Improving Existing Landslide Hazard Zonation Map in KMC Area, Sri Lanka

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Abstract: In Sri Lanka, presently used landslide hazard zonation (LHZ) map which was developed by National Building and Research Organization (NBRO) is based entirely on geological, geomorphological and hydrological factors. As development expands into unstable hill slope areas under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites, etc., have become important triggers for landslide occurrence. The present study was undertaken in highly urbanized Kandy Municipal Council (KMC) area in Sri Lanka. Main objective of the study was to validate the existing LHZ map with current active landslides and the improvement of the LHZ map for further use for management purposes. Validation of the existing LHZ map shows lowest percentage of landslide occurrence in the landslides most likely to occur zone and highest in the landslides are to be expected zone. To evaluate this situation building density and transport lines were used. The relationship between building density and landslide occurrence was 97.1% and the relationship between distance from transport lines and landslide occurrence was 88.3% till 50 m. An improved LHZ map was developed including the effect of building density and distance from transport lines using frequency ratio method and improved LHZ map has an accuracy of 98.5%.

Keywords: Buildings, Hazards, Map, Landslide, Roads

Introduction

Landslide status in Sri Lanka

Landslides, as one of the major natural hazards, account each year for enormous property damage in terms of both direct and indirect costs. Landslides are defined as the movement of a mass of rock, debris or earth down a slope (Cruden, 1991). Most of the time landslides are aggravated by human activities as geological features hardly change with time compared to human activities. In Sri Lanka landslides have become a frequent major natural hazard in terms of both space and time. As a result landslides are attracting increasing attention in recent times. Landslides occur mainly in the hill country surrounded by mountain ranges. In the case of occurrences of landslides in Sri Lanka, ten major districts have been identified as Landslide prone areas. Those are Badulla, Nuwara-Eliya, Rathnapura, Kegalle, Kandy, Matale, Matara, Galle, Hambanthota and Kalutara. Over 12,500 km^2 of landslide prone areas are spread over these ten districts. It is about 20% of the total land area and is occupied by 30% of the total population of the country. Therefore, occurrence of frequent landslides and slope failures could be considered as the most significant natural disaster in Sri Lanka.

According to National Building Research Organization (NBRO) reports, torrential rain in November / December 2010 and January 2011 has caused 675 cases in six districts where a number of slope failures resulted in loss of lives and property.

Existing LHZ map

NBRO has created LHZ maps for most vulnerable areas for landslides in Sri Lanka. It is used to predict the zones that are susceptible for sliding during the rainy season incorporating rainfall intensity and duration. Here landslide hazard analysis focuses mainly on the spatial zoning of the hazard based on geomorphologic and hydrologic factors but not human induced features such as overloading slopes by new constructions associated with development programs, vibrations from heavy traffic and excavation or displacement of rocks etc. LHZ map was developed considering Slope angle, Overburden, Land use, Landforms, Geology and Hydrology. Under geology rock type, dip angle and direction, deviation angle, presence of faults, folds, joints were considered. Soil thickness was considered in overburden. Relative relief, drainage density, Basin area, Basin shape and proximity to water bodies were considered under hydrology. Shape and roughness was taken into account in landform. The basic data on these aspects has been gathered in 1995 from field surveys as well as from desk studies. This existing LHZ map is classified into five hazard zones as, Landslides not likely to occur, Modest level of landslide hazard exists, Landslides are to be expected, Landslides most likely to occur and not mapped area. The existing landslide hazard zonation map consider only the geomorphologic and hydrologic factors that are responsible for the landslide occurrence. But human pressure on earth also induces landslides. Validation refers to comparing predictions of a method with a real-world data set, for assessing its accuracy or predictive power (Begueria, 2006).

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Motivation

The current situation of increase in landslide occurrence in the hill country, especially in highly urbanized areas not only endangers future sustainable living, but also puts the existing built environment at extreme risk. For more than two decades settlements in this area have experienced the catastrophe of landslides. In the past, Kandy did not suffer many landslides compared to other hilly areas of Sri lanka (such as Nuware eliya, Badulla, Hali-ela and Ratnapura) which experienced multitudes of continuous and serious landslide problems over so many years during rainny seasons. Latter stages of 2010 and beginning of 2011 in Sri Lanka, particularly Kandy experience a dramatic increase in landslide incidents and caused damage to infrastructure and human lives. Field surveys shows that most of these landslides occurred on cut slopes or on embankments alongside roads and highways in mountainous areas. Some of these landslides occurred near high-rise apartments and in residential areas, causing great threat to many people. So a logical reason for increased incidents would be due to the high pressure imposed by rapid urbanization. Landslides have been a common phenomenon in Kandy district and KMC area is more prone to landslides as human intervention has been taken place to the maximum in this area. Therefore recognition of landslide prone areas is becoming increasingly important in land use decisions. Zonation maps based on landslide studies resulting in hilly areas are an essential requirement nowadays for the development activities in many countries. This is because occurrence of landslides is a serious constraint to economic development, particularly in developing countries like Sri Lanka. The aim of this study is to identify anthropogenic causative factors responsible for the increased landslide incidents in the KMC area that could be used to improve the existing LHZ map. In order to achieve that, following objectives were chosen as to validate the existing landslide hazard zonation map by using active landslides in the study area, assess the effect of building density, distance from transport lines for the recurring incidence of landslides in this area and develop an improved landslide hazard zonation map including building density and distance to transport lines using frequency ratio method.

Materials and Methods

A. Study area and data collection

Kandy Municipal Council (KMC) area was selected as the study area (Figure1) which consists three divisional secretariat divisions. Those are Gangawatekorale with 42 GN divisions, Pathadumbara with 2 GN divisions and Harispaththuwa with 1 GN division.

The 1:10000 digital maps of building footprint and transport lines in Kandy municipal council area developed in 2010 (54-13, 54-14, 14-18, 14-19, 54-23, and 54 - 24: 1: 10 000 Map tiles named by Survey Department) were obtained from the Survey Department, Colombo, Sri Lanka and the presently used 1: 10 000 digital LHZ map (existing map) developed in 1995 was obtained from NBRO.

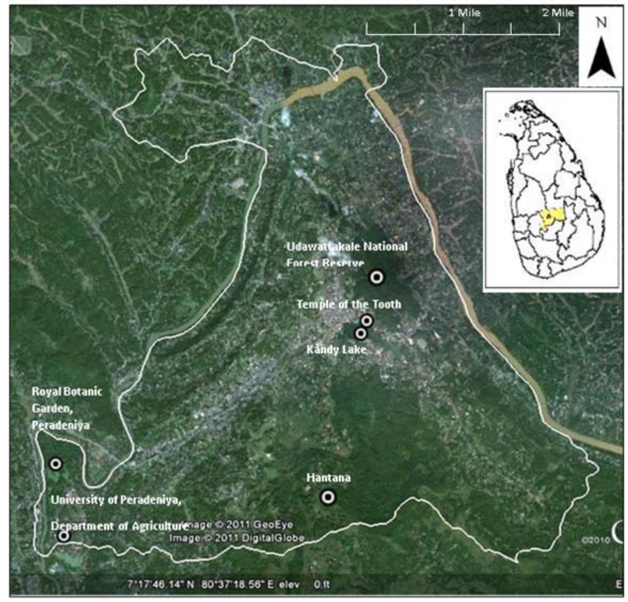

Figure 1. Study area

Locations of active landslide areas were identified from satellite images/Google earth software (2011–February), NBRO reports/field book and historic memory of neighborhood. The active landslide areas were marked on 1:10 000 scale base maps (Air Base Map Projection- Survey department) and GPS points were also taken at the site. The existing LHZ map has been classified into five hazard zones as, Landslides not likely to occur, Moderate level of landslide hazard exists, Landslides are to be expected, Landslides are most likely to occur and not mapped area (Figure 2).

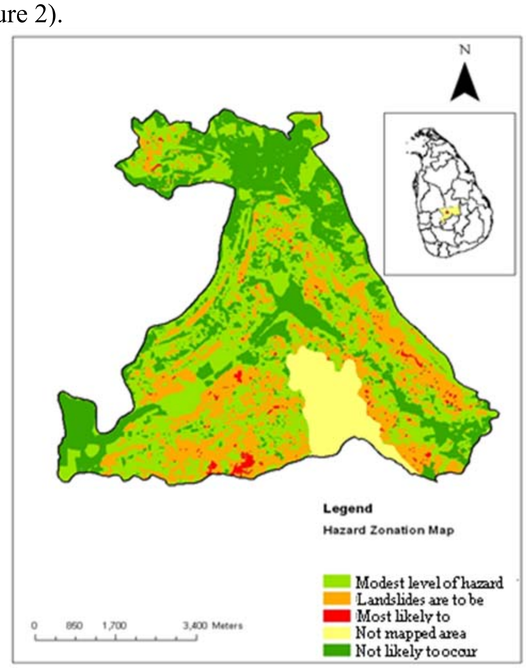

Figure 2. Existing LHZ map

B. Validation of existing LHZ map

Figure 3 shows the consecutive steps which were performed to validate the existing LHZ map. Using this data taken at each site, active landslide areas were digitized to develop the active landslide distribution map in 1: 10000 scale. The scale which was used here was same as in existing LHZ map. Validation of LHZ map was performed by comparing the known landslide location data with the landslide hazard map. The main step was data collection and construction of a spatial database. A key assumption of this approach is that the potential occurrence of landslides will be comparable with the actual distribution of landslides. Active Landslide distribution map (with 10m buffer) was used to validate the existing LHZ map. The landslide distribution map was superimposed on the existing LHZ map in GIS environment as Sarkar et al was done in, 2007.

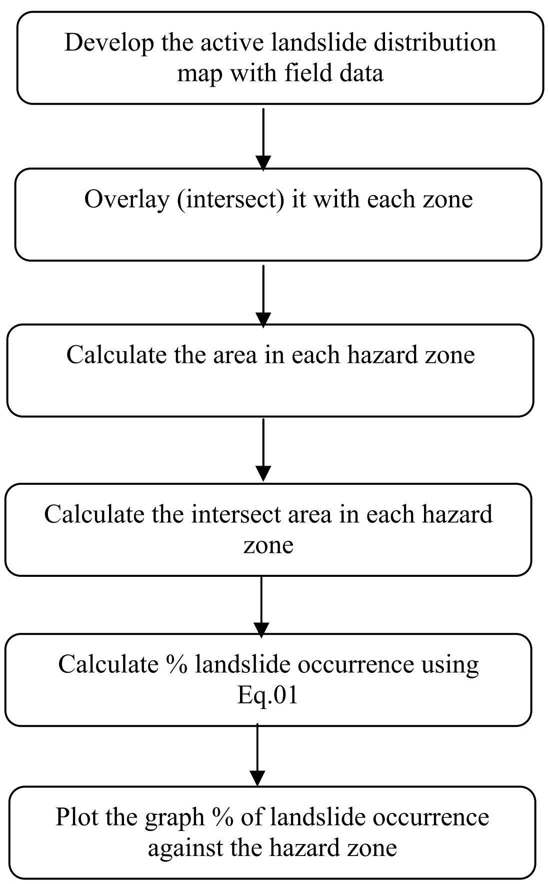

Figure 3. Validating procedure of existing LHZ map

Then calculated the intersect areas of each hazard zone and active landslide distribution to calculate the affected area under each hazard class (Equation 1). Percentage occurrence of landsides related to each hazard class was calculated and the graph of percentage landslide occurrence against the hazard zone was plotted.

Equation 1

$$Percentage\ Landslide\ Occurrence = \frac{\begin{matrix} Area\ that\ have\ been\ affected\ by\ landslides\ in \\ the\ relevent\ hazard\ class \end{matrix}}{Total\ area\ in\ the\ relevent\ hazard\ class} \times 100$$

Assess the effect of building density and distance from transport lines

The effect of building density and proximity to transport lines on occurrence of landslides was evaluated using the active landslide distribution map, building density map and transport lines map. Building density polygon map was classified into equal interval of five density classes. Building density classes were ranked as the highest rank (4) to the highest density class and lowest rank (0) to the lowest density class. Then calculated the total area under each density class and landslide affected areas in those density classes. Six zones were seperated as 0-10 meter, 10-20 meter, 20-30 meter, 30-40 meter, 40-50 meter, 50-60 meter from major transport lines. Then the area of these zones and the active landslide areas in each of these zones were calculated to get the percentage occurrence of landslides with proximity to major transport lines. The relationship between the causative factors and landslide occurance should be a positive linear relationship. Data on building density, proximity to major transport lines and percentage occurrence of landslides were used in linear regression analysis to get the relationship between these two criteria and occurance of landslides (Begueria, 2006).

C. Development of Improved LHZ map

Results of validating the existing LHZ map shows active landslides in the study area does not comply with the existing landslide hazard zones. So as the results show building density and distance from transport lines have a strong effect on landslide occurrence LHZ map.

Frequency Ratio value (Equation 2) for each factor's range was evaluated by the ratio of the area where landslides occurred (landslide-occurrence ratio) to the total study area for a given factor's attribute (area ratio) (Lee and Pradhan, 2006). The improved new hazard zonation map was classified according to expert knowledge (Gokceoglu and Aksoy, 1996; Van Westen et al., 1997; Binaghi et al., 1998; Barredol et al., 2000; David and Paul, 2000; Saha et al., 2002; Lan et al., 2004; Oztekin and Topal, 2005) into four zones (Barredol et al., 2000) as most hazardous, moderately hazardous, landslides not likely to happen and safe zone.

The improved LHZ map was also validated using the same method as for the existing LHZ map using active Landslide distribution map.

Equation 2

$$\text{Frequency Ratio} = \frac{\text{Area of landslide with characteristic / Total landslide area}}{\text{Total area with characteristic / Total area}}$$

Figure 4 shows the methodology of development of improved LHZ map.

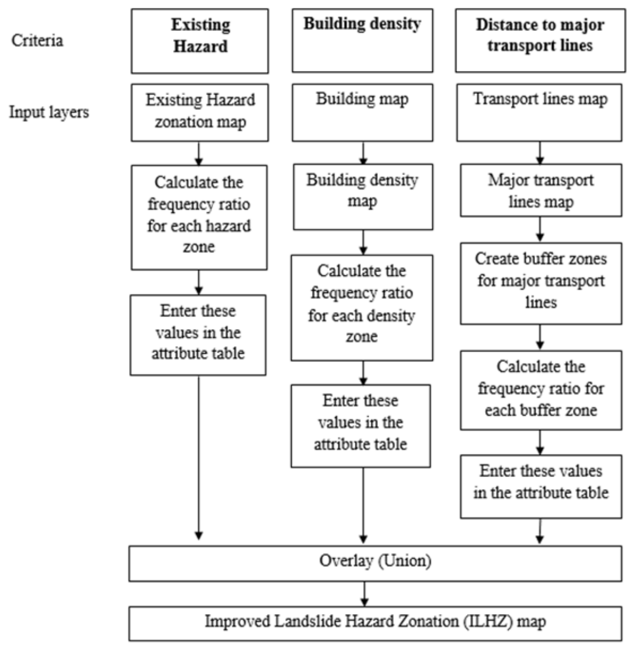

Figure 4. Flow diagram of development of ILHZ map in GIS

Percentage occurrence of landsides related to each hazard class was calculated by using Equation 01 and was plotted the percentage landslide occurrence against the hazard zone. R^2 value of the linear regression was also considered in evaluating the prediction power of landslides. Units of Measurement: All measurements should follow the International System of Units (SI).

Results and Discussions

Validation of existing LHZ map

Table 1 represents the percentage landslide occurrence values. According to the results of validation of landslide hazard zonation map, the lowest percentage of landslide occurrence is in the landslides most likely to occur zone. Highest percentage of landslide occurrence is in the landslides are to be expected zone and the percentage of landslide occurrence has gradually decreased from Modest level of landslide hazard exists zone to landslides not likely to occur zones. The not mapped area also has a 0.34 of landslide occurrence percentage. As the landslides most likely to occur zone represents the highest hazard zone and it does not show the highest percentage of landslide occurrence. Figure 5 shows that highest hazard zone has the lowest percentage of landslide occurrence. Percentage landslide occurrence in other zones which represent fewer hazards has relatively high occurrence of landslides. This results show that the existing landslide hazard zonation map should be updated according to the present situation.

Table 1. Percentage landslide occurrence values

Hazard class	Area of Hazard (m^2)	Area of Landslide (m^2)	% landslide occurrence
Not mapped	3205883	11115	0.34
Landslides not likely to occur	11938243	23540	0.19
Modest level of landslide hazard exists	17267278	62104	0.36
Landslides are to be expected	9554851	48154	0.50
Landslides most likely to occur	461988	676	0.14

Assess the effect of building density and distance from transport lines

Table 2 shows with the increase in building density percentage landslide occurrence increases except for highest density class. It is because the highest building density is found in flat lands where landslides did not occur. The occurrence of landslides in most likely to occur area is the lowest because of the high degree of hazard identified at the early stages. As a result protective/mitigation measures have been implemented in these areas. Human settlements or development activities carried out is minimal due to the identification of high degree of hazard from landslides. So further sliding is under control in these human untouched areas, but the other areas have become more prone to landslides due to lack of attention given to protective measures and rapid development in those areas. As a result earlier safe areas now has been converted to vulnerable areas most probably due to high pressure imposed on earth by inappropriate human activities carried out in hilly areas. Table 3 shows percentage landslide occurrence decreases with the increased distance up to 50 meters from transport lines.

Table 2. Percentage landslide occurrence values in each building density class

Density	Area(m^2)	Landslide area(m^2)	Percentage (%)
0(lowest)	14034510	8641	0.061
1	12871084	8836	0.068
2	11257049	8560	0.076
3	3503700	3255	0.09
4(highest)	761900	0	0

Table 3. Percentage landslide occurrence values in each buffer zone

Distance from transport lines(m)	Active landslide area(m^2)	Total area(m^2)	% landslide occurrence
10	1405	2162530	0.064
20	1395	1993630	0.070
30	737	1855710	0.039
40	325	1721400	0.018
50	215	1591480	0.013
60	219	1490790	0.015
70	325	1428320	0.022

Development of Improved LHZ map

The improved landslide zonation map created based on frequency ratio method, integrating the effect of building density and major transport lines to the existing landslide hazard zonation map (Figure 4). Figure 5 shows that the percentage landslide occurrences in improved landslide zonation map have gradually increased from safe zone to landslides most likely to occur zone. This graph clearly shows that the percentage landslide occurrence has gradually increased as the hazard increases in the zones with highest percentage of landslide occurrence in landslides most likely to occur zone and lowest percentage of landslide occurrence in landslides are not likely to occur zone.

This study shows that the hilly urban areas where building density is moderately high, the landslide risk are high. It is because the slope properties have been modified due to over-urbanization, excessive earth works, natural drain blockages etc. Including the effect of building density and proximity to major transport constructions into the hazard zonation map will make the map more accurate as this study shows there is a significant relationship between those two factors and landslide occurrence in sloppy areas. In the existing hazard zonation map only 1.8 % of total land area was considered as most likely to occur, but after eleven years with the rapid development and human intervention it has increased to 16.6% of the total land area. This identification is very important because, unless proper corrective measures are taken, progressive slipping of earth will continue to take place. Landslides can become aggravated with time because the hill slopes has the potential to slide down when weakened by the absorption of rain water and from other human activities , such as cutting of slopes, denuding of slopes from vegetation and failing to provide adequate drainage conditions.

Regression analysis shows the prediction power of the improved landslide hazard zonation map is 98.5%.

Conclusions

Existing landslide hazard zonation (LHZ) map shows it should be revised according to the present situation. Population pressures and increasing urbanization in the KMC has influenced the increased landslide occurrences. Integrating the effect of building density and proximity to transport lines to the present landslide hazard zonation map increases the prediction power of landslide hazard zonation map. In the improved landslide hazard zonation map Landslides most likely to occur zone has been expanded and the Landslides not likely to occur zone has been shrunken. Improved LHZ map has an accuracy of 98.5%.

Recommendations

A maintained landslide inventory in landslide prone areas including location of the landslide, extent affected, damage caused etc. is important to update and validate the Land Slide hazard (LHZ) maps. Improved LHZ map can be used to alert both the public and the authorities to the real danger posed by potential future landslides in KMC area or in particular, to highlight the threat posed to private dwellings and other buildings such as schools that lie on the path of potential landslides endangering life and property.

People do need protection for their lives, their dwellings,other infrastructure and access roads. If proper regulations governing hillside development work are not established and enforced, the landslide problem in Kandy will continue to get worse during prolonged rainy periods, resulting in enormous threats to life and property in Kandy.

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