Landslide hazard mapping of Chittagong City Area, Bangladesh

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Abstract

Landslide is regarded as one of the most damaging hazards in Chittagong City area of Bangladesh. For safe management and proper urban development planning, mapping of the landslide prone areas of the city is essential. The landslide hazard zoning of the Chittagong urban area has been done using the weighting-rating system of landslide causing factors. The lithology, slope angle and height, cover and aspect of these slopes were selected as landslide causing factors for the area. A data base was developed from different sources including geological map, topographical map, satellite images and field visit. The causing factors were assigned numerical attributes according to their contribution to landslide. The four zones, High hazard, Medium hazard, Low hazard and No hazard were identified based on the collective effects of these attributes. About 39% of the total study area is found to be landslide prone. High Hazard, Medium Hazard and Low Hazard area covers about 3%, 14% and 22% of the total area. This hazard zoning map shows that parts of the Khulshi, Pahartali, Panchlaish and Bayazid Bostami area are categorized as High Hazard Zone. Special attention relating to the landslide problems in Khulshi and Pahartali areas should be given since the urbanization in these areas is growing rapidly.

Introduction

The landslide can be defined as the movement of a mass of rock, earth or debris down a slope (Cruden, 1991). Landslides are almost an annual geological hazard in the hilly areas of Chittagong City of Bangladesh. A number of cases of landslides, reported in the newspapers and in the other media of the country, resulted in considerable losses of lives and properties. Most of the landslides were shallow in nature and occurred generally during and/or after heavy rainfall. Human activities also led to slope unstable in certain slum areas of the city. Analyses of two hill slopes of the study area reveal that the slope failed due to significant loss of soil strength (Khan and Chang, 2006).

The sense of landslide hazard is together related with the physical attributes of potentially damaging landslides in terms of mechanism, volume and frequency. Although it is difficult to predict a landslide event in space and time, an area may be divided into near-homogeneous domains and ranked according to degree of potential hazard due to mass movement (Varnes, 1984). The maps containing such information regarding potential landslides are termed as Landslide Hazard (LH) map. A landslide hazard map significantly includes several zonation of active landslides in various degrees. A common approach to LHZ is based on the idea that the relative potential for slope failure can be assessed by references to the existing allocation of failures for an area. Generally, the following fundamental assumptions are regarded as a basis for a LH map (Varnes, 1984, Hutchinson, 1995). These are i) landslides occur in the same geological, hydrological, geomorphological and climatic conditions as in the past and ii) the factors controlling the landslides can be identified for an evaluation of degree of hazard for classification.

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Traditional approaches of landslides hazard assessment use expert evaluation of extensive fieldwork. But these traditional methods are slow, expensive, labor intensive and often produce low accuracy results due to low repeatability operation, and as such cannot be widely applied. Several other approaches for landslide hazard zoning are basically based on Geographic Information System (GIS) with varying degrees of statistical analyses (Saha et al., 2005; Suzen and Doyuran, 2004; Wu and Abdel-Latif, 2004; Ohlmacher and Davis, 2003; Gritzner et al., 2001; Binaghi et al., 1998; van Westen et al., 1997; Gupta and Joshi, 1990). Recently, methods using landslide controlling factors with the proportionate relative contribution are gaining popularity. Such an approach can make use of different weighted maps produced from contribution of controlling factors in order to produce hazard zones (Saha et al., 2002; Soeters and van Westen, 1999) The weighting system depends on the geology as well as geomorphology of the study area. With the advent of modern computer software, collection, manipulation and integration of a variety of spatial data such as geology, structure, surface cover, slope properties, etc. of an area become possible for use in landslide hazard zoning without extensive field work. The present study is an attempt to prepare a landslide hazard zoning map of Chittagong City areas of Bangladesh using spatial data analysis.

Study area and geologic setting

The urban areas in the Chittagong City (Fig. 1) is about 144 sq km with about 3.3 million population. The area is characterized by low hills of Tertiary to Quaternary sediments. The Chittagong area is situated within the Tertiary hill regions of Folded Flank of Bengal Fore deep. This folded part is comprised of the Tipam Sandstone Formation and Girujan Clay formations of Pliocene age at the bottom and Dupi Tila Formation of Plio-Pleistocene age at top (Reimann, 1993). The Tipam sandstone is hard and compact while other sandstones are mostly moderately to loosely compacted

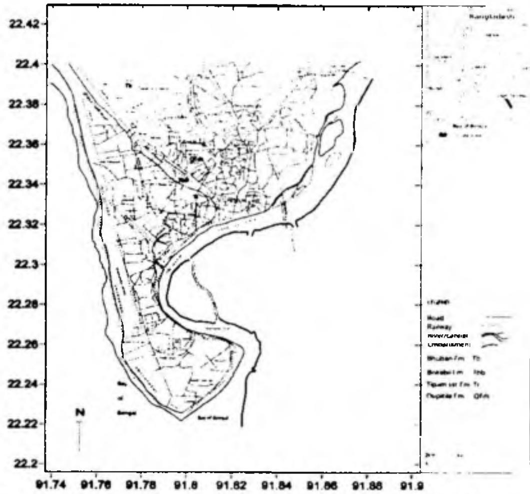

Fig. 1: Map of the Chittagong City with Lithology

and comprised of medium to fine-grained sand with minor amount of silt and clay. The Dupi Tila Formation comprises of sandstone and shale. The plain land of the area consists of stream, deltaic and floodplain deposits of Recent age. The Karnafuli is the main river of the area, which is fed by several hilly streams. The urban areas of Chittagong City mostly developed on the west bank of this river covering the hilly regions.

There are many locations in the area where a number of slopes of several low hills (<20 m) (viz., Dev hill, Goal hill, etc.) seemed to be vulnerable to sliding. Many establishments like colleges, schools, and residential and commercial buildings are situated at or near these hills without proper protection.

Landslide Characteristics

The landslides observed in the study area were mainly shallow slide. A total of 30 landslides were observed in the area, among these 24 slides were shallow slides and rest 6 slides were with circular failure plane. Dominant lithology of these slide prone areas were loose sand with clay but other have loosely compacted sandstones with inter-bedded silty clay lithology. Landslides were rarely found in hard and compact massive sandstone even with steep slopes (45 to 60°). Slope angles of 13 shallow slides were found within a range of 15° to 30°. Slopes with little or no vegetation had been suffered shallow failure even with gentler slope angles (15 to 30°). The relative slope height of most of the shallow slides ranges from 4m to 12m. A total of 14 slides occurred where the slopes faced towards south-south west. The above mentioned characteristics of studied slides were incorporated as the controlling parameters for setting weights and ratings of different classes in these analyses.

Methodology

The methods used in the study were characteristically involved data collection, data processing and field checking. A number of datasets used in the study were collected from various sources. These included topographic map of 1:50,000 scale from the Survey of Bangladesh, geological map consisting of lithological and structural data and satellite image of LANDSAT 7 ETM+mosaic. A field survey was carried out for landslides, lithology, structure and land cover areas.

A study area was divided into 350 x 250 pixels and assigned each with geographic co-ordinates. The boundary of the specific study area and river morphology was digitized, which was used during blanking operations. Blanking is a process used for confining all the digitized data to a specified area of interest. Digitization of lithological and slope cover information, magnitude and aspects of slope and relief of the entire study area were done mainly on PC based software as well as manually. A Digital Elevation Model (DEM) representing spatial variation in altitude was developed using digitized data of slope terrain. All the digitized data sets were assigned to different data-layers and each layer consisted of various classes. A weighting-rating system based on field observation and literature review was assigned to all the data layers. The attribute map or layer of the data was then produced with respective ratings. The individual total ratings of all these data layers were used to produce Landslide Hazard Index (LHI) map. Finally, LHI was classified based on field data set to develop a LHZ map. A schematic flow chart for the above mentioned methods and analyses are given in figure 2.

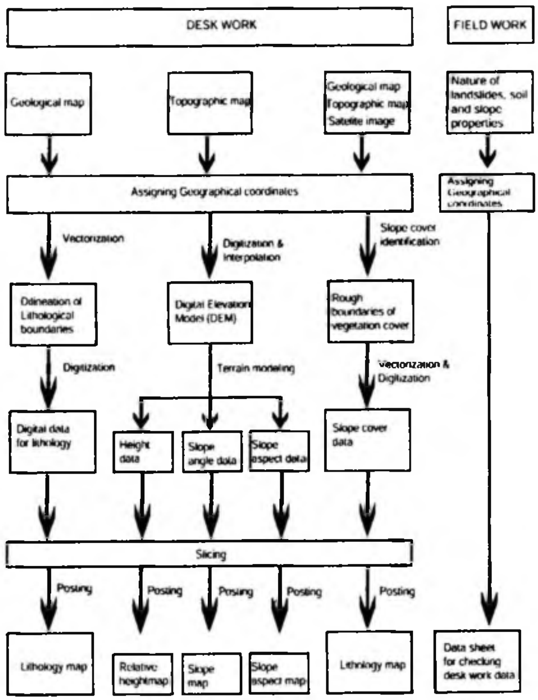

Fig. 2: Methodology flow chart

Data layer preparation

The data layers maps of different contributing factors were prepared in order to prepare the LHI of Chittagong area. The different data layers were as described in next sections.

Lithology map

Lithology is regarded as the most contributing factors to landslide for this area. The lithological units exposed in the area comprised mainly of hard sandstone, moderate to loosely compacted sandstone with significant amount of inter-bedded shale and silt. Hard sandstone is mostly exposed on the higher (>12m) height whereas moderate to loosely packed sandstone with shale found on lower height level. Mixtures of sands, silts and clay of floodplain deposits occur mostly on plain land and at height less than 4m. The lithological boundary from geological map and from field study was digitized to produce a lithology layer map.

DEM derived features

Elevation data of the study area were collected from topographic maps and contour maps as well as from direct field study. All these elevation data were then used to produce a DEM, which represents spatial variation in altitude. The DEM was used to generate data for height, terrain slope and slope aspect to produce the maps of relative height, slope and slope aspect.

Slope is considered as next important factor for landslides. Amount of slope is produced as first derivative of elevation at any pixel location. Slope angle in the area found from the DEM derivatives ranged from 0 to 90°.

Height is the difference between maximum and minimum elevation of a particular area. It was measured from the DEM data and then compared with the contour and topographic maps as well as field data.

Slope aspect is the orientation of slope denoting north facing (0°), east facing (90°), south facing (180°) and so on. In the area of monsoonal rain like the study area, slope aspect should be regarded as one of the important factors for inducing landslide. Generally, it is regarded that the slopes facing south, southwest and west receive maximum rainfall in this part of the region. The degree of water saturation of the slope forming material is a major control over the occurrence of landslide. Any slope faces maximum rainfall is more vulnerable to landslide than others.

All the DEM derived features described above were finally checked with field derived data before using as data layers in the analytical procedure.

Slope cover

Slope cover typically means the vegetation grown on the slope surface. Soil cover plays an important role for vegetation. Naturally, in the gentler slope the soil cover is thicker and hence denser the vegetation. But the vegetation cover is decreasing significantly due to the increase in urbanization in the study area. Data about the slope cover were collected on each pixel locations approximately from topographic map and field survey. These data were then digitized to produce slope cover map of the area.

All the relevant data layers, i.e. the causing factors were served as the input for the following analytical procedure to produce respective class maps.

Data analysis

Landslides occur due to the mutual interactions of various factors. The relative weighting of the governing factors with the corresponding ratings of different classes have been adopted in the following manner for landslide hazard zoning.

Data weights and ratings

The records from the field observation were the main basis for quantifying the relative importance of various causative factors. These factors are then used to make respective class maps namely lithological map, slope map, slope aspect map, etc. All these class maps were arranged in hierarchical order of influence and a weighting number were given to each map layer. The weighting numbers were chosen from 0 to 9 in the increasing order of importance for inducing landslides. Again, each class within a layer was given an ordinal rating from 0 to 9 similarly. A re-adjustment for these weights-ratings system has been done until these matched with field observation.

Field observation depicted the lithology as the most influential causative factor among all. Therefore, the highest weighting was assigned to lithology. Class of loose sand, silt and clay layers within the lithology was given highest weight ranting of 9, because loose sand, silt and clay are very much susceptible to slide with little or no shear resistance. On the other hand, compacted sandstone (rating 0) is found to be most resistive slope material in this area.

Slope angle is the next important factor (layer) with a weight of 7. Generally, steeper slope is more susceptible to landslide, but very few landslide occurrences was found in steeper slopes in the study area as steeper slopes are mostly comprised of hard and compacted sandstone. Most of the observed landslides were found within a slope range from 45 to 15°.

In this area, higher slope height is characterized by compacted sandstone as these posses more resistance to sliding activity and on the other hand, moderate height class of 8-12m range is comprised of relatively weaker soil material. Therefore, highest rating (9) was given to the class of 8-12m range.

All the layers and classes were assigned weights and ranks respectively in similar way (Table-1).

The map for each data layer was produced with the respective rating of individual classes. These maps are called attribute maps having numerical values (attributes). The attribute maps (Fig. 3 to 7) for iithology, slope angles, height, slope cover and slope aspect were produced using individual data weight for each layer.

Landslide hazard index (LHI)

The attribute map for each data layer was produced with the respective rating or attribute of individual classes. All the attributes of these maps were multiplied by the respective weights and summed up to get the Landslide Hazard Index (LHI) for each pixel cell. More than 124,000 pixels were used for all the above mentioned procedures in the present study.

The LHI, thus calculated was found to vary within the range of 83 to 232 in the study area.

Landslide Hazards Zoning (LHZ)

A frequency (Fig.8) diagram for LHI was plotted for classifying the hazard zones. The classification was based on the frequency of landslide hazard index and pattern or peaks in the frequency curve. This frequency diagram was then compared with the field

Table 1: Weights and ratings of different classes

Parameters	Weight	Classes		Ratings
Lithology	9	i)	Loose sand-silt-clay	9
		ii)	Loosely compacted sandstone with inter-bedded silty clay	8
		iii)	Clay/siltstone with sand	6
		iv)	Hard compact massive sandstone	1
Slope angle (deg)	7	i)	more than 60°	1
		ii)	60-45°	2
		iii)	45-30°	4
		iv)	30-15°	9
		v)	Less than 15°	2
Vegetation	6	i)	Little or no vegetation	9
		ii)	Moderate	6
		iii)	Dense	3
Relative height (m)	5	i)	more than 12m	1
		ii)	12-8m	8
		iii)	8-4m	9
		iv)	less than 4m	2
Slope aspect	4	i)	South, south-west facing	9
		ii)	West, north-west	7
		iii)	North, south-east	3
		iv)	East, north-east	2

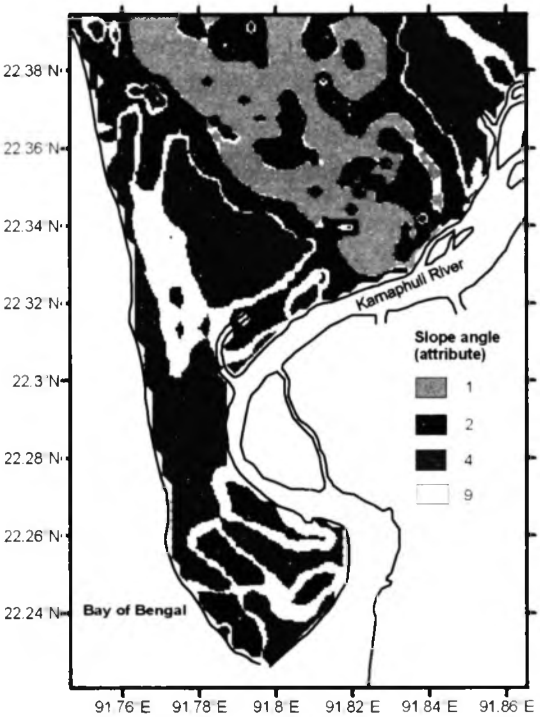

Fig. 3: Attribute map of lithology

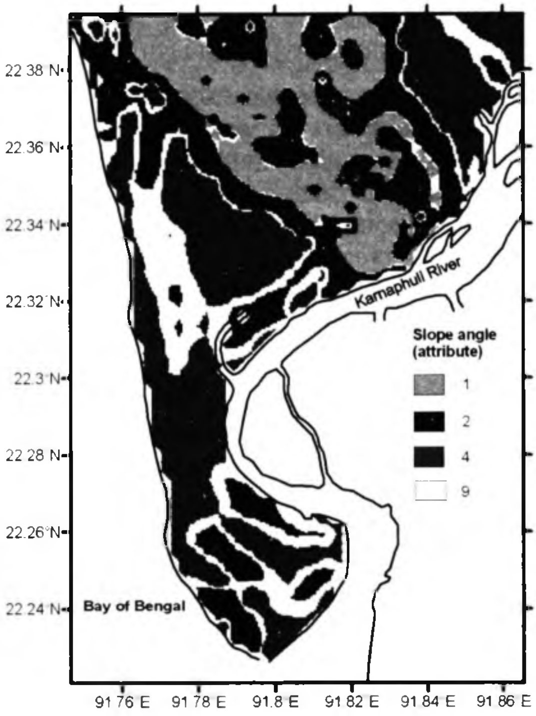

Fig. 4: Attribute map of slope angle

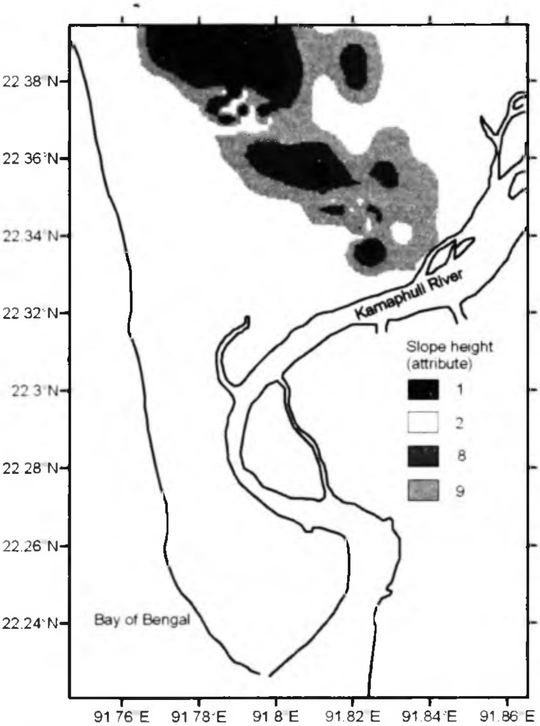

Fig. 5: Attribute map of slope height

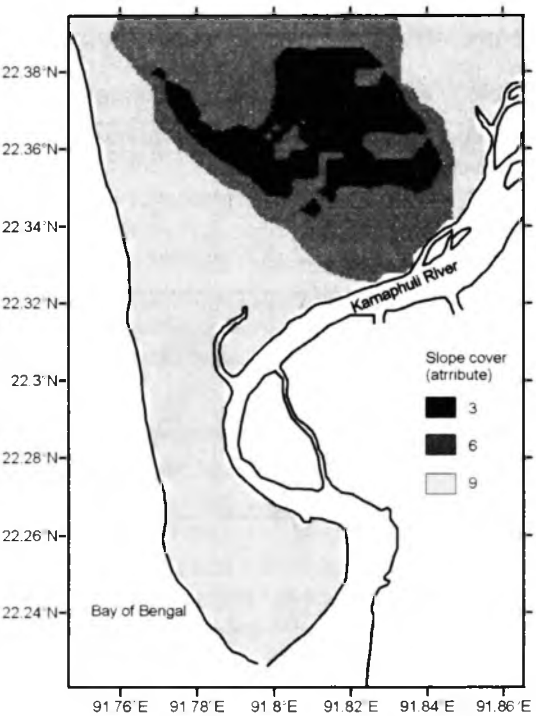

Fig. 6: Attribute map of slope cover

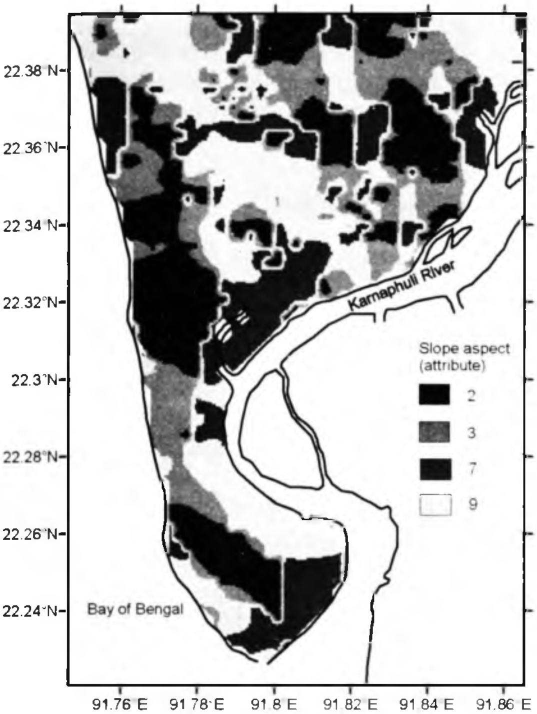

Fig. 7: Attribute map of slope acpect

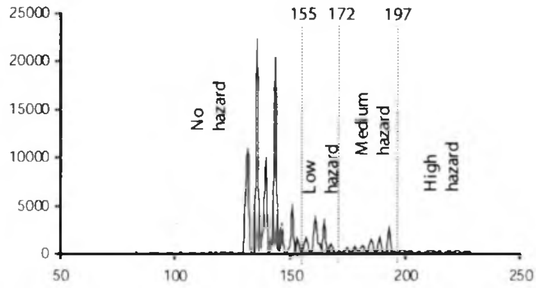

Fig. 8: Frequency distribution and classification histogram

data and the threshold boundaries for different LHI were established. There are four categories of LHI population distributed normally separated by the points 155, 172 and 197. The hazard zoning is, therefore ranging from 84 to 155; from 155 to172; from 172 to 197 and from 197 to 232.

These zoning were then named as *No hazard zone* (LHI 84 to 155), Low hazard zone (LHI 155 to 172), *Medium hazard zone* (LHI 172 to 197) and *High hazard zone* (LHI 155 to 232). The frequency curve also shows that

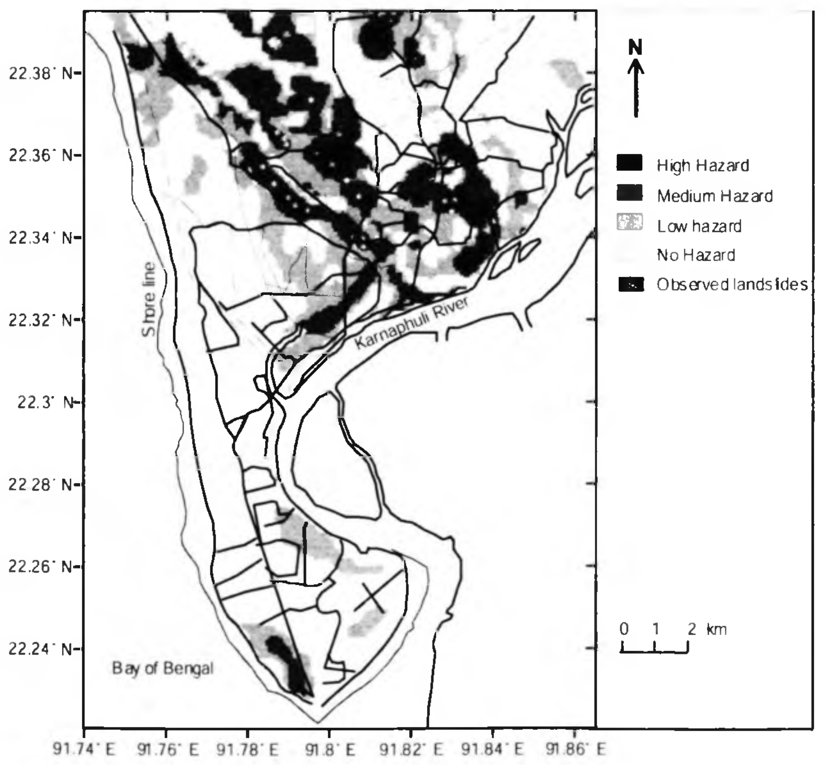

Fig. 9: The landslide hazard map for the Chittagong City

the LHI ranging from 135 to 150 have very high occurrences, whereas the LHI from 195 to 232 have very low occurrences. This means that the area with high LHI values is limited to certain parts of the study area.

Finally, a landslide hazard map was developed using the above zones with corresponding LHI (Fig. 9).

Discussion and conclusion

Landslide hazard zoning map of the Chittagong City area was prepared using the weighting-rating system of landslide causing factors. The zones are categorically recognized as *High hazard, Medium hazard, Low hazard* and *No hazard.* Among the observed landslides, 16 were occurred in the proposed *high hazard zone* and 9 were found in the *medium hazard zone*. About 39% of the total study area is found to be landslide prone. Among this, the *high hazard zone* is comprised of about 3% of the total area with LHI ranging from 197 to 232. *Medium hazard* zone covers about 14% with LHI ranges from 172 to 197. About 22% of the total area is in the *low hazard zone*, while about 61% of the area is in the *no hazard zone*.

The landslide hazard zoning map shows that the some parts of the Khulshi, Pahartali, Panchlaish and Bayazid Bostami areas are categorized as *high hazard zone*. Special attention relating to the landslide problems in Khulshi and Pahartali areas should be given since the urbanization is growing rapidly in these areas. A number of landslides were also observed in these areas during the field visit. The landslides were mainly concentrated in the area where the slope lithology comprised of loose sandstone with inter-bedded clay. The *high hazard zone* also comprised of slope angle ranged from 15 to 45°. The higher angle slope mainly comprised of well compacted sandstone beds in the northwestern part of the study area, which is grouped from medium to low hazard zones.

Collected data from different sources including field visit showed that the observed landslides matched with the proposed hazard map. The proposed hazard map would provide useful information about the location and intensity of landslides especially in the rainy season.

Acknowledgement

The authors express their sincere thanks to the Korea Science and Engineering Foundation (KOSEF) for providing the post-doctoral fellowship (2006-2007) to the first author during this study. This study was a part of a research approved by KOSEF and was carried out at the Chungnam National University, South Korea.

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