Available online at www.most.gov.bd
Volume 05, Page: 119-134, 2023
DOI: https://doi.org/10.3329/jscitr.v5i1.74011

Ministry of Science and Technology
Government of the People's of Bangladesh
Bangladesh Secretariat, Dhaka

An Assessment of the Causes and Consequences of Landslides (2017) Occurred in the Southeastern Areas of Bangladesh

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Abstract

Over the past five decades, an examination of hazard and disaster events reveals that landslides have emerged as the predominant and devastating natural threat in the Chattogram Hill Tracts (CHT) regions of Bangladesh, often leading to loss of life and significant socioeconomic damage. The most catastrophic landslides in the area occurred in 2017, marking a pivotal event in its history. This study aims to analyze and elucidate the characteristics, causes, and impacts of the 2017 landslides in the Chattogram Hill Tracts districts (CHT) of Bangladesh. The analysis is based on comprehensive data examination, considering factors such as rainfall, altitude, slope, and geospatial field data. The research team has established a noteworthy correlation between landslides and factors such as heavy seasonal rainfall accompanied by thunderstorms, as well as altitude, slope, and slope aspects. Examining the period from 1968 to 2021, it was observed that numerous landslides occurred in the region, with sixteen being categorized as severe. The study aims to pinpoint the timing and causes of these landslides, highlighting the onset during the monsoon season from June to July. Results indicate that approximately 53% of landslide occurrences transpired within slopes ranging from 46 to 66 degree, and altitudes spanning from 60 to 109 meters in the study area. Furthermore, areas highly susceptible to landslides were identified, particularly those with significant human activity on hills, including built-up areas and jhum cultivation zones. The implications of this study are crucial for informing policymakers, hill authorities, and stakeholders, facilitating the implementation of precautionary measures within the hill community. By doing so, it is anticipated that the study's findings will contribute to the mitigation and reduction of landslide hazards in the CHT region.

Received: 08.05.2023
Revised: 30.08.2023
Accepted: 12.09.2023

Keywords: Landslide, Chronology, Consequences, Landslide, Slope, Altitude, Hazard

Introduction

The southeastern region of Bangladesh, encompassing the Chattogram Hills Tract districts (CHT), comprises Chittagong, Rangamati, Khagrachari, and Bandarban. Positioned in the tropical monsoon climatic zone, CHT stands as the sole substantial hilly area in the country, rendering it highly susceptible to the dangers of landslides, leading to severe loss of life and property (Kamal et al., 2022; Khatun et al., 2022; Mahmood & Khan, 2010). Culturally, traditionally, and environmentally, CHT holds significant importance within the country (Ahmed et al., 2022). The years 2003, 2007, 2008, 2010, 2011, 2011, 2015, and 2017 witnessed a notable occurrence of landslides in this region (Chisty, 2014). On June 13th, 2017, a particularly devastating landslide claimed 164 lives in these districts, leaving numerous injured and causing extensive damage to roads, houses, and settlements (Bendix, 2017; Chakma & Barua, 2017; NIRAPAD, 2017).

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The CHT region experiences heavy rainfall in June and July, a significant contributing factor to landslide incidents (Abedin et al., 2020; Kamal et al., 2022; Saha et al., 2005; Schuster & Highland, 2003). Flash floods resulting from this rainfall wreak havoc on lowland areas, causing substantial damage to road networks and communication systems (Sarkar et al., 1995). Rainfall analysis from NASA's Goddard Space Flight Center indicates a peak accumulation on June 14th, with an average rainfall exceeding 500 mm (NIRAPAD, 2017). Geologically, the Bangladesh Hills are composed of unconsolidated sedimentary rocks dating back to the tertiary era (Mia et al., 2016). The unique soil structure and composition of Hill clay, with lower storage capacity than common ground, contribute to the heightened vulnerability of the region (Sarwar, 2008). The increasing intensity and magnitude of landslides can be attributed to the indiscriminate cutting of trees, soil erosion from hills, and unplanned land use by the local ethnic community, property owners, and landholders in the Hills (Ahmed et al., 2015).

As human settlement, urbanization, deforestation, and industrial activities escalate, landslides become more frequent and severe (Mahmood & Khan, 2010; Montrasio & Valentino, 2008; Muenchow et al., 2012). Some studies propose the implementation of technology-based landslide warning systems, enabling the dissemination of information through radio, television, and digital mobile phones (Rossi et al., 2017; USGS, 2004). Despite the escalating threats posed by landslides in the CHT region, research efforts have predominantly focused on susceptibility mapping, causes, and management at smaller administrative levels, such as sub-districts, i.e., the upazilas or districts (Ayalew & Yamagishi, 2005; Rabby & Li, 2020). This study, unique in its scope, comprehensively addresses the entire landslide-prone area of the CHT region through field investigations, remote sensing, and GIS data analysis, aiming to elucidate the causes and consequences of landslides.

In the face of the yearly threats to human lives and socio-economic infrastructure posed by landslides, few studies have delved into the quantification of their impact on the socio-economic status (Mertens et al., 2016). This research focuses on chronological landslide events, their causes, and impacts, with a detailed examination of the 2017 landslides. Three primary objectives guide this study: (a) Identifying and analyzing the triggering factors of landslides, (b) Assessing the chronological events, and (c) Examining the consequences of landslides, particularly in the context of the events that unfolded in 2017.

Material and Methods

Study area

The research focuses on the Chattogram Hill Tracts (CHT) situated in the southeastern part of Bangladesh. Geographically, the area spans from a latitude of $21^0$25 N to $23^0$45 N and a longitude of 91.054 E to 92.050 E, as illustrated in Figure 1. The elevation in this region varies, reaching a maximum of approximately 1200 meters and a minimum of 21 meters above sea level. Remarkably, this area stands as the only extensive expanse in Bangladesh, its formation attributed to the collision of the Indian and Asian plates during the Tertiary era. The soil composition is predominantly yellowish-brown loams, transitioning into broken shale or sandstone, occasionally with mottled sand at varying depths, and characterized by high acidity (Hossain et al., 2014).

Renowned for its abundant forests, the CHT region is considered one of the most heavily wooded areas in Bangladesh. However, akin to South and Southeast Asia, it grapples with deforestation caused by environmentally detrimental activities, including slope settlement, shifting cultivation, and the proliferation of diverse private agricultural farms (Biswas et al., 2012). This region experiences a Tropical monsoon climate, with a mean annual rainfall ranging from 2540 mm in the North and East to 2540 to 3810 mm in the South and West (Jamal, 2018).

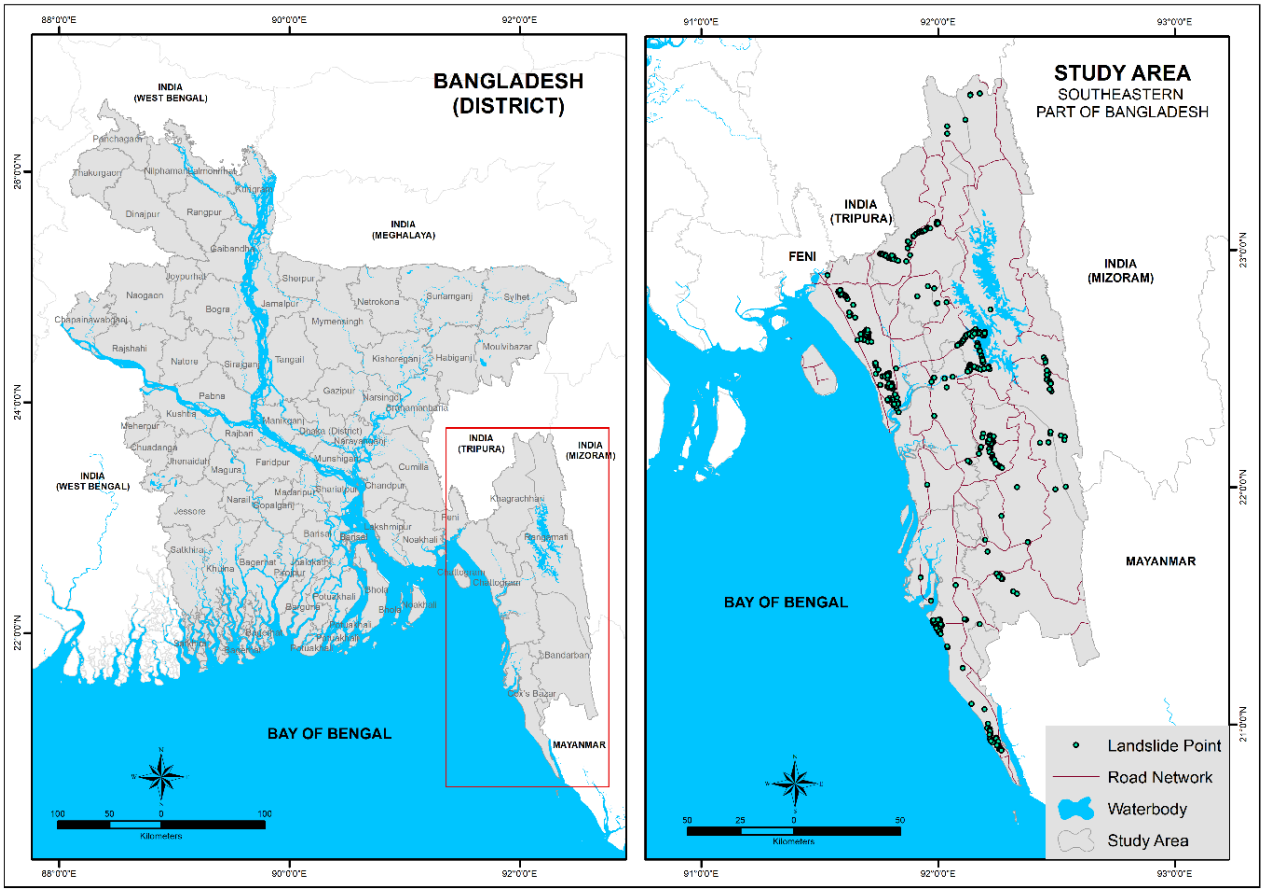

Figure 1. Map of the study area (Data Source: BARC and field survey)

Data Sources

The foundation of this research rests on both primary and secondary data sources. Primary data were collected through field surveys employing Focus Group Discussions (FGD) and utilizing Global Positioning Systems (GPS) surveys. Secondary data were sourced from various governmental and non-governmental entities, including the Bangladesh Bureau of Statistics (BBS), Bangladesh population census, the Centre for Geographical and Information Services (CEGIS), Geographic Information Systems (GIS), and Remote Sensing (RS). These secondary data played a pivotal role in mapping activities and conducting essential analyses.

Field Survey

Following the landslide in 2017, an initial exploratory field survey was conducted, and subsequently, for the purpose of updating field data, another comprehensive field investigation was carried out in the study area in 2021. The utilization of GPS facilitated the identification of precise landslide locations. The field visits involved an analysis of the hill conditions and an examination of the relationship between the hill's populations and settlements. The studies specifically focused on hill slope, aspect, and angle, as depicted in Figure 2.

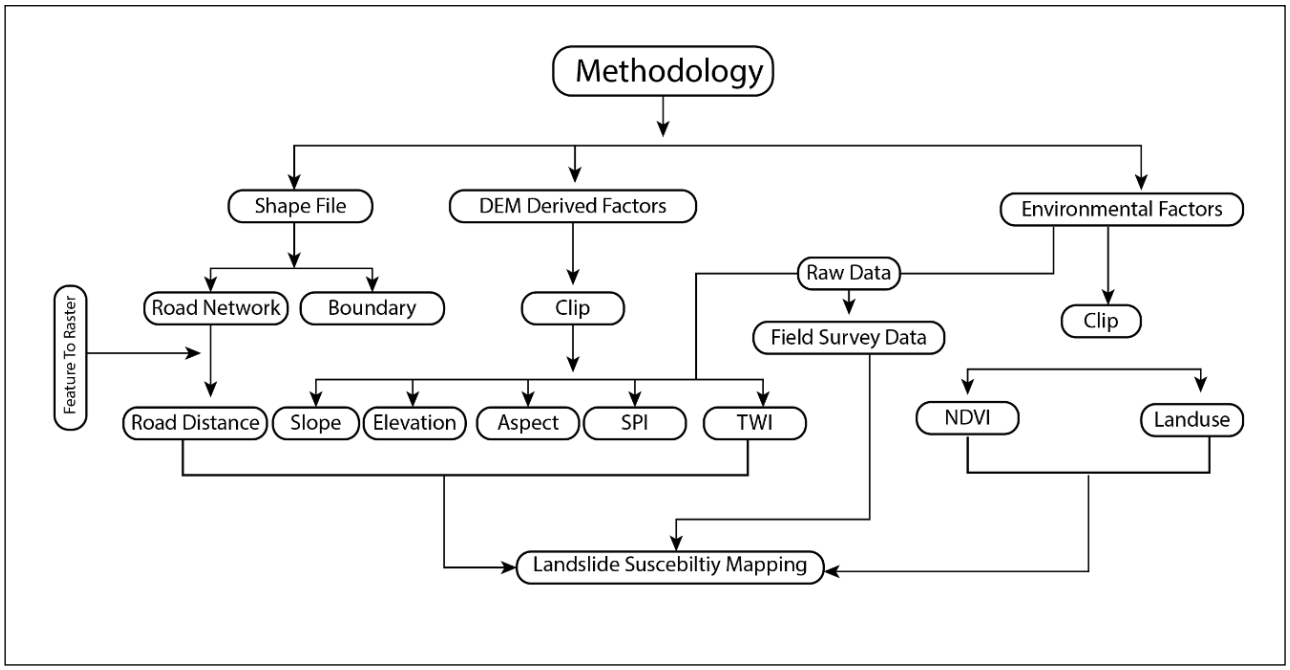

Figure 1. Methods of this research

Primary data collection

Structured questionnaires, focus group discussions (FGD), and key informant interviews were employed to collect primary data directly from the affected area, specifically the Chittagong Hill Tract districts (CHT). The selection of GPS samples and identification of vulnerable hills were based on the frequency and magnitude of landslide occurrences. To measure hill slopes, a clinometer was utilized, and a total of 74 GPS locations were employed to calculate slope aspect and altitude. The survey focused primarily on exploring the causes and consequences of landslides in the CHT region. Maintaining high precision in data collection, a 95% confidence level, as per the standards set by the Bangladesh Bureau of Statistics (BBS), was deemed necessary. The sampling strategy adopted followed a proportionate stratified random sampling method within the study area.

Secondary data collection and analysis

The depiction of rainfall anomalies and elevation primarily relied on secondary data and maps. Secondary information was sourced from various governmental and non-governmental agencies, with rainfall data obtained from the Bangladesh Meteorological Department (BMD) and population data collected from the Bangladesh Bureau of Statistics (BBS). Utilizing this gathered information in conjunction with satellite imagery, the study assessed the causes and consequences of landslides. The research integrated field data, Geographic Information Systems (GIS) data, and Remote Sensing (RS) data simultaneously to analyze both the triggering factors and impact assessment of landslides. For the analysis of field investigation data, descriptive statistical methods, chi-squared tests, and correlation analyses were employed through SPSS 19 software. On the other hand, mapping activities, spatial data processing, and analyses were conducted using ArcGIS 10.3, incorporating resources from ESRI, Landsat, and Sentinel. Other spatial analyses involved overlaying techniques applied to time series satellite images.

Results and Discussion

Triggering Factors of Landslides

Two categories of factors, natural and anthropogenic, can serve as triggers for landslides in the Hills Tracts region. The geological history and conditions of an area are significant contributors to land degradation (Montrasio & Valentino, 2008). In the CHT region, landslides are predominantly triggered by factors such as heavy rainfall, slope conditions, elevation, and various human-induced activities. The livelihoods and occupations of the local population play a direct or indirect role in determining and contributing to the conditions that lead to slope failure (Madaan, 2022).

Land Topography as Driver

In this investigation, we employed slope, elevation, Topographic Wetness Index (TWI), and Stream Power Index (SPI) as topographical factors to explore their relationships with other proxy factors on the Hills surface. Rainfall, elevation, anthropogenic activities on the Hills surface, and road networks emerge as the primary proxy factors influencing landslides in the study area. The collective impact of these proxy factors contributes to the occurrence of landslides. Shuttle Radar Topography Mission (SRTM) data, providing a Digital Elevation Model (DEM) at a 30-meter resolution (Figure 3), was utilized in this study. The elevation data were categorized into two classes (Figure 3). Slope emerges as a dominant factor influencing landslides. In the study area, some slopes are steeper, while others have a lower degree of steepness. Notably, the research reveals that medium slopes are more vulnerable than both high and low slopes (Figure 3). The ArcGIS 10.7 slope tool was utilized in this study. Landslides on slopes are primarily driven by factors such as gravity, reduced potential sliding surfaces, decreased cohesion of grain material, loosening of unconsolidated material, and water infiltration leading to landslide events (Madaan, 2022). Vulnerable slopes, influenced by torrential rainfall, result in the downward movement of dirt, pebbles, rocks, and boulders, leading to landslides (Zhou et al., 2016).

The Topographic Wetness Index (TWI), a tool for measuring groundwater and moisture, serves as a hydrologically based topographic index that describes a cell's tendency to accumulate water. TWI was calculated using Shuttle Radar Topography Mission (SRTM) data (Figure 3). Another topography-related factor is the Stream Power Index (SPI), which measures the erosive power of streams or water. SPI was derived from SRTM data (Fig. 2d).

$$TWI = \mathrm{IN}\left(\frac{A}{\mathrm{bta}n\text{ß}}\right)$$

Where, A= Flow accumulation in square meters; b= pixel width which water flows; ß= Slope in degree. On the other hand, SPI measures the surface water flow of the study area,

$$\mathrm{SPI} = \frac{A\mathrm{tan}\text{ß}}{\mathrm{b}}$$

Higher and lower SPI values measure and indicator of landslides, where the SPI value higher the slope is steeper and more change of landslides. For calculating SPI (Figure 2) is used SRTM tools.

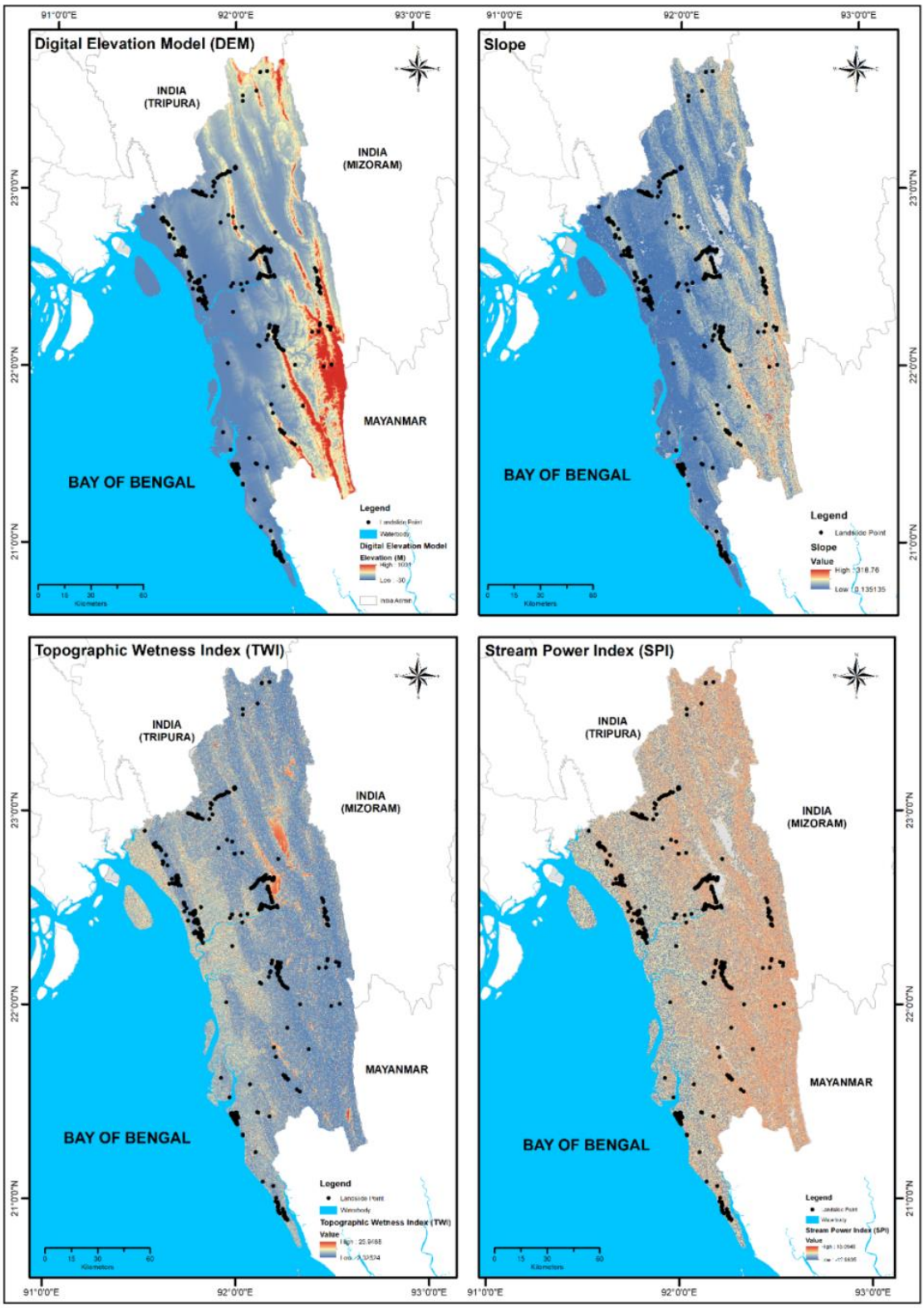

Figure 2. Visualization of Digital Elevation data from the SRTM data and different output of GIS analysis. (Data Source: BARC, USGS and field survey)

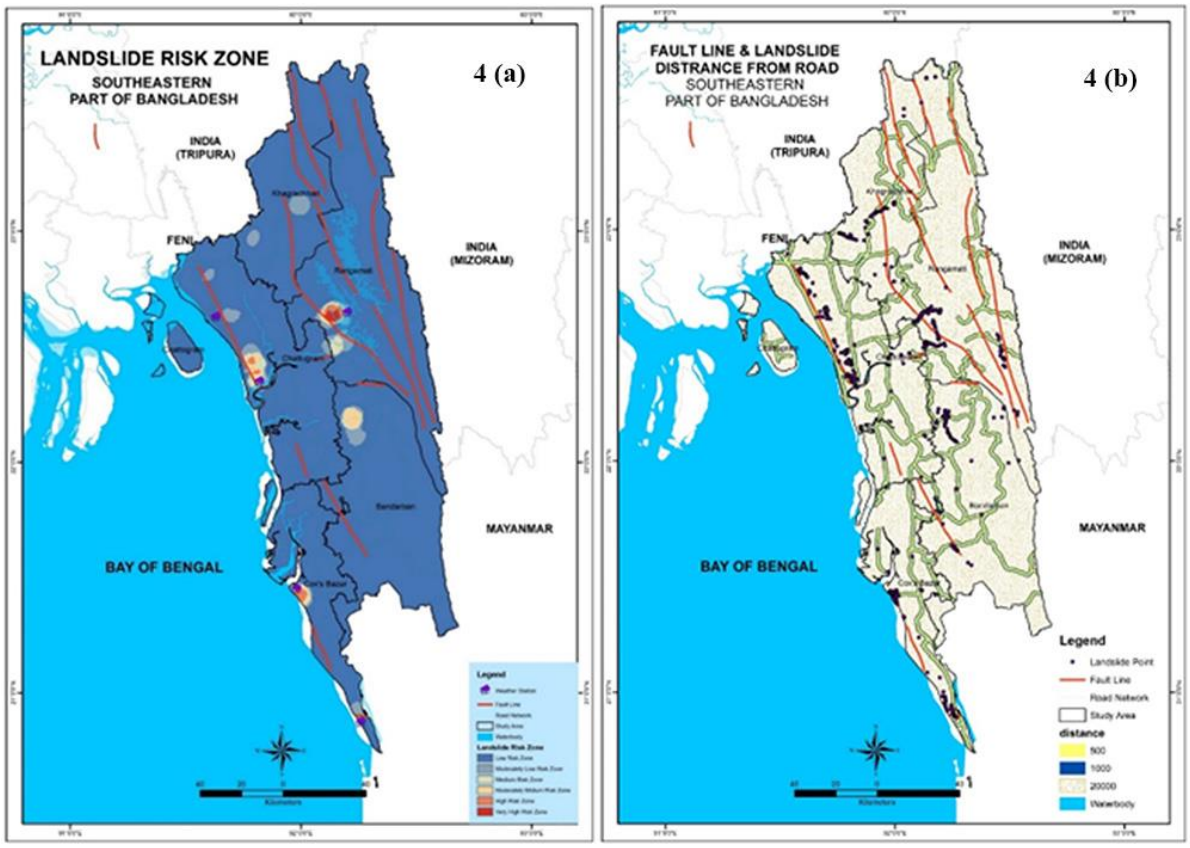

Figure 3. (a) Identifying the landslide risk zones aspect of geological fault line data; (b) Understanding the damages and risk using distribution of landslide events, geological fault line and road network data (Data Source: BARC, USGS and field survey data)

Geological Influences

Geology and the proximity to fault lines in the CHT region, as depicted in Figure 4a and 4b, were considered as geological factors, with data captured by the Bangladesh Agricultural Research Council (BARC). Fault lines are associated with tectonic breaks, causing the weakening of the ground's rock structure (Schuster & Highland, 2003). Typically, areas closest to fault lines are more susceptible to landslides. Fault lines, road networks, and water bodies collectively act as proxy factors for landslides in the CHT region (Bennie et al., 2006). The convergence of road networks, water bodies, and fault lines in the same location, as illustrated in Figure 4a and 4b, signifies a high-risk zone for landslides. The coexistence of water bodies and road networks intensifies the risk of landslides in this zone (Capitani et al., 2013).

Intense Long Spell Rainfall as Trigger

The study area is characterized by a high susceptibility to rainfall, making it one of the rainiest regions globally. Although rainfall is prevalent throughout the year, the primary rainy season occurs from June to July. Consequently, the most common assumption is that the landslide body becomes saturated from below when rainfall infiltration commences (Polemio & Petrucci, 2000). However, the saturation of slopes is not always a straightforward phenomenon. Debris slides, for instance, can explosively burst out of a slope if groundwater flowing in pedological horizons is swiftly discharged to the surface. Through the analysis of rainfall patterns over a span of 20 years, it can be inferred that rainfall anomalies have increased, contributing to the occurrence of sudden landslides and subsequent damages in the study area.

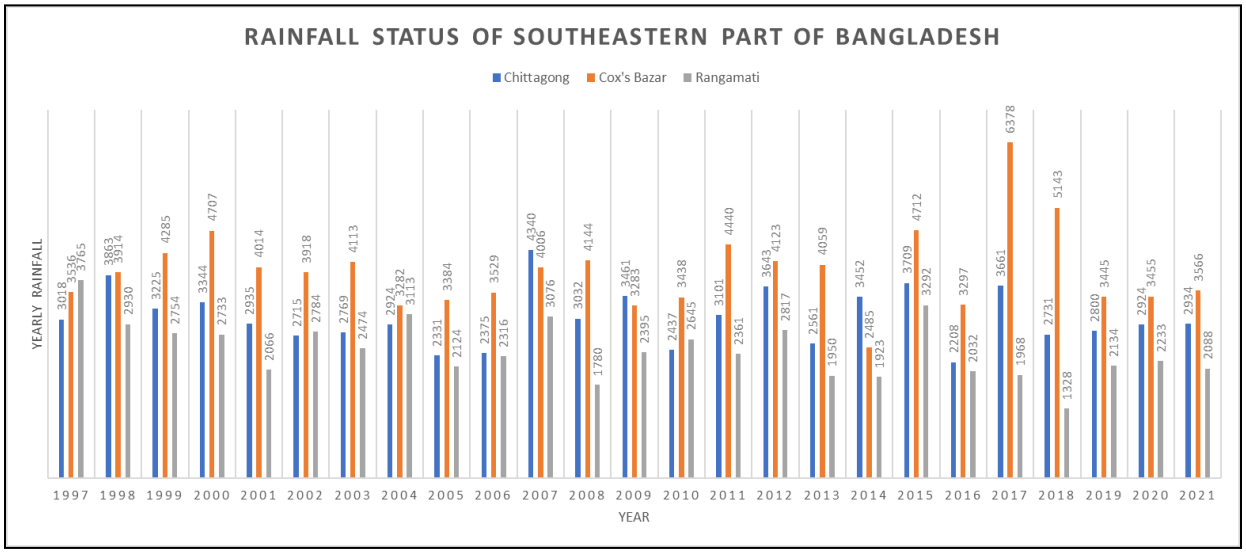

Figure 5. Excessive rainfall Southeaster part of Bangladesh

The study illustrates the overall rainfall patterns in Chittagong, Cox's Bazar, and Rangamati (Figure 5) spanning the years 1997 to 2016. Despite Cox's Bazar experiencing higher rainfall than the other two districts, historical landslide data indicates that most destructive landslides occurred in Rangamati and Chittagong. Notably, in 1999 to 2000, Chittagong Hill Tracts witnessed heavy rainfall, but there were fewer landslides. Conversely, in 2003 and 2005, the rainfall intensity was relatively lower compared to previous years, yet landslide intensity and severity were high. The year 2003 saw a massive landslide in Chittagong and Khagrachari, resulting in the loss of almost 65 lives.

Over the last two decades, the highest rainfall occurred in Chittagong in 2007, leading to extensive landslides in Rangamati, Chittagong, and Bandarban. This highlights a significant correlation between landslides and heavy rainfall. In 2012, 2013, and 2015, Cox's Bazar experienced the highest rainfall recorded in the last two decades, with approximately 4712 mm recorded in 2012. Consequently, massive rainfall-induced landslides occurred in Cox's Bazar, Bandarban, and Chittagong during those years. In 2012 alone, an extensive landslide claimed the lives of about 90 people, causing injuries in Cox's Bazar, Bandarban, and Chattogram regions. The analysis strongly indicates that rainfall serves as a potent influencing factor in land degradation.

Human Induced Factors in the Area

The Chattogram Hills Tracts districts are deemed entirely unsuitable for human settlement and livelihood (Badiuzzaman et al., 2013). This is primarily due to the fact that more than 77.3% of the area consists of hills, 19.3% comprises hillocks, and only 3.4% is flat arid plain land. Since prehistoric times, some ethnic tribal communities have inhabited this region. However, starting from 1970, there has been a continuous increase in the intrusion of Bengalis into this area (Ahmed, 2017). Approximately 9% of Bangladesh's hill forests are located in this region, rendering it environmentally crucial. Over the last three population censuses, there has been an observed increase in the Bengali population compared to the tribal community in the three Hill Tracts districts. Those unfamiliar with living in hilly areas often resort to cutting hills and constructing houses, consequently contributing to the creation of landslides.

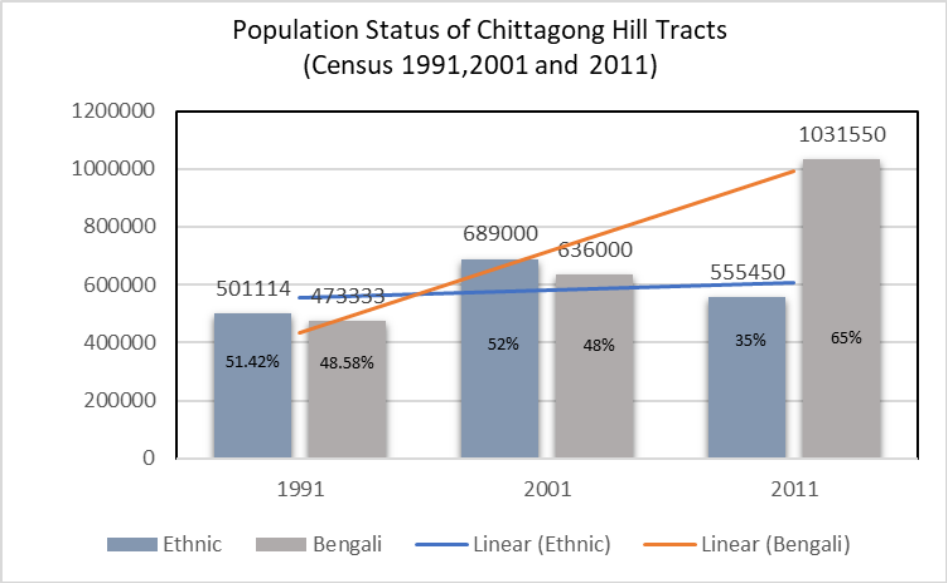

Figure 6. Population status of Chittagong Hill Tracts region. (Sources: Population Census 1991, 2001 and 2011, BBS)

Population growth stands out as a key factor contributing to the escalating incidence of landslides in the Chittagong Hill Tracts region. This study highlights that settlements are more concentrated in the foothills of the hills, characterized by lower elevations, leading to a higher occurrence of landslides in comparison to the less populated and higher altitude areas. The primary driver of this phenomenon is the increasing number of Bengali populations in these unconventional hilly zones.

Analysis of population census data from 1991 to 2011 reveals a significant shift. In 1991, the total population in the three Hill Tracts districts was 974,447, with 501,114 belonging to local minority ethnic communities and 47,333 identified as Bengali people (Figure 6). In contrast, by 2011, a distinct transformation occurred, with the number of Bengalis in the mountainous region more than doubling over the span of two decades. Specifically, in 1991, the mountainous population represented 51.42% of the total, decreasing to 35% in 2011. Bengali populations now constitute a majority, comprising 65% of the total population. Over the same period, the number of local minorities in the hilly area decreased by 16.42%, totaling 54,336, while the number of Bengalis increased by 558,217. The analysis suggests a significant correlation between the rapid increase in the hilly area's population over the past two decades and the heightened frequency of landslides. This connection underscores the involvement of the population in the mountainous region, contributing to the increased intensity, frequency, and casualties associated with landslides.

Chronology and Consequences of Landslides in the Study Area

Chronology refers to the historical background of landslides. Through an analysis spanning over 50 years of landslide history, this research highlights 37 points where landslides were particularly severe, resulting in the loss of more than 600 lives, thousands of injuries, and extensive damage to houses. Examining the chronology of land collapses reveals a pattern where the majority of landslides occurred from 1968 to 2017, primarily in the months of June to July. Notably, the long-term land degradation in Bangladesh has been consistently associated with the timeline of land collapses. However, it is disheartening to note that despite the annual occurrence of landslides in June to July, there has been a lack of exemplary actions to mitigate the loss of life and property among the mountainous population and within the local administration (Figure 7).

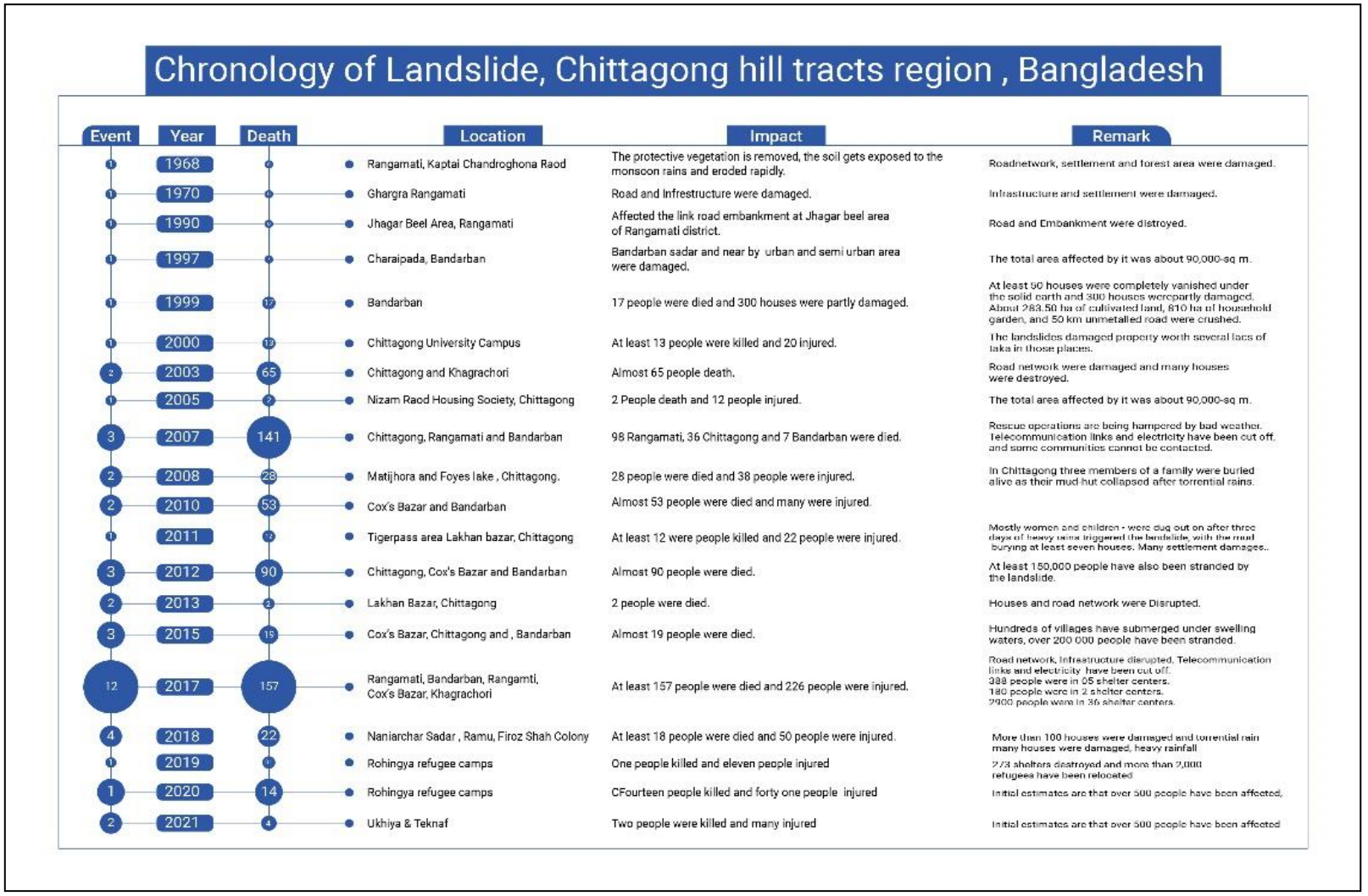

Figure 7. Impacts of landslide, Chittagong Hill Tracts Region, Bangladesh (Sources: Daily newspapers)

Figure 8. Landslide spot scenario status of Bangladesh

Landslides and their impacts from 1968 to 2021

In the chronological study of landslides, the research reveals significant changes and anomalies in landslide frequency from 1968 to 2017. During the period from 1968 to 1997, both the frequency of landslides and their impact on humans were very low, with no reported human injuries or deaths. However, from 1999 to 2017, the impact of landslides on humans increased linearly, with a rise in both casualties and the number of landslide occurrences.

Over the last two decades, the increase in rainfall anomalies has paralleled the rise in landslide anomalies. Specifically, years with notably high rainfall, such as 2007, 2012, 2015, and 2017, experienced a corresponding increase in landslide occurrences. Of concern, the number of casualties has shown a consistent upward trend, attributed to an alarming rate of population growth in the mountainous areas. Recent observations indicate that, among the reported deaths, a significant majority were Bengali people rather than members of the mountain's ethnic communities. This analysis suggests a rising population of Bengali individuals in the hill areas.

Examining the chronology of land collapses over the past 50 years, the year 2017 stands out as the most devastating, with land collapses occurring in 12 points of the Chittagong Hill Tracts region (Figure 8).

Landslide impact scenario of June 2017

Table 1 presents the impacts of landslides occurred in 2017. It reveals that a total of 163 people died of landslides over a period of 10 days (from 13-23 June) in June and 227 people were injured. The highest number of deaths took place in Rangamati Sadar upazila where the death toll was 73 and the second highest deaths were occurred in Kawkhali upazila of the same district. The death toll was highest in the district Rangamati (126 deaths) followed by Chittagong (25 deaths), Bandarban (6 deaths), Cox's Bazar (2) and Khagrachari (2 deaths) districts. The number of injured people (200 people) was also the highest in Rangamati district followed by Chittagong (19 people) and Bandarban (8 people). It suggests that Rangamati is the most sensitive district to landslide hazards compared to other districts in the southeastern hilly terrains of Bangladesh. June is the month when most of the landslide occurred in the study areas when the highest amount of rainfall occurs in the region. Local people indicated that rainfall and associated thunder bolds which create vibration in the soil mass trigger the landslides in the area. The local people informed during the field visits that hill cutting, deforestation happen throughout the year in the hills that cause destabilization of hill slopes and make the areas easy prey to landslide disasters in the case of heavy rainfall and thunderbolt. It was observed in the field survey that the local government agencies construct slope protection concrete walls in some places to stabilize the hill slopes but local people expressed doubts that it will not be able to provide necessary safeguards without stropping hill cutting and deforestation in the hilly terrains. The population density of Rangamati is high since vast areas of the district occupy wetlands and in such circumstances people, especially the poor communities, prefer to settle at the bottom of the unstable hills. The compulsion of constructing the settlements by the poor sections of the communities make them highly vulnerable to landslide hazards. It is important to note that heavy rainfall and thunder bolts events will be more intense/strong, frequent in the upcoming times under the influence of climate change and hence the landslide impacts will also be high in the regions.

Table 1. Landslide impact scenario in the study areas (June 2017).

Districts	Upazilla (Sub-districts)	13 June		14 June		15 June to 16 June		17 June to 18 June		19 June		20 June		21 June		22 June		23 June	
		D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I	D	I
Rangamati	Rangamati Sadar																		
	Kawkhali																		
	Kaptai																		
	Juraichori	88	1	16	199	12	0	3	0	0	0	5	0	0	0	2	0	0	0
	BilaiChori																		
Chittagong	Rangunia	13		3		2		0		1		0		0		0		0	
	Chandanaish	4		0		0		0		0		0		0		0		0	
	Rawzan	1	7	1	10	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Bandarban	Bandarban Sadar	6	1	0	2	0	4	0	1	0	0	0	0	0	0	0	0	0	0
Cox's Bazar	Teknaf	2	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Khagrachori	Lakhmichori	-	-	1	-	0	-	1	-	0	-	0	-	0	-	0	-	0	-
	Ramgar	-	-	-	-	-	-	2	-	0	-	0	-	0	-	0	-	0	-
Total		114	9	21	211	14	6	6	1	1	0	5	0	0	0	2	0	0	0
																	Total	163	227

Conclusion

This study delves into the triggering factors, chronology, and consequences of the landslides that occurred in the CHT region in June 2017. Analyzing the triggering factors and chronology aids in comprehending the causes and frequency of landslides. The chronology of landslides reveals a correlation among hills cutting, human activities, and rainfall as contributors to landslide occurrences. The study area, visited for site analysis, has experienced the impact of human activities, rendering the hills vulnerable. Human interventions make hills susceptible, and intense rainfall in a short period results in soil loosening, leading to landslides. Furthermore, Jhum cultivation on the hills' surfaces weakens the soil, making it susceptible to rainfall infiltration, ultimately causing landslides. The larger landslides are predominantly observed in plantation agriculture fields, while smaller landslides tend to occur near roads and settlement areas (Abedin et al., 2020). Smaller scale landslides significantly impact the community level.

The study also unveils the consequences of major landslides on human fatalities and injuries from 1968 to 2021. Landslides have adversely affected human lives, houses, settlements, roads, and the depletion of hills forests. The analysis emphasizes the significance of altitude slope and slope aspect in identifying vulnerable hills, with slopes ranging from 41 degrees to 66 degrees being particularly susceptible in settlement areas. This paper elucidates the influencing factors, including rainfall, altitude, slope, hill cutting, slope aspect, and increasing population, and presents the chronological events of landslides. The study indicates a strong relationship among rainfall, elevation, slope, and slope aspect with frequent landslides. Analyzing over 50 years of landslide history and 20 years of rainfall data, it is evident that there has been a significant change in landslide frequency and intensities, leading to increased socioeconomic casualties. The landslides in 2017 surpassed all previous records in Bangladesh.

The findings of this study hold importance for hills policymakers, the hills authority, and distributors of hills to instill caution among the hill community. Management authorities and policymakers must prioritize the vulnerability of hills, considering not distributing vulnerable hills among the economically disadvantaged for settlement. The study recommends mitigation strategies, including identifying landslide-prone areas, evaluating the chronology of landslides, and implementing measures such as reducing surface irrigation, draining groundwater away from landslides, and increasing hill forestation. The reduction of steep slope construction and stabilization of existing slopes are also emphasized as effective measures to mitigate landslides. Implementing restrictions, prohibitions, or conditions on hazard-zone activities is proposed as a fruitful approach.

Acknowledgments

This study was supported by the Special Research Grant of Ministry of Science and Technology, The Government of the People's Republic of Bangladesh, given in 2021-2022 (Grant number: ES 374). The authors acknowledge the contributions of the Ministry which helped to accomplish the work.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Statement of author's credit

Sheikh Tawhidul Islam: Conceptualization, methodology, supervision, review and rewrite of the final version of the article. Md. Hiru Miah: Data collection, writing the draft version. Al Jubaer: Data procesing, visualization, geospatial investigation. Krishna Prosad Mondal: Validation, editing, rewriting of the draft article. Md. Munir Mahmud: Writing, reviewing and editing.

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