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Modeling Landslides Catastrophe for Risk Analysis and Management in Chittagong City of Bangladesh

Rathindra Nath Biswas[1]
Mohammad Sujoun Lasker[2]

Abstract: This study was carried out for inventory mapping, landslide-occurring mechanisms, bio-physical risk analysis, and proper mitigation strategies. Therefore, the causal mechanism of the landslide catastrophe was assessed by the DPSIR model framework. Accordingly, technological, structural, and non-structural management models are also applied for landslide catastrophe mitigation in the vulnerable zones of the study area. Technological management models focused on early warning and raising awareness through various communication devices; structural management models prevented structural development and enhanced hilly areas with a green-ecological approach; and non-structural management models included settlement, land use, building code. To accomplished the research goal, both qualitative and quantitative analyses were applied using primary and secondary sources of data. Moreover, GIS cartographic tools and techniques were used for risk mapping, considering the geological, geomorphological, topographical, hydrometrological, and anthropogenic aspects of the study area. Analysis results demonstrated that the probability of catastrophic landslides occurring (67.27%) was far higher than the probability of other hazards, including flooding (0.15%), earthquakes (6.57%), tropical cyclones (0.84%), and waterlogging (25.17%). The findings of the research will help disaster management specialists, environmentalists, urban planners, and decision-makers in mitigation approaches to landslide catastrophes in the study area.

Keywords: Landslides catastrophe, Bio-physical impacts, Risk analysis and management, Sustainable adaptation option.

1. Introduction

Landslide catastrophes have a long history in the rapidly urbanised tertiary hilly region of Chittagong City (Ahmed, 2015). Both natural and human factors contribute to the frequent landslide disasters that occur during the summer's torrential rains. Moreover, landslide catastrophes are accelerated by the physical characteristics of the study area, such as geological formations, geomorphological structures, topographical landforms, and soil textures, and these are weak in their composition, which breaks down downward along the hill slope due to various geomorphic agents and faster with climate change (Biswas et al., 2017). On the other hand, anthropogenic aspects of landslide catastrophe occurring in the

[1] Research Consultant, Remote Sensing Division, Center for Environmental and Geographic Information Services (CEGIS), Gulshan 1, Dhaka 1212, Bangladesh. (E-mail: rathingeoju39@gmail.com)

[2] Research Consultant, GIS Division, Center for Environmental and Geographic Information Services (CEGIS), Gulshan 1, Dhaka 1212, Bangladesh. (E-mail: sujounju40@gmail.com)

study area include fast urbanisation along the top hills, hillslope, and foot hills; increased urban population density through migration from various districts of Bangladesh for their life and livelihood development; improper land use through various structural developments such as road networks and multipurpose concrete buildings; and changing the hilly areas by illegally cutting down hills and trees without following the rules and regulations of the Chittagong Development Authority (CDA) (Khan et al., 2012).

Landslide catastrophes have widespread impacts on the bio-physical environment, socio-cultural landscape, people's lives, and livelihoods. Furthermore, in the study area, there are no proper landslide management strategies for structural planning, legal authorities for hill ownership, or existing hill management policies regarding this catastrophe. As a result, hill-cutting scenarios in the tertiary hilly area within Chittagong City have become a common phenomenon that intends to urbanise the process through structural development and informal settlement dwellers. Along the landslide-prone hill slopes, poor hill management policies encourage the development of informal settlements, which can occasionally lead to severe land tenure disputes between local communities, informal settlers, and formal authorities. These disputes have additionally sapped the institutional framework for reducing the vulnerability of Chittagong City to landslides (Ahammad, 2009; Ahmed, 2015).

Few studies exist regarding the modelling of landslide catastrophes in Chitagong City (Ahmed and Dewan., 2017; Biswas et al., 2017). However, several studies assess landslide susceptibility using geospatial models (Ali et al., 2014; Das and Raja., 2015; Islam et al., 2017). Chist (2014) explored unplanned hill cutting as a major cause of urban landslide disasters. Khan et al. (2012) identified rainfall as the main triggering factor of landslides that are catastrophic in the city. Ahmed et al. (2018) develop a web-GIS-based early warning system to mitigate landslides in the Chittagong Metropolitan Area. Therefore, there is hardly any study regarding modelling landslide catastrophes for risk analysis and management strategies through examination of geology, geomorphology, topography, and field inventory. Unfortunately, in the past, there was hardly any research carried out examining the causal mechanisms of landslide disasters by employing the DPSIR model framework. Furthermore, in the earlier research on mitigation strategies and sustainable solutions for landslide catastrophes in Chittagong City, there was no reliable structural, non-structural, or technological communication model. To reach the research goal and overcome the research gaps left by the earlier study, the present study analyses risk through quantitative investigation and directs sustainable management strategies to reduce landslide risk in Chittagong City.

1.1 Aim and Objectives of the Research

The aim of the study is modeling landslides catastrophe for risk analysis and management strategies in Chittagong City of Bangladesh. The specific objectives under aim are following:

a. Mapping landslide catastrophe inventory through examination of geological formations, geomorphological landforms, topographic elevation and slope, and ground-field investigation with a GPS survey;

b. To explore causal mechanism of landslides catastrophes applying DPSIR model framework; and

c. To assess the risk and a structural, non-structural, and technological communication model for the mitigation of the landslide catastrophe.

2. Geo-physical Environment of the Study Area

Chittagong City lies in a tertiary hilly region, which is the second largest and main seaport city of Bangladesh. Geographically, this city is located between 21°54′ N and 22°59′ N latitude and 91°17′ east and 92°14′ E longitude and is made up of isolated hills and narrow valleys, surrounded to the south-east by the Karnaphuli River, to the west by the Bay of Bengal, and to the north-east by the Halda River (Fig. 1). Chittagong City is a part of Chittagong Hill Tracts (CHT), which is a geologically sensitive area for landslide catastrophes because it originated as a result of collisions between India and Asia during the period of the Tertiary geological time scale. (Chowdhury 2012). The topographical landforms of this city resemble the folded belt of the Bengal Foredeep, and a series of folded belts of tertiary hills extend their range from north to south through Chittagong City. In contrast, the folded region inside the Chittagong City area is characterised by the presence of the Tipam Sandstone formation and the Girujan Clay Formation, which originated during the Pliocene epoch. These formations are situated at the lower section, while the Dupi Tila formation, formed during the Pleistocene epoch, is found at the uppermost layer (Reimann, 1993; Khan et al., 2012). Furthermore, the elevation of the tertiary hills inside the city measures approximately 60 metres above the average sea level. These hills exhibit a gradual decrease in height towards the eastern and southeastern regions, ultimately reaching the Karnaphuli River. In recent years, the city of Chittagong has witnessed an elevated level of monsoon rainfall, resulting in an increased vulnerability to landslides. This phenomenon can be attributed to the effects of climate change (Mangiza, 2011). The climate of Chittagong City is influenced by tropical monsoon climatic characteristics, resulting in an average annual rainfall of approximately 2540 mm in the northeast and 2540 to 3810 mm in the southwest (Ahmed, 2015). Furthermore, rapid urbanisation, industrialization, and multi-structural development modified existing Tertiary hills and illegally cut hills with slopes of 70°–80°, ignoring the significant risk of landslide catastrophe. The occurrence of landslides poses a significant risk to the recently established hillside slums and informal settlements located in the elevated regions of Devpahar, Motijhorna, Khulshi, Baizid Bostami, Foy's Lake, Batali Hill, Nasirabad, and Kusumbagh inside the tertiary hilly parts of Chittagong City.

3. Methods and Materials

3.1 Landslides Catastrophe Inventory

In this study, landslide catastrophe inventory maps are produced with the intention of serving various purposes (Brabb, 1991), among other things, to look into the types, patterns, and spatial distribution of landslides in relation to geomorphological and geologic variables (Guzzetti et al., 1996) in Chittagong City. A field GPS survey was carried out for the identification of landslide catastrophe IDs within the hilly area of Chittagong City, from which 11 landslide IDs were collected with geographical references such as latitude and longitude. The spatial distribution of observed landslides is represented by geological formations, geomorphological landforms, and topographic landform elevation and slope, which data are collected from the Geological Survey of Bangladesh (GSB) with a scale of 1:250,000 (1997) and a satellite image SRTM DEM with a spatial resolution of 30 m×30 m provided by the U.S. Geological Survey (USGS).

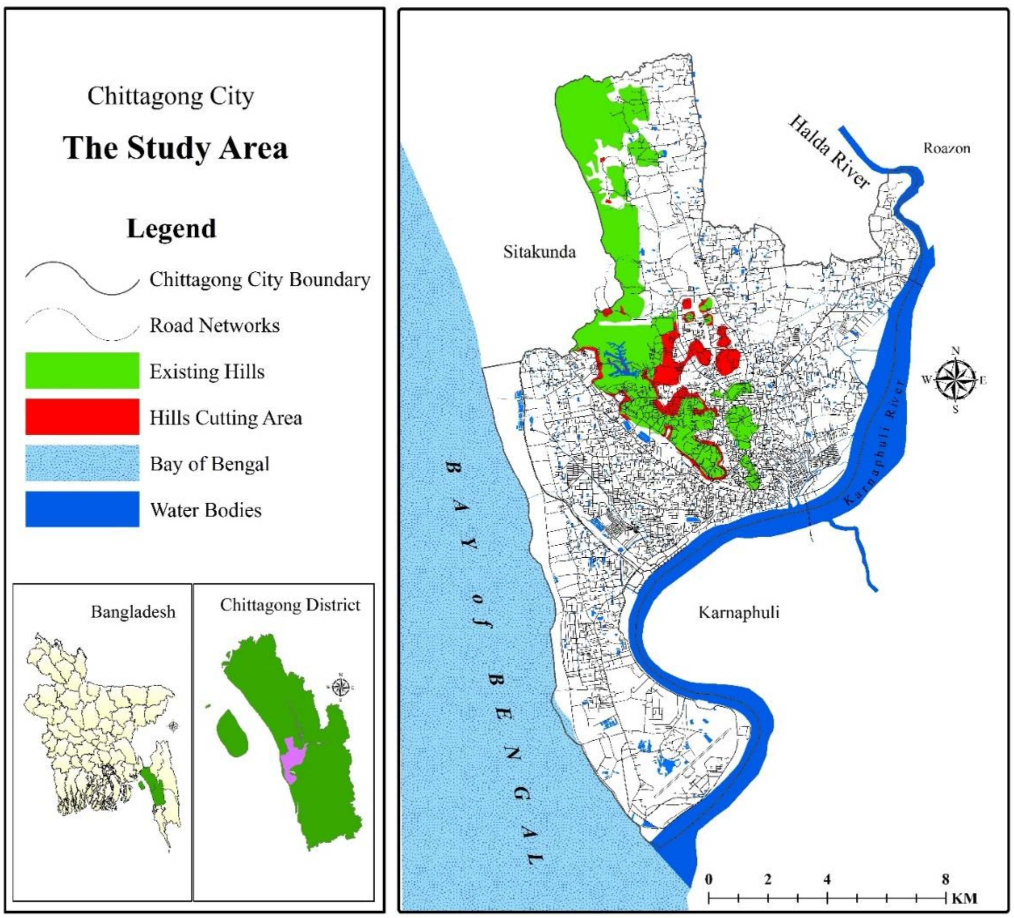

Figure1: Geographical extent of the study area (Chittagong City).

3.2 Causal Mechanism of Landslides Catastrophe with DPSIR Model

Landslides catastrophe underlying mechanism analysis with the concept of DPSIR model (Fig. 2). The European Environmental Agency (EEA) has selected a DIPSIR model concept that is one of the frameworks based on the idea of causality chains for data synthesis, linking information on the environment using indicators of various types

(Kristensen 2004; Islam and Kitazawa). For instance, D= Driving forces refer to the causative mechanisms that contribute to the occurrence of catastrophic landslides, P= indicators of pressure characterize the variables that directly cause catastrophic landslides, S= the indicators pertaining to landslides provide an assessment of their present state, while the impact indicators elucidate the ultimate consequences resulting from alterations in this status. R= indicators of response illustrate the endeavors of society in relation to landslides (i.e. legislators, administrators, and investors are key actors involved in the formulation and implementation of policies and initiatives) to resolve the environmental issues (Thomas, 1995).

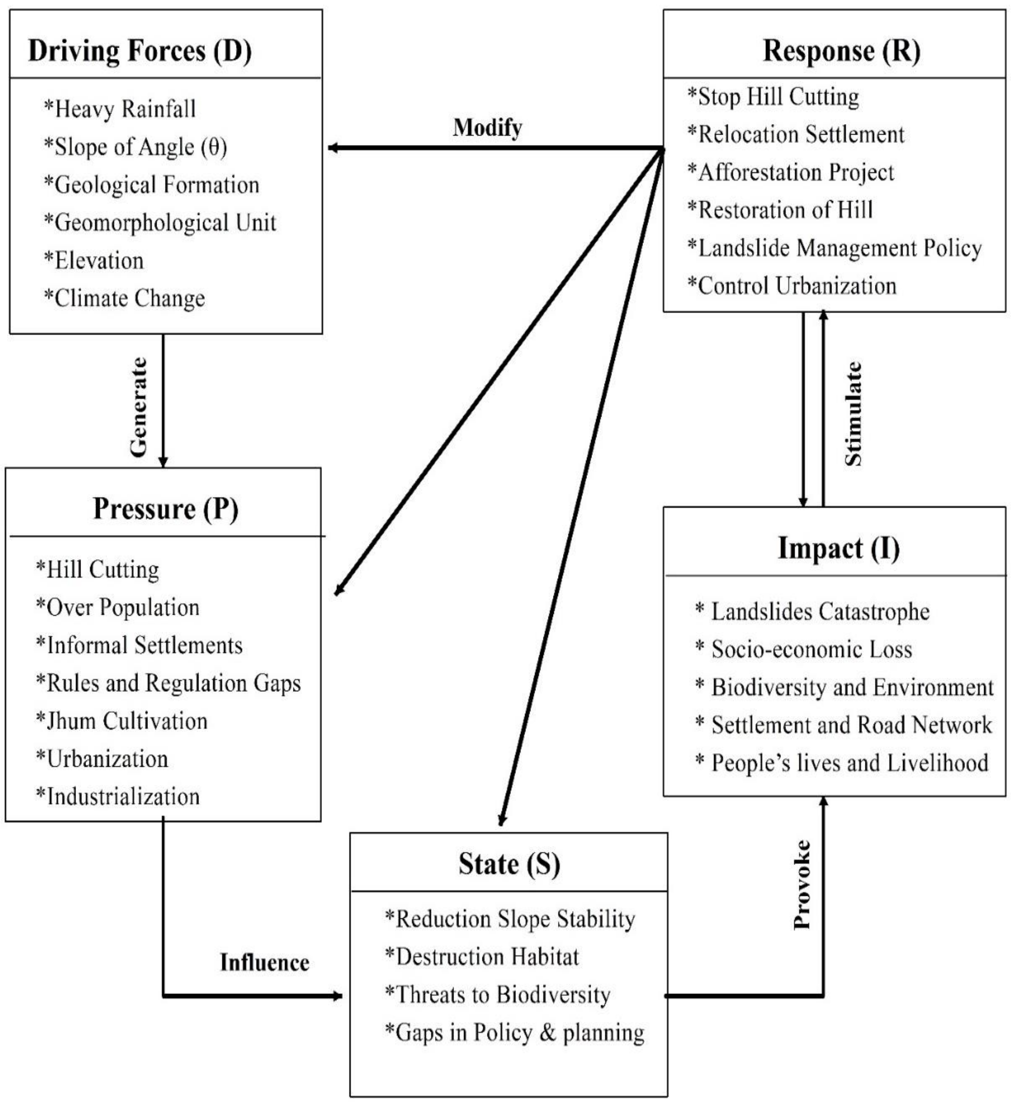

Figure 2: Causal mechanism of landslides in Chittagong City with DPSIR model framework.

3.3 Risk Analysis Assessment

Risk is the actual exposure of something of human value to a particular catastrophe and is often regarded as the combination of probability and losses. Generally, risk is expressed as the product of monetary value and probability. Usually, it is impossible to put a monetary value on the number of lives lost in natural catastrophes. In the current study, the risk that arises from the frequency and probability of hazards and the property damage or loss that they cause is evaluated by determining the monetary value of these hazards. Generally, the present study carried out risk assessment approaches for management strategies by ranking the hazards. Therefore, catastrophe risk analysis encompasses the evaluation of the probability of natural or human-induced disasters occurring within a certain future timeframe, together with an examination of their magnitude and geographical extent of consequences. The most commonly used risk calculation equation is: risk = catastrophe (P) × vulnerability (L) (CEC, 2009). Where catastrophe is an event that can affect life, property, and the bio-physical environment, or the probability of the occurrence of an event or its consequences, and vulnerability is the extent to which a community and the bio-physical environment are likely to be affected by a particular catastrophe or the value of the consequences arising from such a catastrophe, There are three distinct steps required for risk analysis: identification of catastrophic events, estimation of the probability of each catastrophe risk, and evaluation of the losses created by each catastrophe or their consequences. Using methods like in-depth interviews, quantitative surveys of households, household questionnaire surveys (n = 127), direct field observations, focus group discussions, and conversations with government organisations, ward members, committees of wards, ward level volunteers, and community members, as well as secondary sources like newspapers, journals, books, etc., data on different types of disasters was collected and sorted by how likely they were to people property damage.

3.5, Structural, Non-structural and Technological Communication Models

The structural model includes a series of plans for restricted structural development in existing hilly areas. Moreover, this model standardises several measures of hill management policy, rules, and regulations by the government and development authority regarding landslide catastrophes (Fig. 3). The theme of this model is to implement restoration of degraded hills with a green ecological approach, including structural expansion and informal settlement. The goal of the structural model is to unenthusiastic future anthropogenic activities over the hilly area to keep landslides-free hilly environment. On the other hand, the non-structural model provides proper planning of settlements, land use, fire services, and rescue operations for future landslide catastrophe mitigation (Fig. 4). In this study, a technological communication model was developed to raise awareness among vulnerable people about their preparedness in disaster periods. The theme of this model also reflects the role of disaster management's institutions in landslide management strategies.

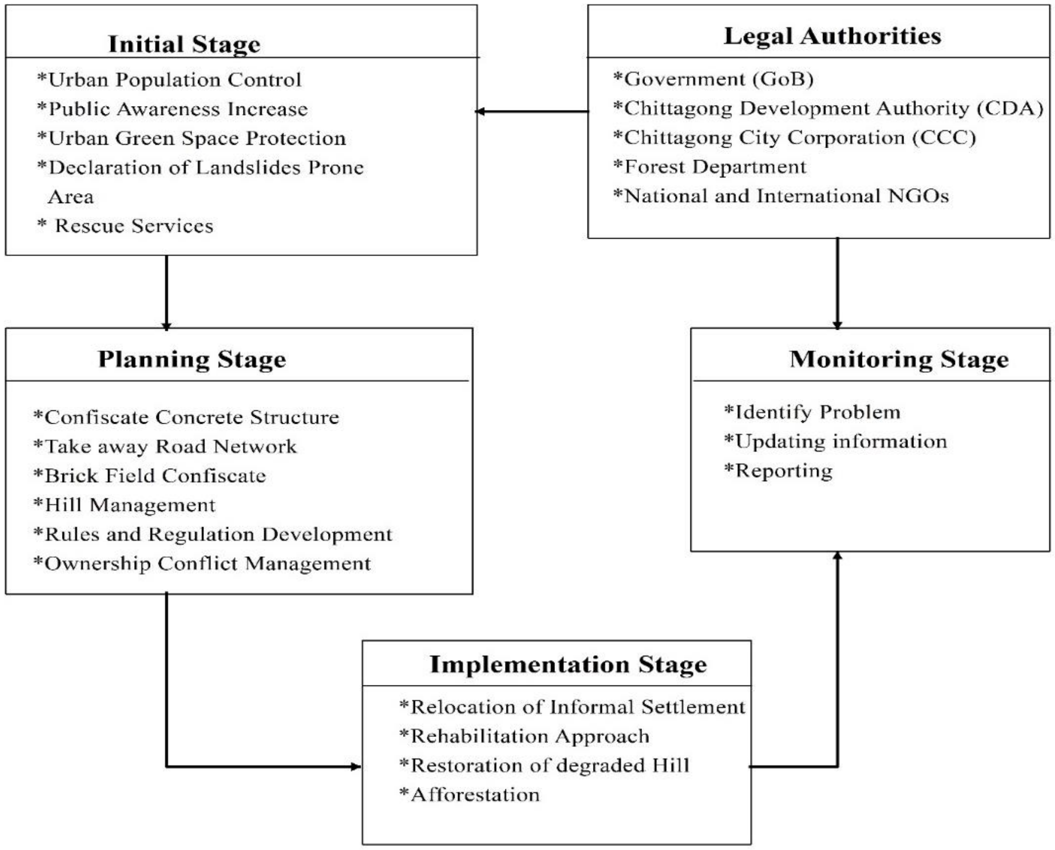

Figure 3: Structural model for landslides catastrophe mitigation strategies.

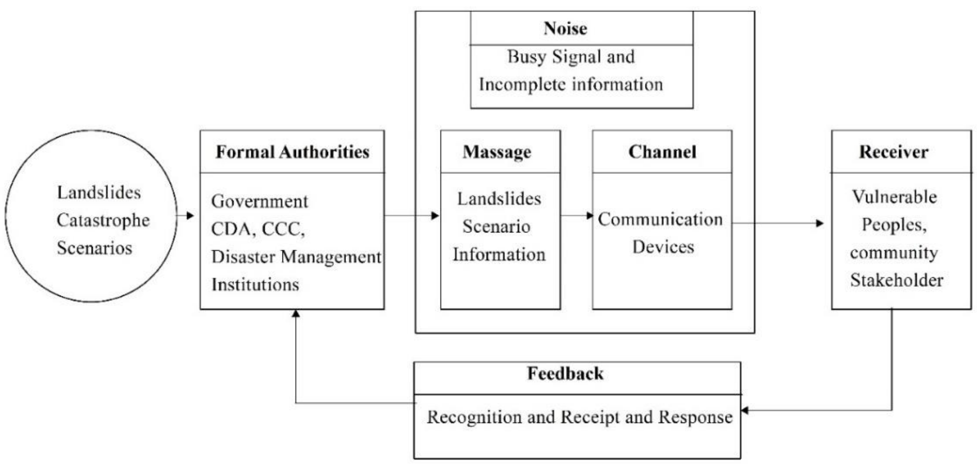

Figure 4: Technological communication model for raise people awareness for landslides catastrophe risk mitigation.

4. Result and Discussion

4.1 Evaluation of Landslides Catastrophe Inventory

The landslide catastrophe inventory database of Chittagong City is summarised in Table 1 with geographical location, slope geometry (minimum, maximum, and standard deviation), and triggering factors. The dataset consisting of 11 instances of landslide disaster ID revealed that the soil texture density values (ρ) varied between 1.47 and 1.77 g/cm3, with a mean value of 1.68 ±0.086, indicating sandy to sandy loam soil texture. The slope of angle (θ) of landslides ID in the tertiary hilly region of Chittagong City varied from 57° to 86° with a mean value of 74.82°±8.43°, and the elevation varied from 69 m to 139 m with a mean value of 104.27±20.73. In geological formation, 55.5% of landslides occur in the Tipam formation and 45.5% in the Upper Tipam formation (Fig. 5(a)). On the other hand, geomorphological landforms are also susceptible to landslide catastrophes, where 45.5%, 36.36%, and 9.09% of landslides occur in the depression, rounded top, highly dissected, and lower hill, respectively (Fig. 5(b)). The inclusion of landslide catastrophic inventory mapping in fieldwork is a fundamental component of conventional geomorphological mapping practices. The spatial distribution of landslides is represented in topographic landform elevation and slope maps (Fig. 5(c, d)).

Table 1: Geographical reference, slope geometry and triggering factors of landslides.

Name	Geographical Location		Soil Texture	Density (ρ)	Angle of Slope (θ)	Elevation (m)	Triggering Factors
Landslides ID	**Latitude**	**Longitude**					
ID 1	22°21'31.10"N	91°49'9.17"E	Sandy Soil	1.65	75.00	81.00	H, R
ID 2	22°21'22.78"N	91°49'19.40"E	Sandy Loam	1.56	85.00	69.00	H, R
ID 3	22°20'48.23"N	91°49'10.09"E	Sandy Loam	1.47	70.00	96.00	R,I
ID 4	22°20'37.97"N	91°49'1.05"E	Sandy Loam	1.75	57.00	110.00	H, R
ID 5	22°20'39.89"N	91°49'3.74"E	Sandy Soil	1.69	80.00	109.00	H, R
ID 6	22°21'49.78"N	91°47'43.65"E	Sandy Loam	1.67	75.00	95.00	H, I
ID 7	22°21'56.43"N	91°47'41.12"E	Sandy Soil	1.77	75.00	110.00	H, I
ID 8	22°21'57.00"N	91°47'39.82"E	Sand Soil	1.71	84.00	120.00	H, I
ID 9	22°21'58.49"N	91°47'37.90"E	Sandy Loam	1.73	66.00	116.00	H, I
ID 10	22°22'2.16"N	91°47'30.48"E	Sandy Soil	1.76	70.00	139.00	H, R
ID 11	22°22'0.97"N	91°47'40.62"E	Sand Soil	1.70	86.00	102.00	H, R
Average				1.68	74.82	104.27	

Note: H= Hill Cutting, R= Rainfall, I=Informal Settlement Intervention

Sources: Field investigation, lab analysis by authors, 2015.

4.2 Causal Mechanism, Impacts and Solution of Landslides Catastrophe

Illegal hill cutting, rapid urbanisation, industrialization, informal settlement, overpopulation density, and Jhum cultivation increase frequency of landslide catastrophes during the rainy season in the Tertiary hilly region of Chittagong City. Historical landslide catastrophe scenario analysis results reveal that Tertiary Hilly City is facing numerous impacts: 1) damage the socio-economic environment; 2) loss of human life and livelihood; 3) damage roads and communication systems; 4) push for migration and accelerated poverty; 5) reduction and extinction of biodiversity, including flora, fauna, herbs, shrubs, birds, and reptiles; 6) loss of mountain forest cover and deterioration of hilly ecology; 7) diversification of landscape culture and people's occupation. The possible solution to landslide catastrophe-induced social and biophysical environmental problems includes a series of steps and planning, such as: 1) tertiary hill management planning; 2) urban urbanisation planning; 3) efficient hill land ownership conflict management policy; 4) long-term sustainable urban development planning; 5) efficient hill ecosystem management rules; 6) relocation and rehabilitation informal settlements policy, rules, and regulations; 7) planning efficient afforestation and forest restoration projects; and 8) efficient urban settlement planning and developing their building code.

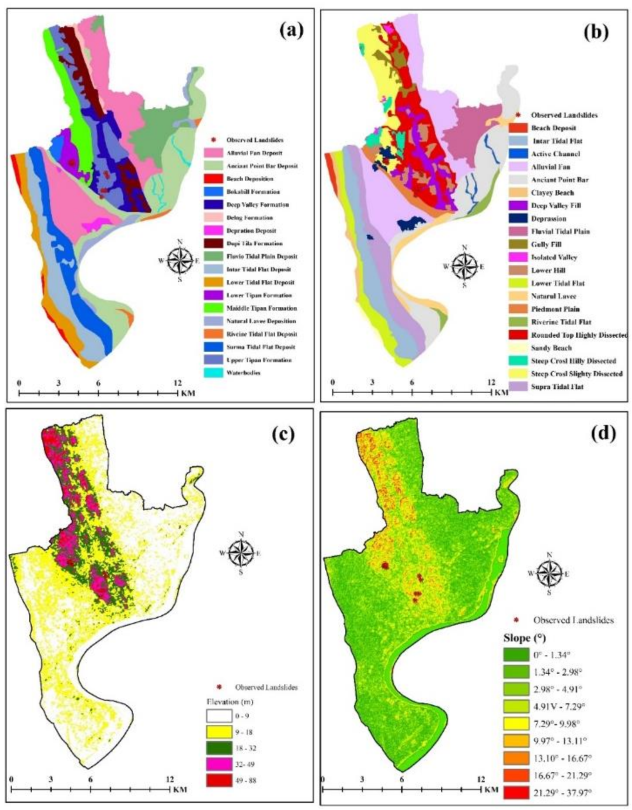

Figure 5: Landslides inventory maps: (a) landslides inventory mapping in geological formation; (b) landslides inventory mapping in geomorphological landforms formation); (c) landslides inventory mapping in topographical elevation; (d) landslides inventory mapping in topographical slope.

Based on the perspectives of stakeholders, the potential implementation of the following steps is suggested as shared solutions: 1) The significance of tertiary hill management strategies for mitigating landslide catastrophes in Chittagong City must be recognised at the national, regional, and community levels; 2) expansion of urbanisation, industrialization, improper landuse pattern, informal settlement, Jhum cultivation practices, and illegally cutting the hills need to be restricted by formal authorities; 3) introduction to sustainable management practices of tertiary hilly forest cover for reduction of landslide catastrophe risk; 4) anthropogenic activities in selected degraded hilly areas must be unenthusiastic; 5) all the human structures like road networks, buildings, and informal settlements must be relocated; 6) raise public awareness through development communication systems in disaster periods; 7) Government and non-government organisations should increase attention to spread awareness among the community; 8) The implementation of scientific and systematic research is needed for the comprehensive assessment of landslides, including inventory mapping, susceptibility mapping, and urban landscape design. This approach is essential at several scales, ranging from community to regional and national levels.

4.3 Risk Analysis

Chittagong City is vulnerable to landslides catastrophe comparing with other hazards such as tropical cyclone, earthquake, waterlogging and flash flood. Moreover, it has significant impacts on the bio-physical environment and socio-economic structure. From Table 2, risk analysis results reveal that the highest property was lost by landslides (44.69%), catastrophe, followed by waterlogging (25.08%), earthquakes (13.10%), tropical cyclones (9.99%), and floods (7.13%). Similarly, probability of risk occurred by landslides catastrophe (67.27%) was significantly higher than the others hazards such as waterlogging (25.17%), earthquakes (6.57%), tropical cyclones (0.84%), and floods (0.15%). Therefore, the results also clearly demonstrated that the risk of landslides in Chittagong City is 2.66 times higher than that of waterlogging. In comparison to tropical cyclones, the risk of landslides was around ten times higher. So, the rank of landslide risk is first, followed by second waterlogging, third earthquakes, fourth tropical cyclones, and fifth floods. Furthermore, tropical cyclone precipitation intensity and frequent earthquake increased the vulnerability of landslides catastrophe in Chittagong City. Risk analysis results strongly suggest that government and development authorities should take necessary steps for landslide catastrophe management regarding the vulnerability of the bio-physical environment and socio-economic infrastructure. Along with government organizations, local and international NGOs should come forward to solve the landslide catastrophe.

Table 2: Matrix analysis for risk estimation of several catastrophe in Chittagong City.

Hazard	Probability (P)	Rank (P)	Damage (L)(BDT)(00)	L %	Rank (L)	Risk (R) =(P×L)	R%	Rank (R)
Landslide	2 month	1	159568	44.69	1	957408	67.27	1
Waterlogging	3 month	2	89567	25.08	2	358268	25.17	2
Flood	12 Year	5	25467	7.13	5	2122.25	0.15	5
Earthquake	6 month	3	46785	13.10	3	93570	6.57	3
Tropical Cyclone	3 Year	4	35669	9.99	4	11889.67	0.84	4

Source: Field questionnaire survey and author's calculation, 2015.

4.4 Structural Model for Landslides Risk Reduction

a) Illegal hill cutting (with steep slope more than 30°) should be stopped and restricted by formal authorities like Chittagong Development Authority (CDA), Chittagong City Corporation (CCC), Forest Department and others associate organization.

b) Urban green space conservation and afforestation project implementation should be carried out in the previously demolished tertiary hills through tree plantation.

c) Strictly stopped residential expansion, rapid urbanization, making brick fields, construction of roads in existing hilly area of this city.

d) Resettlement and rehabilitation approach should be accelerated for informal settlements from vulnerable hills, hills slope and foot hills.

e) Land ownership conflict in tertiary hilly area of this city should be control through well distribution among the legal land owners.

4.5 Non-structural Model for Future Landslides Risk Mitigation

a) Proposed settlement planning (Fig.6) reduce landslides catastrophe risk from vulnerable tertiary hilly area. However, in this model a series of development planning should be done by formal authorities such as: 1) making trench (width 5-10 feet and depth 10-12 feet) along the foot hills.

b) Protective green space and plant wall (width 15-18 feet) should be construct by CDA, CCC, forest department and formals authorities.

c) Transport communication networks should be made after proactive plant wall for fire service and rescue operations services.

d) Along the left side human settlement, urban growth center, market, shopping market, educational institutions, industry, amenities for community should be constructed.

e) Most of Chittagong City's hills have lost their beautiful appeal due to unlawful hill cutting and poor unplanned land use. To restore its beautiful history, a green ecological method to hill ecosystem restoration is advocated for landslip risk reduction.

4.6 Awareness Build up through Technological Communication Model

a) Landslides catastrophe of the study area should be management through early warning systems in effective preparedness stage. Disaster management institutions and development authority of Chittagong City should also develop technological advanced communication systems for raising public awareness in different disaster period.

b) Landslides catastrophe scenarios input and deliver accurate information on time through various communication channel to reach the vulnerable people. In this regards along with tradition communication systems (e.g., loud speaker, lip let, sign board, banner) modern and technological advanced communication systems (e.g., broadcasting media, print media, radio communication, text SMS) should developed for raising public awareness which will reduce the risk of people's property, loss of lives and resources.

c) Landslides mitigation strategies seminar, talk show and educating public through commination channel (television and radio) and print media (newspapers, magazines and journals).

d) Communication systems should be developed in such way which can provided right information in right time. Proper and right information can reduce of probability of any catastrophe risk in disaster periods.

e) Satellite and satellite image should be developed for identification, monitoring an prediction of landslides vulnerable zone and all the information will delivered by various communication systems to reach the vulnerable peoples and development authorities.

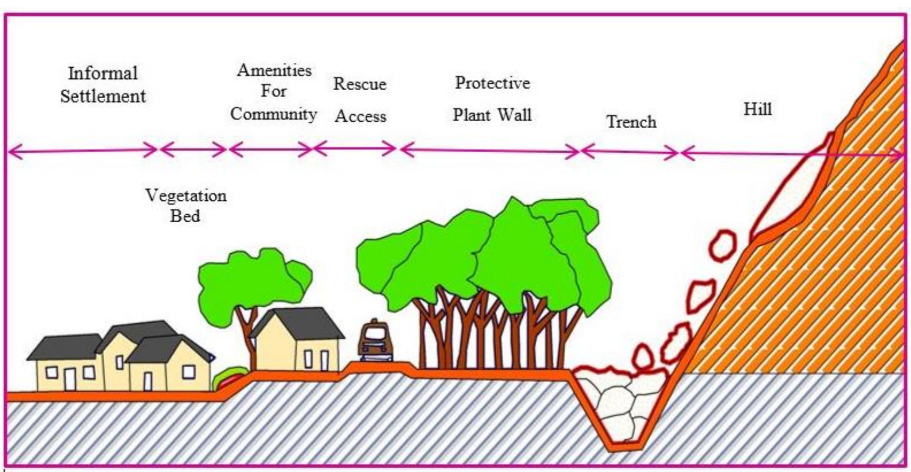

Figure 6: Proposed settlement planning design reducing landslide risk in Chittagong City.

5. Conclusion

A risk assessment, inventory mapping, and cause mechanisms of landslide disasters in Chittagong City, Bangladesh are the subject areas that are investigated in this study. In addition, the research endeavours to incorporate three different models in order to potentially find a mitigate to the landslide disaster that occurred in the city. Landslide disasters are more likely to occur in Chittagong City due to the city's topographical, geological, geomorphological, and environment. During the rainy season, hill cutting with steep slopes, informal settlements, and anthropogenic intervention are the various factors that contribute to the increasing landslide catastrophe. The structural model suggests that all the human development structures relocate and are strongly restricted in vulnerable tertiary hilly areas for landslide risk reduction; the non-structural model provides proper settlement planning for future landslide catastrophe mitigation; and the technological communication model enhances awareness among vulnerable people and development authorities for taking initial steps in preparedness and landslide catastrophe management. In addition, the integrated models that were shown earlier incorporate sustainability in the management of landslide disasters or adaption techniques.

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