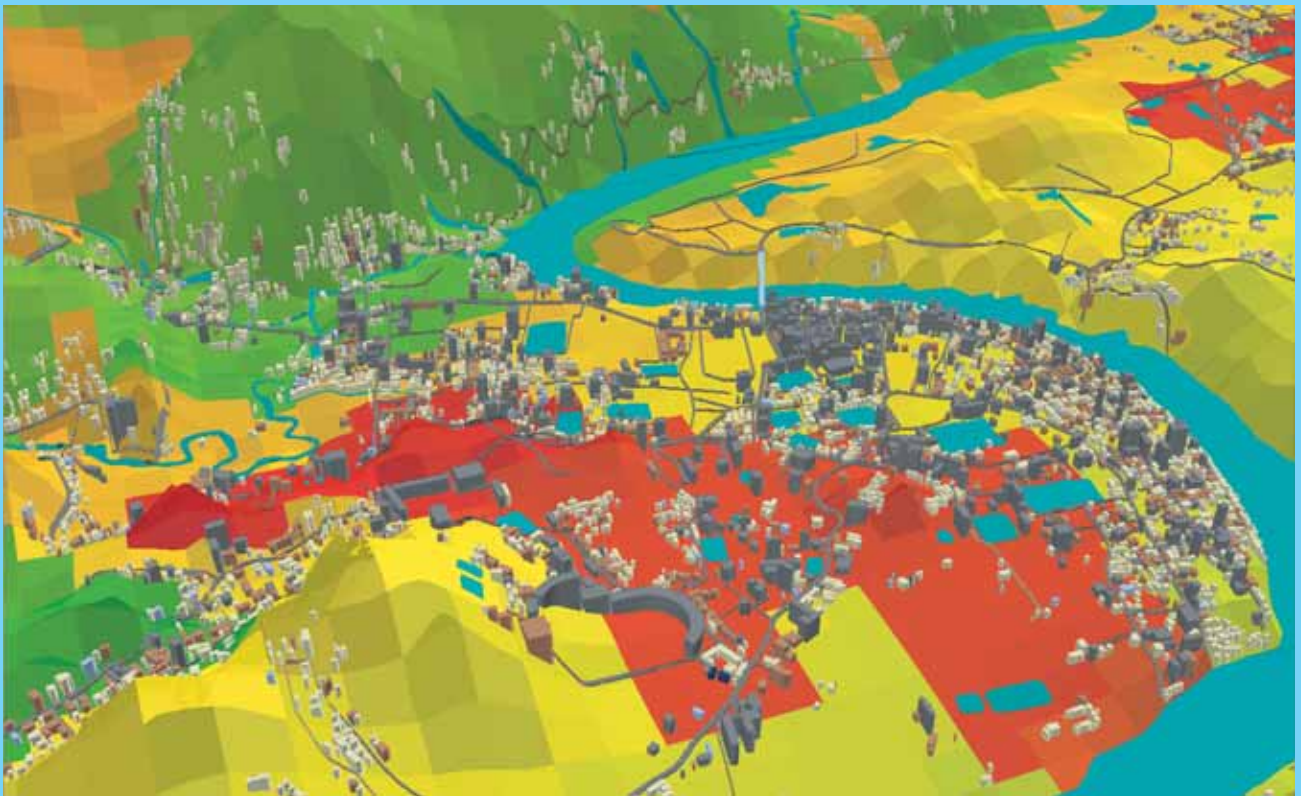




# Report on the Landslide Hazard Zonation mapping at Cox's Bazaar and Teknaf in Bangladesh



**April 2012**

Comprehensive Disaster Management Programme (CDMP II)  
Ministry of Disaster Management and Relief





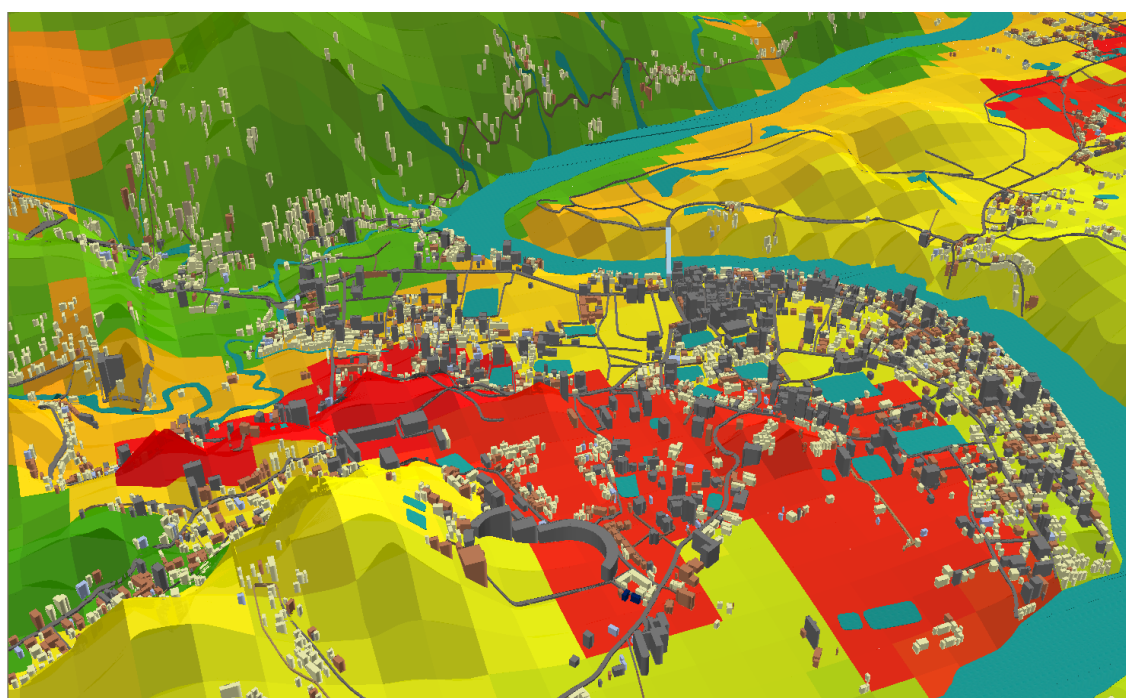
## Comprehensive Disaster Management Programme (CDMP-II)

Ministry of Food and Disaster Management (MoFDM)

Disaster Management and Relief Division (DMRD)

Government of the People's Republic of Bangladesh

## Report on the Landslide Hazard Zonation mapping at Cox's Bazaar and Teknaf in Bangladesh



April 2012

Submitted by

Joint Venture of



Data Experts (Pvt.) Limited  
House 25/3, Road 15 (old 28)  
Dhanmondi, Dhaka-1209, Bangladesh

And



Asian Disaster Preparedness Center  
SM Tower, 24 th Floor, 979/69 Paholyothin Road,  
Samsen Nai Phayathai, Bangkok 10400, Thailand

## **Table of Contents**

1.	Introduction	1
2.	Methods and approaches for landslide hazard mapping	1
a.	Literature survey on Methods used landslide hazard zonation mapping	1
b.	Heuristic qualitative approaches	2
c.	Probabilistic Approaches	2
d.	Deterministic approaches	3
e.	Short description of Methods used in few countries in Asia for National and sub-national level mapping	3
3.	Preparation of maps for zonation of potential landslide hazard	4
a.	Criteria adopted for identification of map units	4
b.	Methodology used for field mapping under each category of map units	5
c.	Explanation on development of rating systems through initial field visit by specialists through observation	5
d.	Inputs from the Landslide inventory preparation	6
e.	Finalization of the Rating system	7
4.	Attribute maps	9
a.	Attribute map of Slope	9
b.	Attribute Map of Geology	9
c.	Attribute Map of Land Use	9
d.	Attribute Map of Over Burden	10
5.	Ranking of slopes as per the risk potential-	10
	• Presentation on the Landslide hazard zonation maps with respect to the slope angle	11
	• Presentation on the Final Landslide hazard zonation maps	12
	• Risk potential in cities	16
6.	Recommendations for risk reduction	16
7.	Conclusion	17

# **Report on the Landslide Hazard Zonation mapping at Cox's Bazaar and Teknaf in Bangladesh**

## **1. Introduction**

Landslides, one of the natural catastrophes, always cause a major problem in the Cox's Bazaar and Teknaf mountain zones, of Bangladesh by killing people every year besides damaging the properties and blocking the public utilities.

Globally, landslides cause hundreds of billions of dollars in damage and hundreds of thousands of deaths and injuries each year. One of the very impotent tasks is to prepare landslide hazard zonation (susceptibility) map (Aleotti and Chowdhury 1999) to get proper idea before take any decision to reduce the risk from landslides. Landslide susceptibility is defined as the proneness of the terrain in a cartographic way. A landslide zonation map describes areas where landslides are likely to occur in the future by correlating some of the principal factors that contribute to landslides with the past distribution of landslides (Brab et al. 1972).

The main purposes of this study are to define the relationship between causative factors on landslide occurrences and to create a landslide hazard zonation map. This will help to reduce the impact of landslides by determining the areas at risk. Identification of the hazard zones will lead to manage the watershed and apply suitable mitigations to the vulnerable areas/locations.

The main scope of this programme to generate landslide hazard zonation maps that can be utilized in the process of development to identify the potential landslide hazard in the two mountainous areas of Cox's Bazar and Teknaf municipally area of Bangladesh.. Considering the time and the cost required for mapping, the scale of 1:10000 was selected. The availability of topographic maps at the scale of 1; 5000 was also used adoption to gather the data for this mapping exercise.

## **2. Methods and approaches for landslide hazard mapping**

### **a. Literature survey on Methods used landslide hazard zonation mapping**

During the last three to four decades, there were many studies that have applied different methods to analyze landslide and to create landslide hazard mapping. A large amount of research on landslide hazard zonation has been done in this context, the consequence of an urgent demand for slope instability hazard mapping. Overviews of the various slope instability hazard zonation techniques can be found in Brabb (1984), Cotecchia (1978), Guzzetti et al., (1999), Hansen (1984), Hartlen and Viberg (1988) and Varnes (1984). Landslide-susceptible areas can be assessed and predicted through scientific analysis of landslides, and thus landslide damage can be decreased through prevention effort. To achieve this aim, landslide susceptibility analysis techniques have been applied, and verified in the study area. In addition, landslide-related factors were assessed and geographic information system (GIS) software was used as the basic analysis tools for spatial management and data manipulation. Many methods and techniques have been proposed to evaluate landslide prone area using GIS and/or remote sensing (Aleotti and Chowdhury 1999; Carrara et al. 1999; Gorsevski et al. 2000; Guzzetti et al. 1999; Lan et al. 2004; Lee and Min 2001; Mantovani et al. 1996; Nichol and Wong 2005; Odajima et al. 1998; Sarkar and Kanungo 2004; Van Westen 2000; Van Westen 2004) and many of these studies have applied probabilistic methods (Guzzetti et al. 2005; J.L.Zézere et al. 2004; Lee et al. 2004a; Luzi

et al. 2000; P.Watts 2004; Refice and Capolongo 2002; Zhou et al. 2003). Probabilistic approaches are based on the observed relationships between each factor and the distribution of landslides. There are other methods for landslide hazard mapping, such as the deterministic approach (or safety factor) used by Gokceoglu and Aksoy (1996) and Van Westen and Terlien (1996), Heuristic approach (Barredo et al. 2000; Van Westen 2000) and Statistical approach (Carrara et al. 1991; Luzi 656 Mehrnoosh Jadda, Helmi Z. M. Shafri, Shattri B. Mansor, Mohammad Sharifkia and Saeid Pirasteh and Pergalani 1996) Fuzzy logic and artificial neural network methods have also been applied in various studies (Binaghi et al. 1999; Chi et al. 2002; Giacinto et al. 2000; Lee et al. 2004b). In some analysis, frequency ratio model, a simple and understandable probabilistic model with an acceptable accuracy, were applied. Dai et al. (2004) and Lee and Pradhan (2007) have used logistic regression method to model landslide distribution Factor ratio was evaluated by the ratio of the area where landslides occurred to the total study area for a given factor's attribute (Lee and Dan 2005; Lee and Pradhan 2006; Yilmaz 2008).. Bivariate statistical approach was used by Cevik and Topal (2003) and Yaclin (2008) to compare each individual factor and landslide distribution map to assign weighting value to the various parameter and finally to prepare a landslide hazard map. Analytical hierarchy process (AHP) was another procedure that was applied by Barredo et al. (2000) and Yaclin (2008) to deal with the paradoxical role of different factors in landslide occurrence.

When making use of GIS techniques for landslide hazard zonation mapping, the following methodological approaches can be used, but they are different each other

#### **b. Heuristic qualitative approaches,**

These approaches are particularly suited for small-scale regional surveys. The scale of such surveys is of the order of 1: 100 000 to 1 : 250 000.They are used mostly by regional planning agencies.

The heuristic qualitative approach is a direct or semi-direct mapping methodology, which implies that during the landslide inventory a direct relationship is made between the occurrence of slope failures and the causative terrain parameters. An a priori knowledge on the causes of landslides is essential in decision making, and therefore the method relies heavily on the professional experience of the expert.

#### **c. Probabilistic Approaches**

Statistical quantitative approaches are very much suite for medium scale surveys. These are in the range of 1: 25 000 -1:500 000 and are mainly used by consulting firms or planning agencies for the preliminary planning of infrastructural works such as the definition of road corridors. The methods at this scale can be sub differentiated as follows:

Data-driven multivariate statistical analysis  
Experience - driven bi-variate statistical analysis.

Predictive modeling through the application of probability and favorability functions. In the statistical approach an indirect mapping methodology is followed. All possible causative terrain parameters are entered into a GIS and crossed for their analysis with a landslide distribution map. When using multivariate statistical methods all parameters at sites of instability can be analysed by multiple regression techniques or parameter maps are crossed with landslide distribution maps and the correlation is established for stable and unstable areas with discriminate analysis.

#### **d. Deterministic approaches**

Deterministic approach is used for detailed studies at large scale (1: 2000-1: 10,000), without entering that level of the engineering geological site investigation. Such small-scale studies are used by consulting firms or local planning agencies for the detailed planning of infrastructural works.

The advantage of the application of deterministic models in landslide hazard studies is that use is made of sound physical models. Stability models, as used in geotechnical engineering, calculate the stability of a slope, using parameters such as normal stress, angle of internal friction, pore water pressure, etc. They result in a safety factor which can be used directly by engineers in the design of infrastructural or remedial works. Deterministic slope stability models have been used since the beginning of this century to calculate the stability of individual slopes (Nash 1987).

Using one of these approaches, the spatial relationships between landslide occurrence locations and each of the factors contributing to landslide occurrence were derived. The method was used to compute the area density values for different classes of the factors. This method requires selecting and mapping causative factors and their classification into a number of classes, to map landslide distribution in the study area, to overlay landslide distribution map with each parameter map, and to determine density of landslide in each parameter class. Then we need to define weighted values, assignment of weighting value to the various parameter maps, and final overlay mapping and calculation of the final hazard or susceptibility value of each identified land unit.

In this study, the four thematic data layers and the landslide distribution layer were the input data for spatial analysis in GIS. The cell size selected for the analysis was  $x \times y$  m. The total number of cells in the area is  $n$ ; the number of cells occupied by each category of all the factors was calculated to compute area density value in GIS. Each layer was integrated with the landslide inventory layer to determine the number of cells in each category of factor containing landslides.

#### **e. Short description of Methods used in few countries in Asia for National and sub-national level mapping**

A large amount of research on landslide hazard zonation has been done over the last 30 years as the consequence of an urgent demand for slope instability hazard mapping. Overviews of the various slope instability hazard zonation techniques were used in Brabb (1984), Cotecchia (1978), Guzzetti et al., (1999), Hansen (1984), Hartlen and Viberg (1988) and Varnes (1984).

Among them in Sri Lanka, a landslide susceptibility assessment model had been developed making attempts to arrive at decisions based on collective wisdom (LHMP user manual, SRL 1989/001). The study was based on the field data collected from 1200 landslides in Nuwara-Eliya and Badulla districts during a five years (1989 to 1995) research project conducted by Landslide Studies and Services Division (LSSD) of the National Building Research Organization (NBRO). Six major causative factors with sub factors were considered and data was collected into 1: 10,000 scales. Although the outputs of the statistical analysis of the terrain factors were considered, relative weightings for major factors and scores for sub factors and factor classes had been designed on the basis of collective wisdom of the experts, as it was not possible to obtain a unanimous agreement on a highly subjective matters relying only on statistical data. The model has been used since 1995 for the prediction of landslide susceptibility of existing slopes in all the parts of the country.

Landslide Hazard zonation maps for Hong Kong have been prepared by using the historical data incorporate with geological, Geomorphological, population, climatic and rainfall data. GIS technology has used to compilation of those data. (K.T. Chau et al 2003)

To evaluate the landslide susceptibility potential in India, various causative factors controlling the slope stability or influencing it have been identified and prioritized such as lithology and structure, geomorphology, stream network, climate, vegetation, land use land cover, existing landslides, slope angle and slope aspect. These factors were identified based on the knowledge of the past events and present conditions prevailing in the area in anticipation of future behavior of slope stability. For each of the identified factors analytical maps are prepared using remote sensing analysis, base map, extensive field mapping and other available information. All the maps have been generated in digital platform in ArcGIS 9.0 software. Each causative factor and their classes have been assigned appropriate rating or weighting both in terms of alphabets (qualitative) and numerals (Quantitative) as per their role in inducing slope instability (Kishor Kumar, 1996). The final grading is provided on the basis of the sum of the total estimated significance of each of the factors. Each of the factor maps were crossed according to the priority assigned which has resulted into a combined map i.e. Landslide Susceptibility Potential Map (LSPM) to evaluate the actual hazard situation in the area.

In Asia there are also many countries have completed landslide zonation maps for only 0–25% from their total landslide areas, but some countries had a greater coverage (above 25% in Korea, 50–60% in Taiwan and more than 75% for Hong Kong and New Zealand).

### **3. Preparation of maps for zonation of potential landslide hazard**

#### **a. Criteria adopted for identification of map units**

In case of most landslides seen in recent time the landslides in Bangladesh can be categorized as shallow to medium in terms of depth of occurrence. The shape and size of slope movements can vary because of the combination of several preparatory and triggering factors (dissolution, deformation and rupture by a static or dynamic load). They may be controlled by the topography (inclination and shape of the slope), the lithology (physical and geo-mechanical characteristics), the geological structure (dip, fault, and discontinuity), the hill slope hydrology (pore pressures, water contents) or a combination of all these factors. Water intervenes in several ways. First, it acts by changing the state or consistency of materials (transition from a solid to a plastic and finally to a liquid state) (Coussot and Meunier, 1996); secondly, it lightens the terrain due to Archimedes' thrust (Terzaghi's law) in relation to water tables increases. The consequence for the slopes is a reduction in the inter-particle forces and the associated friction throughout the length of the rupture surfaces. Finally water acts as an agent in the transport of materials. A failure occurs when the disturbing forces that create movement exceed the resisting forces of the material. Triggering factors may either increase the shear stress; decrease the shearing resistance of the material or both.

JTC- 1, the joint ISSMGE, IAEG and ISRM Technical Committee on Landslides and Engineered Slopes has appointed a Scientific Committee to undertake the development of guidelines for landslide susceptibility and hazard and risk zoning for land use planning and the committee report provide a clear guidelines for selecting map units for landslide hazard zonation in any given situation. Slope failure is caused by the concurrence of permanent conditioning and triggering factors. Permanent factors are terrain attributes (i.e. lithology, soil types and depths, slope, watershed size, vegetation cover, among others) that evolve slowly (i.e. by weathering or erosion) to bring the slopes to a marginally stable state. Triggering events include ground shaking due to earthquakes or rise of groundwater levels and/or pressures due to infiltration of rainfall or snow melt. Only permanent conditioning factors are needed to be considered for mapping to assess landslide susceptibility while the recurrence period of the triggers

is usually used to assess the landslide hazard. The Map units for hazard Zonation mapping has been selected as per the above guidelines.

Considering the above factors main causative factors for the landslide zonation mapping in Cox'S Bazaar and the Teknaf municipality areas were identified and used as main map units. Slope map, Geology map, Land use map and the surface deposit map were the main map units used for the study.

**b. Methodology used for field mapping under each category of map units**

There were no geo-morphological and geological maps available for Cox's Bazaar and Teknaf Municipalities in the scale of 1:0.000. Only Geological Map was available at 1:50,000 scale which indicate the entire area with only one mapping unit. These types of maps were not much useful in landslide hazard zonation. Therefore the study team conducted a extensive field programme to collect the data for each and every map units.

Following major steps were involved in the mapping programme as described by Bandari et el 2003)

- a) Causative factors were identified which influence the instability in the two areas, during the preliminary field visit carried out by the expert team
- b) Short listed the most relevant causative factors and consequent detailing out of the map units.
- c) Extensive field study was carried out to gather the information for each and every map unit.
- d) Gathered data were put into the maps separately according to their category
- e) Holistic study of maps in the background of other related information and searched for inter-relationship between the causative factors
- f) Figured out the degree of instability based on the criteria developed
- g) Field verification was done at last to confirm the gathered data

**c. Explanation on development of rating systems through initial field visit by specialists through observation**

With the previous experience in carrying out mapping in several countries in Asia and tentative ranking system for each and every factor were submitted with the inspection report. Mainly to create such sample ranking system was based on the methodology used in Sri Lanka under similar conditions and the observations during the initial field visit.

With the field data gathering and continuous field visits by the specialists during the field mapping submitted ranking system had to change according to the relationship of selected map units to the landslide vulnerability of two cities. Landslide inventory map data in two cities and the geological, geomohpological , and terrain conditions had to be considered for final ranking system. Finalized ranking system will be included in later chapter and seek further advice from the CDMP and TAC before using in Landslide Hazard Zonation Mapping.



**Table 1 Proposed ranking for landslide hazard zonation mapping based on expert knowledge**

Major Facotrs (Weight,linguistic, numerical)	Subfacotrs (Weight,linguistic,numerical)	Rating criteria X - Subjective, Y - Linguistiv, Z - Numerical			
		Subfactor elements	X	Y	Z
(high, B, 20)	Lithology* (very high,A,8)	Marble, limestones, sandstones	very low	E	0
		Weathered rock	low	D	1
		Granite,garnet,biotite gneiss,and all others	medium	C	3
		Massive rock,granulite,or bedrock not exposed	high	B	5
		Quartzite	very high	A	8
	Amount and direction of dip (degrees) (medium,C,4)	Dip and scarp 70 - 90	very low	E	0
		Dip and scarp 55 - 70	low	D	1
		Dip 10 - 30, scarp 45 - 55,and interm slopes	medium	C	2
		Dip 0 - 10, scarp 30 - 45	high	B	3
		Dip 30 - 55, scarp 0 - 30	very high	A	4
	Deviation angle (degrees) (high,B,6)	Angle 25 - 120	very low	E	0
		Angle 10 - 25 or 120 - 155	low	D	2
		Angle 155 - 180	high	B	4
		Angle 0 - 10	very high	A	6
	Discontinuities, lineaments,faults, & master joints (very low,E,2)	Decided on case to case basis	very low	E	0
			very high	A	2
Surface deposits (colluvium & residual soi (low,D,10)	soil cover (m) (very high,A,10)	Bare bedrock	very low	E	0
		colluvium < 1, or residual soil < 2	low	D	2
		colluvium 1-3, or residual soil 2-8	medium	C	8
		colluvium 3-8, or residual soil > 8	high	B	9
		colluvium > 8, or residual soil > 8	very high	A	10
Slope range & Category (very high,A,25)	Slope angle range (degrees) (very high,A,25)	Slope category V (angle 0 - 11)	very low	E	5
		Slope category IV (angle 11 - 17)	low	D	7
		Slope category III (angle 17 - 31)	medium	C	13
		Slope category II (angle 31 - 40)	high	B	16
		Slope category I (angle > 40)	very high	A	25
Land use & Management (medium,C,15)	Land use & Management** (very high,A,15)	Land users with minimum impacts to land degradation	very low	E	3
		Land users with medium impacts to land degradation	medium	C	8
		land users with very high impacts to land degradation	very high	A	15

\* Detail changes to rck types will be made during mapping

Land use categories will be detailed out according to this classification during field mapping

**d. Inputs from the Landslide inventory preparation**

Accurate detection of the location of landslides is very important to analyze landslide hazard. The landslide inventory map shows the noticeable landslides on the land (van Westen 1994; Lee and Ryu 2004; Yaclin 2008). Landslide inventory maps were prepared in a different format by gathering the information related with landslides. or. In this study, 1:10,000 scale field mapping was carried out by the team and the data gathered were compiled and interpreted to detect the landslide locations. These locations were verified too by the information gathered from the community in two cities.

A total of 149 from Cox's Bazaar and 18 from Teknaf landslides were detected in the study area.

Most of the inventory data was used in order to assess the landslide susceptibility maps of the various factors contributing to the landslide occurrence in the area.

**e. Finalization of the Rating system**

The factors considered in this study were slope angle, geological condition, land use type, surface deposits. To assess the landslide hazard and risk with a minimum set of data, a reproducible methodology, and GIS techniques are being used by earth scientists, government authorities, and resource managers.

Therefore the quantitative statistical approach which is the most important in landslide susceptibility mapping techniques was used to identify the most appropriate ranking system for this landslide hazard zonation mapping. This approach is more objective to associate a little expert knowledge. Effective factors associated with landslide occurrence are analyzed and ranked by statistics. This method was a bivariate statistical method consists of the idea to compare a landslide inventory map with landslide-influencing parameters maps in order to rank corresponding classes according to their role in landslide occurrence (Ayalew and Yamagishi 2005).

Area density method, one of the bivariate approaches, was used to observe the relationship between distribution of landslides and each landslide-related parameter to determine correlation between landslide locations and the factors. This is a very useful method to map susceptibility areas to landslide formation by determining the influence of parameters governing landslide occurrence in two cities

Using this approach, the spatial relationships between landslide occurrence locations and each of the factors contributing to landslide occurrence were derived. The method was used to compute the area density values for different classes of the factors. Selecting and mapping causative factors and their classification into a number of classes, to map landslide distribution in the study area, to overlay landslide distribution map with each parameter map, and to determine density of landslide in each parameter class were used for this methodology. Then the weighted values, assignment of weighting value to the various parameter maps, and final overlay mapping and calculation of the final hazard or susceptibility value of each identified land unit were defined.

In this study, the four thematic data layers and the landslide distribution layer were the input data for spatial analysis in GIS. The cell size selected for the analysis was 5 X 5m and 1 X 1m for Cox Bazar and Teknaf respectively.. The total number of cells in Cox's Bazar was 1470667 and in Teknaf was 6914791 the number of cells occupied by each category of all the factors was calculated to compute area density value in GIS. Each layer was integrated with the landslide inventory layer to determine the number of cells in each category of factor containing landslides. From the above data susceptible values for all the categories were computed. (Table 2 for Cox's Bazar and Table 3 for Teknaf).

**Table 2 Proposed Landslide Factors For Landslide Hazard mapping in Bangladesh (Cox's Bazaar)**

Main Category 1	Type/ Thickness/Range 2	Total Area 3	Area of the type 4	No of Landslide 5	Susceptibility (4/3)(5)	Assigned rates
Geology	Sandstone			21		
	Inter bedded sandstone and clay with Shale			71		
	Shale			7		

Main Category 1	Type/ Thickness/Range 2	Total Area 3	Area of the type 4	No of Landslide 5	Susceptibility (4/3)(5)	Assigned rates
Slope	0-15			14		
	15-30			47		
	30-45			37		
	45-60			2		
	60+			0		
Over burden	0-5			119		
	5-10			11		
	10-15			6		
	15<			0		
Landuse	Homestead			59		
	Forest			4		
	No Vegetation			37		

Table 3 Proposed Landslide Factors For Landslide Hazard mapping in Bangladesh (Teknaf)

Main Category 1	Type/ Thickness/Range 2	Total Area 3	Area of the type 4	No of Landslide 5	Susceptibility ((4/3)(5))%	Assigned rates
Geology	Sandstone with thin layer of clay			4		
	Shale			2		
	Shale with thin layer sand			2		
	Shale with inter bedded sand and clay			10		
Slope	0-15			3		
	15-30			2		
	30-45			9		
	45-60			4		
	60+			0		
Over burden	0-5			2		
	5-10			3		
	10-15			1		
	15<			12		
Landuse	Homestead			11		
	Forest			3		
	No Vegetation			4		

## **4 Attribute maps**

The project team analyzed the past landslides reported in the Inventory (around 147 landslide events in Cox's bazaar and 18 landslide events in Teknaf ) to correlate between events in two municipalities and attributes of the slope , geology, land use and the surface deposits. The results of the analysis are given below

### **a. Attribute map of Slope**

During the field work, an attempt was taken to analyse the slope angles of failed slopes to see whether any dominance could be seen in the various slope angles. From the evidence of the past landslides it was seen that the most dominant category among failed slopes are the slopes between slope angle of 16-30. Similar correlation can be seen in both the municipality areas. The other dominant category is the slopes with slope angle of 31-45. The slopes with slope angle of 45 or less than 15 are less dominant among failed slope categories. The other factor evident from the past landslides is the fact that when the slope angle increases number of landslides in slopes higher than 45 becomes less. It is mainly due to the fact that, when the slope becomes higher the probability of retention of any weaker layer or soil mass is becoming less and under the gravity such slopes tend to get eroded systematically. So the retained mass thickness will not be so high and such slopes probably will not fail easily. In certain cases apparently there are block failures which have been occurred along near vertical joints along escarpment slopes elsewhere but such failures have not been seen as the dominant failure mode within the two target cities.

### **b. Attribute Map of Geology**

It is seen from the past landslide Inventory that there are 4-5 categories of rock types observed on the failed slopes but predominant rock types to be shale and sandstones. All other rock types are variations of the same with thinner inter-bedding and presently highly to completely weathered. It is seen that all such main Rock types also are subjected to weathering to a different degree or covered with a Residual soil layer where the relic structure was intact .In certain cases it have had a colluviums layer that has been accumulated on the slope, which overlay the weathered bed rock layer or the residual soil layer. Since the mapping has been carried out several months in some cases year or more, it is difficult to establish the proper boundaries or to postulate the situation within the failure mass. However it is evident that the major impact in destabilizing the slope is due to inter-bedding of clay and sand layers in predominant rock types of Shale and Sandstone weathering penetrated along the thinner layers to a greater depth. Apparently these inter-bedded layers are result of weathering along the bedding plane which usually occurs in a near horizontal angle. Combination of weathering along bedding planes and two fracture zones observed in the area are influencing the detachment of rock mass from the main bed rock and tend to destabilize under gravity. It is easy to have water saturation along such layers and interplay of several joints with bedding plane always create wedge failures or down slope movement of blocks. However since majority of the layer is in highly weathered condition or covered with residual soil or weathered colluviums now we see it as a mass dislocation containing a mixture of rock and soil so it is imperative to see such movements as Debris flows. The vegetation also play a major role in destabilization of such mass as root systems developed in whether thin layers can help expansion of joint systems as well as bedding planes which help water penetration deep in to rock mass which always increases the potential of failure.

### **c. Attribute Map of Land Use**

The project team has observed several land use classes in the area subjected to mapping in two target municipalities. However the dominant land use classes seen in failed slopes are either abandoned land after cultivation or land covered with homesteads. This is seen as major reason for death of people as near settlements always communities used to grow vegetables; fruit trees such as banana on slopes

and such land use practices are responsible for destabilization of slopes. The abandoned slopes also are previously used land for cultivation of vegetables; lentils etc and absence of vegetation cover increased the water percolation which increases the potential for destabilization. Many types of human activities caused disturbances to natural slope such as cultivation, removal of earth for construction purposes, excavations etc. The human settlement areas are mainly subjected to land sliding due to such human interventions (pl. see fig). Thick forests areas have not been subjected to landslides and however partially forested areas were subjected to landslides.

**d. Attribute Map of Over Burden**

Overburden deposits usually are consists of colluviums, residual soil and completely weathered rock. In certain cases weathering penetrated highly in to rock mass and thick overburden has failed under gravity. It is seen from the past landslides thicker the overburden tendency for failure becomes also higher. Communities used to stay in areas closer to thick overburden layer as it can be used for cultivation purposes but such slopes also have seen as most vulnerable slopes for landslides.

**5 Ranking of slopes as per the risk potential**

With the field investigations and the analysis carried with the help of data collected it is understood the most of the slopes were failed due the angle of the slope. Therefore tentative landslide hazard map can be prepared by using the slope categories and ultimately it can be verified by adding the other categories.

**Table 4 Teknaf Slope category calculations**

Slope category	No of Landslides (a)	Area of the Slope category (b)(m <sup>2</sup> )	Total area of the Study (c)	Area % (d) =(b/C)%	No of LS in specific area % (e) = (a/d)%	Rating system( this will allocate according to the values in Colum (e)
0-15	3	4438792	4803732	92.400	0.0	safe
16-30	2	283020	4803732	5.890	0.3	low
31-45	9	72780	4803732	1.510	6.0	Medium
46-60+	4	9140	4803732	0.19	21.4	High

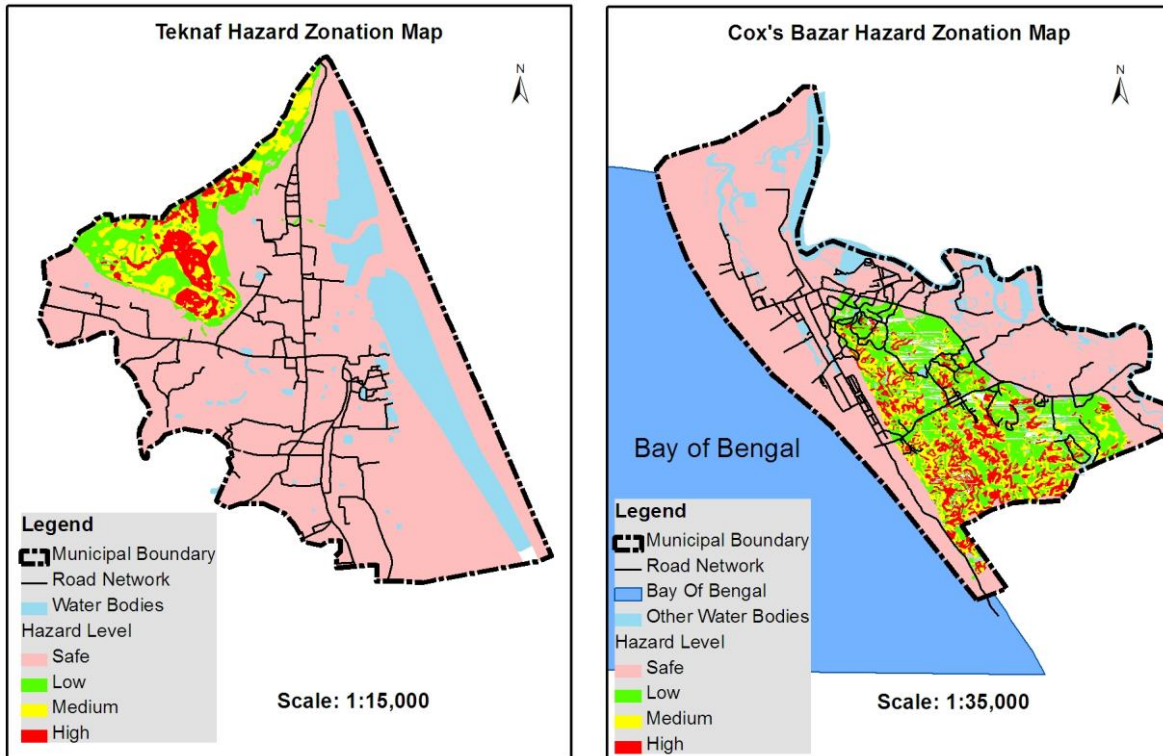
**Table 5 Cox's Bazaar Slope category calculations**

Slope category	No of Landslides (a)	Area of the Slope category (b)(m <sup>2</sup> )	Total area of the Study (c)	Area % (d) =(b/C)%	No of LS in specific area % (e) = (a/d)%	Rating system( this will allocate according to the values in Colum (e)
0-15	11	27917424	32669380	85.45	0.1	safe
16-30	65	3919388	32669380	12.00	5.4	low
31-45	55	765896	32669380	2.35	23.4	High
46-60+	2	66672	32669380	0.21	11.4	Medium

With the results calculated it is clear that two cities give different hazard indicators according to the slope angles. This will be more classified with the consideration of other categories.

**Presentation on the Landslide hazard zonation maps with respect to the slope angle**

Two slope hazard maps are as follows



**Map 1a** Landslide hazard map of Teknaf

**Map1b** Landslide hazard map of Cox's Bazaar

Map 1 (a&b) Tentative Landslide hazard map of Teknaf and Cox's Bazaar with respect to the slope angles

Assessment of slopes from the landslide hazard zonation map (% of area as per the classification and spatial distribution)

**Table 6 Hazard zonation assessment results at Teknaf area**

Hazard category	Area of the category	Total area of the Study	Hazard %
safe	4438792	4803732	92.4
low	283020	4803732	5.89
Medium	72780	4803732	1.52
High	9140	4803732	0.19

**Table 7 Hazard zonation assessment results at Cox's Bazaar area**

Hazard category	Area of the category	Total area of the Study	Hazard %
safe	27917424	32669380	85.454
low	3919388	32669380	11.997

Hazard category	Area of the category	Total area of the Study	Hazard %
Medium	66672	32669380	0.204
High	765896	32669380	2.345

- **Presentation on the Final Landslide hazard zonation maps**

It is very clear that in both areas are over 85 % belongs to safer slope areas. But in the actual situation it is not. This was confirmed during the field observations. Actually the results of the landslides in two areas are completely not due to the slope angles. Because of those other categories such as geological conditions, land use practices etc should be combined for better landslide hazard assessment. It is revealed clearly with the following landslide zonation maps prepared considering the all major categories which are the main causes for Cox's Bazaar and Teknaf area landslides. With the field observations it was decided to consider all the factors which are mainly affected to the landslides in those two areas. Therefore categories which were proposed in the table 1 & 2 were further detailed. Same time the affect of drainage pattern also considered for final calculations. Considering the collected and all available data of these two areas Bi-Variate statistical analysis methodology was used to find the suitable rating system for all categories as well as for the subcategories.

**Table 8 Weight values derived from Bi-Variant Statistical Analysis for Teknaf**

Major Category	Sub Category	Calculated weights
<b>Geomorphology</b>	Alluvial Plain	-0.877
	Channel	0.709
	Inter Tidal Flat	-1.000
	Low Steep Slope	0.279
	Medium Steep Slope	0.979
	Piedmont	-1.000
	Steep Slope	1.996
	Sub Tidal Flat	-1.000
	Tidal Channel	-1.000
	Valley	-1.000
<b>Land use</b>	Agricultural Land	-1.285
	Drainage Channel	-1.085
	Forest (Natural)	1.919
	Low Land	-6.000
	Settlement Area	-0.392
	Uncovered Soil	-5.749
	Water Body	-6.000
<b>Geology</b>	Alluvial Plain Deposit	-1.201
	Channel	0.879
	Inter Tidal Flat Deposit	-9.000
	Piedmont Deposit	-5.704
	Sandstone, Siltstone and Shale	1.691
Silty Shale and Sand	2.044	

Major Category	Sub Category	Calculated weights
	Sub Tidal Flat Deposit	-8.671
	Tidal Channel	-9.000
	Valley	-9.000
<b>Deviation Angle</b>	Dip	-0.068
	Intermediate	0.087
	Scarp	-1.613
<b>Slope</b>	0-15	0.734
	15-30	1.996
	30-45	2.185
	45-60	3.058
	60+	1.398
<b>Drainage Density</b>	Class1 (0-100)	-0.898
	Class2 (101-200)	-0.635
	class3 (201-300)	-2.000
	class4 (301-400)	0.606
	class5 (401-500)	-0.870
	class6 (ABOVE 501)	-0.238

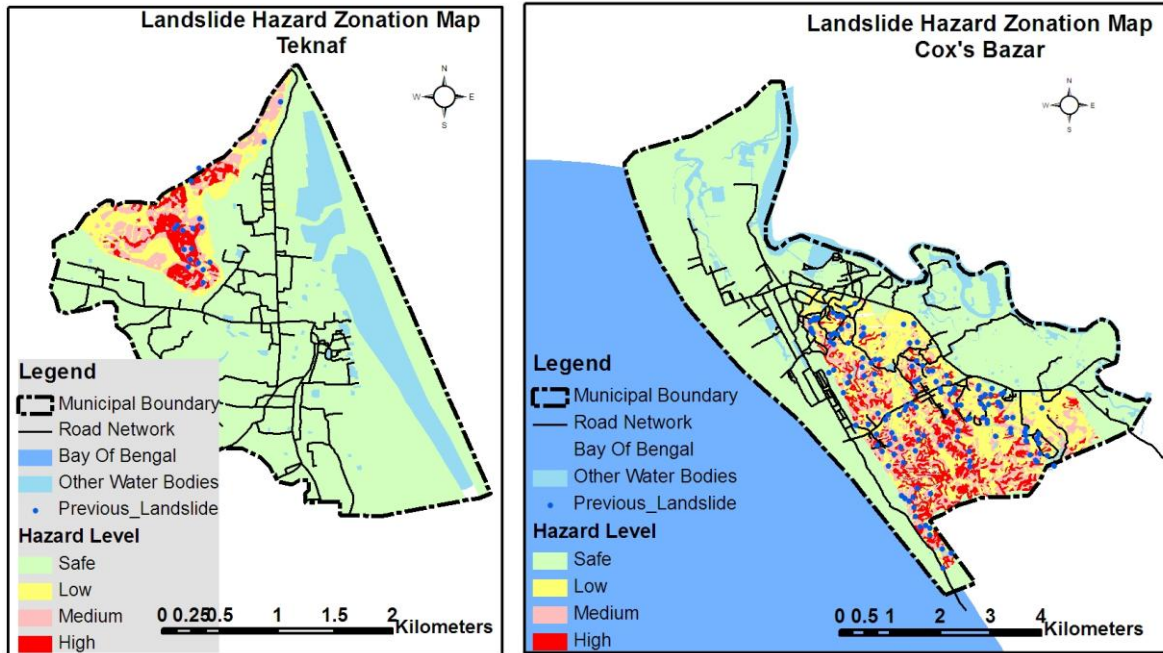
**Table 9 Weight values derived from Bi-Variant Statistical Analysis for Cox's Bazaar**

Major Category	Sub Category	Calculated weights
<b>Geomorphology</b>	Alluvial Fan	-3.000
	Alluvial Plain	-2.458
	Beach	-3.000
	Channel	-3.000
	Channel Bar	-3.000
	Depression	-3.000
	Dune	-3.000
	Flood Plain	-2.458
	Hill	0.944
	Level Hill	-3.000
	Point Bar	-3.000
	Ridge	-3.000
	Spit	-3.000
	Tidal Bar	-3.000
	Tidal Flat	-3.000
	Valley	0.721
<b>Land use</b>	Agricultural Land	0.600
	Air Port	-3.000
	Beach	-3.000
	Drainage Channel	-2.696
	Forest (Planted)	-3.000
	Hilly Area	0.395



Major Category	Sub Category	Calculated weights
	Low Land	-3.000
	Play Ground	-3.000
	Settlement (Dense)	-3.000
	Settlement Area	0.137
	Uncoverd Soil	-1.598
	Vegetation	-3.000
	Water Body	-1.310
<b>Geology</b>	Alluvial Fan Deposit	-3.000
	Alluvial Plain Deposit	-2.272
	Beach Deposit	-3.000
	Channel	-3.000
	Channel Bar Deposit	-3.000
	Depression	-3.000
	Dune	-3.000
	Flood Plain Deposit	-2.454
	Hill	-3.000
	Level Hill	-3.000
	Point Bar Deposit	-3.000
	Ridge Deposit	-3.000
	Sand (Thick sand and thinn shale)	1.024
	Sand (thin shale)	0.842
	Sand and shale alteration	0.769
	Spit Deposit	-3.000
	Tidal Bar Deposit	-3.000
	Tidal Flat Deposit	-3.000
	Valley	-3.000
Deviation Angle	Flat	-0.100
	dip	-0.098
	Intermediate	0.510
	Scarp	0.007
Slope	Class 1 (0-15 deg)	0.007
	Class 2 (16-30 deg)	1.394
	class 3 (31-45 deg)	1.617
	Class 4 (45-60 deg)	1.617
	Class 5 (above 60 deg)	3.534
Drainage Density	Class1 (0-100)	-0.372
	Class2 (101-200)	0.573
	class3 (201-300)	-0.015
	class4 (301-400)	-1.624
	class5 (401-500)	-1.700
	class6 (ABOVE 501)	-0.238

Landslide Zonation Maps of the Teknaf and Cox's Bazaar prepared according to the weights received through the bi-variant analysis







Map2a Landslide Zonation map of Teknaf

Map 2b Landslide Zonation map of Cox's Bazaar

Map 2(a&b) Final Landslide Hazard zonation maps of Teknaf and Cox's Bazaar

Both landslide zonation maps were categorized in to four major units according to the vulnerability of the landslides in the areas. Each and every unit was given a colour and the guideline for construction and development within the each unit.

Table 10 Guidelines for Construction and Development procedures for each landslide hazard type

Landslide Hazard type	Colour	Guidelines for Construction and Development
Safe		No visible signs of slope instability or danger exist based on the present state of knowledge. No blanket limitation need to be imposed particularly on well managed lands and engineered construction. Location specific limitations may become necessary, particularly for areas prone to flooding and erosion
Low		Slight danger of landslides exists. Engineered and regulated new construction and well planned cultivations are permitted. Plans for construction should be technically evaluated and certified
Moderate		Moderate levels of landslide danger exist. New construction should be discouraged and improved land use planning practices should be introduced to halt and reverse the process of slope degradation. All essential constructions, developments and remediation be subjected to landslide hazard assessments
High		Danger and potential threat to life and property exists. No new construction should be permitted. Essential additions in the existing structures may be


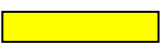
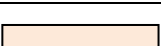

Landslide Hazard type	Colour	Guidelines for Construction and Development
		allowed only after thorough site investigation and adequate precautions to be certified by specialist(s). Early warning systems should be established if symptoms of Landslides are clear and risk levels are high.

- Risk potential in cities

**Description of the Landslide Hazard situation of each cities according to the final landslide hazard zonation maps**





**Teknaf City landslide hazard situation**

Following table indicate the area vice distribution of the landslide vulnerability of Teknaf area

Landslide Hazard type	Colour	Area m <sup>2</sup>	Area %
Safe		6016891	87.22
Low		370032.3	5.36
Moderate		312693.1	4.53
High		198651.9	2.88

**Cox's Bazar City Landslide hazard situation**

Following table indicate the area vice distribution of the landslide vulnerability of Teknaf area

Landslide Hazard type	Colour	Area m <sup>2</sup>	Area %
Safe		24552790	66.78
Low		6470185	17.60
Moderate		3259849	8.87
High		2483371	6.75

**6 Recommendations for risk reduction**

With the data collected from the study and the zonation mapping exercise of the two cities it is understood and confirmed that the most landslides occurrences of the area are due to manmade factors as well as due to the natural factors. Because of that the introducing of better landslide risk reduction measures will help to reduce the landslide vulnerability in these two cities. Among them introducing of better land use practices throughout the area will be more important. Most of the construction practices which are used by the peoples in those areas are not appropriate.

It is highly recommended to incorporate the following factors in the development activities.

- Utilization of better land use practices and construction practices
- Impose rules and regulations during any type of construction
- Awareness creation among stake school children, community members, planners, decision makers

## **7 Conclusion**

With the achieved results from the landslide hazard zonation mapping exercise of Cox's Bazaar and the Teknaf cities it is revealed that the landslide prone areas are very small with related to the total area of the cities. But with the developments and the increasing population within the city area most of the settlements are extending towards the hilly areas. Due to bad and unplanned settlements in the hilly terrain landslide occurrences are also increasing and highly affected to the stability of the slopes in the area. This was well considered during the preparation of these zonation maps. Therefore considering the effect of the land use practices and relevant hazard zones in the hilly terrains of these two cities, it can be highly recommended to introduce suitable construction guidelines and strict planning procedures to each and every hazard zones according to their vulnerability (high, moderate, low). Most of the risk reduction practices introduced in the previous chapter can be used and adopted in this task.

## Report on the Landslide Hazard Zonation mapping at Cox's Bazaar and Teknaf in Bangladesh

---

Submitted by

Joint Venture of



And



Data Experts (Pvt.) Limited  
House 25/3, Road 15 (old 28)  
Dhanmondi, Dhaka-1209, Bangladesh

Asian Disaster Preparedness Center  
SM Tower, 24 th Floor, 979/69 Paholyothin Road,  
Samsen Nai Phayathai, Bangkok 10400, Thailand

