037	-

Source: https://darjeeling.gov.in/demography/;Census of India documents; Hydrome Division, India

Table 1 *Mean Annual Temperature and Rainfall: Sikkim & Darjeeling District*

Meteorological Department, New Delhi (average of 5-9 yrs.)
#Data pertains to the headquarters of the districts;
##Average of the four districts of Sikkim.

No.	State/ District	Location	Area (km²)	Population	No. of Blocks	No. of inhabited Villages	No. of Households
1	Darjeeling (W.B)	27013'-26027'N 88053E-87057'E	3149	1846823	12	616	391234
2	Sikkim	27004'46"-28007'48"N 88000'58"-88055'25"E	7096	610577	31	425	128906

Table 2 *Basic Geographical Information: Sikkim and Darjeeling*

Label ID	Country	District	Block/ Sub-district
1	India	West Sikkim	Soreng
2	India	South Sikkim	Yangyang
3	India	South Sikkim	Ravong
4	India	North Sikkim	Kabi
5	India	North Sikkim	Dzongu
6	India	East Sikkim	Rangpo
7	India	East Sikkim	Rongli
8	India	East Sikkim	Pakyong
9	India	East Sikkim	Gangtok
10	India	West Sikkim	Yuksom
11	India	North Sikkim	Chungthang
12	India	South Sikkim	Jorethang
13	India	West Sikkim	Dentam
14	India	South Sikkim	Namchi
15	India	West Sikkim	Gyalshing
16	India	North Sikkim	Mangan
17	India	Darjeeling	Darjeeling Pulbazar
18	India	Darjeeling	Rangli Rangliot
19	India	Darjeeling	Part of Matigara Block
20	India	Darjeeling	Kalimpong-II
21	India	Darjeeling	Kurseong
22	India	Darjeeling	Kalimpong-I
23	India	Darjeeling	Gurubathan
24	India	Jalpaiguri	Rajganj

Label ID	Country	District	Block/ Sub-district
25	India	Jalpaiguri	Mal
26	India	Jalpaiguri	Matiali
27	India	Jalpaiguri	Jalpaiguri
28	India	Koch Bihar	Mekliganj
29	India	Jalpaiguri	Maynaguri
30	India	Koch Bihar	Haldibari
31	Bangladesh	Lalmonirhat	Aditmari
32	Bangladesh	Kurigram	Chilmari
33	Bangladesh	Nilphamari	Dimla
34	Bangladesh	Nilphamari	Domar
35	Bangladesh	Rangpur	Gangachara
36	Bangladesh	Lalmonirhat	Hatibandha
37	Bangladesh	Nilphamari	Jaldhaka
38	Bangladesh	Lalmonirhat	Kaliganj
39	Bangladesh	Rangpur	Kaunia
40	Bangladesh	Nilphamari	Kishoreganj
41	Bangladesh	Lalmonirhat	Lalmonirhat sadar
42	Bangladesh	Lalmonirhat	Patgram
43	Bangladesh	Rangpur	Pirgachha
44	Bangladesh	Kurigram	Rajarhat
45	Bangladesh	Rangpur	Rangpur Sadar
46	Bangladesh	Gaibandha	Sundarganj
47	Bangladesh	Kurigram	Ulipur

Table 3 *Description of administrative boundaries of the Teesta Basin*

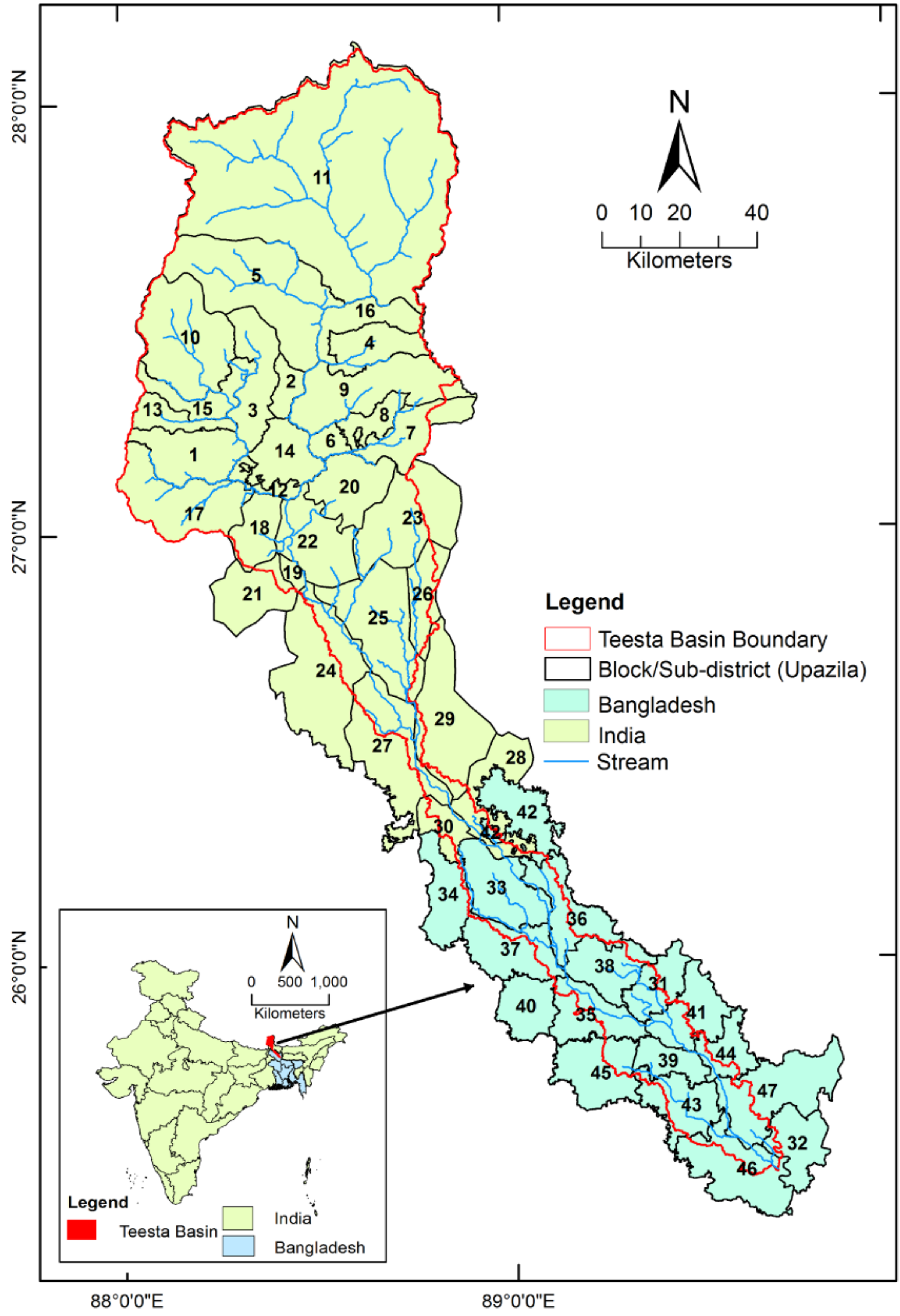


Fig.1 *Study area map with label IDs of block/sub-district boundaries. Label IDs-wise name of the block/sub-district is listed in Table 1.*

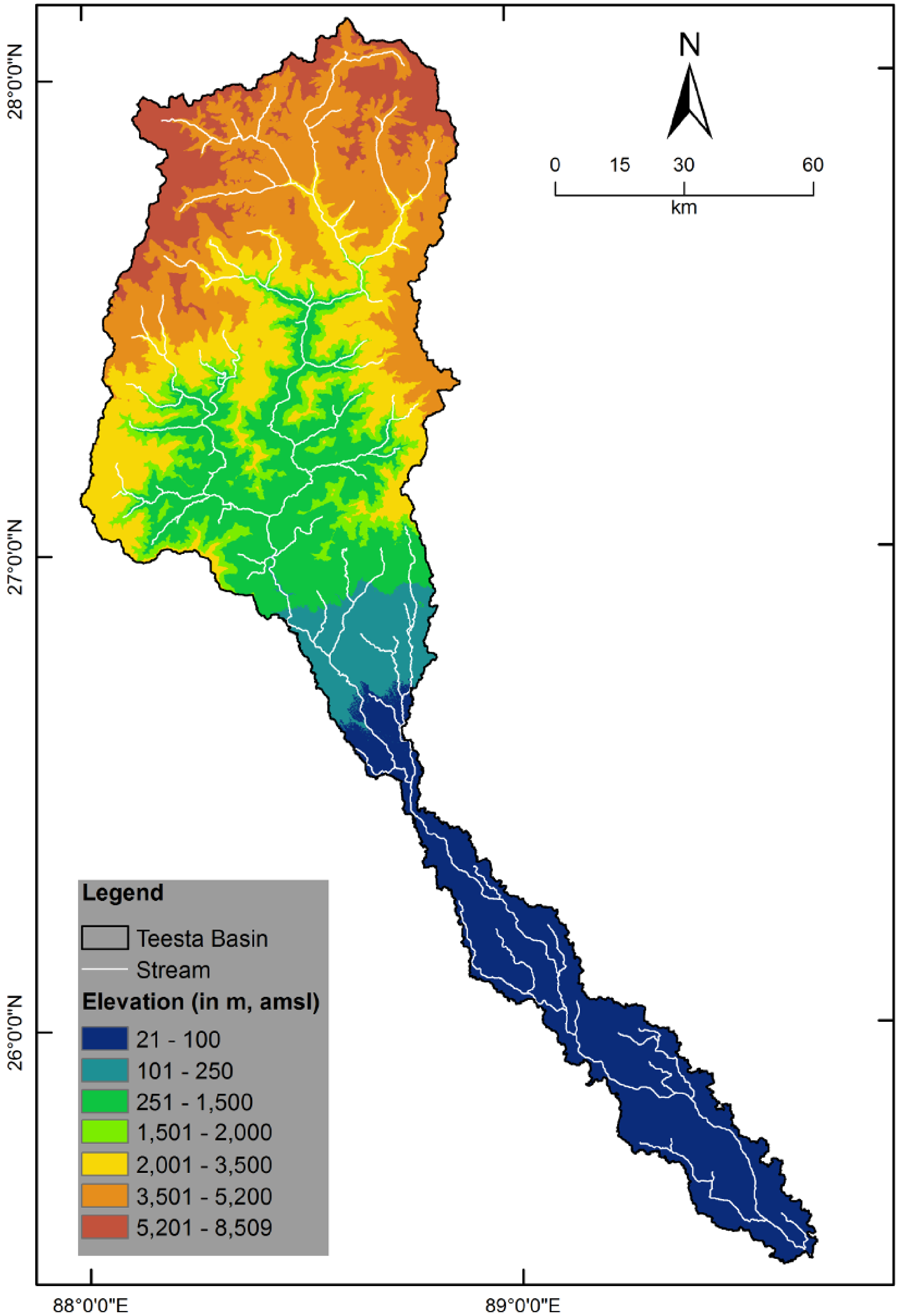


Fig. 2 *Elevation zones of the Teesta basin*

Elevation Range (m)	Geomorphic/Ecological/Natural hazards characterisation	Area (in km2)	% of Area
21-100	Plain (Agriculture, Flooding)	2483.3	21
101-250	Piedmont Plain (Agriculture and Plantation, Flooding)	728.1	6
251-1500	Lower Hills (Forest, Terrace Farming, Forest Fires, Flash Floods, and Landslides)	2167.9	18
1501-2000	Mid-hills (Forest, Terrace Farming, Forest Fires, Flash Floods, and Landslides)	938.9	8
2001-3500	Higher-hills (Forest, Terrace Farming, Forest Fires and Landslides)	1895.1	16
3501-5200	Alpine Meadows, Scrub, Pro-glacial Lakes (High GLOF Potential)	2625.3	22
5201-8509	Frozen Land (Permafrost, Supra Glacial Lakes, Snow & Glaciers, Snow Avalanche)	1049	9
Total		**11,888**	**100**

Table 4 *Elevation range-wise geomorphic/ecological and natural hazards characterisation of the Teesta basin*

3. Objectives

The main objectives of this report are (a) to identify and map the known natural hazards occurring frequently in the basin and (b) to prepare a multi-hazard map at the block/sub-district level for the basin.

4. Materials and Methods

Disastrous weather events (1968-2017) data were collected from the India Metrological Department (IMD), Pune (IMD 2021)[5]. IMD, Pune considers earthquakes, landslides, flooding, heavy rainfall, heavy snowfall, lighting, thunderstorm, hail, cyclone, drought, Tornado, dust storms, heat waves, cold waves and squalls as disastrous weather events (IMD 2021)[5]. Mean annual temperature data were taken from the climate research unit (CRU 2022)[6]. Data on landslides (1965-2017) and earthquakes (1934-2019) were obtained from the Bhukosh geoscientific data portal of the Geological Survey of India (GSI) (GSI 2021)[7]. Forest fire incidents (2002-2018) location data were obtained from the Forest Survey of India (FSI) (FSI 2021)[8]. Flood-affected area (1984-2018) of the Teesta basin was obtained from Pekel et al. (2016)[9] and Brakenridge and Kettner (2019)[10]. Flood damage data for Sikkim were collected from the Central Water Commission (CWC), Govt. of India (CWC 2019)[11]. Monthly peak discharge data recorded at Kaunia station (Bangladesh) were obtained from Mondal and Islam (2017)[12].

A simple overlay analysis was accomplished using geographic information system (GIS) to obtain block/sub-district-wise mean moment magnitude of earthquakes, landslide areas, no. of forest fires incidents and flooded areas. After getting block/sub-district-wise parameters of natural hazards, normalisation of each parameter had been done. Normalisation is a scaling technique in which values are shifted and rescaled in a way that they end up ranging between 0 and 1. This is also known as Min-Max scaling. When data do not follow a Gaussian distribution, the normalisation is an appropriate method to use to make the data scale-free. The formula for normalisation is given in Eq. (1).

$$X' = \frac{(X - X_{min})}{(X_{max} - X_{min})} \quad \text{.............................(1)}$$

Where X´ is the product after normalisation, X is parameter for example block/sub-district-wise flooded areas (in km2), Xmin is the minimum value and Xmax is the maximum value of a series.

After normalisation of block/sub-district-wise hazard parameters such as mean moment magnitude of earthquakes, no. of forest fire incidents, landslide and flooded areas, these parameters were added to make a composite index of multi-hazard for the Teesta basin.

Disastrous weather event data for the Indian part of the basin were analysed and grouped into 5 decades.

5. Interpretation

5.1 Decadal Disastrous Weather Events and Warming in Upper Teesta Basin

Decadal analysis of IMD disastrous weather events data shows that the maximum number of disastrous weather events occurred during 1998-2007 while minimum disastrous events occurred during 1968-1977. Overall, in the Indian part of the basin, decadal disastrous weather events are showing an increasing trend (**Fig.3A**).

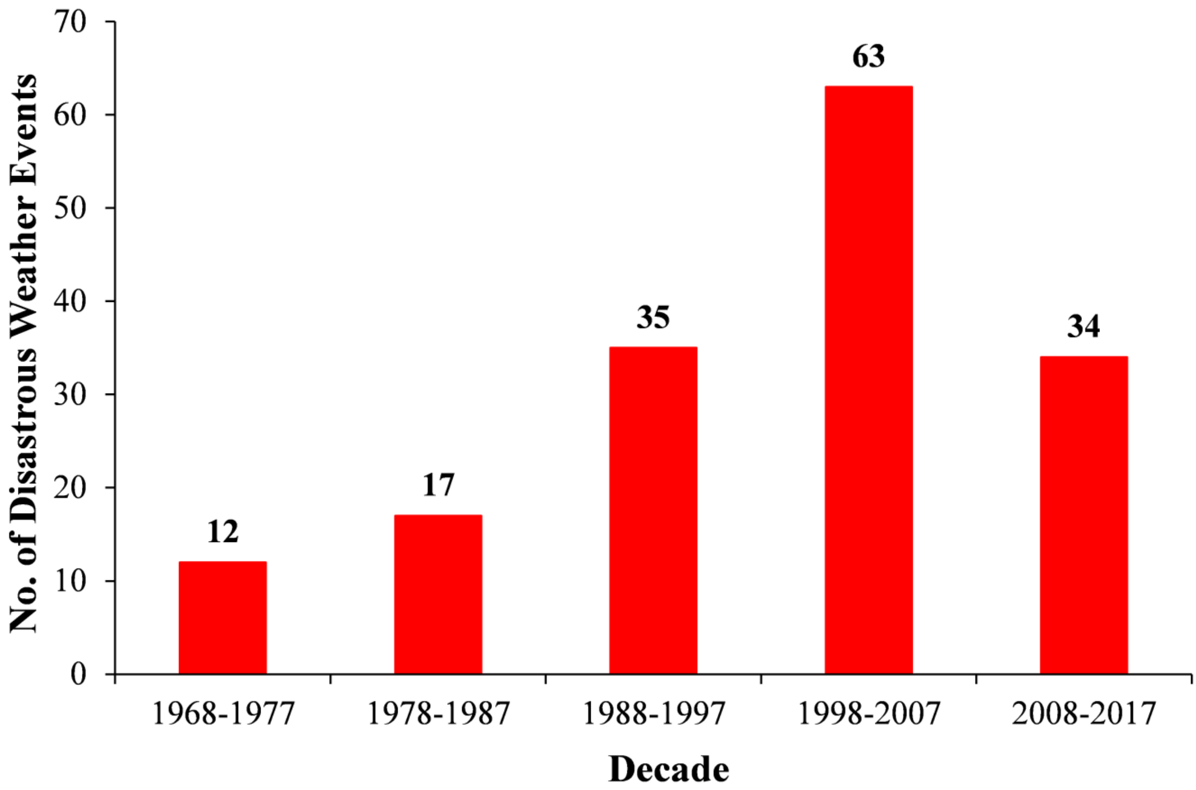


Fig.3A *Decadal distribution of disastrous weather events in the Indian part of the Teesta basin*

An increasing trend in mean annual temperature indicates that climate change-induced warming is taking place above and below 2400 m amsl during 1968-2017. In these two elevation zones, a sharp increase in the mean annual temperature occurred during 1998-2007 and such an increase in temperature induced cloud bursts and forest fire incidents which in turn caused landslides (**Fig 3B**).

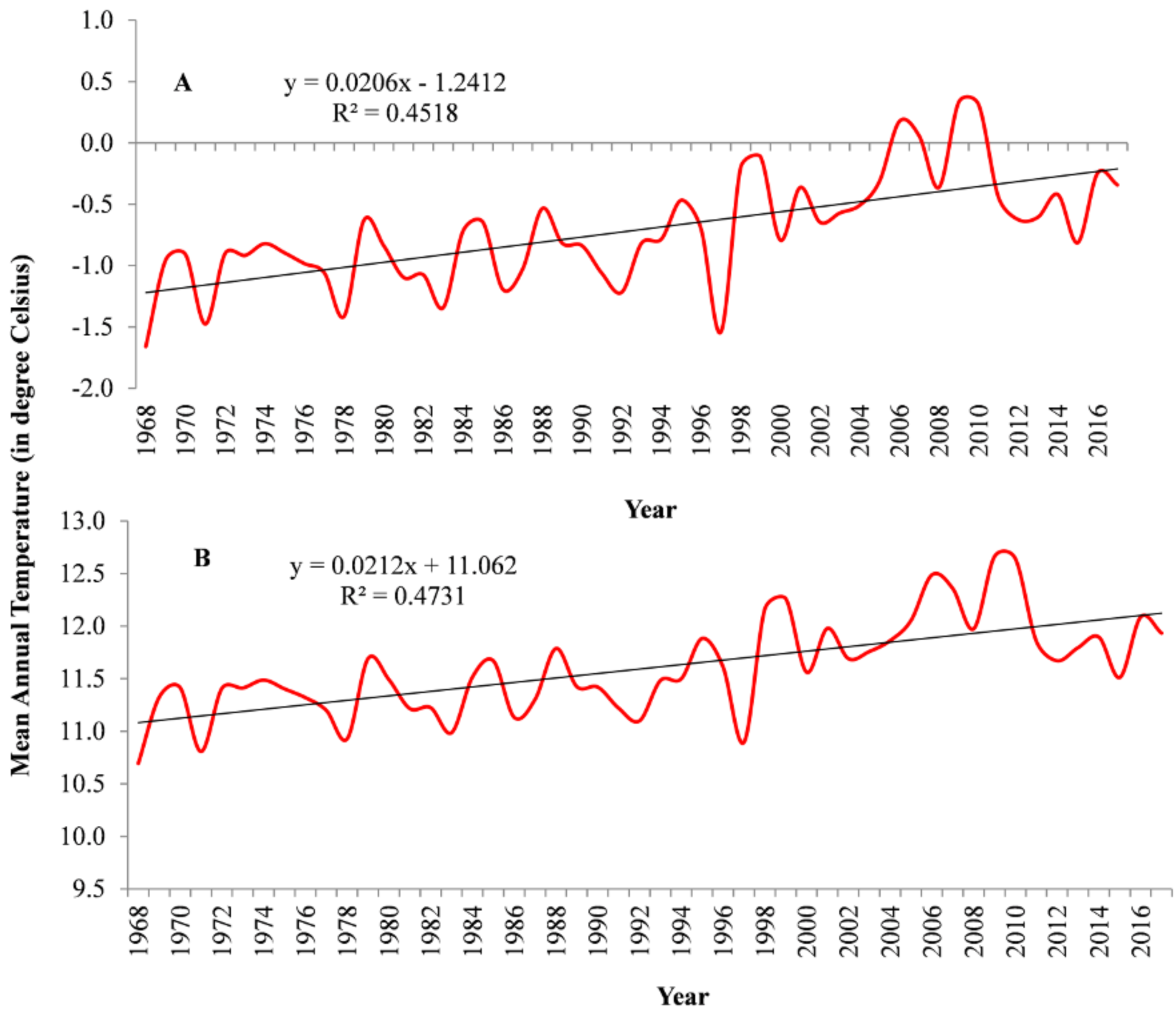


Fig.3B *Increasing trend in mean annual temperature in the elevation zone of (A) above 2400 m and (B) below 2400 m, amsl.*

5.2 Earthquakes

Subduction of the Indian lithospheric plate into the Eurasian plate is a major factor for earthquakes in the Teesta basin. The Indian part of the basin comes under seismic zone IV. There were 254 epicenters in the region near the Teesta Basin during 1934-2019. The depth of focus varies from 1 km (2002) to 100 km (2004). Based on the depth of focus, shallow and intermediate-focus earthquakes are common in and around the Teesta basin. Earthquakes lead to landslides in the basin.

The moment magnitude (Mw) of earthquakes is a numerical scale of the amount of energy released by an earthquake. It is calculated on the basis of the total area of the fault rupture, how far the rocks move along the fault during the earthquake and the strength of the rock that ruptures. Mw varies from 3.66 (2005) to 7.66 (1934). The Mw of the 2011 earthquake was 6.55. The block/sub-district-wise distribution of mean Mw of the earthquakes in the Teesta basin is shown in **Fig.4.** Very high to high mean moment magnitude of earthquakes is observed in the upper and lower Teesta basin.

5.3 Landslides

In the basin, extension and expansion of roads, construction of dams, heavy rainfall, earthquakes and forest fires are the major causal factors for landslides. The occurrence of landslides is distributed between 300 m and 4700 m, amsl in the basin. Darjeeling, Kalimpong districts of West Bengal and all districts of Sikkim are frequently affected by landslides. As per the GSI (2021), there were 5073 landslides which are covering 24.58 km^2 of area of the basin. The block/sub-district-wise distribution of landslide areas in the Teesta basin is shown in **Fig.5**. Chungthang, Dzongu, Yuksom blocks of Sikkim and Kalimpong-1 block of Kalimpong are highly prone to landslides.

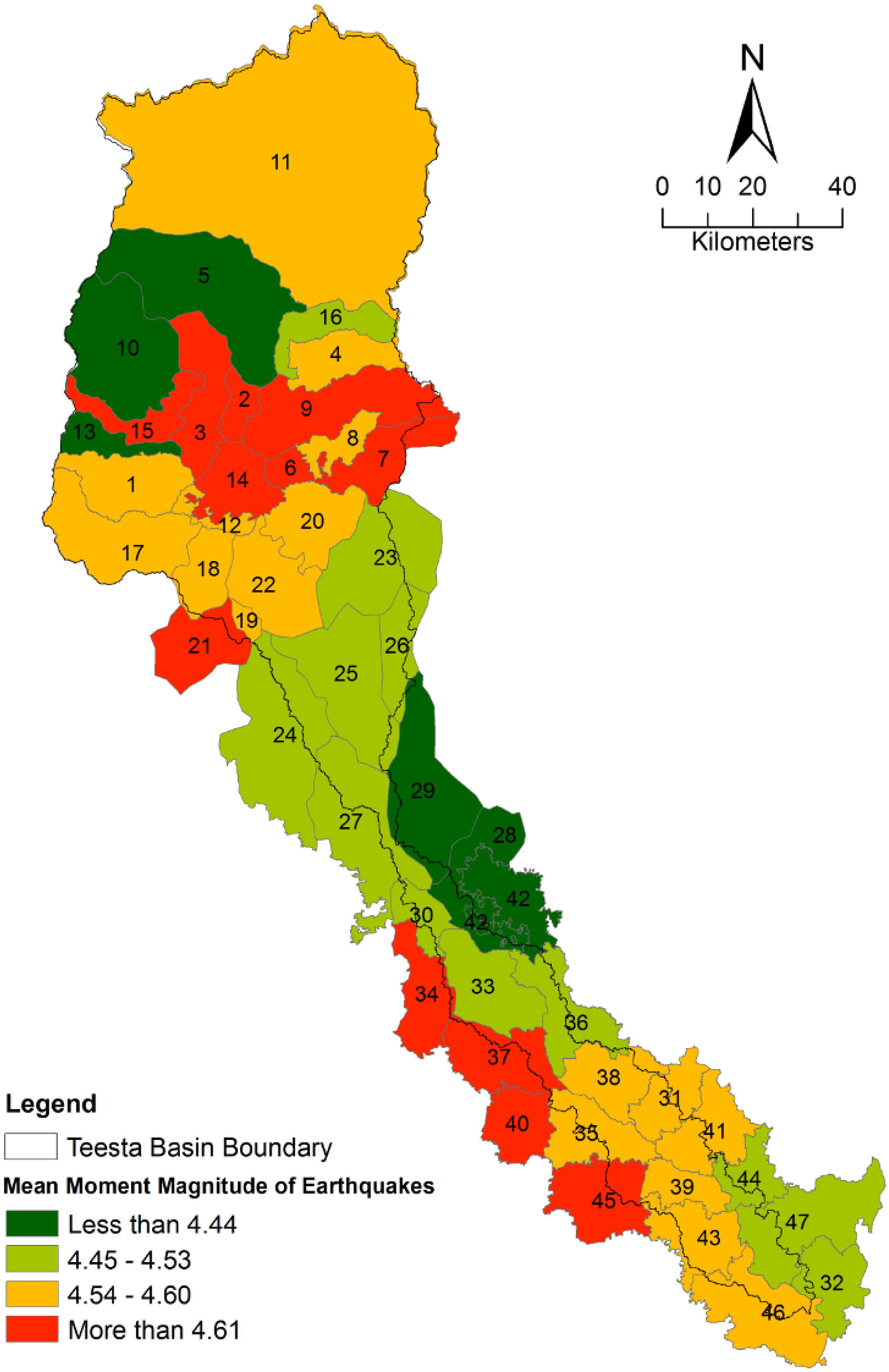


Fig.4 *Block/sub-district-wise distribution of Mean Moment Magnitude of the earthquakes in the Teesta basin*

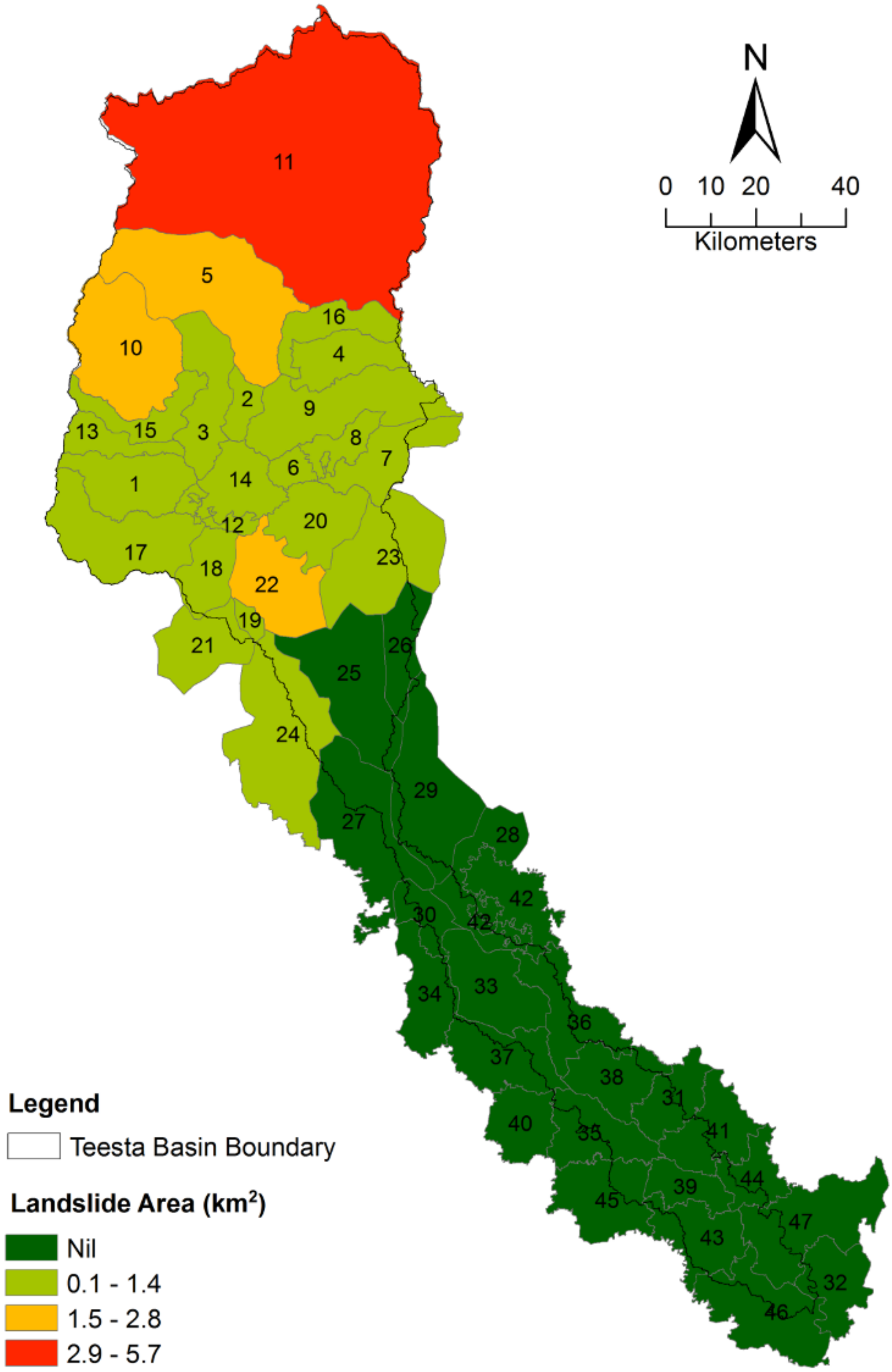


Fig. 5 *Block/sub-district-wise distribution of landslide areas in the Teesta basin*

5.4 Forest Fires

Occurrence of forest fires is common in post- and pre-monsoon season in the basin. There were 1044 forest fire incidents during 2002-2018. With continuing effects of climate change, more frequent and larger wildfires emit greater amounts of carbon into the atmosphere—primarily carbon monoxide (CO), black carbon (BC) and carbon dioxide (CO2). Longer and drier summers contribute much larger amounts of burnable vegetation as a consequence more fire incidents are occurring.

Forest fire incidents in the Teesta basin accelerate soil erosion, landslides and siltation in the river beds. The year-wise number of forest fire incidents is given in Fig.6. An increasing trend is observed in forest fire incidents in the basin (**Fig.6**). On average, 61 forest fire incidents are occurring in the basin in a year. The highest forest fire incidents were recorded in 2012 while the lowest was in 2002. Forest fire incidents were above average (61) in 2005, 2006, 2009, 2011, 2012 and 2014. Tropical Sal forest areas are highly prone to the forest fire in the basin. Block-wise forest fire incidents and landslide areas are positively correlated in Sikkim as well as Darjeeling district of West Bengal (**Fig.7**). Spatial distribution of forest fire incidents is shown in **Fig.8**. Kalimpong-1, Gurubathan blocks of Kalimpong district and Mal block of Jalpaiguri district are highly prone to forest fire incidents (**Fig.8**).

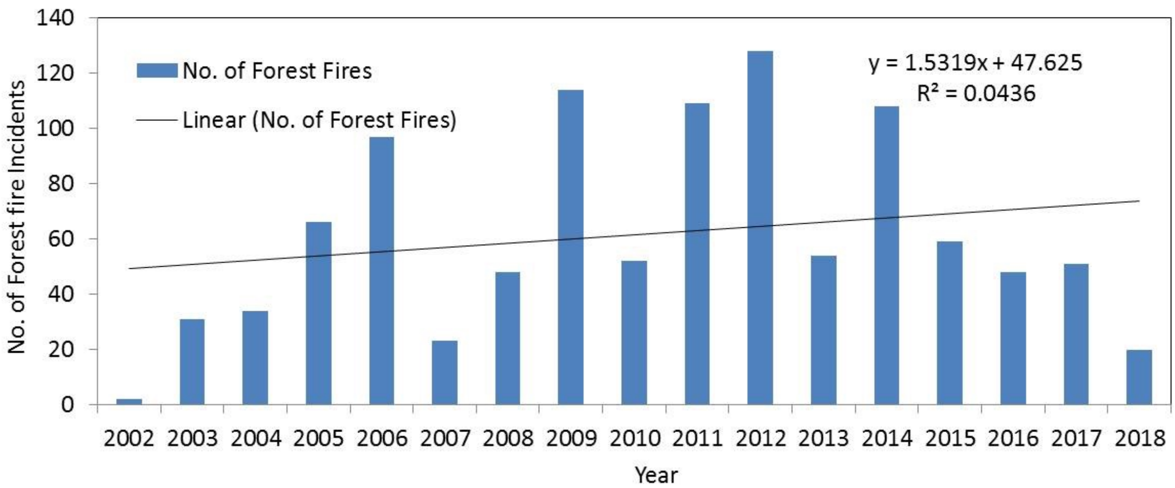
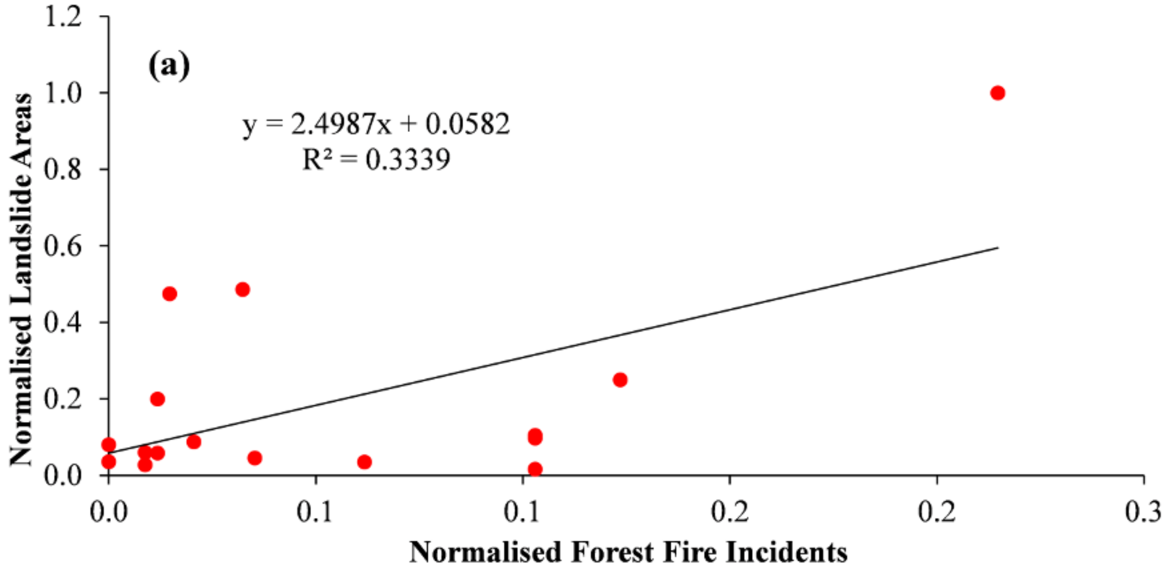


Fig.6 *Year-wise forest fire incidents in the Teesta basin*



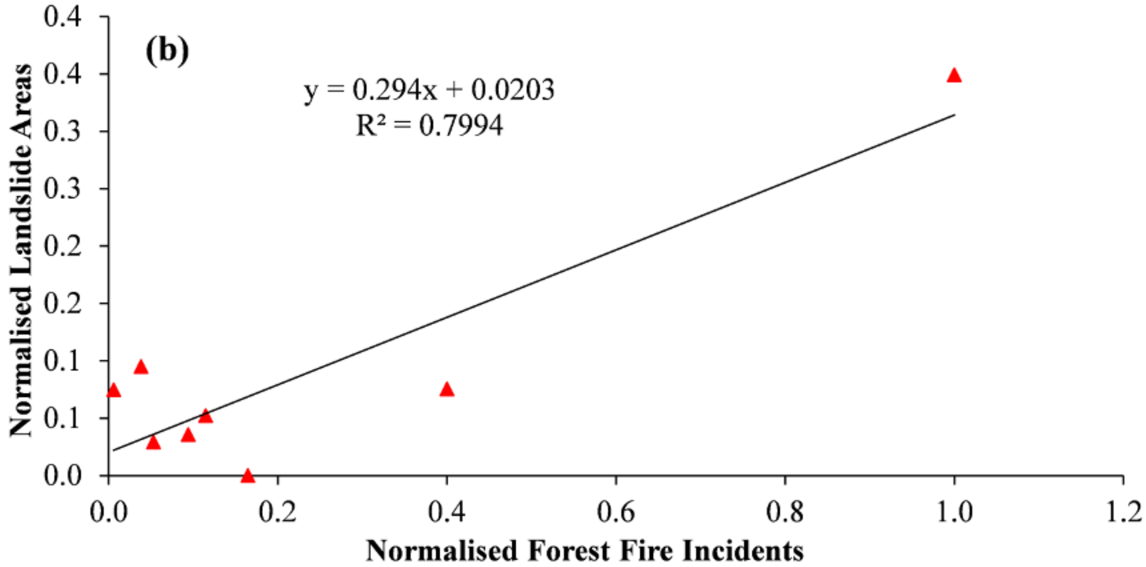


Fig.7 *Association between forest fire incidents and landslide areas in (a) Sikkim and (b) Darjeeling district of West Bengal*

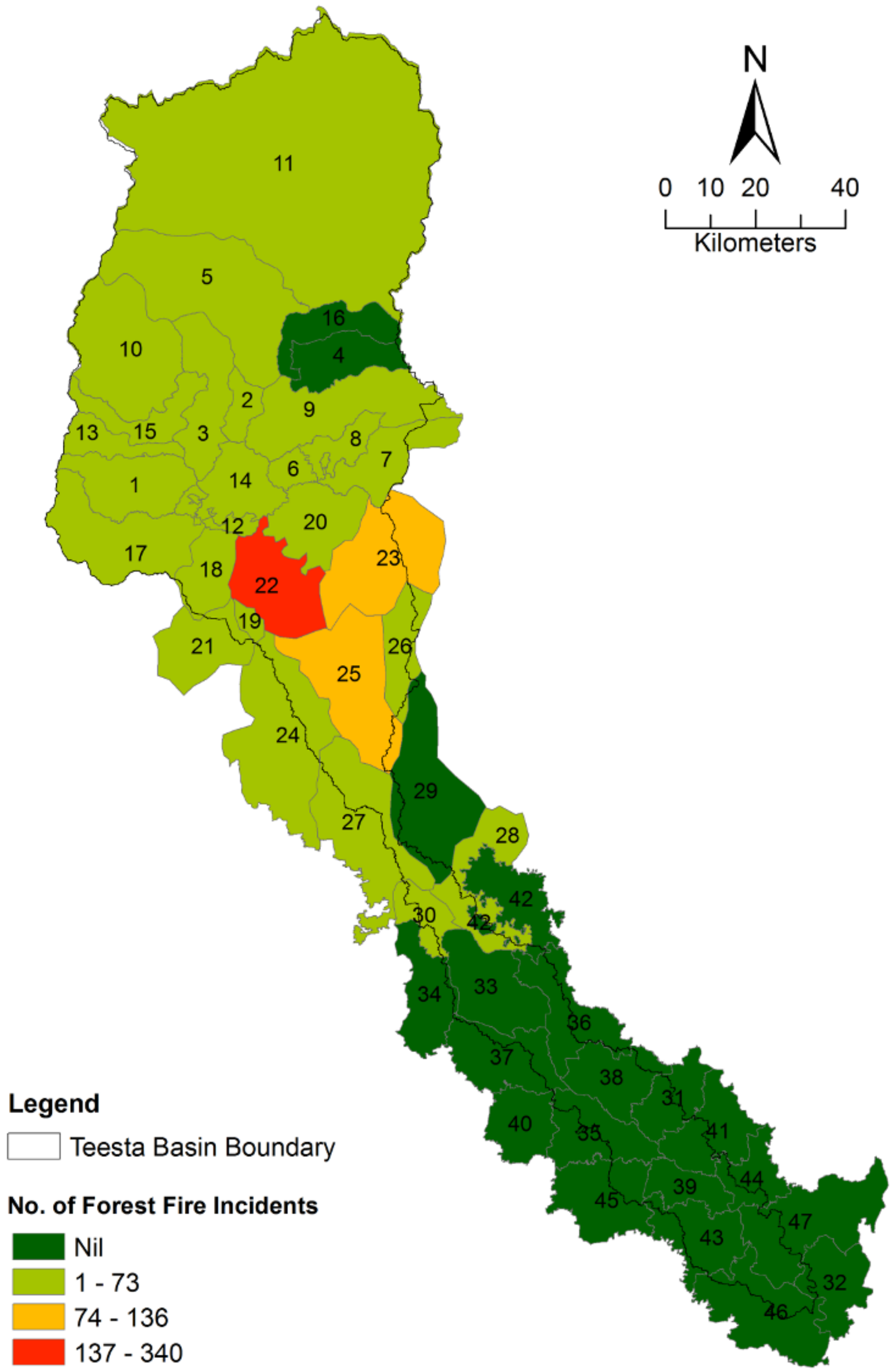


Fig. 8 *Block/sub-district-wise distribution of forest fire incidents in the Teesta basin*

5.5 Floods

The upper part of the basin is susceptible to glacial lake outburst floods. Rising temperature is the main causal factor of glacier retreat and the formation of pro-glacial lakes in the upper part of the basin. In the middle and lower parts of the basin, floods are mainly produced by cloud bursts and localised heavy rainfall. Major cloudbursts in the basin occurred in 1902, 1915, 1950, 1968, 1969, 1972, 1977 and 1978. Flood damage data of Sikkim shows that the flood-induced damage to crops, houses and public utilities is 978.9 crore rupees during 1953-2017 (CWC 2019)[11]. Such losses are occurring in the basin due to encroachment of high-value land use such as built-up areas on the frequently flooded areas. One of the major reasons for encroachment in the extreme lower part of the basin is high population pressure and decreasing peak flood discharge (**Fig.9**).

Block/sub-district-wise flood-affected areas of the basin are shown in Fig.10. Flooding is a recurrent natural phenomenon in the extreme lower part of the basin due to low elevation and slope. However, in the extreme upper part of the basin, rivers are incised and flowing along the relatively high slope as a consequence flooding is flashy and in general, vertical rise in water level is only possible. The sub-districts namely, Sundarganj, Ulipur and Chilmari located in the extreme lower part of the basin are extremely flood-prone as these sub-districts are located in the confluence area of Teesta and Brahmaputra River. Rajganj, Mal and Jalpaiguri blocks of West Bengal are highly flood-prone (**Fig.10**).

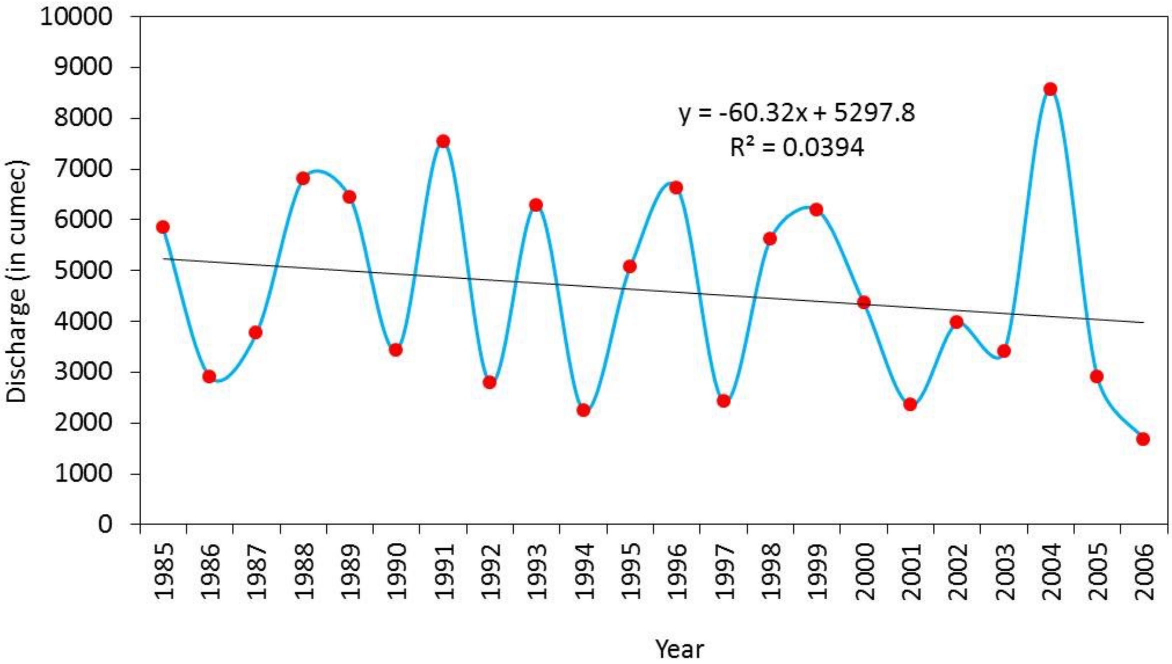


Fig.9 *Peak discharge (m3s-1) recoded at Kaunia station (Bangladesh) during 1985-2006*

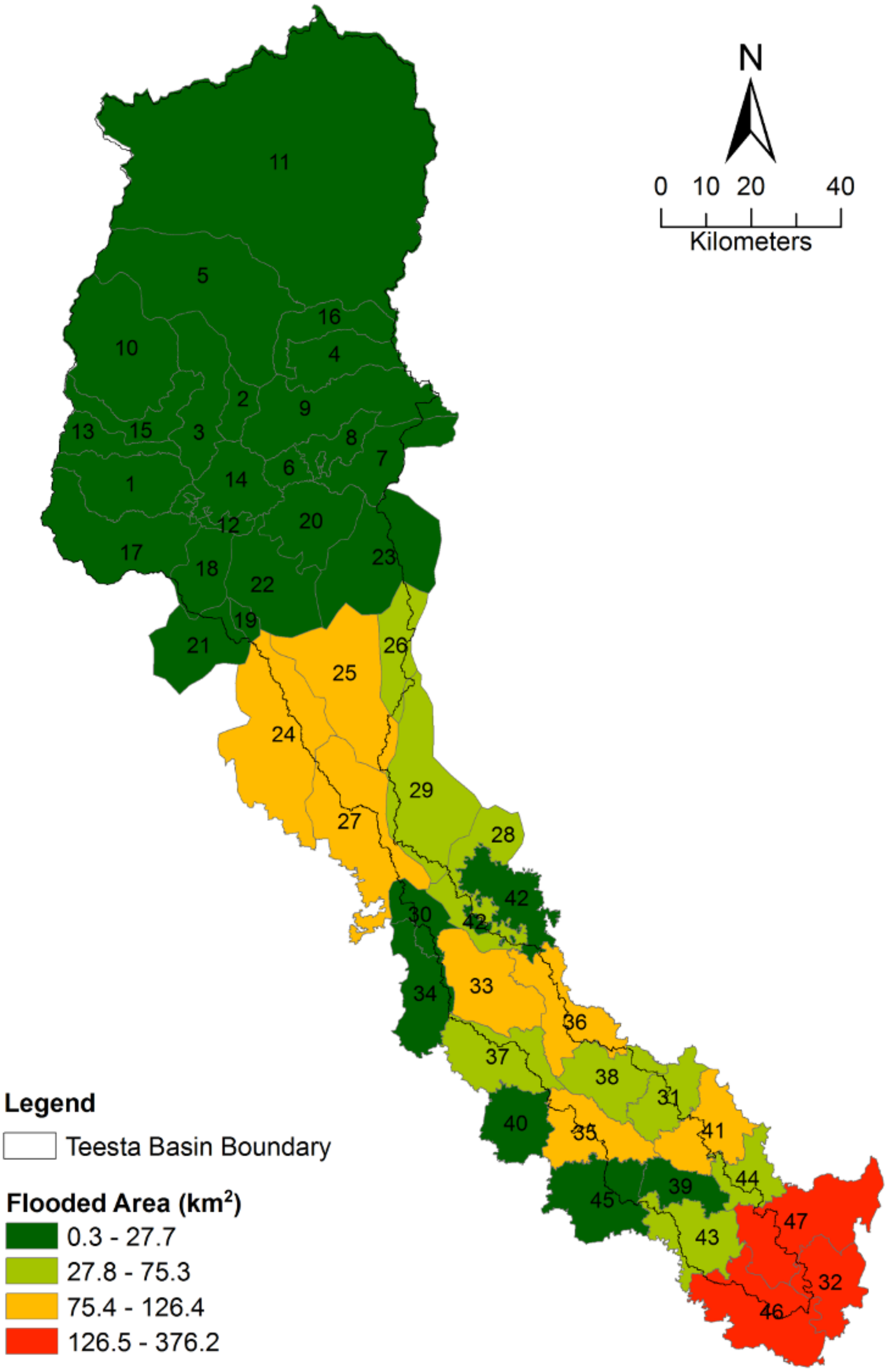


Fig.10 *Block/sub-district-wise flooded area (in km2) in the Teesta Basin*

5.6 Multi-hazard Map of the Teesta Basin

Block/sub-district-wise composite index of natural hazards parameters such as moment magnitude of earthquakes, landslide areas, no. of forest fire incidents and flooded areas shows the distinctive distribution of blocks and sub-district under low, moderate, high and very high multi-hazard categories. Out of the total number of blocks and sub-districts (47), 17%, 53%, 21% and 9% of blocks and sub-districts fall into low, moderate, high and very high multi-hazard categories. Sundarganj, Ulipur sub-districts of Bangladesh, Chungthang block of Sikkim and Kalimpong-I of West Bengal are under the very high multi-hazard category. Namchi and Gangtok blocks of Sikkim covering two important cities are under the high multi-hazard category (**Table 3** and **Fig. 11**)

Multi-hazard Index Values	**GNo. of Block/Sub-district/ (%)**	**Block/Sub-district Name (Label IDs)**
0.04-0.38 (Low)	08 (17)	Patgram (42), Dentam (13), Mekliganj (28), Mangan (16), Maynaguri (29), Matiali (26), Haldibari (30) and Kabi (4)
0.39-0.63 (Moderate)	25 (53)	Hatibandha (36), Kaliganj (38), Aditmari (31), Dimla (33), Kaunia (39), Rajarhat (44), Soreng (1), Yuksom (10), Darjeeling Pulbazar (17), Kalimpong-II (20), Rangli Rangliot (18), Pakyong (8), Jorethang (12), Rangpur Sadar (45), Part of Matigara Block (19), Domar (34), Jalpaiguri (27), Pirgachha (43), Rangpo (6), Kishoreganj (40), Kurseong (21), Dzongu (5), Lalmonirhat sadar (41), Jaldhaka (37) and Rongli (7)
0.64-1.07 (High)	10 (21)	Gangachara (35), Rajganj (24), Gurubathan (23), Gyalshing (15), Gangtok (9), Mal (25), Ravong (3), Chilmari (32), Namchi (14) and Yangyang (2)
1.08-1.76 (Very High)	04 (09)	Sundarganj (46), Ulipur (47), Chungthang (11) and Kalimpong-I (22)
Total	**47 (100)**	

Table 5 *No. of block/sub-districts in different multi-hazard categories*

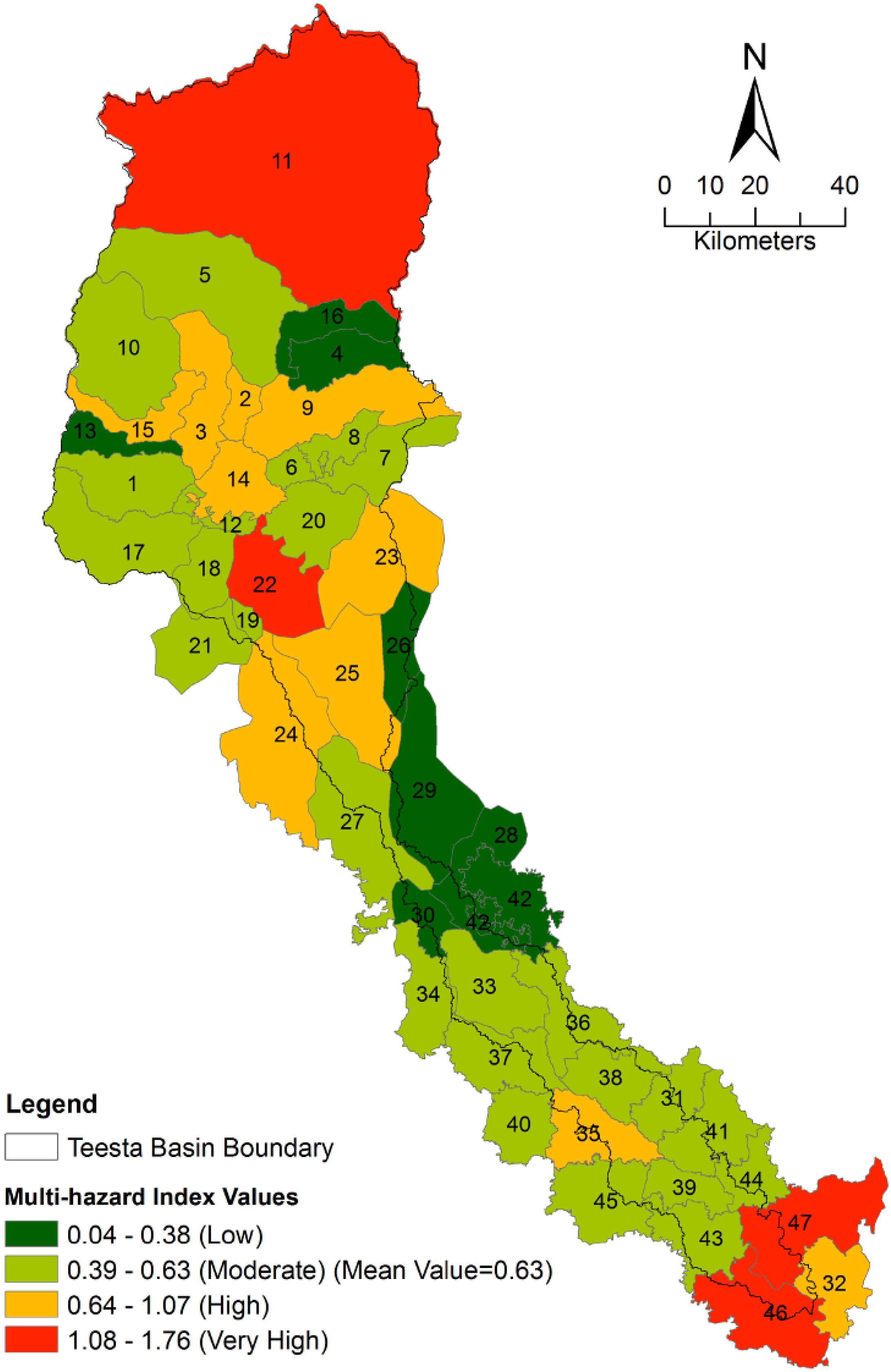


Fig.11 *Block/sub-district-wise multi-hazard map of the Teesta basin*

Conclusions

The MHM reflects that the topography, land cover and natural/land surface processes precipitate different types of natural hazards in the Teesta basin. For example, Chungthang block of North Sikkim is highly vulnerable to earthquakes, landslides and GLOFs but least vulnerable to forest fires. Kalimpong-I block of Darjeeling district of West Bengal is highly vulnerable to forest fires, landslides and earthquakes but least vulnerable to flooding. Sundarganj sub-district of Gaibandha district of Bangladesh is highly vulnerable to flooding as it is located near the confluence area of the Teesta and Brahmaputra Rivers where the slope is below 1°.

Variation in multi-hazard is caused by topography, land cover (tropical Sal forest) and land surface processes. Since the disastrous weather events are increasing, the multi-hazard map can play a vital role in the planning of new development projects as well as the incorporation of hazard reduction techniques into existing developments in different bio-regions of the basin.

Way Forward

There should be simultaneous horizontal and vertical lenses to look at a river basin because gradient (slope) presents a distinctly contrasting scenario over short distances while retaining some general homogeneity. This is so because rivers are not merely a physiographic and hydrological entities but also been economic, ecological and social corridors.

For flood management, both structural and non-structural measures should be taken up in such river basins. Ecologically viable anti-erosion works and floodplain zoning are effective structural and non-structural measures respectively for flood management in the rivers originating from the Himalayas. Ecologically viable anti-erosion works such as planting indigenous plant species along the banks and designating a few meters along rivers as non-construction areas. The floodplain zoning along most of the Himalayan rivers including Teesta has not been taken up. Floodplain zoning is important for the identification of vulnerable areas due to floods and associated hazards and the minimisation of flood-induced damage and disruptions along rivers in the Himalayas. The study of the behaviour of rivers and how people have been responding to it may be taken up for effective management of hazards in the Teesta and similar such basins. A study pertaining to how communities have been living symbiotically along rivers and a general disconnect with the river ecology in recent times can be further investigated. Thus, the oral history project of rivers can be taken up with being conscious of the altitudinal diversity of the basin.

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Appendix

Sebu Tso: Head waters of Lachung chhu; a tributary of Tista in Norhth Sikkim

One of the head-waters of Tista near Gurudongmar Peak in North Sikkim

Lachung Chhu, tributary of Tista, at Yumthang Valley in North Sikkim

River Tista in its upper reaches near Thangu village at 3900 meters.

Zemu Glacier at foot Mt Kanchendzonga near Goechhala- Prominent source of Tista River's head water.

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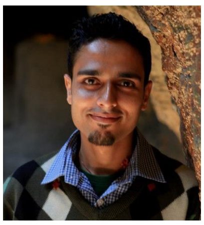

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About South Asia Bioregionalism Working Group

The South Asia Bioregionalism Working Group, is a voluntary network of members re-imagining an ecoregional and bioregional governance for South Asia. It was initiated at a Democracy Vikalp Sangam (Alternatives Confluence) in October 2019. Our ecologies in the region are contiguous and so is the culture, which the group aims to highlight through documentation, dialogues, and action.

https://vikalpsangam.org/south-asia-bioregionalism-working-group/

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