Perceived Human-induced Causes of Landslide: A study in Chattogram Metropolitan Area of Bangladesh

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Abstract

This study investigates Land Use Land Cover changes in the Chattogram metropolitan area, the second largest city in Bangladesh. Using a questionnaire survey of 150 local inhabitants, the study explores perceived human-induced causes of landslides. Using time series Landsat images this study also analyzes Land Use Land Cover changes from 1990 to 2020. The analysis reveals built-up area extended rapidly during 1990 to 2020. In 1990, total built up area was 82.13km², which in 30 years, stood at 451.34km². Conversely, total vegetative area decreased rapidly. In 1990, total vegetation area was 364.31km², which reduced to 130.44 km² in 2020. The survey results show that most of the respondents faced landslide therefore; it is nothing new among them. Respondents were identified several reasons for landslide like extensive rainfall, hill cutting, steep hill, weak soil texture etc. A large number of local people opined that diverse human activities are causes landslide in their local area and it has impacted on their livelihood. Chi-square test suggests that there are statistically significant differences between local and non-local inhabitants regarding their opinion on whether excessive hill cutting is alone responsible for landslide and whether deforestation is the sole reason for landslide. This study also used four multinomial logistic regression (MLR) to particularly examine the effects of independent variables like gender, age, level of education, income, housing pattern and experience of facing landslide on their perception of human induced causes of landslide. Findings show that age and experience of facing landslide are two significant predictors for the first model explaining excessive hill cutting was alone responsible for landslide. Level of education and experience of facing landslide are found statistically significant for explaining our second model that is building infrastructures solely causes landslide. Moreover, our third model only deforestation can be blamed for landslide is significantly explained by three predictors namely gender, age and income. Finally, fourth model that is landslide occurs only due to excessive sand collection is significantly explained by gender, level of education, and income.

Keywords: Landslide, Human-induced causes, Local perception, Bangladesh

1. Background and Introduction

Landslide is the third most crucial natural disaster in the worldwide that takes place over a broad range of velocities (Zillman, 1999). It is a poly-causal phenomena, in which it is very difficult to separate man-made causes from natural ones, but human intervention has played a key role in stimulating the natural antecedents of landslides (Alexander, 1992). Almost 9% of the world's natural disasters are caused by this phenomenon, which is particularly common in mountainous regions (Galli et al., 2008). Mohan et al. (2021) found that soil rock slope lowering was the primary cause of landslides. Climate change and increased urbanization have also been mentioned as contributing factors. In addition to natural causes (Magar et al., 2021) various human activities like; road construction, deforestation, hillslope cutting, agricultural cultivation, and vibrations caused by high traffic can also be claimed for causing landslides (Shaw et al., 2013; Rabby, 2021). This type of hazard causes severe damage to resources people's and nature's resources in the world (Zumpano et al., 2018). A landslide's aftereffects are tremendous, taking into account the number of people died, the amount of money lost, and the damage to property and infrastructure that results (Cullen et al., 2016).

In Bangladesh, most of the areas are floodplain on physiographic basis, with an exception of 18% of the hilly and tracked regions where a significant proportion of citizens live (Islam and Uddin, 2002). particularly north-eastern, north–south and northern hilly regions are vulnerable to landslide due to lack of land use planning and weak enforcement by the local authorities (Sarker and Rashid, 2013). In the last decades, devastating landslides have constantly hit the hilly areas in Bangladesh, because of climate change along with other anthropogenic influences such as high population density, indiscriminate land use, and uncontrolled hill cutting (Sultana, 2020). Chattogram, the second largest city, contained over 200 hills in the early 1910. As the commercial and business importance of the city had substantially increased after the independence in 1971, the hill cutting activities severely increased to accommodate excessive land demands. Since late 1990, unlike academic studies, traditional newspaper reporting explored the problem of hill cutting as a major cause of water logging and landslide incidences in the city area of Chattogram (Alam, 2017). In terms of frequency and magnitude of damage, Chattogram Metropolitan Area (CMA) is extremely vulnerable to landslide hazards, with a growing tendency of frequency and damage (Ahmed, 2015). In addition to the natural cause of excessive rainfall, Chattogram Metropolitan area's landslide vulnerability is exacerbated by a variety of human-induced factors, such as rapid urbanization, increased population density, inappropriate land use, modifications in the hilly regions by illegal hill-cutting, random deforestation, weal soil structure, de-vegetation, and agricultural practices (Islam, 2018; Ahmed et al., 2014). Major effects of landslide on the local communities are loss of natural scenic beauty, economic loss, destruction of lives and environmental problems (Islam, 2018). In the recent time, human activities of indiscriminate hill cutting for slum expansion and residential housing development have resulted in many landslides in the Chattogram metropolitan area. Landslides that occur because of rainfall pose a severe threat in the Chattogram Hill Districts (CHD) of Bangladesh. Inhabitants living on the steep slopes are highly vulnerable to landslide disasters. A heavy rainfall in 2017 led to a major fatal

landslide in Bangladesh history that caused 168 deaths and smashed around 40,000 houses in Rangamati, Chattogram, and Bandarban regions (Ahmed et al., 2018).

Human-induced landslides (HIL) refer to landslide incidents that are directly triggered or partially aggravated by anthropogenic activities. These anthropogenic causes are the modifications of topography, changes of water circulations, land use changes, and constructions of infrastructure (Jaboyedoff et al., 2016). Studies have found that the human and geomorphological factors are more significant to cause landslide hazards than geological influences (Dahal et al., 2008). Landslides cause community disruptions, and involves in both direct and indirect costs. Direct costs are the damages immediately attributable to the landslide, but the indirect costs include economic constraints and ecological effects that often exceed the direct costs (Turner, 2018) which have crucial effects on the socio-economic structure (Saina et al., 2016). However, it is difficult to separate the losses from direct and indirect causes of landslide, because losses are not well documented (Kjekstad and Highland, 2009). Different effects of landslides have increased in the recent time because of the rapid expansion of urbanization in the developing world and causes damaged in the many aspects of human life as well as the natural environment. Physical or socio-economic losses seriously affect populated regions (Krivoguz and bespalova 2017). Human-caused landslides have been acknowledged by Alam (2020), Ahmed (2021), Jaboyedoff et al. (2018), and Fell (2018). Bangladesh was the focus of Alam's (2020) and Ahmed's (2021) research, who pointed to unsustainable and unplanned growth, unlawful hill cutting, settlement along hill slopes, and overpopulation as the primary causes of the problem.

Land Use and Land Cover (LULC) change can enhance or reduce susceptibility of landslide in the mountainous and hilly areas (Chen et al., 2019). Landslides are influenced by different climatic and environmental factors such as topography, morphology, hydrology, lithology, and land use. The changing magnitudes of LULC potentially increase the quantity of unstable hillslopes (Reichenbach et al., 2014). Landslides result a major constraint on development, causing high levels of economic loss and substantial numbers of fatalities each year (Petley et al., 2007). It causes loss of life and injury to people and their domestic animals and damage to infrastructure, agricultural lands and housing (Perera et al., 2018). It is well known that stability of slopes changes based on land use land cover changes because vegetation changes may influence the mechanical and hydrological characteristics of slope (Greenway, 1987). Geographical Information System (GIS) and Global Positioning System (GPS) can be used to measure the landslide catalog (Amatya et al., 2019; Moayedi et al., 2019). Moreover, the remote sensing method for landslide detection is supported by many studies including Mohan (2021), Zhao and Lu (2018), Kalantar et al. (2020), Zhong et al. (2020) etc. Mostly, environmental factors can be measured by using Remote Sensing (RS) images, which encompasses Digital Elevation Model (DEM), aerial Imagery, LIDAR, and the Landsat8 TM image (Zhang et al., 2016; Zhao and Lu, 2018; Zhu et al., 2020).

In this study, we aim to identify local people's perception regarding human-induced causes of landslide in the Chattogram metropolitan area of Bangladesh. We also tried investigating land use land cover change over the last forty years. We started this manuscript with a background and introduction of the study. In the next section we elaborately discussed our methodology of this research. In Section 3, we present our results in different subsections.

Finally, we add a concluding discussion section incorporating some limitations and recommendations for further studies (Section 4).

2. Materials and Methods

2.1 Study area

Every year, landslide occurs in the south-eastern parts of Bangladesh (Mia et al., 2015). Compare to other regions, Chattagram city has been known as one of the most susceptible cities to landslide. The most devastating case of landfall occurred on 11 June 2007 in the Chattogram which is one of the major landslides in the history of Bangladesh (Sultana, 2013). The present study explores anthropogenic causes on landslides in Chattogram metropolitan areas (Figure 1) of Bangladesh. The population of Chittagong city is about 5 million and is growing. This area is within 22° 14′ and 22° 24′ 30″ north latitude and between 91° 46′ and 91° 53′ east longitude (Ahmed, 2015). As mentioned above, a landslide is a major geologic hazard in Bangladesh. Some specific zones of the Chattogram Metropolitan area are more landslide-prone than other zones. For example; *Motijharna, Baizid Bostami, Kushumbag, Batali Hill* and *Lichu Bagan (locally called)* are mostly populated and more vulnerable to landslide. We select *Lichu Bagan, Batali Hill* and *Motijhorna* as the study area of this study.

2.2 Data collection tools and techniques

This study adopts descriptive-explanatory strategy (Babbie, 2004; Islam, 2008), combining a survey using a self-administered questionnaire (Mugambiwa and Dzomonda, 2018) technique and GIS approach. The questionnaire was organized in a way to help achieve the aim of this study. The questionnaire had several parts highlighting the socio-demographic characteristics of respondents. This study collected data from 150 respondents about their education, age, income, occupation, breadwinners, family size, and housing patterns. In the next part, the respondents were asked about their challenges and experiences related to landslide hazards in their area. The respondents returned their understanding about causes of landslide, including human activities, how do they consider landslide effects their life, do they follow any preventive strategy to mitigate landslide hazards, and do they experience any pre-management activities the governmental and nongovernmental actors take. A categorical response was provided for respondents to check off the option according to their own choice. In the last part of questions, each respondent was asked about their more specific opinions regarding different causes of human induced landslide such as, excessive hill cutting, infrastructural development, deforestation and excessive sand collection.

In the GIS approach, to determine LULC change, this study collected secondary data from the USGS. The study collected Landsat images for the years 1990, 2000, 2010 and 2020. Each satellite image reflects the dry season and sensor was Landsat TM and OLI/TIRS (Table-1). After pre-processing of satellites images (atmospheric and radiometric correction) it was classified into four different classes (water body, barren land, buildup area and vegetation). After images classification accuracy assessment was conducted (Table-2) to verify the correctness of images classification.

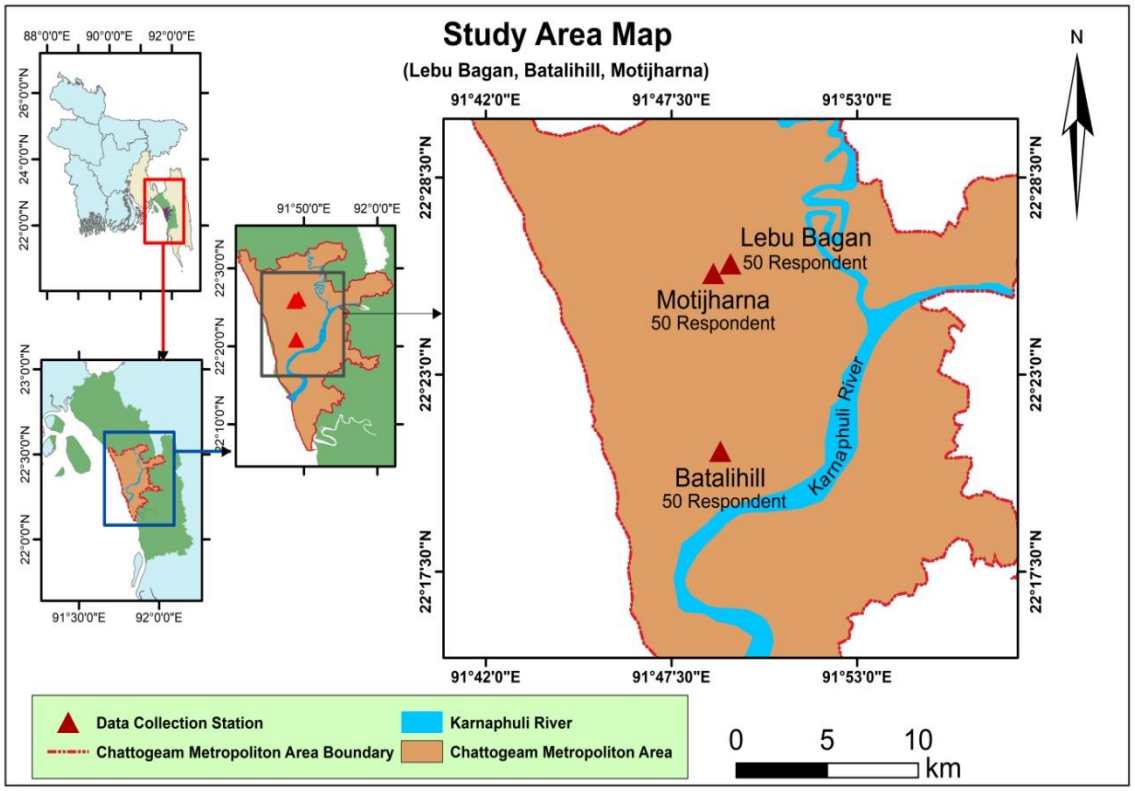

Figure 1: Map of study area.

Table 1: Data set information, sensors and their resolution

Satellite Id	Sensor Id	Path/Row	Acquisition Date	Spatial resolution
Landsat 5	TM	136/44	31-10-1990	30
Landsat 5	TM	136/45	31-10-1990	30
Landsat 5	TM	136/44	29-12-2000	30
Landsat 5	TM	136/45	29-12-2000	30
Landsat 5	TM	136/44	23-11-2010	30
Landsat 5	TM	136/45	23-11-2010	30
Landsat 8	OLI /TIRS	136/44	04-12-2020	30
Landsat 8	OLI /TIRS	136/45	04-12-2020	30

2.3 Measurement and data analysis

In this study, the outcome variable is the local people's perception about human induced causes of landslide. The questions about this variable attempt to measure whether excessive hill cutting is responsible alone for landslide. The explanatory variables of this study include gender, age, level of education, income, housing pattern, and landslide experience. The study employed Chi-square test and multinomial logistic regression models to determine the effects of independent variables on the people's perception about human induced causes of landslide. Researchers use these statistical techniques to analyze perceptions of local people (Manandhar et al., 2014, Brouder and Landmark, 2011).

Pre-preparation of satellite images

Radiometric Correction

In this study, only green and near infrared band of each image receive the radiometric and atmospheric corrections. Using radiance value, we converted the respective DN value:

$$L_\lambda = \frac{(L_{max} - L_{min})}{\left(Q_{cal_{max}} - Q_{cal_{min}}\right)} \times \left(Q_{cal} - Q_{cal_{min}}\right) + L_{min} \text{----------(1)}$$

By aiding Erdas Imagine application, we created a model to perform the conversion.

$Q_{cal_{max}}, Q_{cal_{min}}, L_{max}$, and L_{min} values were taken from the Metadata file provided with Image file. We followed the same procedure to convert the DN values for Green and NIR bands of each image. After converting the DN value into radiance value (L_λ) equation 2 was used to get top of atmospheric reflectance.

$$\rho = \frac{\pi \times L_\lambda \times d^2}{E_{Sun} \times Cos(\theta_{s)}} \text{----------(2)}$$

The value of the Earth-Sun distance, d was calculated using Julian calendar and solar zenith angle θ_s was taken from MLT file. E_{sun} is the mean solar exo-atmospheric irradiance in $\frac{w}{m^2}$ µm, the E_{sun} value varies with the super craft and sensor of satellite. The E_{sun} values for Landsat 7 and Landsat 5 were collected from Landsat 7 handbook (Irish, 2000; Chander et al., 2009).

Atmospheric correction

Dark Object Subtraction is a simple image-based method of atmospheric correction which assumes that there are at least a few pixels within an image which should be black (% reflectance) and suck black reflectance as dark object which extracts clear water body and shadows with DN values zero (0) or close to the zero in the image (Chavez, 1988).

Table-2: Classification accuracy and overall accuracy

Land Use Type	1990		2000		2010		2020	
	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy
Water Body	92	92	93.13	95	93.27	97	97.08	100
Barren Land	88.30	83	85.43	88	87.62	92	92.23	95
Vegetation	81.13	88	88.89	88	91.67	88	94.62	88
Build Up Area	82.85	87	91.67	88	90.53	86	91.09	92
Overall Accuracy	87.5		89.75		90.75		93.75	

NDVI Index

Normalized Difference Vegetation Index (NDVI) is a globally accepted remote sensing index widely used to sense the vegetation, forest extension and the water bodies over the surface using red and near-infrared light. An NDVI value always ranges from -1 to +1 where a value of +1 shows heavy vegetation, while -1 implies an extensive deep-water body , with 0 signifying the absence of any vegetation. NDVI equation is given below in equation 3 and Table-3 denotes the NDVI values which was used in this study.

$$NDVI = \frac{NIR-Red}{NIR+Red} \text{----------(3)}$$

Table 3: NDVI value for present work

Feature's Name	NDVI Value Range
Water Body	<0.08
Build Up Area	0.07- 0.30
Barren Land	0.30- 0.54
Vegetation Land	0.54- 1

3. Results

3.1 Background of participants

Table-4 demonstrates socio-demographic background of the respondents. In this study, 62.7% respondents are male and 37.3% are female. Based on age, we categorized our respondents into three different groups. 72% participants are from middle-aged group (31-60 years of age). Moreover, young-aged group comprised of 26% participants who are less than 30 years of age and old-aged group consisting participants more than 60 years representing 2% of the study population. In response to the question related to educational attainment, this study finds that 45.3% people can read and write only, 36% of the respondents have primary education, and 10.7% have secondary education. Only 8% respondents have higher secondary education. Table 1 shows housing types of participants where more than half of the respondents (54.0%) have tin shed house, while only 7.3% have building and 32.7% have semi building. In this study, 65.3% respondents informed their monthly earning is below 10,000 Tk., while 34.7% people earn more than that. Most (46.7%) of the family have at least two earning members followed by 37.3% and 16.6% have one and three breadwinners, respectively. A large (78%) percentage of participants are local compared to only 22% non-local respondents. Additionally, 17.3% respondents are involved with small business, 16% involve in service, and the remaining 6.7% people are engaged with other jobs.

223 Table 4: Background information of participants

Background Characteristics	Categories	Frequency (f)	Percentage (%)
Gender	Male	94	62.7
	Female	56	37.3
Age	Young (below 30 years)	39	26
	Middle Age (31-60 years)	108	72
	Old Age (more than 60 years)	3	2
Education	Illiterate	68	45.3
	Primary	54	36.0
	Secondary	16	10.7
	Higher secondary	12	8.0
Housing pattern	Building	11	7.3
	Semi-building	49	32.7
	Tin Shed	81	54
	Earthen	9	6
Income	Below 10,000 Tk.	98	65.3
	More than 10,000 Tk.	52	34.7
Earning members	1 person	56	37.3
	2 persons	70	46.7
	3 persons	24	16.6
Locale of the Area	Yes	117	78
	No	33	22.0
Occupation	Daily wage labor	56	37.3
	Small business	26	17.3
	Service	24	16.0
	Housewife	34	22.7
	Others	10	6.7

224

225 ## 3.2 Respondent understandings of landslides

226 Figure 2 recapitulates respondents' understanding about landslide related issues. The results indicate landslide is a
227 familiar hazard in the study area as most of the respondents experienced landslide (62%) in their life. However, 32%
228 of the respondents reported that they do not have any such experience. Regarding causes of landslide, over two-
229 quarter of the respondents spoke of extensive rainfall as the major cause compared to almost one-quarter who
230 identified hill cutting as the principal cause. In contrast, some other participants replied steep hill (8%) and weak soil
231 texture (8.7%) as primary reasons for landslide hazards. The findings indicate 94% respondents believe different

human activities cause landslide and 95.3% pointed out it has impact on local people. A more than half of the participants (51.3%) replied that they adopt any kind of strategy that can help to avoid risk of causing landslide. In contrast, 48.7% do not follow any such strategies. Most of the participants adhered to resettlement (68.5%) for avoiding risk whereas 24.6% respondents preferred stopping hill cutting and enhancing afforestation (6.9%) could be a better solution. Majority of the respondents opined they comply with pre-management initiatives by Government or Non-governmental Organizations (NGOs) to minimize the risk. Major policy actions that the respondents try to comply with are stopping illegal activities (40%), identifying landslide prone area (24%), expanding tree plantation (19.3%), and developing water drainage system (16.7%).

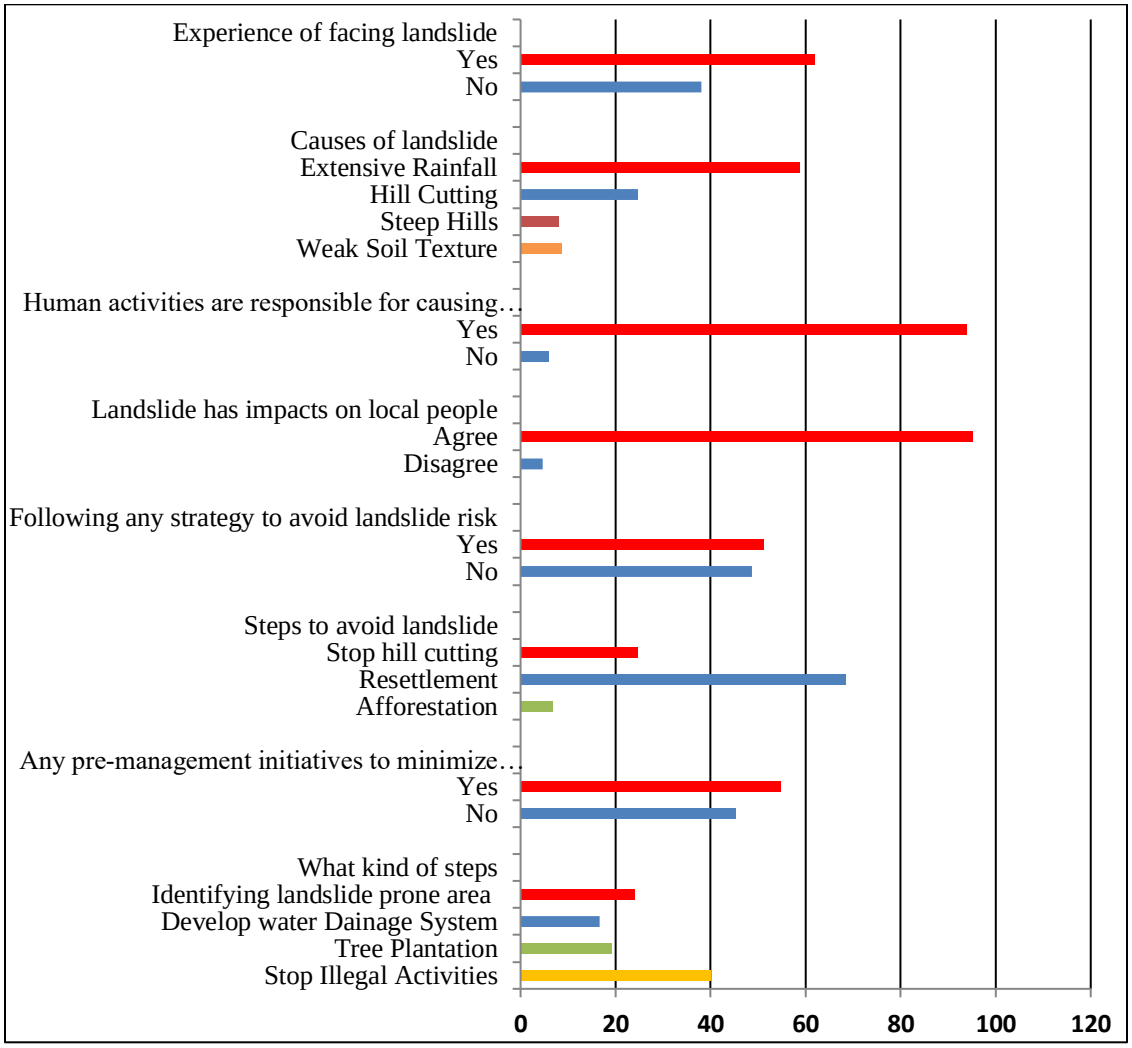

Figure 2: Respondents understanding of landslide related issues

3.3 Locality and perception regarding human-induced landslide

Most of the local and non-local respondents do not agree that excessive hill cutting is solely responsible for landslide (58.1% local and 63.6% non-local). In contrast, 41.9% local and 36.4% non-local respondents believe that excessive hill cutting is a solitary cause for this hazard. The test of significance (Chi-square test) suggests that there is a statistically significant difference between local and non-local participants regarding their perception of excessive hill cutting as the only cause for landslide hazard ($p<0.05$). 75.2% local and 66.7% non-local respondents said they do not agree on infrastructural development as the only cause for landslide. However, this finding is not statistically significant ($p>0.05$).

24.8% local and 33.3% non-local residents opine that building infrastructure is the only cause for landslide. Table-5 also depicts that non-local respondent (78.8%) show more disagreement than local people (72.6%), when they were asked whether deforestation is the only cause for landslide. A good percentage of respondents agree that deforestation is only to blame for it (27.4% local and 21.2% non-local). Chi-square test result confirms a significant variation between the testimonies of local and non-local respondents ($p<0.05$). Regarding excessive sand collection as the principal reason for landslide, there is no significant ($p>0.05$) difference between the opinions of local and non-local respondents (94.0% local and 90.9% non-local). Only 6.0% of local and 9.1% non-local responders think excessive sand collection is the only reason for it.

Table-5: Locality of the respondents and perception on hill cutting

Perception	**Local**		**Nonlocal**		**P value**
	Agree % (n)	Disagree % (n)	Agree % (n)	Disagree % (n)	
Excessive hill cutting is alone responsible for landslide	41.9 (49)	58.1 (68)	36.4 (12)	63.6 (21)	0.009
Building infrastructures solely causes landslide	24.8 (29)	75.2 (88)	33.3 (11)	66.7 (22)	0.374
Only deforestation can be blamed for landslide	27.4 (32)	72.6 (85)	21.2 (7)	78.8 (26)	0.032
Landslide occurs only due to excessive sand collection	6.0 (7)	94.0 (110)	9.1 (3)	90.9 (30)	0.459

3.4 Perception regarding human-induced causes of landslide: multinomial logistic regression

We try to examine the factors that are affecting the perception regarding human induced causes of landslide by using four multinomial logistic regression models. Outcome variables used for the models are statements asking whether "excessive hill cutting was alone responsible for landslide", "building infrastructures solely cause landslide", "only deforestation can be blamed for landslide", and "landslide occurs only because of excessive sand collection." The response categories of the outcome/dependent variables are coded with '0' if they agree with the statement and '1' if they do not agree with the statement. For all models, the reference category is 'disagree'.

The result shows (Table-6) that two predictors age and experience of facing landslide have significant effects for the first model about "excessive hill cutting was alone responsible for landslide." The result illustrates that middle- and old-aged respondents compared to young respondents are less likely to agree with the statement that excessive hill cutting is alone responsible for landslide. Respondents who do not experience landslide compared to their counterpart are less likely to agree that landslide occurs mainly because of excessive hill cutting. Although the result is not significant, but the table presented below also suggests that females compared to males, respondents who earn over 10,000 Tk. per month compared to these who earn less than that and who obtained more than secondary level study than who have below secondary level study are more likely to agree with the statement.

We found that two predictors such as, level of education and experience of facing landslide are statistically significant for the second model about "building infrastructures solely causes landslide." Respondents having more than secondary level study are less likely to agree with the statement compared to their counterpart. The result also shows that people who have no experience of facing landslide in their area are 2.5 times more likely to agree with the statement "building infrastructures is the only cause for occurring landslide" compared to their counterpart. Although the result is insignificant, the tables below shows that middle and old aged people are 1.5 times more align with the statement than young people do.

Table-6 illustrates that three predictors gender, age, and income significantly explain the model dealing with "only deforestation can be blamed for landslide." Females compared to males, middle- and old-aged respondents compared to young and respondents whose monthly income over 10,000 Tk. compared to these who earn less than 10,000 Tk. per month are less likely to agree with the statement "deforestation is the only reason for landslide." We also found that respondents who have tin shed and earthen house compared to these who have building or semi-building house and respondents who do not have experience of facing landslide compared to people who have experienced landslide in their home area are more likely to blame deforestation as the sole reason for landslide. The results are not statistically significant.

Finally, three predictors gender, level of education, and income significantly explain the model regarding "landslide occurs only because of excessive sand collection." Females are 4.8 times more likely to agree than males that

297 excessive sand collection causes landslide, and that is the only causes. Respondents having more than secondary
298 level study compared to having below secondary level study are 2.3 times more likely to agree with the statement.
299 Findings also show that respondents who earn over 10,000 Tk. per month are less likely to blame excessive sand
300 collection as a solitary cause to landslide compared to their counterpart. While the results are not statistically
301 significant, yet middle- and old-aged people compared to young people and respondents who have not experienced
302 landslide than respondents who have experience are more likely to agree with the statement.

303 ## 3.5 NDVI analysis of Chattogram metropolitan area

304 Table-7 reveals the value of NDVI analysis of CMA that shows a speedy increase in the built-up areas between 1990
305 to 2020. In 1990, built up area was 82.13km² which stood at 451.34km² in December 2020. However, the total
306 vegetative area decreased rapidly in the same period. In 1990, total vegetation area was 364.31 km², which came
307 down to the CMA of 130.44 km² in 2020. We conduct NDVI analysis with local people's perception to investigate
308 which process further intensifies the landslide process. NDVI result reveals that in CMA built up area increased
309 quickly in the last 40 years and total vegetative area decreased, which further intensify the landslide susceptibility in
310 the metropolitan area of Chattogram.

Table -6: Parameter estimates for perception of human induced landslide

Independent variables	Categories and coding	Excessive hill cutting is alone responsible for landslide	Building infrastructures solely causes landslide	Only deforestation can be blamed for landslide	Landslide occurs only due to excessive sand collection
		Agree	Agree	Agree	Agree
		Coefficient (Odds ratio)	Coefficient (Odds ratio)	Coefficient (Odds ratio)	Coefficient (Odds ratio)
Gender	Male = 0 Female = 1	0.144 (1.154)	-0.618 (.539)	-0.089 (.915)*	1.587 (4.887)***
Age	Young Age = 0 Middle and Old Age = 1	-0.320 (.726)*	0.462 (1.588)	-0.088 (.915)**	0.145 (1.157)
Level of education	Below Secondary = 0 More than Secondary = 1	0.381 (1.464)	-0.807 (.446)*	-0.073 (.930)	0.850 (2.339)*
Income	Below 10,000 Tk. = 0 More than 10,000 Tk. = 1	0.011 (2.011)	-0.078 (.925)	-0.157 (.855)*	-0.616 (1.852)*
Housing Pattern	Building and Semi Building = 0 Tin Shed and earthen = 1	-0.079 (1.803)	-0.249 (.779)	0.326 (1.386)	-0.600 (.549)
Experience of facing landslide	Yes = 0 No = 1	-1.014 (.363)**	0.953 (2.594)*	0.111 (1.118)	0.389(1.476)

The reference category is: Disagree.

*** p<.005, **p<.010, *p<.05

Table-7: NDVI analysis of CMA

Year	Water	Built Up Area	Barren land	Vegetation
1990	50.8392	82.1367	234.0162	364.3155
2000	49.3344	167.2056	172.5705	342.1971
2010	52.3008	217.9719	238.7268	222.3081
2020	51.1668	451.3428	98.3502	130.4478

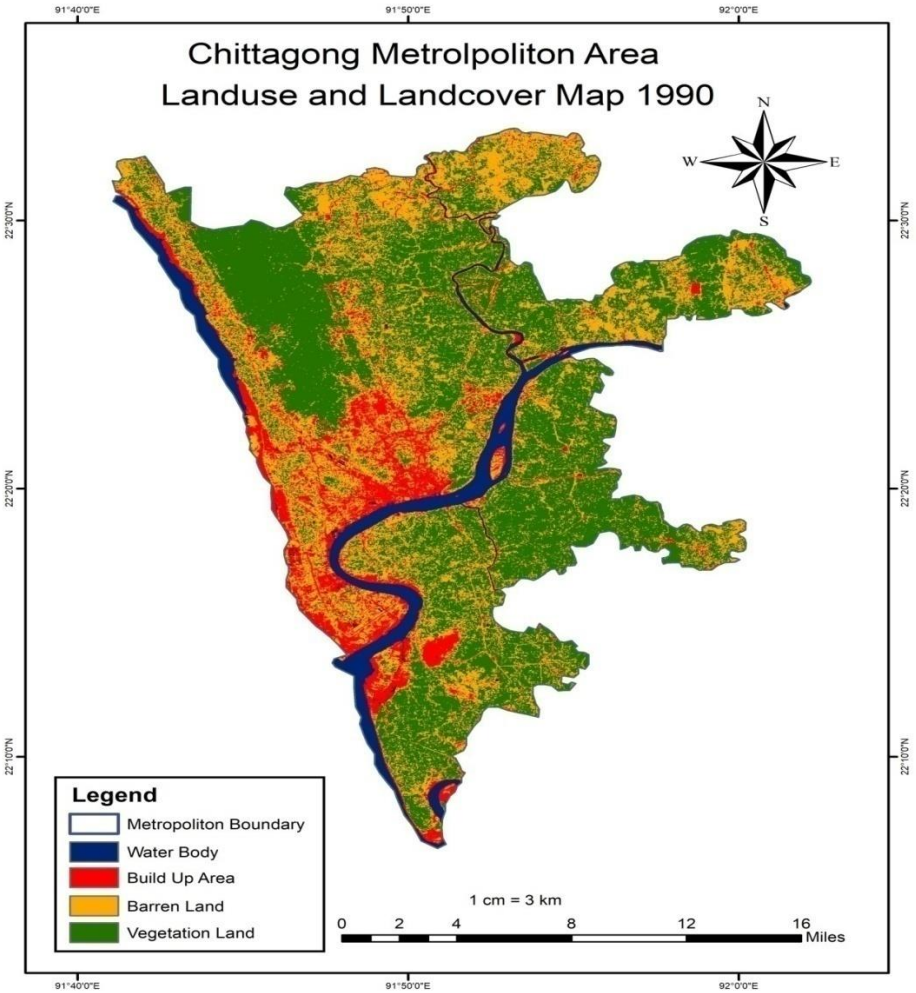

Figure 3: Land Use and Land Cover map of 1990

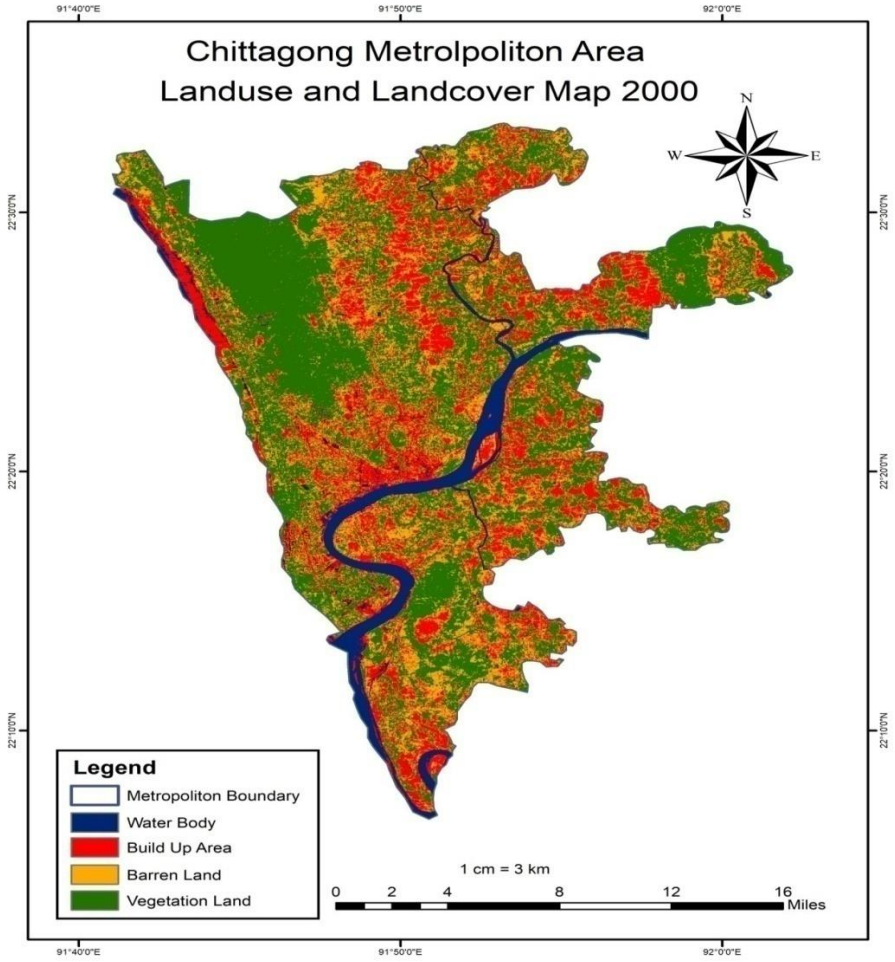

Figure 4: Land Use and Land Cover of 2000

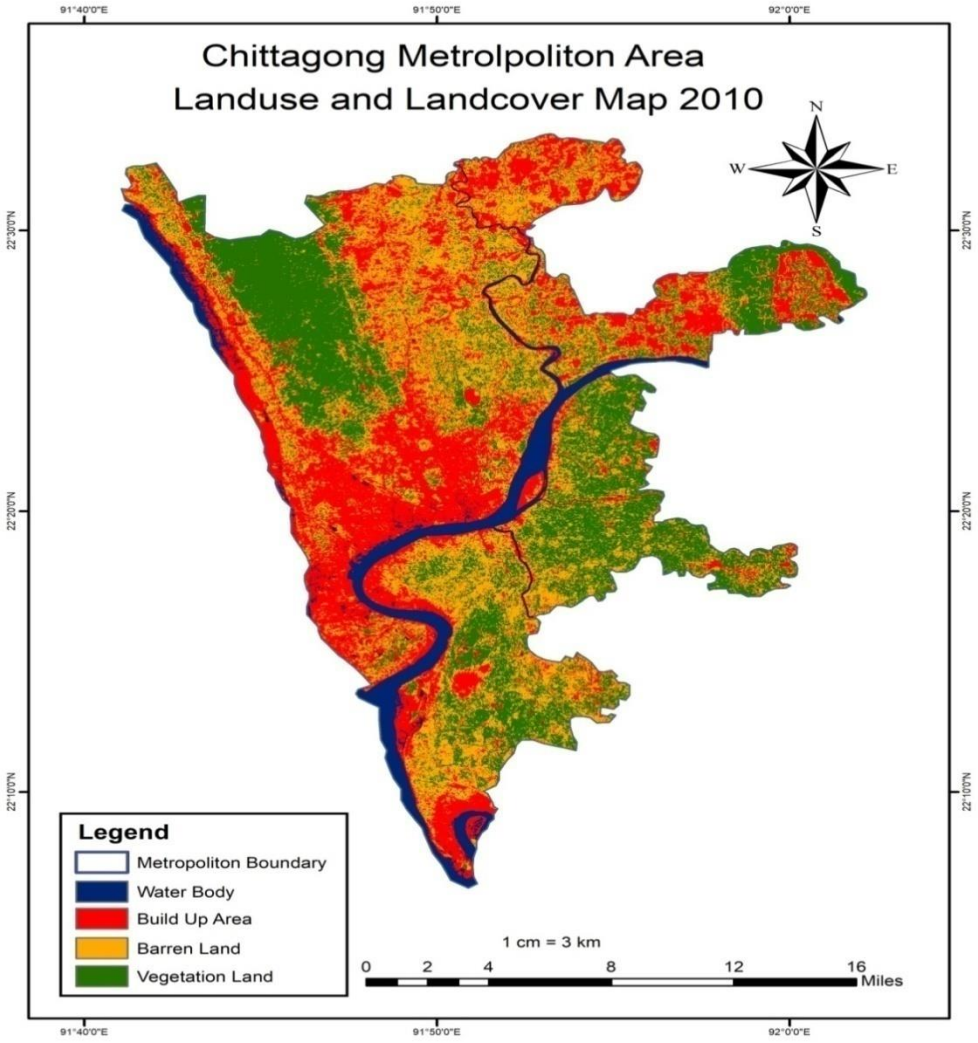

Figure 5: Land Use and Land Cover map of 2010

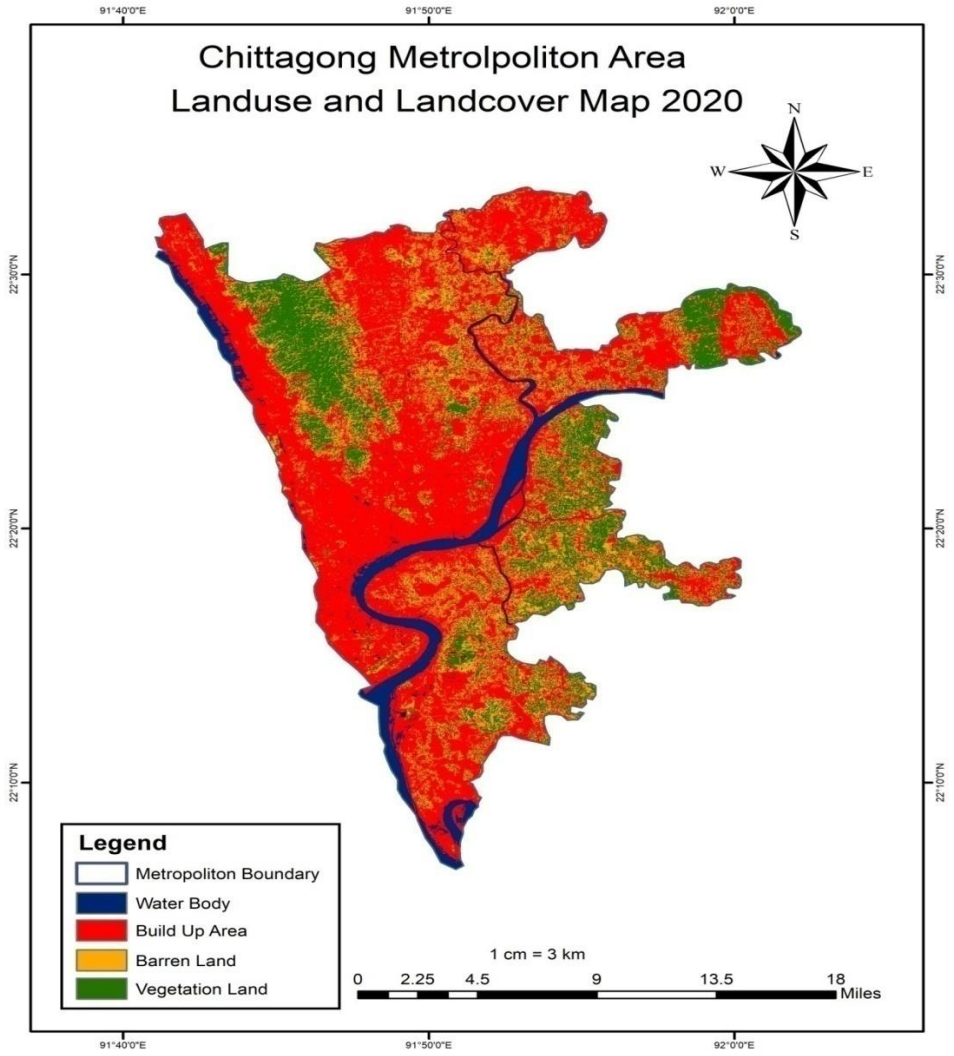

Figure 6: Land Use and Land Cover map of 2020

4. Discussion and Concluding Remarks

For the last thirty years, Bangladesh has been experiencing hill cutting problems and consequent landslide incidence in the southeastern hilly region (Alam, 2020). The present study finds that more than half (mention the %) of the total participants have experience of facing landslide compared to the remaining 32% who do not have this experience. This result clearly shows that landslide is not surprising among the inhabitants of the study area. Moreno and Ayala (2017) argue in their study that a better understanding of how landslide is perceived is one of the most important issues in enhancing landslide disaster risk awareness and knowledge. They suggest a knowledgeable landslide perception among people to create a resilient community.

In terms of causes of landslide, extensive rainfall (58.7%) has been identified as the most critical cause followed by hill cutting (24.7%), steep hill (8%), and weak soil texture (8.7%). This study also suggests that only 41.9% local and 36.4% non-local respondents believe that excessive hill cutting is solely responsible for landslide, and there is also a statistically significant difference found between local and non-local participants regarding their perception of excessive hill cutting as the main reason for landslide. Hassan et al. (2015) found similar results where they identified hill cutting as the principal reason for the subsequent landslide occurrence in Chattogram city area.

The findings in this study show that most of the local and non-local inhabitants opine that different human activities cause landslide in the study area, which is detrimental to their local life. As landslide is not uncommon to most of the respondents, more than half of the participants followed any kind of strategy, which helps them avoid risk of happening landslide. Alam (2020) and Burton (1993) hold in their study that it is crucial to recognize how people living in the unstable environment perceive hazards and risks and to understand their indigenous knowledge and awareness regarding particular hazards. The authors argue that this kind of perception may be critical to lessen the consequent effects of natural hazards. The current study asked participants to mention what strategy particularly they follow to avoiding risk of landslide. Most of the people responded they follow resettlement (68.5%) to avoid risk followed by stopping hill cutting (24.6%) and enhancing afforestation (6.9%). They also recommended some pre-management activities, such as blocking illegal activities, identifying landslide prone area, expanding tree plantation and developing. In the risk mitigation approaches, hazard knowledge and risk discernment are vital components (Gaillard, 2008). It is also suggested that human interference has played a key role in stimulating the natural precursors of landslides occurring and risk appreciation does not promote adequate risk mitigation (Alexander, 1992).

A study conducted by Hassan and Nazem (2016) about LULC change and urban growth in Chattogram city and result of the study reveal that because of the increase of built-up areas 56% of the land cover have undergone change. This change trigger further encroachment and degradation because of other human activities near urban areas. Roy and Saha (2016) explore the temporal pattern of land cover change in Chattogram district that show that urban area and barren land is rising, whereas the forestland is declining at an alarming rate during 2002 and 2014. Gazi et al. (2020) conducted a study about Spatio-temporal changes of land cover in Chattogram metropolitan area that reveals urban structures increased rapidly (from 20.83 to 58.93%) while vegetation area decreased from 56.54 to 20.24% in the study period. The present study also found that built up (in 1990 the area was 82.13 km². and in 2020 it was 451.34 km²) area increased rapidly and vegetation (in 1990 it was 364.31 km², but in 2020 it was 130.44 km²) decreased in the study period.

We found that young respondents and respondents who experienced landslide in their local area are more likely to agree that excessive hill cutting is the only reason for landslide compared to their counterparts. Respondents having more than secondary level education and who have experienced landslide in their local area are more likely to agree that building infrastructures is the only cause for occurring landslide than their counterparts. We also found that females, middle and old aged and these to earn over 10,000 Tk. per month are comparatively less likely to think that

deforestation is the only reason for landslide. Females compared to man, respondents having more than secondary level education compared to below secondary level education and respondents having less than 10,000 Tk. earning per month compared to these who earn over 10,000 Tk. monthly are more likely to agree that excessive sand collection is the alone cause of landslide. A study conducted on an indigenous community living in Taiwan by Roder et al. (2016) where their results suggest that gender, age education and experience of natural hazards were significant predictors in hazards knowledge and risk perception also paying attention to the indigenous perception of a hazard and risk can increase the effectiveness of projects implemented by government or any organization. Rieux et al. (2012) work on coping strategies and landslides in two villages of Central-Eastern Nepal and finding suggest that importance of investing in organizational skills, while building on local knowledge about landslide mitigation for reducing landslide risk.

This study explores the perception of local people about human induced causes of landslides. The results show that human alteration influences natural causes of landslides and people's perception vary based on gender, age, educational attainment, experience of facing landslide and their financial condition. As local inhabitants face the effects of landslide directly, their perceptions and opinions important especially for making them more resilient. This kind of information is significant for decision makers and authorities who need to recognize and take action for effective landslide management at the local level in the hilly area of Bangladesh and beyond. Findings of this study uncover the local perceptions regarding landslide causes that may be helpful for the policy makers and other stakeholders in order to find a better solution to this problem and assist the responsible bodies for taking better plan related to landslide. The present study can be an example for the future study which will be combined topography, geology, geography, climatic data and land use and land cover change helps the decision-maker for the formulation of rules and guidelines about human induced causes of landslide especially in hill cutting, infrastructure development in the hilly area and sand mining in the hilly region and aid in minimizing negative effects on local inhabitants. One of the major limitation of the study is that it only looks at one particular area and our sample size was 150, which are too small to generalize the overall scenarios of perception regarding this issue. A comparative study among different parts taking large samples could be an interesting work. However, these limitations will certainly pave the way for future studies to overcome these weaknesses.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

This manuscript does not contain any studies with animals performed by any of the authors.

References

Ahmed, B., Rahman, M. S., Rahman, S., Huq, F. F., & Ara, S. (2014) Landslide Inventory Report of Chittagong Metropolitan Area, Bangladesh. https://doi.org/10.13140/RG.2.1.2314.7046/1

Ahmed, B. (2015) Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh. Landslides 12**,** 1077–1095 https://doi.org/10.1007/s10346-014-0521-x

Ahmed, B. (2021). The root causes of landslide vulnerability in Bangladesh. Landslides, *18*(5), 1707-1720. https://doi.org/10.1007/s10346-020-01606-0

Ahmed, B., Rahman SM., Islam R., Sammonds P., Zhou C., Uddin K., Al-Hussaini TM. (2018). Developing a Dynamic Web-GIS Based Landslide Early Warning System for the Chittagong Metropolitan Area, Bangladesh. International Journal of Geo-Information, 7(12). https://doi.org/10.3390/ijgi7120485

Akhand, M. H. (2013). Disaster Management and Cyclone Warning System in Bangladesh, Early Warning Systems for Natural Disaster Reduction ,9-64. https://doi.org/10.1007/978-3-642-55903-7_8

Alam, E. (2017). Locational Analysis of Hill Cutting Areas in Chittagong city, Bangladesh. J Earth Sci Climate Change, 8 (11). https://doi.org/10.4172/2157-7617.1000420

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

Alexander, D. (1992). On the causes of landslides: Human activities, perception, and natural processes, Environment, Geology, Water Sci, 20,165–179. https://doi.org/10.1007/BF01706160

Amatya, P., Kirschbaum, D., and Stanley, T. (2019). Use of very high-resolution optical data for landslide mapping and susceptibility analysis along the Karnali highway, Nepal. Remote Sensing, 11(19), 2284. https://doi.org/10.3390/rs11192284

Babbie, E. (2004). The practice of social research (10th ed.). Belmont: Thomson Learning.

Broude, P., and Lundmark, L. (2011). Climate change in Northern Sweden: Intra-regional perceptions of vulnerability among winter-oriented tourism businesses, J. Sustain. Tour. 19 (8) 919–933. https://doi.org/10.1080/09669582.2011.573073

Burton, I., Kates, RW., White GF. (1993). The Environment as Hazard; The Guilford Press: New York, NY, USA, , 290.

Chander, G., Markham, B. L., & Helder, D. L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, *113*(5), 893–903. https://doi.org/10.1016/j.rse.2009.01.007

Chavez, P. S. (1988). An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment*, *24*(3), 459–479. https://doi.org/10.1016/0034-4257(88)90019-3

Chen, L., Guo, Z., Yin, K., Shrestha, DP., and Jin S. (2019). The influence of land use and land cover change on landslide susceptibility: a case study in Zhushan Town, Xuan'en County (Hubei, China). Natural hazards and earth system sciences, 19(10), 2207-2228. https://doi.org/10.5194/nhess-19-2207-2019

Cullen, CA., Al-Suhili, R., and Khanbilvardi, R. (2016). Guidance index for shallow landslide hazard analysis. Remote Sensing, 8(10), 866. https://doi.org/10.3390/rs8100866

Dahal, R.K., Hasegawa, S., Nonomura, A., Yamanaka, M., & Dhakal, S., Paudyal, P. (2008), Predictive modelling of rainfall-induced landslide hazard in the Lesser Himalaya of Nepal based on weights-of-evidence, Geomorphology, 102, (3-4),496-510. https://doi.org/10.1016/j.geomorph.2008.05.041

Fell, R. (2018). Human induced landslides. *Landslides and Engineered Slopes. Experience, Theory and Practice*, 171-199.

Gaillard, JC., Dibben, CJL. (2008). Volcanic risk perception and beyond.J. Volcanol. Geotherm.,172,163–169. https://doi.org/10.1016/j.jvolgeores.2007.12.015

Galli, M., Ardizzone, F., Cardinali, M., Guzzetti, F., & Reichenbach, P. (2008). Comparing landslide inventory maps. Geomorphology, 94(3-4), 268-289. https://doi.org/10.1016/j.geomorph.2006.09.023

Gazi, MY., Rahman, MZ., Uddin, MM. (2020). Spatio-temporal dynamic land cover changes and their impacts on the urban thermal environment in the Chittagong metropolitan area, Bangladesh. GeoJournal (2020). https://doi.org/10.1007/s10708-020-10178-4.

Greenway, DR. (1987). Vegetation and slope stability. In: Anderson MG, Richards KS (eds) Slope stability. Wiley, Chichester, pp 187–230

Hassan, MM., Ahmed, S., Patwary, NH., Yeasmin, L., Shahidullah, SM., Sattar, MA. (2015). Environmental degradation through hill cutting in Chittagong district of Bangladesh, Int. J. Nat. Soc. Sci. 2, 41–54.

Hassan, MM., Nazem, MNI. (2016). Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city, Bangladesh. Environ Dev Sustain 18, 697–716 (2016). https://doi.org/10.1007/s10668-015-9672-8

Irish, R. R. (2000). Landsat 7 automatic cloud cover assessment. *Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VI*. https://doi.org/10.1117/12.410358

Islam, MN., and Uddin, MN. (2002). Hydrogeology Section in International Workshop on Arsenic Issue in Bangladesh, 14-16.

Islam, M. N. (2008). an introduction to research methods: A handbook for business and health research (2nd ed.). Dhaka: Mullick& Brothers.

Islam, MS. (2018). Effect, Causes, and Possible Measure of Landslide in Bangladesh (Chittagong). Engineering Science, 3(4),58-63. https://doi.org/10.11648/j.es.20180304.1

Jaboyedoff, M., Michoud M., Derron MH, Voumard J., Leibundgut G., Sudmeier RK., Nadim F., and Leroi E. (2016). Human-induced landslides: toward the analysis of anthropogenic changes of the slope environment. 217-232.

Jaboyedoff, M., Michoud, C., Derron, M.-H., Voumard, J., Leibundgut, G., Sudmeier-Rieux, K., . . . Leroi, E. (2018). Human-induced landslides: toward the analysis of anthropogenic changes of the slope environment *Landslides and Engineered Slopes. Experience, Theory and Practice* (pp. 217-232): CRC Press.

Kalantar, B., Ueda, N., Saeidi, V., Ahmadi, K., Halin, A. A., & Shabani, F. (2020). Landslide susceptibility mapping: Machine and ensemble learning based on remote sensing big data. *Remote Sensing*, *12* (11), 1737

Krivoguz D and Bespalova L. (2017). Spatial analysis of topography of Kerch peninsula using GIS and its impact on landslides. International Journal of Professional Science.

Kjekstad, O., Highland, L. (2009) Economic and Social Impacts of Landslides. 573-587. https://doi.org/10.1007/978-3-540-69970-5_30

Magar, Y. R., Dhamala, M. K., Mathema, A., Chauhan, R., & Bhatta, S. (2021). On the impact of earthquake-induced landslides on Red Panda Ailurus fulgens (Mammalia: Carnivora: Ailuridae) habitat in Langtang National Park, Nepal. *Journal of Threatened Taxa*, *13*(9), 19191-19202.

Manandhar, S., Pratoomchai, W., Ono, K., Kazama, S., & Daisuke, K. (2014).Local people's perceptions of climate change and related hazards in mountainous areas of northern Thailand. International Journal of Disaster Risk Reduction, 11, 47–59 https://doi.org/10.1016/j.ijdrr.2014.11.002

Mia, M. T., Sultana, N., and Paul, A. (2015). Causes, Impact and Mitigation Strategies of Landslide in Chittagong city. Bangladesh J. Environ. Sci. & Natural Resources, 8(2), 1-5.

Mohan, A., Singh, A. K., Kumar, B., & Dwivedi, R. (2021). Review on remote sensing methods for landslide detection using machine and deep learning. *Transactions on Emerging Telecommunications Technologies, 32*(7), e3998.

Moreno, H. G., Ayala, A. I. (2017). Landslide risk perception in Mexico: a research gate into public awareness and knowledge. Landslides 14,351–371. https://doi.org/10.1007/s10346-016-0683-9

Moayedi, H., Osouli, A., Tien Bui, D., & Foong, L. K. (2019). Spatial landslide susceptibility assessment based on novel neural-metaheuristic geographic information system based ensembles. *Sensors, 19*(21), 4698.

Mugambiwa, S.S. & Dzomonda, O. (2018). Climate change and vulnerability discourse by students at a South African university', Jàmbá: Journal of Disaster Risk Studies 10(1), a476. https://doi.org/10.4102/jamba.v10i1.476.

Perera, E.N.C., Jayawardana, D.T., Jayasinghe, P.(2018). Direct impacts of landslides on socio-economic systems: a case study from Aranayake, Sri Lanka. Geo. Environ. Disasters 5(11). https://doi.org/10.1186/s40677-018-0104-6

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(1), 23–44. https://doi.org/10.1007/s11069-006-9100-3

Rabby, Y. W. (2021). Landslide Mapping and Susceptibility Assessment of Chittagong Hilly Areas, Bangladesh.

Reichenbach, P., Busca, C., Mondini, A.C. et al. (2014) The Influence of Land Use Change on Landslide Susceptibility Zonation: The Briga Catchment Test Site (Messina, Italy). Environmental Management 54,1372–1384 (2014). https://doi.org/10.1007/s00267-014-0357-0

Rieux, K. S., StephanieJaquet, S., Derron, M. H., Jaboyedoff, M., Devkota, S. (2012).A case study of coping strategies and landslides in two villages of Central-Eastern Nepal.Applied Geography 32(2),680-690.

Roder,G., Ruljigaljig T., Lin, C. W., & Tarolli, P. (2016). Natural hazards knowledge and risk perception of Wujie indigenous community in Taiwan. Nat Hazards 81, 641–662. https://doi.org/10.1007/s11069-015-2100-4

Roy, B. and Saha, P. (2016). Temporal Analysis of Land Use Pattern Changes in Chittagong District of Bangladesh using Google Earth and Arc GIS, Annual Int'l Conference on Chemical Processes, Ecology & Environmental Engineering (ICCPEE'16) April 28-29, 2016 Pattaya (Thailand)

Saina, CK., Arusei, E., Kupti, M., Jemutai, JJ. (2016). The causes and socio-economy impacts of landslidein Kerio Valley, Kenya. Agricultural Science and Soil Sciences, 4, 58–66.

Sarker, A. A., & Rashid, A. K. M. M. (2013). Landslide and Flashflood in Bangladesh. *Disaster Risk Reduction Approaches in Bangladesh*, 165–189. https://doi.org/10.1007/978-4-431-54252-0_8

Shaw, R., Mallick, F., Islam, A.(2013) Disaster Risk Reduction Approaches in Bangladesh. Science & Business Media,31 – 366.

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

Sultana, T. (2013). Landslide disaster in Bangladesh: a case study of Chittagong University campus. International journal of research in applied, natural and social sciences, 1(6), 35-42.

Turner, K. A. (2018). Social and environmental impacts of landslides, Innovative Infrastructure Solutions,1.

Zhang, B., Zhang, L., Yang, H., Zhang, Z., & Tao, J. (2016). Subsidence prediction and susceptibility zonation for collapse above goaf with thick alluvial cover: A case study of the Yongcheng coalfield, Henan Province, China. *Bulletin of Engineering Geology and the Environment, 75*(3), 1117-1132.

Zhao, C., & Lu, Z. (2018). Remote sensing of landslides—A review. *Remote Sensing, 10*(2), 279.

Zhu, L., Huang, L., Fan, L., Huang, J., Huang, F., Chen, J., . . . Wang, Y. (2020). Landslide susceptibility prediction modeling based on remote sensing and a novel deep learning algorithm of a cascade-parallel recurrent neural network. *Sensors, 20*(6), 1576.

Zhong, C., Liu, Y., Gao, P., Chen, W., Li, H., Hou, Y., . . . Ma, H. (2020). Landslide mapping with remote sensing: challenges and opportunities. *International Journal of Remote Sensing, 41*(4), 1555-1581.

Zillman, J. (1999). The physical impact of the disaster. In Natural disaster management, ed. J. Ingleton, 320. Leicester: Tudor Rose Holding Ltd.

Zumpano, V., Pisano, L., Malek, Z., Micu, M., Aucelli, P. C., Rosskopf, C. M., Balteanu, D., & Parise, M.(2018)Economic Losses for Rural Land Value Due to Landslides, Front. Earth Sci.,6. https://doi.org/10.3389/feart.2018.00097

Appendix
Questionnaire
on
Perceived Human-induced Causes of Landslide
(A study in Chattogram Metropolitan Area)
[All these information is going to be used only for research]

Question No. Date……..

1. Socio-economic status of Respondent-

Name	Age	Sex	Occupation	Family Member

a) How many members in your family are employed?

_____

b) What is the monthly income of your family?

1. < 5000 2. 5000 – 10000
2. 3. 10000 – 15000 4. > 15000

2. Educational qualification of the respondents?

1. Illiterate 2. Primary level

3. Secondary level 4. Higher secondary

3. Are you native of the area?

1. Locally originated 2. Migrated from outside

4. What is the maximum house pattern of the area?

1. Building 2. Semi Building

3. Tin Shed 4. Earthen

5. Do you aware about the natural calamities, land slide?

1. Yes 2. No

6. Did you face any landslide occurrence in your life time?

1. Yes 2. No

7. According to you what is the main cause of landslide?

1. Hill cutting 2. Weak soil structure

3. Extensive rainfall 4. Stepper hill

8. Does the human activity responsible for landslide along with natural causes?

1. Yes 2. No

9. If yes, what is the major human induced cause of landslide?

1. Infrastructure 2. Deforestation

3. Hill cutting 4. Sand Collection

10. Which factor influences human induced causes?

1. Establishment of settlement 2. Jhum cultivation

3. Demographic pressure 4. Mining and quarrying

11. Is there any socio-economic impact of landslide on local people?

1. Yes 2. No

12. If yes, what kind of impact is visible?

1. Positive 2. Negative 3. Both

13. What is the negative impact of landslide?

1. Human life risk
2. Loss of natural beauty
3. Economic loss
4. Environmental Problem

14. What is the major impact of landslide on human being?

1. Effects on their homes and possessions
2. Farms and livestock
3. Destruction of human life
4. Others

15. What is the impact of landslide on natural beauty?

1. Declining natural beauty
2. Destruction of scenic beauty
3. Destroy natural resources

16. What is the impact of landslide on the daily life of local people?

1. Destruction of infrastructure
2. Destruction of household utilities
3. Destruction of materials for daily life

17. What is the environmental problem due to landslide?

1. Block of drainage connection
2. Loss of soil fertility
3. Loss of biodiversity

18. Do you take any strategies to avoid landslide risk?

1. Yes
2. No

19. Which strategies do you take to manage the risk?

1. Stop hill cutting
2. Resettlement
3. Afforestation
4. No Strategy

20. Have you made any complain related to landslide?

a) Yes
b) No

21. If yes, to whom did you complained?

a) Local b) Govt. c) Others

22. What was the result of the complain?

a) Prompt action taken b) Delayed action taken c) No action taken

23. Why don't you migrate from this risky place?

1. Due to low economic condition
2. Political Factor
3. Because of inherited place

24. Do you face any political influence?

1. Yes 2. No

25. What kind of political influence have you faced?

1. Hindrance to resettlement
2. Biasness of landholders
3. Others

26. What kind of steps/actions has taken to manage the incidence instantly?

1. Resettlement of people 2. Provide adequate relief
3. Medical supplies 4. Manpower

27. Does the govt/NGO's take any pre-management initiatives to minimize the risk?

1. Yes 2. No

28. Is there any developed Govt. policy used for hill tracts area management?

1. Yes 2. No

29. What kind of steps should have taken by Govt. to reduce the problem?

1. Identifying landslide prone area 2. Develop water drainage system
3. Tree plantation 4. Stop illegal activities

30. What is your suggestion to minimize the landslide problem in your locality?

....

Thanks for your participation