Quantitative Landslide Risk Assessment and Mapping

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ABSTRACT: The Landslide is one of the major hazards in Sri Lanka affecting by people in ten districts in Sri Lanka. During the period from 1989 to 2003, there were about 178 reported landslides all over Sri Lanka, causing over 455 deaths. Impacts of landslides have increased during the past 25 years and about 85 % of the deaths occurred during this period. For the period from 1982 to 2007 landslides have affected almost 150,000 families and around 2,800 million rupees had to be spent on relief measures. It is mostly the Central Highlands of Sri Lanka and the surrounding slopes that are frequently affected by landslides.

National Building Research organisation (NBRO) is the prime research and development institution which has been mapping landslide hazard areas since 1992. However for the planning purpose the landslide risk levels are needed to develop the strategies in development planning. Due to this reason hazard map were not taken in the planning process. NBRO develop a risk map to overcome this gap which is connecting the hazard mapping and development planning activities. This paper presents the landslide risk mapping methodology for Sri Lanka.

Key words – Landslide, Risk Assessment, Development Activities, Development Planning

1 INTRODUCTION

National Building Research Organisation (NBRO) has been preparing landslide hazard zonation maps since 1992. Landslide hazard mapping in Sri Lanka may be considered as a unique experience and in this context it is perhaps the first comprehensive attempt to generate maps of human settlements and infrastructure on 1: 10,000 scale conjointly with other nature maps. The landslide hazard maps display the distribution of severity of potential landslide hazard in a given area. Risk maps needs to be prepared based on hazard maps already being prepared under Landslide Hazard Zonation Mapping exercise. Risk maps will be developed taking in to consideration of potential damages to human lives and properties. The risk maps will lead to further investigations and proper planning of risk mitigation actions. In fact such maps serve as a tool to guide investments in development and utilization of lands susceptible to landslides.

Development activities implemented without considering potential landslide risks will directly and indirectly affect the regional economic growth as well as the national economy. Therefore, it is vital to establish a mechanism to incorporate results of landslide risk assessments into development planning processes and disaster management. Therefore landslide risk profiles can guide the decision makers in planning processes such as Urban Development Authority and National Physical Planning Department to design their development actions.

2 THE METHODOLOGY

The methodology adopted to preparation of risk profiles is describe under this section. A new map named as “Human Settlement Map” is developed for this specific purpose. Secondly Landslide Hazard Map has to be overlay with completed Human Settlements Map. For this overlaying components should be weighted in proper manner. Pairwise ranking method use to weighting the human settlement categories. Adopted methodology is illustrated bellow.

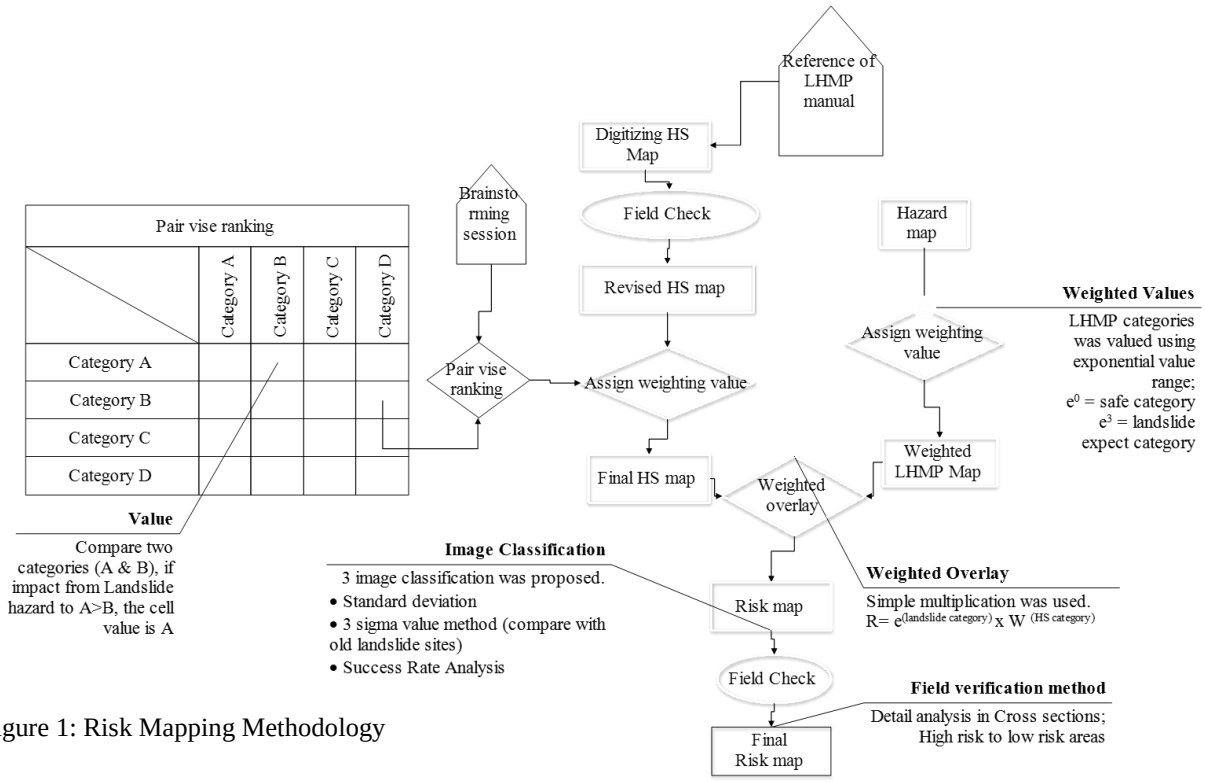

Figure 1: Risk Mapping Methodology

2.1 *Human Settlements Mapping*

Human Settlements and infrastructure map can be produced in two stages as all the details are usually not obtainable from a single source. First the details of human settlements are obtained mainly from the satellite images by using QGIS open source software. Secondly obtained details relevant to human settlements and infrastructure will be verified through sources such as already publish maps and field observations.

2.1.1 Preparation of suitable legend

The legend for preparation of a land use map is the most important factor of the mapping process. In this context it was decided to use the legend defined for Human Settlement map in 1995 under Landslide Hazard Zonation Mapping Project. In evolving this legend the type of details required in assessment of risk have been considered. Also consideration has been given to the ability to obtain these details from aerial photographs. With these considerations the following categories were considered as being of major importance for the human settlement mapping.

Based on previous studies and literature, following parameters were identified for assess the vulnerability and carrying capacity of the human settlements.

The parameters are;

1. Building Density
2. Open spaces
3. Percentage of forestry type land uses
4. Rate of productivity of natural/market land uses

1. Building Density [BD]: Building density is a built environment parameter which gives the details about how congested the buildings in the settlement. Building density is found to be high in urban areas and it is low in rural settlements.

2. Open Spaces [OS]: Open spaces are free movement areas; where can be suitable for agglomerate activities in the settlements. These areas are not highly developed areas but people gather for their recreational purposes.

3. Percentage of forestry type land uses [PF]: This indicator gives the idea on natural lands availability in the land. If more forestry lands available in the site, it is concerned as a natural area.

4. Rate of productivity of natural/market land uses [RP]: The economic crops, perennial crops and other productive lands will be categorised under this category. If one crop type is more productive, then it is selected as higher vulnerability crop.

Based on above description; landslide risk can be discussed as follows;

$$Risk = [LHMP\ category] \times \frac{[BD] \times [RP]}{[OS] \times [PF]}$$

Human Settlements

2.1.2 Preparation of Human Settlement Map

Mapping process was carried out by using QGIS which is an open source GIS application. Instead of aerial photos used in past satellite images through QGIS application were used. Using of satellite images gave more advantages rather than the photo interpretation. Satellite images are more updated than the aerial photos. Also we could produce soft copy of the human settlements layer which can be used to analysis through the mapping process.

2.1.3 Application of the map

Possible applications of the Human Settlements Map could be listed as follows

1. Preliminary application of risk

Determination of risk attributes of the map is a difficult exercise. The difficulty in agreeing on a precise value for each of the map units due to lack of data and the difficulty that arises in assessing and quantifying risks to human lives and agricultural components.

2. As a basic planning tool

Because of the greater attention given to the socio-economic aspect, the information on this map will be used as a guide in exercises related to human settlements, such as deciding the project specific requirements, determination of the risk, determination of the locations for resettlements and also selecting suitable areas for the construction of temporary shelters in case of emergencies.

2.1.4 Weighting the Human Settlements Categories

Human settlement categories were divided in to four main subcategories and as the first step of the process these sub categories were weighted. Diagram below describes the pairwise ranking method used in this process.

Table 1: Weighting of human settlements categories

Human Settlements Categories	Human Settlements Categories			
	1	2	3	4
1		1	1	1
2			2	2
3				3/4
4				

1 – Settlements
2 – Residential + small holder agricultural
3 – Small Holder Agricultural
4 – Other major uses

First each factor was compared with each other and a number of relatively important factors mentioned at the relevant box. If both factors are equally important, then both the values are mentioned in the relevant box.

E.g. – when comparing factor number 1 and 2, settlements are more important than the Residential cum small holder agricultural areas in terms of risk. Settlements are important since it has higher number of human lives than the residential and agricultural areas.

Secondly, the total number of valued cells were counted and 100 is divided by the counted number. The result represents the value of one valued cell.

E.g. – Count of valued cells = 6
Value of one valued cell = 100/6 = 16.66

Thirdly, the total number of valued cell in each row was multiplied by the value of one cell.

E.g. – Count of valued cells in row 1 = 3
Weight of row number one = 3 x 16.66 = 49.98

Count of Valued Cells in Row 2 = 2
Weight of row number two = 2 x 16.66 = 33.32

Count of Valued Cells in Row 3 = Count of Valued Cells in Row 4 = 1/2
Weight of row number two = 1/2 x 16.66 = 8.33

Fourthly, the resulted weights were rounded up in to 10^1 place.
E.g. - Row number 1 = Settlements = 50
Row number 2 = Settlements + Small holder Agricultural = 30
Row number 3 = Small holder Agricultural = 10
Row number 4 = Other major uses = 10

Resulted values were defined as the weights of each category. In the same method, sub components under each main factors were weighted. Weighting tables are illustrated below

Table 2: Human Settlement categories and Weights

Human Settlement Category	Map Symbol	Weight	
1. Settlements		**50**	
1.1 Urban Center	S_1	34	0.1700
1.2 Urban Residential	S_2	34	0.1700
1.3 Urban Amenities	S_3	2	0.0100
1.4 Estate Settlement	S_4	20	0.1000
1.5 Rural Settlement Center	S_5	10	0.0500
2. Residential + small holder agricultural		**30**	
2.1 Homestead and Upland Crops			
2.1.1 Homestead + Perennial crop cultivation	SH_1	25	0.0750
2.1.2 Homestead + annual crop cultivation (Type A)	SH_2	21	0.0630
2.1.3 Homestead + annual crop cultivation (Type B)	SH_3	14	0.0420
2.1.4 Homestead + Market gardens	SH_4	13	0.0390
2.1.5 Forestry type Homestead Agriculture (Land cover >70%)	SH_5	7	0.0210
2.1.6 Forestry type Homestead Agriculture (20% < Land cover <70%)	SH_6	2	0.0060
2.1.7 Recently occupied Homestead (Land cover < 20%)	SH_7	2	0.0060
2.2 Homestead and Wetland Crops			
2.2.1 Homestead + Paddy	SH_8	16	0.0480
3. Small Holder Agricultural		**10**	
3.1 Upland Cultivation			
3.1.1 Market gardens	H_1	35	0.0350
3.1.2 Annual crop gardens (improved)	H_2	20	0.0200
3.1.3 Annual crop gardens (unimproved)	H_3	5	0.0050
3.1.4 Sparsely used cropland	H_4	5	0.0050
3.2 Wetland Cultivation			
3.2.1 Paddy	H_5	35	0.0350
4. **Other Major Uses**		**10**	
4.1 Tea Plantations		30	0.0300
4.2 Rubber Plantations	JR	30	0.0300
4.3 Forest Plantations	JW	13	0.0130
4.4 Natural Forest	W	20	0.0200
4.5 Grass Land	G	3.5	0.0035
4.6 Rocky Land	RK	3.5	0.0035

2.2 *Weighting Landslide Hazard Zones*

Landslide hazard maps have been prepared by NBRO since early 90's. The maps consist of five hazard categories according to criticality of hazard. For the purpose of calculation of risk levels these five hazard categories were weighted based on exponential equation. Exponential values were used by assuming impact of landslide hazard is increasing in increasing rate when categories are changing.

Table 3: Hazard levels and their values

Hazard Level	**Value**
Landslides & Rock fall have occurred in the past (e^3)	20.0855
Landslides most likely to occur (e^3)	20.0855
Landslides are to be expected (e^2)	7.3891
Modest level of landslide hazard exists (e^1)	2.7183
Landslides not likely to occur (e^0)	1.0000

2.3 *Calculation of Risk*

$$\text{Risk} = \frac{\text{Hazard Value x Vulnerability Value}}{\text{Capacity}}$$

Equation 1: Risk calculation equation

$$Risk = [LHMP\ category] \times \frac{[BD] \times [RP]}{[OS] \times [PF]}$$

In a scale of 1:10,000, it is very difficult to assess the capacity of each and every element in a given area. Hence vulnerability values and capacity are taken from values of the Human Settlements Map. Human Settlements Categories are weighted considering human

lives are the most important factor among all of these. Resulted values are ranged from 3.4145 to 0.0035 and resulted values have been classified in to four major categories as High, Medium, Low risk and safe areas. The classifications were done based on standard deviation method. Data set divide by the standard deviation and classify in to four categories. Following table shows risk of human settlements in different hazard categories

3 RESULTS AND DISCUSSION

Few field visits were conducted to verify the landslide risk assessment results. Objective in this verification is to validate the results and to identify where the marked high risk areas are actually the correct areas having high risk or not. The risk values are categorised into the following range:

High Risk	: 3.4145 ~ 0.6900
Modest level Risk	: 0.6900 ~ 0.3735
Low level risk	: 0.3735 ~ 0.056983
Safe	: 0.056983 ~ 0.00

Two methods had been used to find out whether the risk areas are exactly correct or not. The two methods are;

1. The high risk areas consist any settlements or economically valued sites.
2. Draw a transect line across the site, which is starting from high risk area to safe area and analyse the risk value changes in every segment.

Several sites were visited in this analysis and figure 2 shows an example of a verified field.

Figure 2 - Thotalagala Tamil Primary School Line, Diyatalawa

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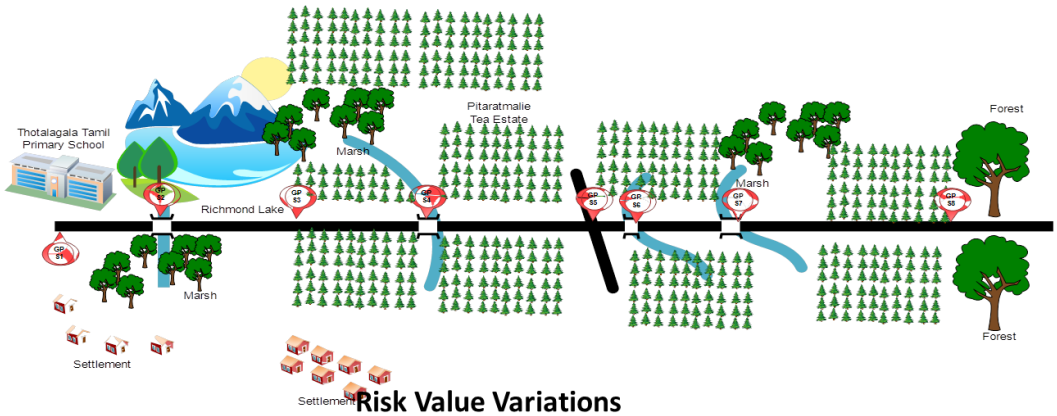

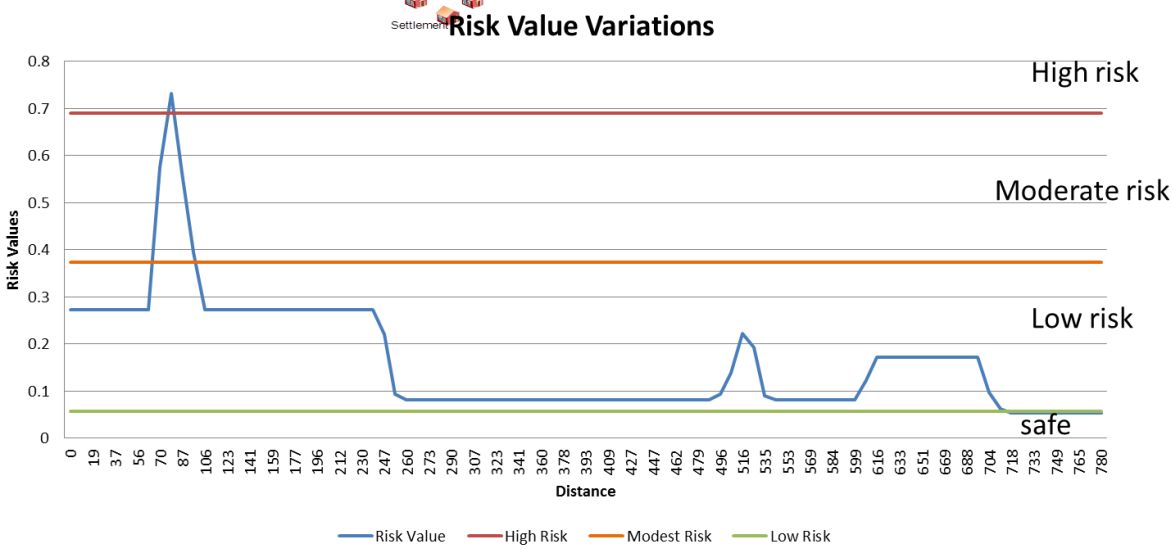

Table 4: Risk of Human Settlements in different hazard categories

Human Settlement Category	Map Symbol	Weight	value	Landslides are expected (85%)	Lanslides to be expected (10%)	Landslides are likely to be occurred (5%)	Safe area
1. Settlements		**50**		20.08554	7.38906	2.71828	1
1.1 Urban Center	S_1	34	0.1700	3.4145	1.2561	0.4621	0.1700
1.2 Urban Residential	S_2	34	0.1700	3.4145	1.2561	0.4621	0.1700
1.3 Urban Amenities	S_3	2	0.0100	0.2009	0.0739	0.0272	0.0100
1.4 Estate Settlement	S_5	20	0.1000	2.0086	0.7389	0.2718	0.1000
1.5 Rural Settlement Center	S_4	10	0.0500	1.0043	0.3695	0.1359	0.0500
2. Residential + small holder agricultural		**30**					
2.1 Homestead and Upland Crops							
2.1.1 Homestead + Perennial crop cultivation	SH_1	25	0.0750	1.5064	0.5542	0.2039	0.0750
2.1.2 Homestead + annual crop cultivation (Type A)	SH_2	21	0.0630	1.2654	0.4655	0.1713	0.0630
2.1.3 Homestead + annual crop cultivation (Type B)	SH_3	14	0.0420	0.8436	0.3103	0.1142	0.0420
2.1.4 Homestead + Market gardens	SH_4	13	0.0390	0.7833	0.2882	0.1060	0.0390
2.1.5 Forestry type Homestead Agriculture (Land cover >70%)	SH_5	7	0.0210	0.4218	0.1552	0.0571	0.0210
2.1.6 Forestry type Homestead Agriculture (20% < Land cover <70%)	SH_6	2	0.0060	0.1205	0.0443	0.0163	0.0060
2.1.7 Recently occupied Homestead (Land cover < 20%)	SH_7	2	0.0060	0.1205	0.0443	0.0163	0.0060
2.2 Homestead and Wetland Crops							
2.2.1 Homestead + Paddy	SH_8	16	0.0480	0.9641	0.3547	0.1305	0.0480
3. Small Holder Agricultural		**10**					
3.1 Upland Cultivation							
3.1.1 Market gardens	H_1	35	0.0350	0.7030	0.2586	0.0951	0.0350
3.1.2 Annual crop gardens (improved)	H_2	20	0.0200	0.4017	0.1478	0.0544	0.0200
3.1.3 Annual crop gardens (unimproved)	H_3	5	0.0050	0.1004	0.0369	0.0136	0.0050
3.1.4 Sparsely used cropland	H_4	5	0.0050	0.1004	0.0369	0.0136	0.0050
3.2 Wetland Cultivation							
3.2.1 Paddy	H_5	35	0.0350	0.7030	0.2586	0.0951	0.0350
4. Other Major Uses		**10**					
4.1 Tea Plantations	JT	30	0.0300	0.6026	0.2217	0.0815	0.0300
4.2 Rubber Plantations	JR	30	0.0300	0.6026	0.2217	0.0815	0.0300
4.3 Forest Plantations	JW	13	0.0130	0.2611	0.0961	0.0353	0.0130
4.4 Natural Forest	W	20	0.0200	0.4017	0.1478	0.0544	0.0200
4.5 Grass Land	G	3.5	0.0035	0.0703	0.0259	0.0095	0.0035
4.6 Rocky Land	RK	3.5	0.0035	0.0703	0.0259	0.0095	0.0035

High	
Medium	
Low	
Safe	

Observations	LHMP category	Remarks/ Arguments
The school is marked as high risk zone	Modest level Hazard	The LHMP identified as modest level hazard exist and HS map identified as settlement. This result to high risk zone.
Lake is marked as Low risk zone	Landslide likely to be occurred	Lake is environmental area, but in here it marked as low level risk. Sometime, the values for water bodies should be revised compared to tea lands. However, the lake is located in upper side of the valley. This may result to hydrological changes in the area related to landslides.
Low risk Tea estate value	Landslide likely to be occurred	The values may be upper limit of low risk area category. The values may change based on the hazard value variations.
Safe zone in forest area	Landslide likely to be occurred	Low Risk value, this result

4 CONCLUSION AND WAY FORWARD

- Landslide Hazard Mapping Programme of NBRO was initiated on 1993 and since then, landslide maps were used to identify the hazard prone area by different stakeholders. However, with the increasing rapid development, landslide risk is an essential factor for the development sector.
- Environmental investment is needed to have proper rational and the landslide risk mapping will be a guide plan for the development.
- Landslide risk mapping programme can be further enhanced by gathering further information on demographic and housing. Combination of triggering factors such as rainfall with the risk mapping can be developed a better early warning system for the landslide prone area.

5 REFERENCES

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