IDRiM (2025) 15 (2) ISSN: 2185-8322
DOI10.5595/001c.143100

Journal of Integrated Disaster Risk Management

Regular Article

Influential Factors of Landslide Occurrence in the South-Eastern Part of Bangladesh

Najmun Nahar[1*], Md. Mohiuddin[1], Samshad Nowreen[2] and Mallik Akram Hossain[1]

Received: 14/01/2025 / Accepted: 10/06/2025 / Published online: 21/08/2025

Abstract Landslides pose an intensifying and recurring hazard in the southeastern region of Bangladesh, especially in Cox's Bazar district. It mainly occurs due to various causative, triggering, and anthropogenic factors. This study investigated the significant causes of landslide incidents in high, moderate, and less landslide-vulnerable locations of Ramu, Ukhiya, and Teknaf subdistricts in Cox's Bazar district. The research used primary and secondary data regarding the determinants of landslides. As a part of primary data collection, a triangulated approach involving soil analysis on 22 soil samples, topographic mapping on slope angle and elevation, and a semi-structured questionnaire survey on 300 respondents was used for this study. Monthly total rainfall data (2000-2018) were collected from the Bangladesh Meteorological Department as secondary data. Findings revealed that sandy loam or loamy sand soils with low cation exchange capacity (4.9-9.4 $cmol_c/kg$) and slightly acidic pH (4.9-5.7) and steep slopes (12°–21°) at elevations ranging from 89 to 177 meters were the common characteristics of high landslide vulnerable locations in the study area. Survey responses attributed that heavy rainfall in June was identified as the primary triggering factor in 63.7% of landslides in the study area. Regression analysis also showed a strong correlation between monthly total rainfall and the percentage of monthly landslide incidence. Deforestation, jhum cultivation, hill cutting, and refugee settlement were also identified as significant anthropogenic activities that are related to landslide occurrence. The findings of the study can be applied in disaster risk reduction, urban planning, environmental management, and geotechnical engineering. It offers a scientific foundation for policymakers, local authorities, and development agencies to implement slope stabilization, strengthen environmental regulations, and promote community awareness. Overall, it supports the development of integrated resilience strategies for landslide-prone regions in hilly areas at the national and international level.

Keywords: landslide, causative factors, triggering factors, deforestation, hill cutting

[1] Geography and Environment, Jagannath University, Bangladesh
[2] Tourism and Hospitality Management, University of Dhaka, Bangladesh
* Corresponding author email: najmun.nahar@geography.jnu.ac.bd

1. INTRODUCTION

Landslides occur due to physical factors in hilly areas in different places of the world (Roy et al., 2022; Chen et al., 2017; Martin et al., 2021; Dasanayaka & Matsuda, 2022). A landslide results from soil, rock, and sediment gravitationally moving from an upper slope to a lower slope due to various factors, including topography, climate, land use, and geology (Guzzetti et al., 2012; Alkevi & Ercanoglu, 2011). The population is increasing with the demand for basic needs, particularly food, and settlement, thus pushing the disaster intensity of cyclones, floods, erosion, and landslides (Mohiuddin & Nowreen, 2023; Fakhruddin & Rahman, 2015). Likewise, the land use pattern is changing for the population's demand, not exceptional in the hilly areas due to deforestation, hill cutting for agriculture, road and network, and settlement. Consequently, the landslide is apparent during the rainy season on the hill track worldwide (M. J. U. Khan et al., 2020; Alam, 2020; Yilmaz, 2009). Features that cause the landslides can be divided into causative and triggering factors (Guzzetti et al., 2012). Causative factors facilitate favorable landslide conditions, including slope, elevation, geology, soil and rock, and land-use land cover (Matori & Basith, 2012). On the other hand, triggering factors involve natural phenomena like prolonged rainfall, volcanic eruption, swift snowmelt, and earthquakes (Wieczorek, 1996). Landslide is also generated by anthropogenic factors like unplanned land use, hill cutting, deforestation, population growth, intense plantation agriculture on slopes, and increased interest in tourism and infrastructure (Yilmaz, 2009). Mainly, a landslide occurs at the exact location or nearby location of the previous occurrence, indicating that a landslide depends heavily on the soil's specific condition, climate, and topography (Chen et al., 2017).

Landslides pose a significant global concern (Parker et al., 2011; Alexander, 2005) because of their catastrophic effects, including numerous deaths , socioeconomic loss, and depletion of natural resources (Tandrila et al., 2020; Haque, 2016; Martin et al., 2021). Sometimes, the influence of landslides is more significant than any other disasters like cyclones, hurricanes, floods, earthquakes, etc. (Anderson et al., 2011; Guzzetti et al., 1999; Schuster, 1996). Globally, 5,741 landslide locations are pointed out through spatial and temporal aspects (Kirschbaum et al., 2015). Statistics indicate that 32,322 fatalities occurred from 2620 landslides during 2004-2010, and another 4862 non-seismic landslides caused 55,997 deaths throughout 2004- 2016 (Petley, 2012). As a continent, Asia is the most vulnerable to landslide fatalities (Froude & Petley, 2018; Petley et al., 2007). Recently, South Asian countries, particularly Bangladesh, Nepal, and India, have become hotspots for landslides because of the heavy rainfall in the monsoon season (Haque et al., 2019; UNICEF, 2019).

Bangladesh is a rapidly growing developing country in South Asia, and in this country, landslides are recurring and devastating disasters (Nowreen & Mohiuddin, 2017; Sultana, 2020). Landslides mainly occur in hilly districts of Bangladesh's southeastern part (Banglapedia, 2021). In Bangladesh, 350 deaths have occurred in the last three decades, and the major landslide vulnerability is mainly seen in Chittagong and Cox's Bazar areas (M. A. Islam et al., 2017). Chittagong metropolitan area, Cox's Bazar Sadar, and Teknaf Sadar areas are the most vulnerable to landslide disasters, which have experienced 730 landslides so far (Rabby & Li, 2019). In this region, 130 deaths occurred, and 1.5 million people were affected due to a major landslide in 2007 (M. A. Islam, 2018). The Dhaka Tribune (2024) reported that six people died from separate landslide incidents that happened in September, in Cox's Bazar Sadar and the Rohingya camp in Teknaf Subdistrict due to heavy rainfall, which triggered the unplanned settlement. The database shows that the highest number of landslides has occurred in the Chittagong district, and the second highest number is Cox's Bazar district. Chittagong's landslide events were 65, and for Cox's Bazar, the number was 63 (Sultana, 2020). However, Alam (2020) has assessed the knowledge level, awareness, and preparedness about landslides in southeast Bangladesh. Sultana (2020) has discovered a landslide-related number of deaths and wounds in Bangladesh. Several studies have revealed the causes, impacts, and mitigation measures of landslides (Mia et al., 2015; M. A. Islam et al., 2017; M. S. Islam, 2018; Ahmed, 2021) and landslide mapping (Ali et al., 2014; Ahmed, 2015; Rabby & Li, 2019) of Chittagong hilly areas. Very little or no research has been conducted on landslides in Cox’s Bazar district. Therefore, Ramu, Ukhiya, and Teknaf Subdistricts of Cox’s Bazar district have been considered the study area. The research questions of the study are: i) What are the main causative factors that make southeast Bangladesh more vulnerable to landslides? ii) What is the relationship between triggering factors and landslide occurrence in the area? iii) How much do anthropogenic activities increase the possibility of landslides in the study area? Considering the research questions of the study, the primary objective of this research is to discover the various significant causes of landslides in the southeastern part of Bangladesh. Investigating the location-specific causative, triggering, and anthropogenic factors behind landslide hazards is essential for planning sustainable land use and effective disaster risk management. The research will help policymakers and planners solve the landslide-related problem and create better plans for landslide mitigation.

2. MATERIALS AND METHODS

2.1 The Study Area Selection

Cox's Bazar is a district located in the southeastern part of Bangladesh under the Chittagong division. The district is bordered on the south by the Bay of Bengal, east by Bandarban District, Arakan (Myanmar), and the Naf River, and on the west by the Bay of Bengal. The district is situated between 20°43' and 21°56' north latitudes and between 91°50' and 92°23' east longitudes. This district, with an area of 2491.86 sq. km, has the longest sea beach, 155 km in the world (Banglapedia, 2023). The climate of Cox's Bazar district is almost similar to other parts of the country, mainly determined by its location in the tropical monsoon region, high temperature, heavy rainfall, and generally excessive humidity (Ahmed, 2012). Most of the soils of this district are composed of tertiary and quaternary unconsolidated sedimentary rocks containing sandstone, shale, siltstone, and conglomerate sediments (Ahmed, 2014; Y. A. Khan et al., 2012; Rashid, 1991) where quartz, feldspars, and mica minerals are in abundance and for the clay particles, the dominant minerals are kaolinite with minor amounts of illite and vermiculite (Kumari & Mohan, 2021). Landslide disasters frequently occur in this area due to heavy rainfall in the monsoon period, a higher average slope gradient than other parts of this country, hill-cutting activities, and deforestation (ACAPS and Start Network 2018). In the last two decades, the highest number of landslides occurred in the Chittagong district, followed by Cox's Bazar (Sultana, 2020).

Recently, the rampant destruction of forests along with hill-cutting has increased alarmingly due to the Rohingya refugees' inflow (ACAPS and Start Network 2018). CDMP (2012) states that rainfall-caused landslides occurred in Cox's Bazar and Teknaf municipalities. The most vulnerable hotspots of landslides include Ukhiya, Chakaria, Ramu, and Cox's Bazar Sadar in Cox's Bazar district (Sultana, 2020). Considering the above scenario, Ramu, Ukhiya, and Teknaf Subdistricts in Cox's Bazar district were chosen as the study area to determine the causative, triggering, and anthropogenic causes of landslide-vulnerable locations. The locations of prior landslides in the study area from 2000 to 2018 were collected from various studies (Rabby & Lee, 2019; Sultana, 2020). Thereafter, the study primarily identified the landslide-vulnerable locations by asking the local people about the frequency, casualties, and property damage, and the recognized landslide-vulnerable locations were collected through GPS. Highly vulnerable location indicates the regular landslide occurrence with casualties and property loss; moderately vulnerable location is the occasional landslide occurring and damaging lives and properties; and less vulnerable location expresses the previously happened landslide but are likely to experience a landslide in the future (Table 1). Some soil samples were collected from the landslide vulnerable locations to investigate the soil properties linked to landslide occurrence. Moreover, the slope angle and elevation of the landslide vulnerable locations were measured for this study. The study area with previous landslide locations (2000-2018) and soil sampling points in the investigated landslide vulnerable locations is shown in Figure 1.

Table 1. Definition and index of the landslide-vulnerable locations

Landslide Vulnerable Location	Definition of landslide vulnerable location	Index
High Landslide Vulnerable Location	The regular landslide occurrence with casualties and property loss	HLVL
Moderate Landslide Vulnerable Location	Moderately vulnerable is the occasional landslide that occurs and damages lives and properties	MLVL
Low Landslide Vulnerable Location	Less vulnerable expresses a previously happened landslide, but is likely to occur in the future	LLVL

 ISSN: 2185-8322

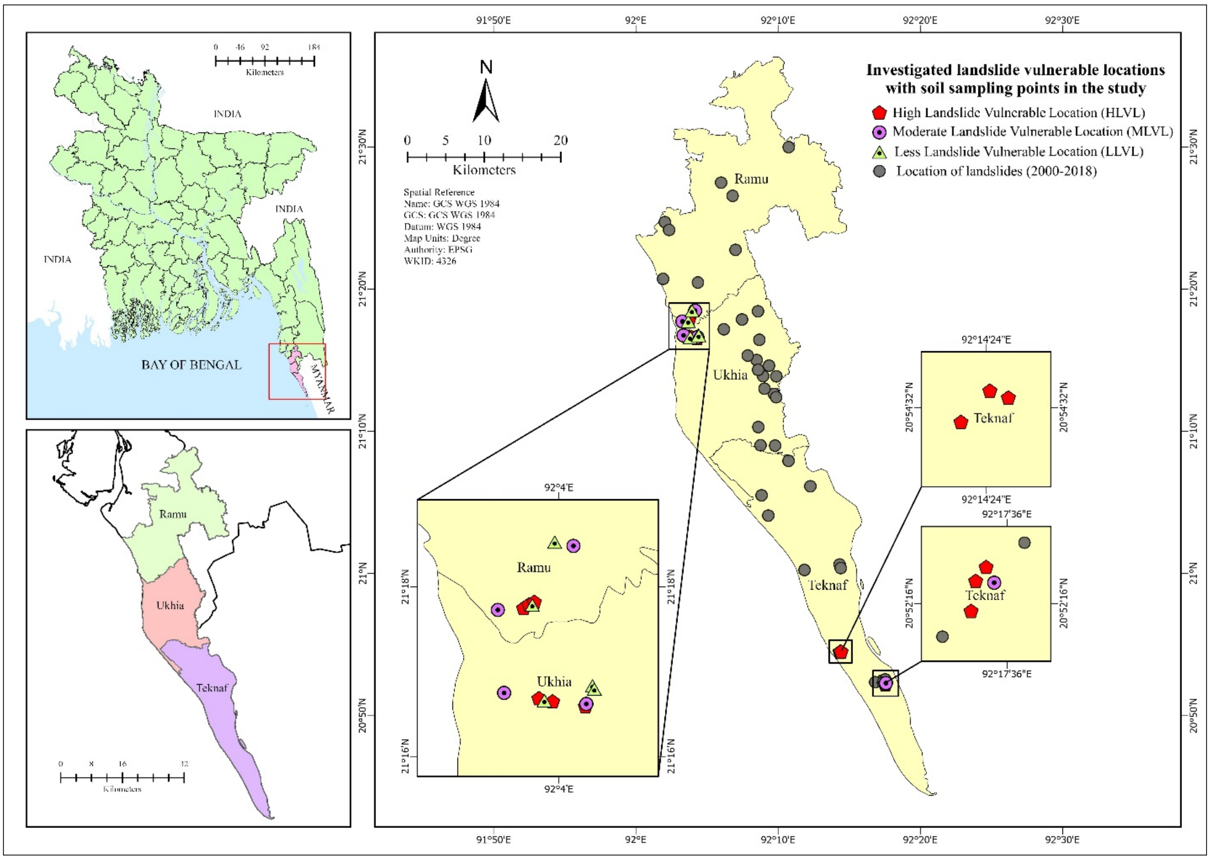

Figure 1. Locations of the study area with landslide-vulnerable locations (2000-2018) and soil sampling points

2.2 Data and Information Collection

This study used primary and secondary data to understand the causative, triggering, and anthropogenic factors that contribute to the occurrence of landslides. As a primary data collection, a triangulated approach combining topographic mapping by preparing the slope angle and elevation maps, analysis of soil properties by laboratory tests of soil samples, and perception surveys using a semi-structured questionnaire. Monthly total rainfall data from 2000 to 2018 were collected for Cox's Bazar and Teknaf stations from the Bangladesh Meteorological Department (BMD) as secondary data, and a linear regression analysis was applied between monthly average total rainfall and the percentage of perceived landslide incidence by the respondent. Field observations and photographic documentation were also conducted as evidence of the relevant issues, providing visual support to the perception data in this study.

Information on essential mapping techniques

The study area maps were produced using the GIS software ArcGIS 10.8, and the study area shapefiles were downloaded from the Bangladesh Bureau of Statistics (BBS). The Geographic Coordinate System (WGS) 1984 is the coordinate system for all map projections. The methodology for analyzing landslide vulnerability in Ramu, Ukhia, and Teknaf involved a systematic data collection, processing, and map generation approach. Initially, shapefiles were acquired from the Bangladesh Bureau of Statistics (BBS), which included administrative boundaries and other geographical features essential for delineating the study area. Digital Elevation Model (DEM) data was obtained from the USGS ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) at a 30-meter resolution for topographic information.

This DEM data allowed for calculating elevation and slope, critical factors in assessing landslide susceptibility. An elevation and slope analysis was conducted using the DEM data to map the gradient across the region. Map composition included layering the DEM data as an overlay on a base map, displaying elevation and slope gradients across the region. In the slope map, different colors represented varying degrees of inclination, while in the elevation map, colors indicated altitude variations. The categorized sampling points were overlaid with distinct symbols and colors for each vulnerability location. A comprehensive legend was added, detailing color codes for slope and elevation and markers for the High Landslide Vulnerability Location (HLVL), Moderate Landslide Vulnerability Location (MLVL), and Low Landslide Vulnerability Location (LLVL). Soil sampling points within the vulnerable areas were then marked on the maps. These sampling locations were labeled (R for Ramu Upazila, U for Ukhiya Upazila, and T for Teknaf Upazila) and classified according to their respective vulnerability locations. This spatial arrangement allowed for a focused analysis of high landslide-vulnerable areas. To aid readability, each map featured a north arrow, scale bar, and coordinate system (WGS 1984). Key regions, such as Ramu, Ukhia, and Teknaf, were highlighted, with inset maps providing zoomed-in views of significant sampling points. The final maps were exported as high-resolution images suitable for detailed analysis and reporting. This methodology, facilitated by the GIS software ArcGIS, provided a precise spatial analysis of landslide-vulnerable locations in the study area.

Soil sample collection

As a part of primary data collection, soil samples were collected and tested in the laboratory to find the causative factors. The soil sampling points and locations are presented in Figure 1 and Table 2. Soil samples were collected to measure the soil's physical and chemical properties, which act as catalysts for the occurrence of landslides.

In this case, soil samples were taken from 5-8 cm underneath the soil surface (Figure 2a) in the study site's highly, moderately, and less vulnerable landslide locations. Twenty-two soil samples were collected from three subdistricts in Cox's Bazar district based on local people's landslide frequency information and judgmental sampling techniques (Ngole et al., 2007). Seven soil samples from the Ramu Subdistrict, eight from the Ukhiya Subdistrict, and seven from the Teknaf Subdistrict were collected with GPS location (Table 2). The soil samples were labeled before being kept in airtight containers and transported from the field to the laboratory in Dhaka. Collected soil samples were kept in the sunshine for drying (Figure 2b), crushed, sieved by a 2 mm sieve to remove the unwanted organic roots and leaves, and tested in the laboratory at the Department of Soil, Water, and Environment, University of Dhaka, Bangladesh. The physical and chemical parameters of collected soil samples considered for this research include the soil texture, soil pH, electrical conductivity (EC), and Cation

Exchange Capacity (CEC). Sieve analysis and hydrometer methods (Figure 2c) were applied to determine the particle size of soil samples. Chemical analysis also measured the samples' cation exchange capacity (Figure 2d). The Model 3305 pH Meter was used to measure the soil pH (Figure 2e), and the YSI 5560 multimeter was used to calculate the Electrical Conductivity (EC). Tables and diagrams interpreted the results of the soil samples.

Table 2. Coordinates of the locations of collected soil samples in the study area

Level of landslide vulnerable Location	Sample label	Geographic Coordinates		Location
		Latitude	Longitude	
High Landslide Vulnerable Location (HLVL)	R2	21°17′45.36″ N	92°3′34.92″ E	Goaliapalong, Ramu, Cox's Bazar
	R3	21°17′48″ N	92°3′38.82″ E	Khunipalong, Ramu, Cox's Bazar
	R5	21°17′49.74″ N	92^{0}3′42.54″ E	Khunipalong, Ramu, Cox's Bazar
	U2	21°16′41.52″ N	92°3′45.78″ E	Jaliapalong, Ukhia, Cox's Bazar
	U4	21°16′39.3″ N	92°3′55.44″ E	Jaliapalong, Ukhia, Cox's Bazar
	U8	21°16′35.88″ N	92°4′18.66″ E	Jaliapalong, Ukhiya, Cox's Bazar
	T1	20°54′30.8″ N	92°14′21.8″ E	Chandrakilla, Teknaf, Cox's Bazar
	T2	20°54′33.5″ N	92°14′24.3″ E	Chandrakilla, Teknaf, Cox's Bazar
	T3	20°54′32.9″ N	92°14′25.9″ E	Teknaf Hill, Cox's Bazar
	T4	20°52′15.4″ N	92°17′32.9″ E	Teknaf, Hill Cox's Bazar
	T5	20°52′18.0″ N	92°17′33.3″ E	Teknaf, Cox's Bazar
	T6	20°52′19.2″ N	92°17′34.2″ E	Teknaf, Cox's Bazar
Moderate landslide vulnerable location (MLVL)	R1	21°17′43.74″ N	92°3′16.68″ E	Khunipalong, Ramu, Cox's Bazar
	R6	21°18′'29.04″ N	92°4′10.2″ E	Dhoapalong, Ramu, Cox's Bazar
	U1	21°16′45″ N	92°3′21.12″ E	Jaliapalong, Ukhia, Cox's Bazar
	U7	21°16′37.2″ N	92°4′19.32″ E	Jaliapalong, Ukhiya, Cox's Bazar
	T7	20°52′17.8″ N	92°17′34.9″ E	Teknaf, Cox's Bazar
Less landslide vulnerable location (LLVL)	R4	21°17′47.76″ N	92°3′41.04″ E	Dhoapalong, Ramu, Cox's Bazar
	R7	21°18′32.28″ N	92°3′56.88″ E	Dhoapalong, Ramu, Cox's Bazar
	U3	21°16′40.14″ N	92°3′49.56″ E	Jaliapalong, Ukhia, Cox's Bazar
	U5	21°16′50.58″ N	92°4′23.64″ E	Jaliapalong, Ukhiya, Cox's Bazar
	U6	21°16′48.18″ N	92°4′24.96″ E	Jaliapalong, Ukhiya, Cox's Bazar

Questionnaire survey

In addition, a semi-structured questionnaire was developed and surveyed (Figure 2f) to understand people's perceptions regarding landslide occurrence. The questionnaire focused on perceived causes, frequency, and patterns of landslides, particularly about anthropogenic activities, such as hill cutting, deforestation, and jhum cultivation. Purposive sampling techniques were applied to select respondents. A total of 300 respondents were interviewed in 2018. The 300 respondents were selected from three sub-districts: Ramu, Ukhiya, and Teknaf. From each sub-district, 100 respondents were chosen with a 95% confidence level and ±10% precision level (Yamane, 1967), where the total population of Ramu was 266,640, Teknaf was 264,389, and Ukhiya was 207,379 (BBS, 2011).

DOI10.5595/001c.143100

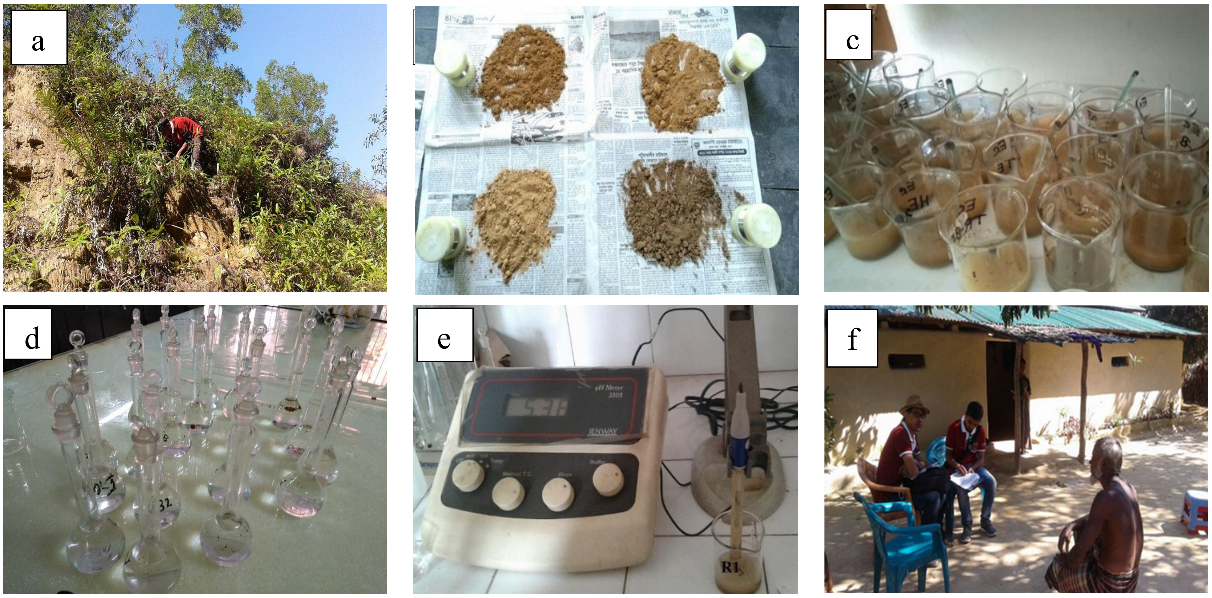

Figure 2. Techniques of primary data collection

(a) Collection of soil samples from the study area, (b) Keeping collected soil samples in the sunshine, (c) Mixing Hydrogen peroxide with the soil sample before the hydrometer test, (d) Titration of the soil sample, (e) Measuring soil pH, (f) A questionnaire survey

The demographic characteristics of the respondents are shown in Figure 3. Among 300 respondents, 60% are male, while 40% are female. A significant proportion (29%) of respondents was 18-30 years old, and the next age group, 40-50 years high in the study area, was 26%. Most of the respondents (68 %) are illiterate. The rest of them have primary to the higher secondary level of education. Almost 40% of the population are farmers, and approximately 75% of the people's income range is 1000-10,000 (BDT). About 47% of respondents had lived more than 15 years in the study area (Figure 3).

Rainfall data collection and analysis

In this study, the monthly observed total rainfall data for eight consecutive years (2000-2018) were taken to determine the relationship between monthly total rainfall and the percentage of monthly landslide occurrence in the study area as secondary data. The rainfall data on Cox's Bazar and Teknaf stations were collected from the Bangladesh Meteorological Department (BMD), Dhaka, Bangladesh. The rainfall data from 2000 to 2018 was then averaged monthly. The percentage of monthly landslide incidence data was obtained from the respondents' perception through a semi-structured questionnaire survey. Microsoft Excel was used to prepare a combined bar and line chart to show the monthly average total rainfall (2000-2018) and the percentage of monthly landslide occurrence as perceived by the respondents of the study area. Further, a linear regression analysis was conducted using monthly average total rainfall as the independent variable and the percentage of landslide occurrence as the dependent variable to investigate their statistical relationship. Origin Lab software was used to perform the regression analysis on this data.

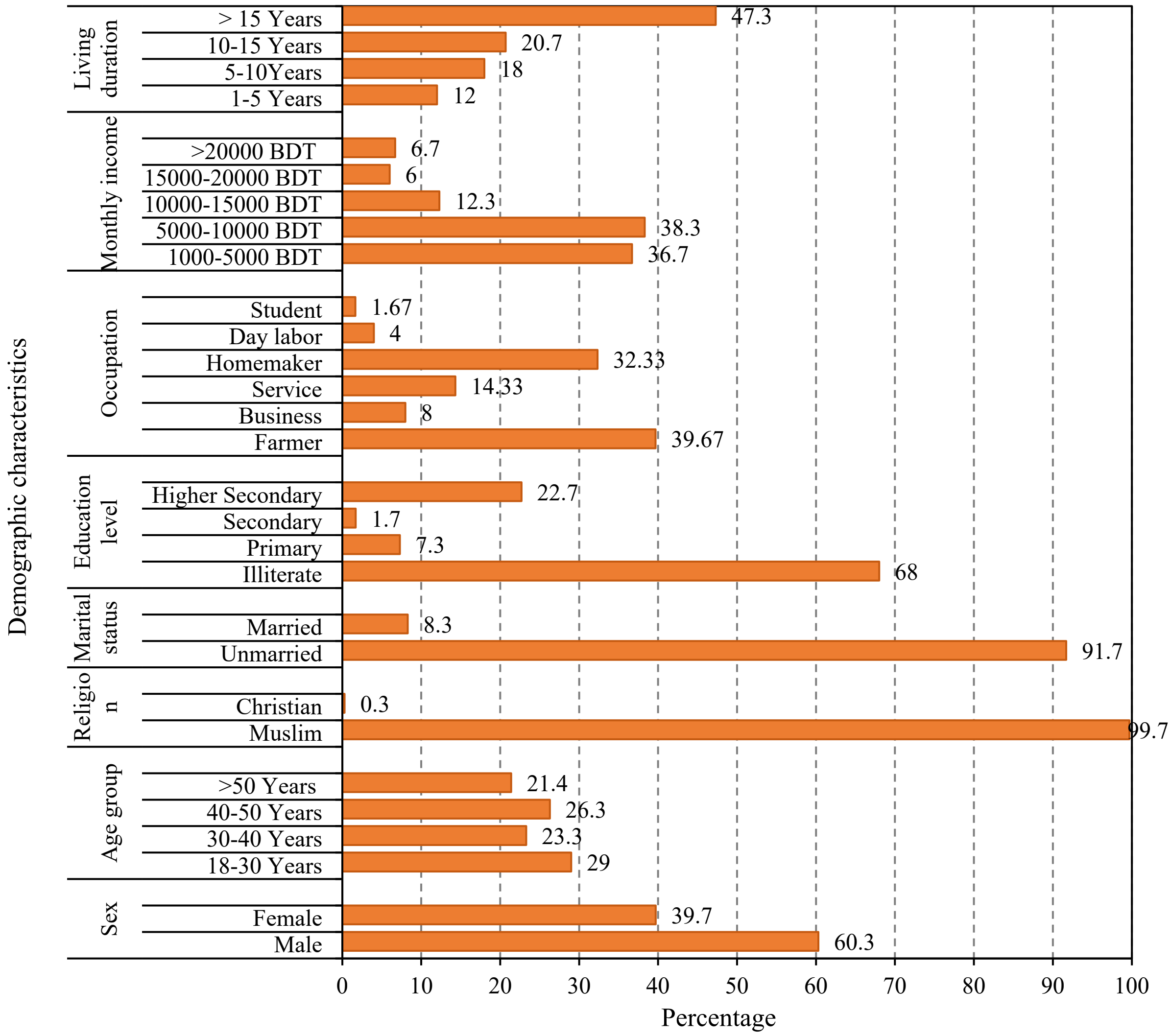

Figure 3. Demographic characteristics of the respondents

3. RESULTS AND DISCUSSIONS

During the questionnaire survey, respondents were asked about the causes of the landslide in the study area. At first, the basic perception of local people about the causes of landslides was that they occurred due to natural and anthropogenic causes. About 88.0% of respondents stated that natural causes are responsible for landslides. In comparison, 12.0% identified anthropogenic causes. Moreover, previous geological events or modern irrigation practices may cause the loss of soil particles and ease the saturation process. Recent studies focusing on the effect of human-induced land-use changes on slope stability have shown that humans' impact on the environment in populated regions contributes significantly to the initiation and reactivation of landslides (Ahmed, 2015). The study area had three leading causes of landslides: causative, triggering, and anthropogenic factors. These are elaborated in the following sections.

3.1 Causative Factors

Causative factors create a favorable condition for landslide occurrence. For this study, soil characteristics, slope conditions, and elevation were chosen as causative landslide factors. The soil properties, that is, soil texture, pH, Electrical Conductivity (EC) of soil, and Cation Exchange Capacity, were considered causative factors of landslide-vulnerable locations. Soil texture measures the ratio of sand, silt, and clay particles in the soil. It is a vital physical property of soil that influences other properties of soil. Among the 22 soil samples, 12 soil samples were found: sandy loam, loamy sand, and sandy soil, while sand, with moderately coarse to fine particles (> 65%), dominates the soil (Table 3). Six soil samples were clay loam texturally, which were from MLVL to LLVL, considering the elevation of the sample location; one sample was loam at MLVL, one was sandy clay loam at MLVL, and another was silty clay, which was at HLVL. In the Ramu Subdistrict, three soil samples were clay loam, two sandy loam, and one loamy sand soil. Sandy, sandy loam, loamy, sandy clay, clay loam, and sandy clay loam with varying sand ratios were found in the soil samples of the Ukhiya subdistrict. Sand particles are commonly high in five out of 8 samples. Out of seven samples, sands dominate the five samples, and clay particles dominate one sample in the Teknaf subdistrict, indicating high vulnerability to landslides. There is no significant difference between the three different subdistrict soil textures in the study area, as elevation with the soil sample's texture determines the level of vulnerability of landslide locations (Table 3).

Soil texture is critical in causing a landslide in a hilly area (Sharma et al., 2012). The permeability of loamy sand is rapid; sandy loam is moderately fast, clay loam and sandy clay loam are moderately slow, and silty clay is slow (O'Geen, 2013). The soil texture results indicate that the soils originate from the loamy siltstone, sandstone, and conglomerate sedimentary rocks of the tertiary and quaternary periods (Ahmed, 2014), which have fold, faults, and undulation features (Brammer, 1996). The soil samples in the study area are radish, yellowish, and brown (Ahmed, 2014). The nature of soil and hill fault absorbs the rainwater, then saturated soil and steep slopes enhance the landslide disaster (Mahmood & Khan, 2010). The study area's soil texture is susceptible to landslides due to the low bonding in the sand particles, which can easily dislocate from their origin during and after heavy rain (Sultana, 2013). Lesser sand particles in the soil where silt and clay particles are comparatively higher are also vulnerable to landslides. During monsoons, loose, muddy soil holds ample moisture, causes extra weight, decreases the shear strength of soil, and results in landslides (M. S. Islam, 2018).

Soil pH indicates the soil's acidity or alkalinity, influencing the soil's biogeochemical processes (Neina, 2019). The laboratory analysis of the soil samples in the study area revealed that 12 samples with textured sandy loams, loamy sand, and sand from HLVL were moderately to slightly acidic, with a pH range from 4.9 to 5.7 (Figure 4). Usually, sandy soil is acidic, and clayey soil is alkaline (Tahir & Marschner, 2016). Clay loams, sandy clay, sandy clay loam, and silty clay soils from MLVL to LLVL were slightly acidic to a neutral level (pH: 6.5 to 7.3). The average soil pH in landslide-prone areas is between 4.9 and 6.5 (Van Eynde et al., 2017), which is strongly acidic to slightly acidic, and the pH range of the

 ISSN: 2185-8322

soil in humid tropical regions is between 5 and 7 (NDSU, 2020) where the highest amount of rainfall occurs in the monsoon period.

Table 3. Particle sizes and texture of soil samples in the study area

Level of landslide vulnerable Location	Sample label	Sand (%)	Silt (%)	Clay (%)	USDA soil textural class name
High Landslide Vulnerable location (HLVL)	R2	68.0	21.0	11.0	Sandy loam
	R3	70.0	15.0	15.0	Sandy Loam
	R5	77.5	12.5	10.0	Loamy sand
	U2	47.5	7.5	45.0	Sandy clay
	U4	72.5	10.0	17.5	Sandy Loam
	U8	90.0	2.5	7.5	Sand
	T1	60.0	20.0	20.0	Sandy loam
	T2	65.0	23.0	12.0	Sandy loam
	T3	72.0	15.0	13.0	Loamy sand
	T4	7.5	32.5	60.0	Silty clay
	T5	80.0	2.5	17.5	Sandy loam
	T6	70.0	2.5	27.5	Sandy Loam
Moderate Landslide Vulnerable location (MLVL)	R1	25.0	25.0	50.0	Clay Loam
	R6	35.0	15.0	50.0	Clay loam
	U1	50.0	17.5	32.5	Loam
	U7	70.0	7.5	22.5	Sandy clay loam
	T7	36.0	27.0	37.0	Clay loam
Less Landslide Vulnerable location (LLVL)	R4	37.0	25.0	38.0	Clay loam
	R7	27.0	34.0	39.0	Clay loam
	U3	22.0	43.0	35.0	Clay loam
	U5	52.5	17.5	30.0	Sandy loam
	U6	80.0	5.0	15.0	Sand

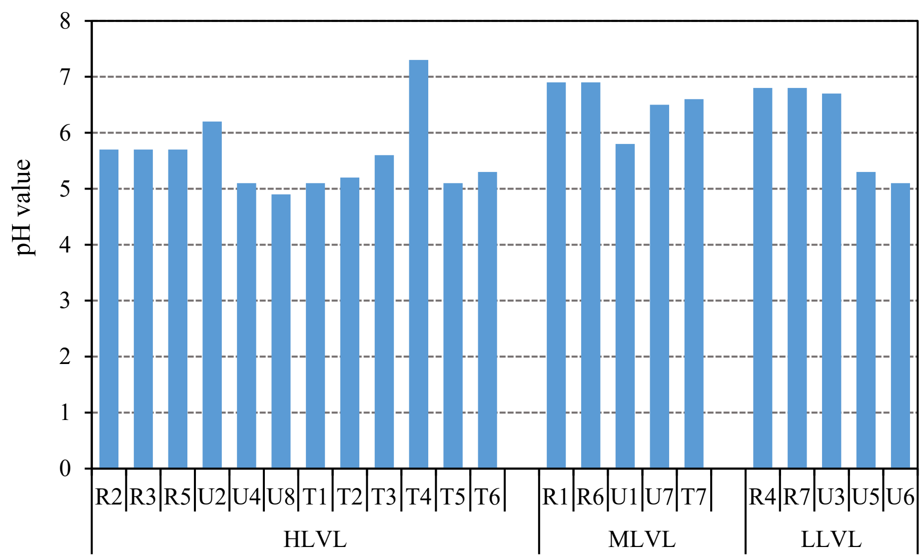

Figure 4. Soil pH of High Landslide Vulnerable Location (HLVL), Moderate Landslide Vulnerable Location (MLVL), and Less Landslide Vulnerable Location (LLVL) in the study area

Soil electrical conductivity (EC) measures the dissolved salts in soil or soil salinity. Climate and soil texture influence the EC of soil. In higher rainfall, soluble salts are washed away from the topsoil and leached from the top layer to deep groundwater (USDA and NRCS, 2020). Since the study area records high rainfall in the monsoon period, the amount of dissolved salts is lower in sandy loams, loamy sand, and sand soil due to a higher infiltration rate. Figure 5 indicates that 12 soil samples from the highly vulnerable areas had low dissolved salts (EC 11.5-22.7 µS/cm). The EC of the soil samples from LLVL to MLVL was 45.2-56.2 µS/cm. The silty clay soil from an HLVL had the highest EC (60.7 µS/cm).

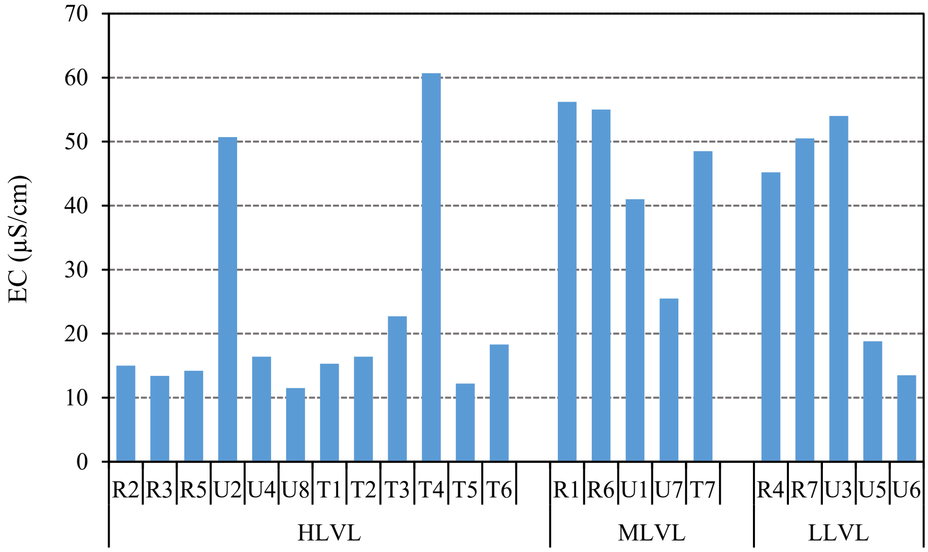

Figure 5. Soil EC of High Landslide Vulnerable Location (HLVL), Moderate Landslide Vulnerable Location (MLVL), and Less Landslide Vulnerable Location (LLVL) in the study area

Cation exchange capacity (CEC) measures the soil's ability to attract and hold the exchangeable cations to neutralize its negative charge (Tomašic et al., 2013). There is a strong relationship between soil pH and CEC. Neutral soil has a higher CEC than acidic soil (Nel, 2021). Sandy soils are strongly acidic and have low organic matter, water-holding capacity, and CEC (Walpola & Arunakumara, 2010). However, clayey soils are mildly alkaline and have a high water-holding ability with a high CEC (Hamarashid et al., 2010). From Table 3 and Figure 6, it is evident that the sandy loam, loamy sand, and sand-textured soils (12 samples) were strong to moderately acidic (pH: 4.9 to 5.7), and CEC of these soil samples were 4.9 – 9.4 (cmol$_c$/kg) in HLVL, and for the clay loams soils, it was 14.8 – 16 (cmol$_c$/kg).

The slope angle and elevation in landslide-vulnerable areas are presented in Figures 8a and 8b. Landslides happen in this area yearly during the rainy season. Flooding may cause landslides by undercutting the banks of streams and rivers and by saturating slopes with surface water. Conversely, landslides can also cause flooding when sliding rock and debris block stream channels and other waterways, allowing large volumes of water to back up behind such dams. Exposed slope and soil quality significantly enhance landslide vulnerability (Dai & Lee, 2001). Landslides often occur with specific crucial slope angles (Jayanthi et al., 2016). From Figures 7a and 8a, it is observed that most of the HLVL were at

IDRiM (2025) 15 (2) ISSN: 2185-8322
DOI10.5595/001c.143100

12˚ to 21˚, and MLVL and LLVL were at 6.5˚ to 12˚. Usually, the weathering zone is narrow at high slope angles, landslides typically do not occur there (Çellek, 2020). Many researchers have found that the maximum landslides developed on slopes with angles between 15˚ and 35˚ in their study area (Hong et al., 2017; Lee & Min, 2001; Ercanoğlu et al., 2004; Pham et al., 2017). It is believed that slope instability also escalates with the increment of slope extent and elevation (Çellek, 2020). In the study area, most landslide sites were between 89 and 177 meters in elevation (Figures 7b and 8b). It is a fact that slopes with the same slope value but different elevations are not equally dangerous (Ahmed, 2014). Slope instability is caused by decreased base area and loose, muddy soil generated by rainwater absorption, which cannot hold the extra weight added by rainwater, resulting in downward soil movement or landslides (Sarwar, 2008).

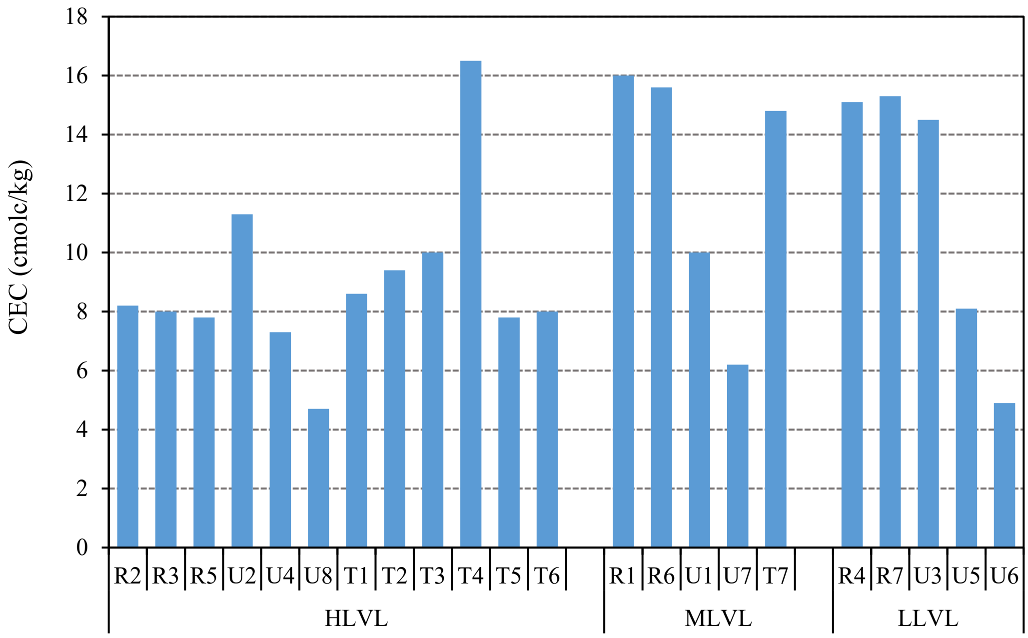

Figure 6. Soil CEC of High Landslide Vulnerable Location (HLVL), Moderate Landslide Vulnerable Location (MLVL), and Less Landslide Vulnerable Location (LLVL) in the study area

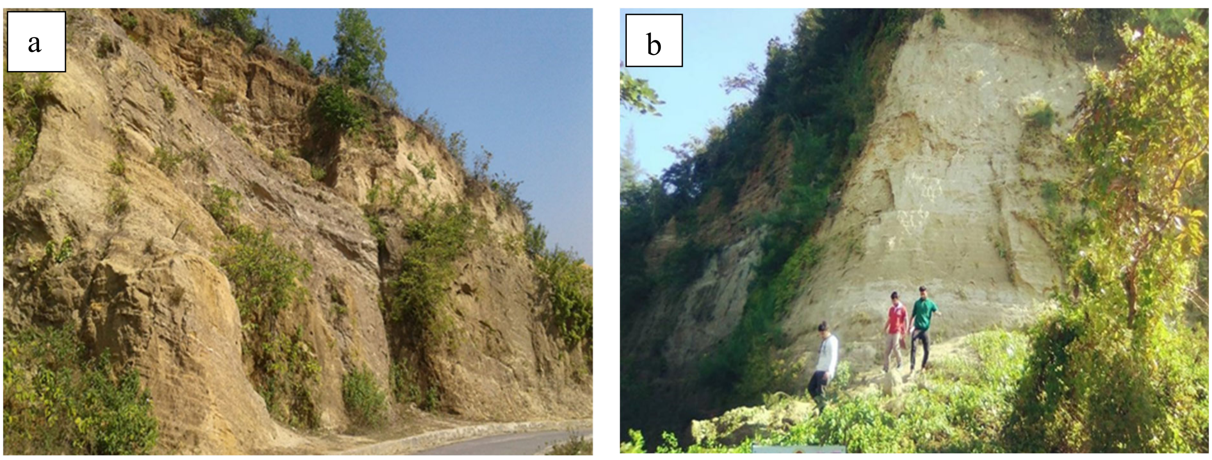

Figure 7. Landslide areas in Cox's Bazar District (a) Slope angle (b) Elevation in the study area

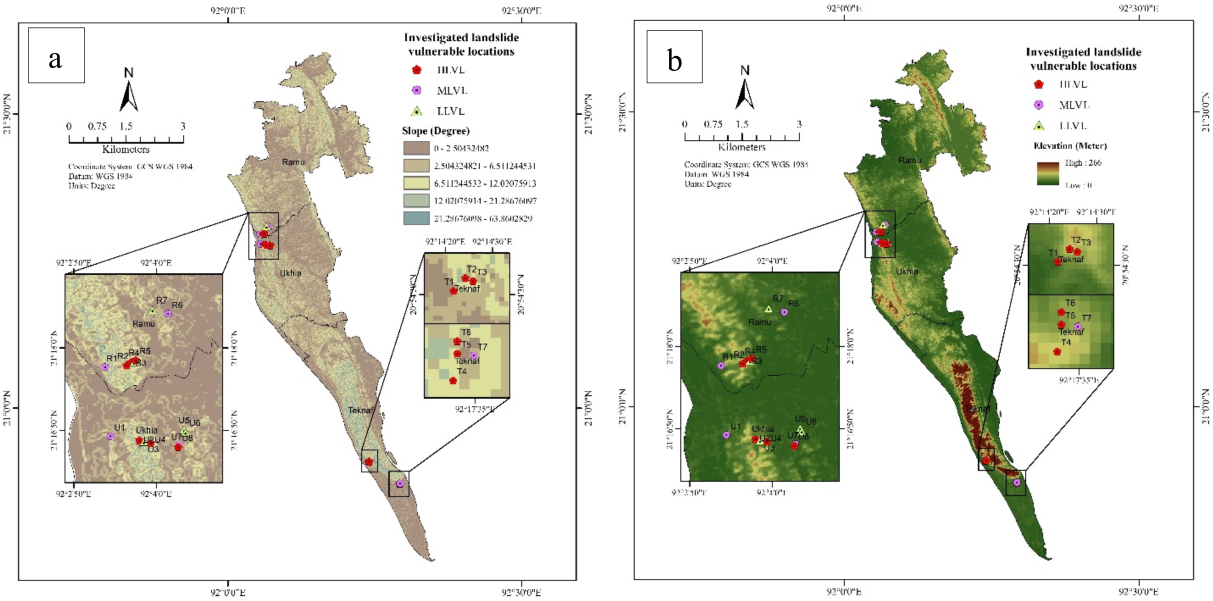

Figure 8. (a) Slope and (b) elevation map of the different landslide-vulnerable locations

3.2 Triggering Factors

Almost 80% of the total yearly precipitation in Bangladesh occurs during the monsoon period from June to October (Ahammed et al., 2014), with maximum temperatures at 32°C to 38°C (BMD, 2019). The rainfall average is between 400 and 600 mm per day. Heavy rain in a short period will likely lead to a landslide in a hill area. In the study area, 86% of respondents perceived that heavy rainfall might cause a landslide. Bangladesh experienced landslides in 2007, 2012, 2015, and 2017 because of heavy rain in Cox's Bazar (Ahmed, 2014; Mutizwa-Mangiza et al., 2011). A study confirms that 83 % of landslides happen during the monsoon season due to heavy downpours, which lead to fatalities for local people (Haque et al., 2019; Petley, 2012). About 80% of rainfall in this country occurs in the monsoon period from June to October (Lyster & Verchick, 2018). An intense rain of 70mm per hour or more is likely to create a favorable condition for a landslide. Figure 9 shows that June exhibited the highest rainfall in Cox's Bazar (1011mm) and Teknaf (1243mm) stations, with the highest percentage of landslide occurrence, and the second-highest rainfall was observed in July at both weather stations. In the study area, respondents reported that 63.7% of landslides occur in June, the beginning of the monsoon period, 33.7% in July, 2% in August, and 0.6% in September (Figure 9).

A linear regression analysis was performed to assess the relationship between monthly average total rainfall (2000-2018) and the percentage of landslide occurrence in Cox's Bazar and Teknaf stations in Figure 10. The findings show a strong positive correlation in the Cox's Bazar region (Pearson's r = 0.76) and the Teknaf region (Pearson's r = 0.75). The R^2 values of 0.53 for Cox's Bazar and 0.52 for Teknaf indicate that rainfall alone is responsible for more than half of the variation in landslide occurrence. The intensity of rain triggers landslides in unstable hills where sandstones, siltstones, and shales rich in pyrites and lime form hills in the study area. Besides, excess rainwater dissolves these compounds, breaking

ISSN: 2185-8322
DOI10.5595/001c.143100

the strength of the hill's basement, which could lead to landslides (Y. A. Khan et al., 2012). Around 83 % of landslides happen during the monsoon season due to heavy rainfall, which results in fatalities in hillside areas (Haque et al., 2019; Petley, 2012).

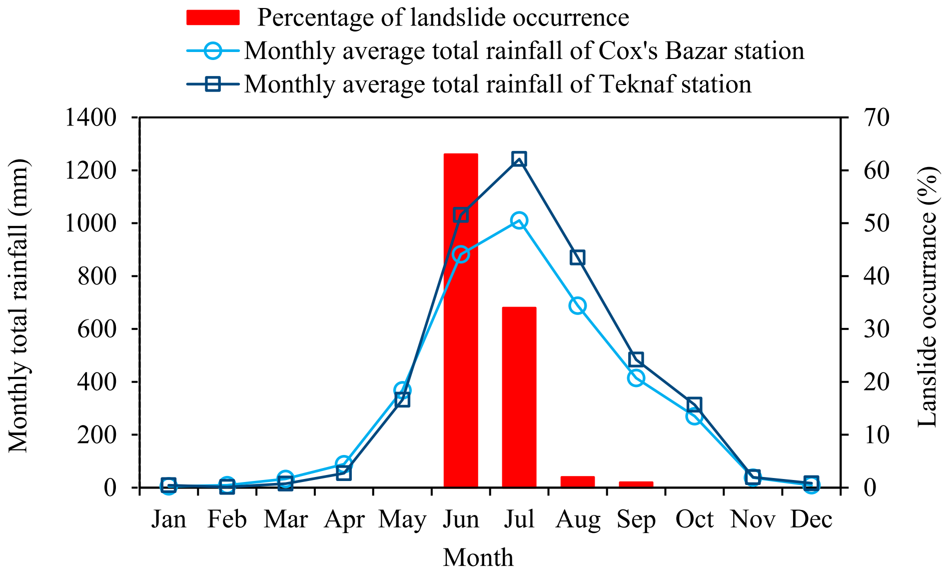

Figure 9. Monthly average total rainfall distribution of Cox's Bazar Station and Teknaf Station from 2000 to 2018 (Source: Bangladesh Meteorological Department), and perceived monthly landslide occurrence in percentage by the respondents of the study area

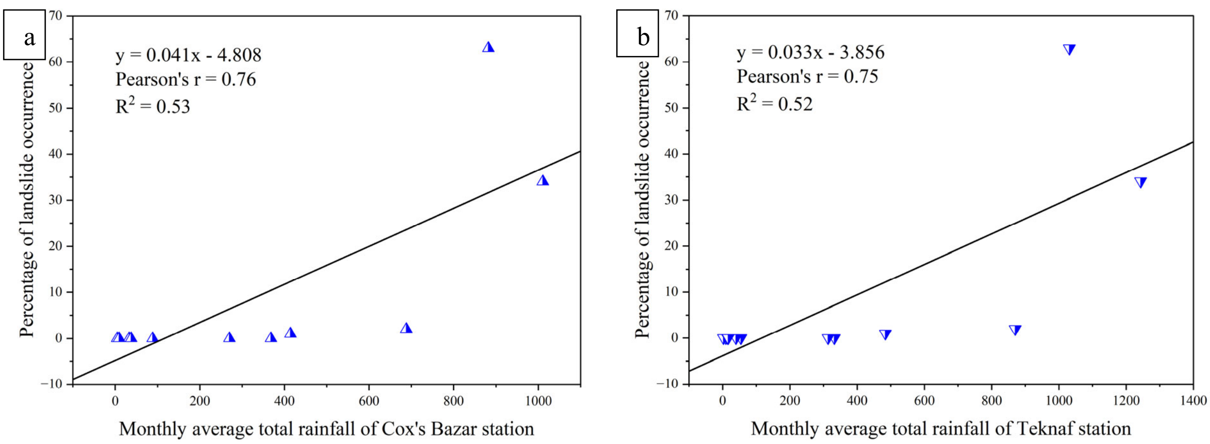

Figure 10. Relationship between monthly average total rainfall (2000-2018) and perceived monthly landslide incidence in percentage by the respondents of the study area, with a linear regression line

3.3 Anthropogenic Factors

In addition to causative factors, triggering factors accelerate the probability of landslides. In this research, hill cutting, traditional agriculture, and deforestation are triggering factors of landslides in the study area. Around 40% of respondents think hill cutting might be a significant part of landslides in the study area (Figure 11a). During the monsoon season, the forest and topsoil protect the hill area. Recently, the Rohingya people and also the local community have caused severe destruction to forests and hills by cutting trees and hills, making the area exposed to landslides (ISCG, 2019). The rapid increase in hill cutting for settlement and construction has increased the propensity of landslides in the monsoon season (Islam et al., 2006; Islam, 2008; Chisty, 2014). Research shows that over 100 hills in Cox's Bazar district have been demolished in the last 30 years (Mia et al., 2015).

Deforestation in the study area is more prone to landslides, and about 36 % of respondents state that deforestation is the leading cause of landslides (Figure 11b). Deforestation helps remove topsoil from the surface of the hill. Vegetation protects the soil. It makes the slope stable, which reduces the risk of landslides. Large trees provide strong structures in the earth that anchor the soil and protect it from erosion (I. Khan, 2008). Human intervention in the form of deforestation in hilly areas sometimes turns landslides into a calamity (Kumar & Bhagavanulu, 2008). Population increase in the landslide-prone area is one of the prime reasons for causing landslide disasters. Remarkably, the Rohingya influx has fueled the deforestation process in the study area by cutting trees for the construction of houses and also for fuel wood, and the host community also collects wood for fuel purposes (ACAPS, 2018).

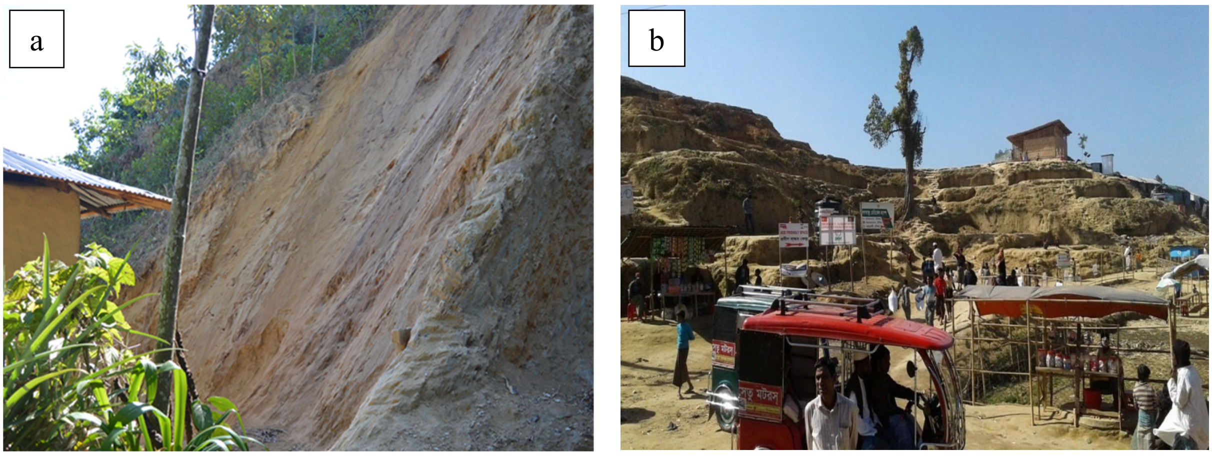

Figure 11. Hill cutting by local people (a) A house adjacent to a hill-cutting place, (b) Deforestation by the host community

About 17% of respondents believed that conventional agriculture (Jhum cultivation) is responsible for landslide disasters. Jhum cultivation (slash-and-burn agriculture technology practiced mainly by pre-plough age) is practiced on the hill slopes. In many cases, local communities clear the natural forest and various plants to make land for Jhum cultivation, causing soil exposure to erosion, which boosts landslide disasters (Rasul et al., 2004). Consequently, the Cox's Bazar coastal cliff suffers from weathering and erosion, causing many shallow failures of the loosely consolidated sandstones. Rapid urbanization, poor land use planning, and inadequate law enforcement also enhanced the frequency of landslides in this area.

Although the individual effects of topography (slope and elevation), climate (rainfall), and geotechnical (soil properties) factors have been discussed, their interconnections further clarify the intricate nature of landslide events in the study area. For instance, areas with steep slopes (12°–21°), moderate to high elevations (89-177 meters), and sandy loam or loamy sand soils-especially those with moderately acidic pH (4.9-5.7), low cation exchange capacity

(4.9-9.4 $cmol_c/kg$), and low electrical conductivity (11.5–22.7 µS/cm) showed a higher vulnerability to slope failure in high landslide vulnerable location (HLVL) in the study area. The structural stability of the hill slope is weakened by these soil conditions when the soil is saturated with heavy rainfall (up to 1200mm/month), which infiltrates the soil, increasing pore pressure and reducing cohesiveness. Regression analysis between monthly total rainfall data from 2000 to 2018 and the percentage of respondents' perceived monthly landslide occurrence showed strong correlations ($r = 0.76$ in Cox's Bazar and $r = 0.75$ in Teknaf), with R^2 values above 0.5, confirming rainfall as a primary triggering factor for landslide events in the study area. However, this hazard is significantly increased with anthropogenic disturbances, such as hill cutting or deforestation, which remove vegetation cover and reduce slope resistance. In contrast, locations with clay loam soils, near-neutral pH (6.5-7.3), and higher cation exchange capacity (14.8-16 $cmol_c/kg$) were found in moderately or less landslide vulnerable zones (MLVL or LLVL), which indicates better soil cohesion and moisture retention compared to the HLVL in the study area.

4. CONCLUSION

The study demonstrated an understanding of the causes of landslide incidence in the southeastern region of Bangladesh, focusing on Cox's Bazar district based on the triangulated methodological framework, including soil sample analysis, topographic mapping, and a semi-structured questionnaire survey with regression analysis between rainfall and landslide incidence. The findings of the study showed that the landslides are caused by the intricate interaction of geotechnical, topographic, climatic, and anthropogenic factors. Particularly during the monsoon season, the area's mountainous terrain with steep slopes and primarily sand-dominated soil particles, which are slightly acidic and have high EC concentrations with dissolved salts, are factors that contribute to the occurrence of landslides. Heavy and incessant rainfall was found to be the most significant natural trigger, increasing the likelihood of soil erosion and slope failures while also exacerbating slope instability. Furthermore, the research also found that anthropogenic factors such as deforestation, uncontrolled hill cutting, hilly agriculture, refugee concentration, and unplanned settlement in densely populated areas were the reasons for the devastating landslides. So, it is urgent to effectively and sustainably manage natural mitigation strategies to combat this disaster. This problem requires multidisciplinary strategies that combine government policies, disaster management officials, community engagement, legislators, and development agencies to increase resilience and reduce the risks of landslides in this area. The study can be useful for disaster risk reduction, geotechnical engineering, environmental management, and urban planning at both the national and international levels. Moreover, the study supports the development of integrated strategies to build resilience against landslides in hilly areas. While the current study used bivariate and perception-based analysis, future research should focus on applying multivariate statistical models or spatial modeling techniques, such as machine learning or GIS-based susceptibility mapping, and integrating long-term climate data to improve landslide prediction and support early warning systems in the study area.

ACKNOWLEDGEMENTS

The authors are indebted to Professor Dr. Sirajul Haque, Department of Soil, Water, and Environment, University of Dhaka, Bangladesh, for his guidance, suggestions, and support with laboratory analysis. Sincere appreciation is also extended to the residents of landslide-prone areas in Cox's Bazar for their voluntary participation in the survey. Special thanks to Rahul Saha, Junior GIS/RS Expert at the Urban Development Directorate (UDD), for his assistance with mapping and spatial analysis. The authors also acknowledge the 9th batch students of the Department of Geography and Environment, Jagannath University, for their participation in the field survey conducted as part of the GEOL-4107 course (Land Use and Environmental Survey).

REFERENCES

ACAPS and Start Network. (2018). *Bangladesh landslide disaster summary sheet*. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/180605%20Start%20Fund%20Bangladesh%20Landslide%20Disaster%20Summary%20Sheet.pdf [Accessed: 26 May 2025].

ACAPS. (2018). *Rohingya crisis: Host communities review*. Thematic Report: NPM-ACAPS, Analytical Hub, USA.

Ahmed, B. (2014). Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh. *Landslides*, 12(6), 1077–1095. https://doi.org/10.1007/s10346-014-0521-x

Ahmed, B. (2015). Landslide susceptibility modelling applying user-defined weighting and data-driven statistical techniques in Cox's Bazar Municipality, Bangladesh. *Natural Hazards*, 79, 1707–1737.

Ahmed, B. (2021). The root causes of landslide vulnerability in Bangladesh. *Landslides*, 18(5), 1707–1720.

Ahmed, R. (2012). Climate. In Islam, S. and Jamal, A. A. (eds.), *Banglapedia: National Encyclopedia of Bangladesh* (2nd edn). Dhaka: Asiatic Society of Bangladesh.

Ahammed, F., Hewa, G. A., & Argue, J. R. (2014). Variability of annual daily maximum rainfall of Dhaka, Bangladesh. *Atmospheric Research*, 137, 176–182. https://doi.org/10.1016/j.atmosres.2013.10.013

Alam, E. (2020). Landslide hazard knowledge, risk perception and preparedness in Southeast Bangladesh. *Sustainability*, 12(16), Article 6305. https://doi.org/10.3390/su12166305

Alexander, D. (2005). Vulnerability to landslides. In Hungr, O., Fell, R., Couture, R. and Eberhardt, E. (eds.), *Landslide Hazard and Risk*. Chichester: Wiley, pp. 175–198.

Ali, R. M. E., Tunbridge, L. W., Bhasin, R. K., Akter, S., Khan, M. M. H. & Uddin, M. Z. (2014). Landslide susceptibility of Chittagong city, Bangladesh and development of landslide early warning system. In Sassa, K., Canuti, P. and Yin, Y. (eds.), *Landslide Science for a Safer Geoenvironment*, Vol. 2: Methods of Landslide Studies. Cham: Springer, pp. 423–428.

Alkevi, T., & Ercanoglu, M. (2011). Assessment of ASTER satellite images in landslide inventory mapping: Yenice Gökçebey (Western Black Sea region: Turkey). *Bulletin of Engineering Geology and the Environment*, 70, 607–617.

Anderson, M. G., Holcombe, E., Blake, J. R., Ghesquire, F., Holm-Nielsen, N. & Fisseha, T. (2011). Reducing landslide risk in communities: Evidence from the Eastern Caribbean. *Applied Geography*, 31(2), 590–599.

Banglapedia. (2023). *Cox's Bazar District*. Available at: https://en.banglapedia.org/index.php/Cox%E2%80%99s_Bazar_District [Accessed: 26 May 2025].

Banglapedia. (2021). *Landslide*. Available at: https://en.banglapedia.org/index.php/Landslide [Accessed: 26 May 2025].

BBS (Bangladesh Bureau of Statistics). (2011). *Bangladesh Population and Housing Census 2011*. Statistics Division, Ministry of Planning, Dhaka.

BMD (Bangladesh Meteorological Department). (2019). *Bangladesh Meteorological Department Records (2000–2018)*. Agargaon, Dhaka: Bangladesh Meteorological Department.

Brammer, H. (1996). *The Geography of the Soil of Bangladesh*. Dhaka: University Press Limited, pp. 1–277.

CDMP (Comprehensive Disaster Management Programme). (2012). *Rainfall triggered landslide hazard zonation in Cox's Bazar and Teknaf municipalities as well as introducing community-based early warning system for landslide hazard management*. Ministry of Food and Disaster Management, Disaster Management and Relief Division, Government of the People's Republic of Bangladesh. Available at: http://203.76.123.197/egls/public/assets/uploads/documents/61b1edb205ad7_4.pdf [Accessed: 26 May 2025].

Çellek, S. (2020). Effect of the slope angle and its classification on landslide. *Natural Hazards and Earth System Sciences Discussions*, 2020, 1–23.

Chen, C.-W., Oguchi, T., Hayakawa, Y. S., Saito, H., & Chen, H. (2017). Relationship between landslide size and rainfall conditions in Taiwan. *Landslides*, 14, 1235–1240. https://doi.org/10.1007/s10346-016-0790-7

Chisty, K. U. (2014). Landslide in Chittagong City: A perspective on hill cutting. *Journal of Bangladesh Institute of Planners*, 7, 1–17.

Dai, F. C., & Lee, C. F. (2001). Frequency–volume relation and prediction of rainfall-induced landslides. *Engineering Geology*, 59(3–4), 253–266. https://doi.org/10.1016/S0013-7952(00)00077-6

Dhaka Tribune. (2024). 6 from 2 families killed in Cox's Bazar landslide. *Dhaka Tribune*, 13 September. Available at: https://www.dhakatribune.com/bangladesh/nation/358310/6-killed-in-cox%E2%80%99s-bazar-landslides [Accessed: 26 May 2025].

Dasanayaka, U., & Matsuda, Y. (2022). Consensus of local knowledge on landslide hazard in depopulated mountain communities in Japan – A case study on Matsunoyama Village. *IDRiM Journal*, *12*(2), 1–22.

Ercanoğlu, M., Gökceoğlu, C., & Van Asch, Th. W. J. (2004). Landslide susceptibility zoning north of Yenice (NW Turkey) by multivariate statistical techniques. *Natural Hazards*, 32, 1–23. https://doi.org/10.1023/B:NHAZ.0000026786.85589.4a

Fakhruddin, S., & Rahman, J. (2015). Coping with coastal risk and vulnerabilities in Bangladesh. *International Journal of Disaster Risk Reduction*, *12*, 112-118. https://doi.org/10.1016/j.ijdrr.2014.12.008

Froude, M. J., & Petley, D. N. (2018). Global fatal landslide occurrence from 2004 to 2016. *Natural Hazards and Earth System Sciences*, *18*(8), 2161–2181. https://doi.org/10.5194/nhess-18-2161-2018

Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology*, *31*(1–4), 181–216.

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M., & Chang, K.-T. (2012). Landslide inventory maps: New tools for an old problem. *Earth-Science Reviews*, 112, 42–66.

Hamarashid, N., Othman, M., & Hussain, M. (2010). Effects of soil texture on chemical compositions, microbial populations and carbon mineralization in soil. *Egyptian Journal of Experimental Biology*, *6*, 59–64.

Haque, U., Blum, P., Da Silva, P. F., Andersen, P., Pilz, J., Chalov, S. R., Malet, J.-P., Auflič, M. J., Andres, N., Poyiadji, E., Lamas, P. C., Zhang, W., Peshevski, I., Pétursson, H. G., Kurt, T., Dobrev, N., García-Davalillo, J. C., Halkia, M., Ferri, S., Engström, J., & Keellings, D. (2016). Fatal landslides in Europe. *Landslides*, *13*, 1545–1554. https://doi.org/10.1007/s10346-016-0689-3

Haque, U., Da Silva, P. F., Devoli, G., Pilz, J., Zhao, B., Khaloua, A., Wilopo, W., Andersen, P., Lu, P., Lee, J., Yamamoto, T., Keellings, D., Wu, J., & Glass, G. E. (2019). The human cost of global warming: Deadly landslides and their triggers (1995–2014). *Science of The Total Environment*, *682*, 673-684. https://doi.org/10.1016/j.scitotenv.2019.03.415

Hong, H., Ilia, I., Tsangaratos, P., Chen, W., & Xu, C. (2017). A hybrid fuzzy weight of evidence method in landslide susceptibility analysis on the Wuyuan area, China. *Geomorphology, 290*, 1–16.

ISCG (Inter Sector Coordination Group). (2019). Situation report: Rohingya refugee crisis, Cox's Bazar – July 2019. Cox's Bazar, Bangladesh. Available at: https://reliefweb.int/report/bangladesh/iscg-situation-report-rohingya-refugee-crisis-cox-s-bazar-july-2019 [Accessed: 26 May 2025].

Islam, M. A. (2018). Measures for landslide prevention in Chittagong Hill Tracts of Bangladesh. M.Sc. Eng. Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET).

Islam, M. A., Islam, M. S., & Islam, T. (2017). Landslides in Chittagong Hill Tracts and possible measures. In Proceedings of the International Conference on Disaster Risk Mitigation, Dhaka, Bangladesh, 23–24 September 2017.

Islam, M. S. (2008). Hill cutting in Chittagong and environmental degradation. Paper presented at the Special Conference on Hill Cutting, Forum for Planned Chittagong, Chittagong.

Islam, M. S. (2018). Effects, causes, and possible measures of landslide in Bangladesh (Chittagong). *Engineering Science, 3*(4), 58–63.

Islam, M. S., Hasan, G. J., & Chowdhury, M. A. I. (2006). Destroying hills in the north eastern part of Bangladesh: A qualitative assessment of extent of the problem and its probable impact. *International Journal of Environmental Science & Technology, 2*(4), 301–308. https://doi.org/10.1007/BF03325890

Jayanthi, J., Raj, T. N., & Gandhi, M. S. (2016). Identification of landslide-prone areas using remote sensing techniques in Sillahalla watershed, Nilgiris District, Tamilnadu, India. *International Journal of Engineering & Technology, 3*(6),1947–1952.

Khan, I. (2008). Hill cutting in Chittagong City Corporation area: Its causes and the consequences. PhD Dissertation, Khulna University.

Khan, M. J. U., Islam, A. S., Bala, S. K., & Islam, G. T. (2020). Changes in climate extremes over Bangladesh at 1.5° C, 2° C, and 4° C of global warming with high-resolution regional climate modeling. *Theoretical and Applied Climatology, 140*,1451–1466.

Khan, Y. A., Lateh, H., Baten, M. A., & Kamil, A. A. (2012). Critical antecedent rainfall conditions for shallow landslides in Chittagong City of Bangladesh. *Environmental Earth Sciences, 67*(1), 97–106. https://doi.org/10.1007/s12665-011-1483-0

Kirschbaum, D., Stanley, T., & Zhou, Y. (2015). Spatial and temporal analysis of a global landslide catalog. *Geomorphology, 249*, 4–15.

Kumari, N., & Mohan, C. (2021). Basics of clay minerals and their characteristic properties. *Clays and Clay Minerals, 24*(1).

Kumar, S. V., & Bhagavanulu, D. V. S. (2008). Effect of deforestation on landslides in Nilgiris district—A case study. *Journal of the Indian Society of Remote Sensing, 36*, 105–108.

Lee, S., & Min, K. (2001). Statistical analyses of landslide susceptibility at Yongin, Korea. *Environmental Geology, 40*(9), 1095–1113. https://doi.org/10.1007/s002540100310

Lyster, R., & Verchick, R. R. M. (eds.) (2018). Research Handbook on Climate Disaster Law: Barriers and Opportunities. UK & USA: Edward Elgar Publishing Limited. https://doi.org/10.1163/26662531-01001035

Mahmood, A. B., & Khan, M. H. (2010). Landslide vulnerability of Bangladesh hills and sustainable management options: A case study of 2007 landslide in Chittagong city. Paper presented at the SAARC Workshop on Landslide Risk Management in South Asia, Thimphu, Bhutan.

Martin, J. G. C., Khadka, P., Linnerooth-Bayer, J., Velev, S., Russell, C., Parajuli, B. P., Shaky, P., Vij, S., & Liu, W. (2021). Living with landslides: Perceptions of risk and resilience in far West Nepal. *IDRiM Journal, 11*(2).

Matori, A. N., & Basith, A. (2012). Evaluation of landslide causative factors towards efficient landslide susceptibility modelling in the Cameron Highlands, Malaysia. *WIT Transactions on Engineering Sciences*, *73*, 207-217.

Mia, M. T., Sultana, N., & Paul, A. (2015). Studies on the causes, impacts and mitigation strategies of landslide in Chittagong City, Bangladesh. *Journal of Environmental Science and Natural Resources, 8*(2), 1–5.

Mohiuddin, M., & Nowreen, S. (2023). Climate change-induced livelihood vulnerabilities in south western coastal region of Bangladesh. *Jagannath University Journal of Life and Earth Sciences, 9*(2), 163–178. https://doi.org/10.3329/jnujles.v9i2.72922

Mutizwa-Mangiza, N., Arimah, B., Jensen, I., Yemeru, E., & Kinyanjui, M. (2011). Cities and climate change: Global report on human settlements. UN-HABITAT, 250 pp.

Nel, T. (2021). Conversion of soil pH values and exchangeable base cation quantities determined by different methods. Doctoral dissertation, Stellenbosch University, Stellenbosch.

Ngole, V. M., Georges-Ivo, E. E., & Ayonghe, S. N. (2007). Physico-chemical, mineralogical and chemical considerations in understanding the 2001 Mabeta New Layout landslide, Cameroon. *Journal of Applied Sciences and Environmental Management, 11*(2).

NDSU (North Dakota State University). (2020). pH range for North Dakota soils. Available at: https://www.ndsu.edu/soilhealth/?page_id=350 [Accessed: 26 May 2025].

Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science, 2019*(1), 5794869. https://doi.org/10.1155/2019/5794869

Nowreen, S., & Mohiuddin, M. (2017). An assessment on application of indigenous knowledge as disaster risk reduction strategies in Kutubdia, Cox's Bazar, Bangladesh. *Dhaka University Journal of Science, 65*(2), 125–132.

O'Geen, A. T. (2013). Soil water dynamics. *Nature Education Knowledge, 4*(5), 9. https://www.nature.com/scitable/knowledge/library/soil-water-dynamics-103089121/

Parker, R. N., Densmore, A. L., Rosser, N. J., De Michele, M., Li, Y., Huang, R., Whadcoat, S., & Petley, D. N. (2011). Mass wasting triggered by the 2008 Wenchuan earthquake is greater than orogenic growth. *Nature Geoscience, 4*(7), 449-452. https://doi.org/10.1038/ngeo1154

Petley, D. N., Hearn, G. J., Hart, A., Rosser, N. J., Dunning, S. A., Oven, K., & Mitchell, W. A. (2007). Trends in landslide occurrence in Nepal. *Natural Hazards, 43*, 23–44.

Petley, D. (2012). Global patterns of loss of life from landslides. *Geology, 40*(10), 927–930. https://doi.org/10.1130/g33217.1

Pham, B. T., Bui, D. T., Prakash, I., & Dholakia, M. B. (2017). Hybrid integration of multilayer perceptron neural networks and machine learning ensembles for landslide susceptibility assessment at Himalayan area (India) using GIS. *Catena, 149*, 52–63. https://doi.org/10.1016/j.catena.2016.09.007

Rabby, Y. W., & Li, Y. (2019). An integrated approach to map landslides in Chittagong Hilly Areas, Bangladesh, using Google Earth and field mapping. *Landslides, 16*, 633–645.

Rashid, H. (1991). Geography of Bangladesh. Dhaka: University Press Limited.

Rasul, G., Thapa, G. B., & Zoebisch, M. A. (2004). Determinants of land-use changes in the Chittagong Hill Tracts of Bangladesh. *Applied Geography, 24*(3), 217–240. https://doi.org/10.1016/j.apgeog.2004.03.004

Roy, R., Haque, D. M. E., Sifa, S. F., Tasnim, S., Mahmud, T., & Hayat, T. (2022). Empirical approach-based rainfall threshold estimation for landslide occurrence in Cox's Bazar District, Bangladesh. *IDRiM Journal, 11*(1), 81–94.

Sarwar, G. M. (2008). Landslide tragedy of Bangladesh. United Nations University (UNU), pp. 18–21.

Schuster, R. L. (1996). Socioeconomic significance of landslides. *Landslides: Investigation and mitigation*, *247*, 12-35.

Sharma, L. P., Patel, N., Debnath, P., & Ghose, M. K. (2012). Assessing landslide vulnerability from soil characteristics—a GIS-based analysis. *Arabian Journal of Geosciences, 5*, 789–796.

Sultana, N. (2020). Analysis of landslide-induced fatalities and injuries in Bangladesh: 2000–2018. *Cogent Social Sciences, 6*(1), 1737402.

Sultana, T. (2013). Landslide disaster in Bangladesh: A case study of Chittagong University campus. *International Journal of Research in Applied, 1*(6), 35–42.

Tandrila, A. T., Mohiuddin, M., Hossain, M. A., Rahman, M. S., & Samad, A. (2020). Causes of landslides in Chittagong Hill Tracts, Bangladesh. National Geographical *Journal of India (NGJI), 66*(1), 41–50.

Tahir, S., & Marschner, P. (2016). Clay addition to sandy soil: Effect of clay concentration and ped size on microbial biomass and nutrient dynamics after addition of low C/N ratio residue. *Journal of Soil Science and Plant Nutrition, 16*(4), 864–875.

Tomašic, M., Zgorelec, Ž., Jurišic, A., & Kisic, I. (2013). Cation exchange capacity of dominant soil types in the Republic of Croatia. *Journal of Central European Agriculture, 14*(3), 937–951.

UNICEF. (2019). Monsoon rains bring severe flooding and landslides across South Asia, affecting more than five million children. Available at: https://www.unicef.org/press-releases/monsoon-rains-bring-severe-flooding-and-landslides-across-south-asia-affecting-more [Accessed: 26 May 2025].

USDA and NRCS (United States Department of Agriculture and Natural Resources Conservation Service). (2020). Soil electrical conductivity—Soil quality kit: Guide for educators. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053280.pdf [Accessed: 26 May 2025].

Van Eynde, E., Dondeyne, S., Isabirye, M., Deckers, J. and Poesen, J. (2017). Impact of landslides on soil characteristics: Implications for estimating their age. *Catena, 157*, 173–179.

Walpola, B. C., & Arunakumara, K. K. I. U. (2010). Decomposition of Gliricidia leaves: The effect of particle size of leaves and soil texture on carbon mineralization. *Tropical Agriculture Research, 13*, 19–23.

Wieczorek, G. F. (1996). Landslides: investigation and mitigation. Chapter 4-Landslide triggering mechanisms. *Transportation Research Board Special Report*, (247).

Yamane, T. (1967). Statistics: An introductory analysis (2nd edn). New York: Harper and Row; Evanston and London; and John Weatherhill, Inc., Tokyo.

Yilmaz, I. (2009). Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks, and their comparison: A case study for Kat landslides. *Computers & Geosciences, 35*, 1125–1138.