A GIS based Approach for Landslide Susceptibility Mapping

PGRNI Pussella[1, 2#], Lin Li[1], MHB Fernando[2], DS Munasinghe[2] and CA Karadana[2]

[1]*Wuhan University, China*
[2]*Sabaragamuwa University, Sri Lanka*
[#] <indikapussella@gmail.com>

Abstract— *A methodology for landslide susceptibility mapping using an integrated GIS approach is presented under this study. Imbulpe Divisional Secretariat Division in Ratnapura district of Sri Lanka was selected as the study area. Topographic maps and other informative maps were used as inputs to the model. Slope, aspect, drainage proximity, lineament proximity, road proximity, landuse, lithology and soil type were identified as important terrain factors, contributing to landslide occurrences in the region and corresponding thematic data layers were generated. These data layers represent the geological, topographical, and hydrological conditions of the terrain. A numerical rating scheme for the factors was developed using the knowledge of expertise via Analytical Hierarchical Process (AHP) method for spatial data analysis in the GIS. The resulted landslide susceptibility map delineates the area into four different zones as high, moderate, low and very low potential for future landslide occurrences. It was introduced the Landslide Potential Index (LPI) value in this study. The study revealed that about 19.6% of the study area has very low susceptibility, 49.5% has low susceptibility, 22.9% has moderate susceptibility and 8.0% has high susceptibility for landslides. This model can be recommended with finer details for other areas as well, since the model shows that well known Puwakgahawela landslide which was occurred in 2002 and 2016 is in the moderate susceptible area.*

Keywords— **Landslides, GIS, Susceptibility**

I. INTRODUCTION

Landslides are major threats to life and property in the mountainous terrains around the world. On global scale, there is an increasing trend of landslide hazard and associated risk due to increased urbanization, development, continued deforestation in landslide prone areas and also increased regional precipitation caused by changing climate patterns (Cees Van Westen, 2010). It is obvious to believe that, landslides take more environmental concern at present, because it is one of the most serious geological hazards and can result in enormous damage to both property and life every year. A global risk assessment study by Nadim et al. (2006) indicates that the regions with the highest risk of such danger can be found in Colombia, Tadjikistan, India, and Nepal, where the estimated number of people killed per year per 100 km^2 was found to be greater than one. Schuster et al (2004) estimated that the annual direct and indirect cost due to landslide damages is in the order of 2-5 billion US dollars. The development of human activity has demanded the utilization of unstable slopes which often results in severe damage to the constructions and residential areas. The increasing trend of landslide occurrences will continue in future with the increased unplanned urbanization and development.

It is also apparent that over 95% of all the landslide disasters occur in the developing countries (Hansen et al., 1984). Due to the higher relative cost of damage (cost in terms of GDP), those living in developing countries and especially those with limited resources tend to be more negatively affected from such hazards. Thus the recent trend throughout the world and especially for the affected developing countries is to develop effective mitigation measures and safer land utilization regulations rather than cost-intensive projects of slope stabilizations (Guzzetti et al., 1999). At present for landslide mitigation, assessment of landslide hazard risk and identification of landslide prone areas at national, regional and local scales are being considered as important decision-making tools for making improved mitigation plans and preparedness for such hazards.

When considering about Sri Lanka, the central highlands of the country is frequently threatened by landslides making it the number one natural disaster in the country. More than 20% of the total land area and 30% of the total population are occupied by this region. Damages and losses to investments on various development projects, infrastructure and more importantly to lives are the major impacts due to frequent landslide occurrences. Therefore, identification of the landslide prone areas is vital in any disaster mitigation measure. The heavy loss of life as well as the unprecedented damages to property and infrastructure resulting from landslides during the monsoon periods in the years of 1968 and 1986 prompted the Government of Sri Lanka to take serious notes of the losses and initiate appropriate measures for the reduction of the impact of landslides.

In 1990, the National Building Research Organization (NBRO) of Sri Lanka proposed on implementing a comprehensive program to identify the vulnerable areas to reduce the susceptibility to landslide and it was accepted by UNDP and UNCHS and this initiated a hazard zonation program to identify landslide areas under the “Landslide Hazard Zonation Mapping Project (LHMP)”. This project identified Badulla, Kandy, Matale, Nuwara-Eliya, Kegalle, Ratnapura, Matara, Galle and Hambantota districts as the regions which are prone to landsides and the existing inventory on landslides occurred within last few decades are provided enough evidence to understand it and how much it has made impact to the social life.

The main objective of this study was to prepare a landslide susceptibility map for the Imbulpe DS Division of Ratnapura district. The priority of this research is to build up a GIS based model using modern GIS techniques by considering all the factors which are caused directly and indirectly to landslide hazards with a multi weighted approach to prepare a map that indicate the risk areas.

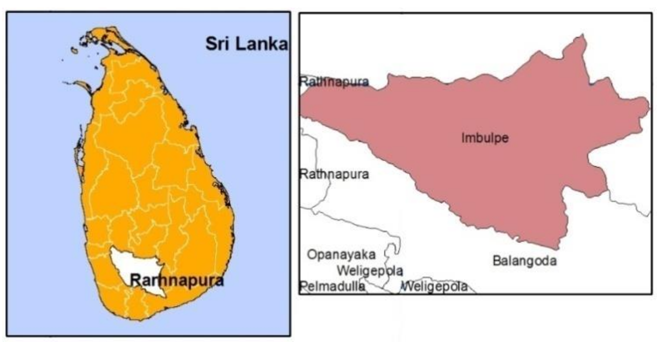

Figure 01 Study area

The study area covers an area of 256 square kilometers and consisted with 27 villages. About 5645 household provide shelter to approximately 23,500 human lives. It covers one side from set of mountains and other sides with Balangoda and Rathnapura DS Divisions which are constantly under threat to possible landslides according to the NBRO.

II. METHODOLOGY

The methodology involved selection of factors, generation of data layers in GIS, numerical rating and weighting assignment to the factors, data integration in GIS, computation of the landslide potential index, suitable classification of landslide susceptibility and validation of the final resulting map using existing landslide inventory.

To achieve the final objectives of the study, the following methodology was adapted (Figure 02). The data were collected from existing maps which were prepared by the Survey Department of Sri Lanka and the views from ten experts in the landslide analysis through a semi structured questionnaire. The experts were from different institutions such as NBRO (04 Experts), Disaster Management Center (03 Experts) and Universities (03 Experts) and views were used in calculating weights to GIS layers and model.

THEMETIC DATA LAYERS

Based on the information collected from available maps and field investigations, thematic data layers were generated for each and every causative factor. A landslide inventory map was also prepared. The mapping was done at a scale of 1:10,000. The details of all the data layers related to the each factors are described as follows.

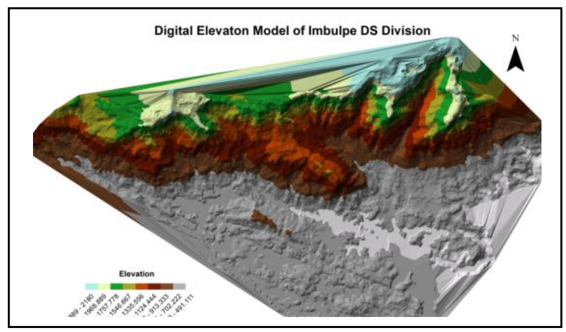

Figure 02 Digital Elevation Model

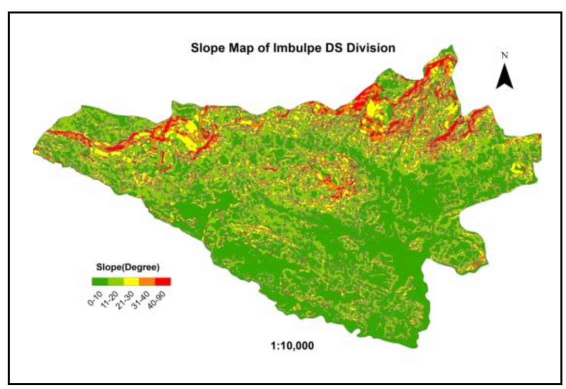

Figure 03 Slope Map

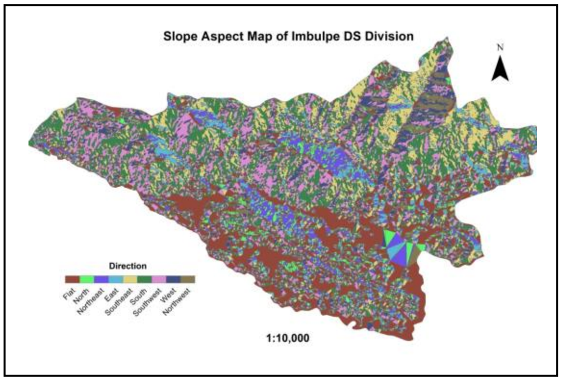

Figure 04 Slope Aspect Map

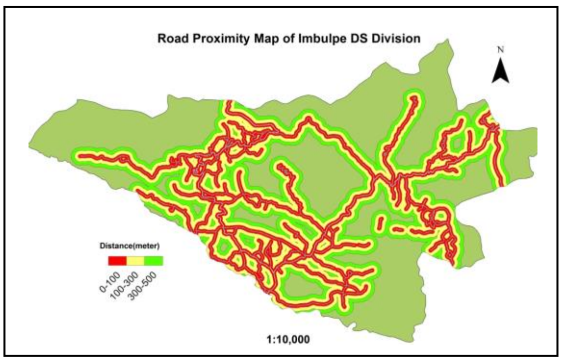

Figure 05Road Proximity Map

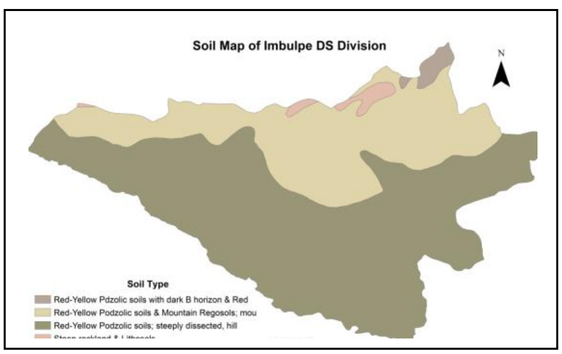

Figure 06 Soil Map

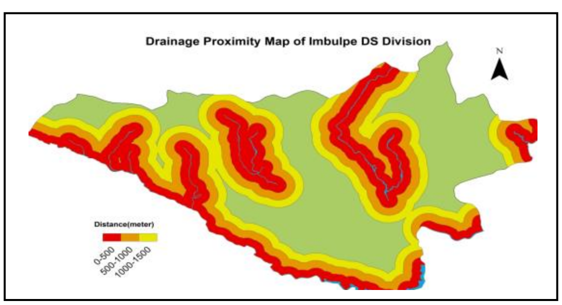

Figure 07 Drainage Proximity Map

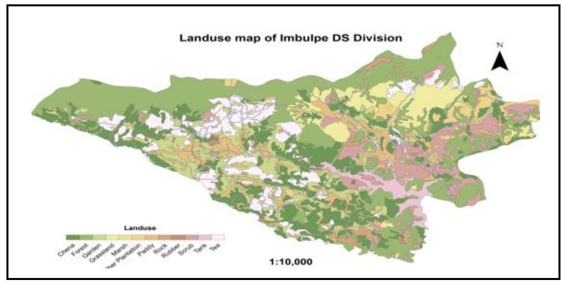

Figure 08 Landuse Map

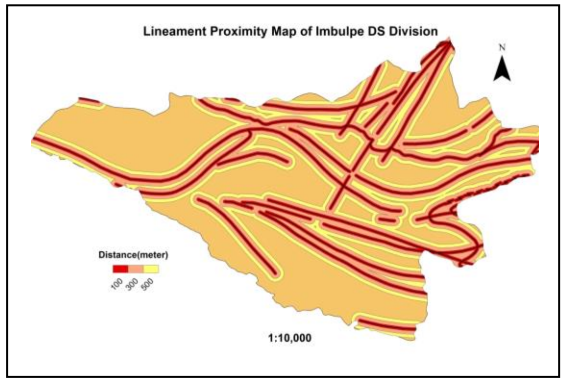

Figure 09 Lineament Proximity Map

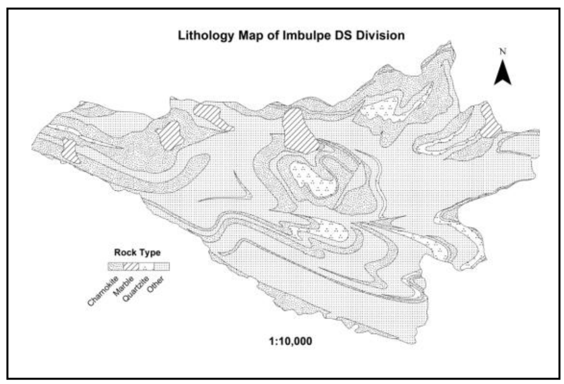

Figure 10 Lithology Map

RATING AND WEIGHTING SCHEME

Assigning appropriate rates and weights for causative factors and their sub classes was the vital part of the study as these values showcase a preview of logical concepts which was leaded to the final output of the study. The identification of potential landslide areas requires that the factors considered be combined in accordance with their relative importance to landslide occurrence. This was achieved by developing a rating scheme for factors and their classes by assigning numerical values for them (Table 01).

LANDSLIDE POTENTIAL INDEX (LPI)

To compute Landslide Potential Indices a new field named **"LPI"** was added into the attribute table of the resultant layer and field values were calculated by following equation.

$$\boldsymbol{LPI = (R1 \times W1) + (R2 \times W2) + (R3 \times W3) + (R4 \times W4) + (R5 \times W5) + (R6 \times W6) + (R7 \times W7) + (R8 \times W8)}$$

Where R1- Rank of landuse, R2- Rank of road proximity, R3- Rank of lineament proximity, R4- Rank of soil type, R5- Rank of lithology, R6- Rank of drainage proximity, R7- Rank of slope aspect and R8- Rank of slope

Factor	Rank value (W)	Sub-class	Weight value
Landuse	3	Chena	6
		Forest	1
		Garden	9
		Grass	9
		Marsh	7
		Paddy	1
		Rock	3
		Rubber	3
		Scrub	1
		Tea	7
		Tank	0
		Other plantation	3
Road Proximity	5	100m	9
		300m	7
		500m	5
Lineament Proximity	6	100m	9
		300m	5
		500m	2
Soil Type	2	C1	9
		C2	3
		C3	1
		C4	8
Lithology	4	Charnokite	5
		Marble	0
		Quartzite	9
		Other	3
Drainage Proximity	8	500m	9
		1000m	5
		1500m	1
Slope Aspect	1	Flat	0
		North	1
		Northeast	4
		East	7
		Southeast	8
		South	9
		Southwest	6
		West	3
		Northwest	2
Slope	7	0-10	1
		11-20	2
		21-30	5
		31-40	7
		41-90	9

Table 01: Weights for Different GIS Layers

The landslide potential index obtained ranged from 12 to 290. These could be classified into several landslide susceptible classes. A judicious way for such classification is to search for abrupt changes in values. For this purpose, a graph showing LPI frequency was prepared which showed many oscillations (Figure 11). By analyzing above graph, LPI values were classified into four classes by dividing the distribution into four equal intervals as very low, low, medium and high (Figure 12).

By using above mentioned weight values attribute tables of each and every data layer was edited by adding a new field that including their corresponding weight values.

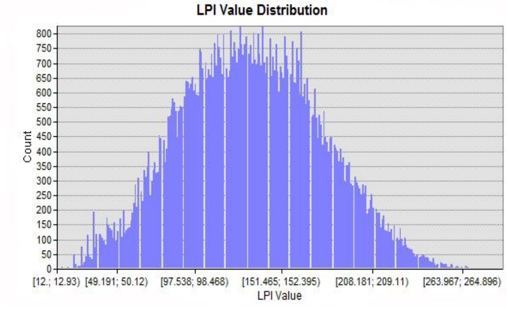

Figure 11: LPI Value Distribution

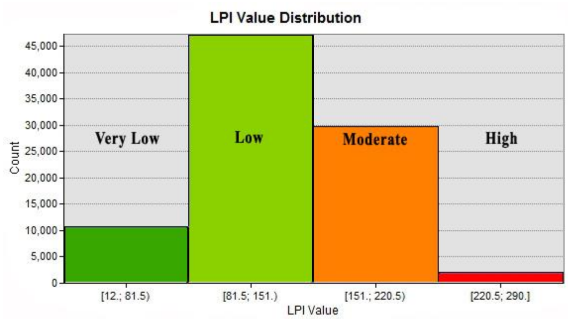

Figure 12: LPI Value Classification

III RESULTS AND DISCUSSION

According to the classes derived with respect to the LPI values landslide susceptibility map of the Imbulpe DS Division was prepared (Figure 13). According to the susceptibility map and Table 02, 2.2km² of the study area had higher tendency for future landslides, but with the availability of triggering factors it can be change. Due to the higher ranking values given to the slope, drainage proximity and road proximity factors, areas with higher tendency to landslide occurrences are mostly can be seen in hilly areas which are closer to water courses and roads. However according to the map, about 70% of the study area has very low probability for landslides and only 8% has higher tendency for landslides. So it can be predicted that the study area will not cause to consistent landslide threats in the future. But, with geological and climatic changes, this situation can be change. For a proper validation for the map more information on previous landslide events or already prepared susceptibility map of the study area from a different approach is required to make necessary comparisons.

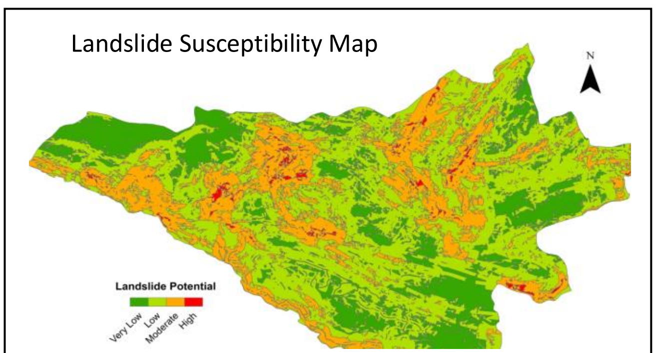

Figure 13: Landslide Susceptibility Map

LPI Value Range	Susceptibility Class	Area(km²)
12-82	Very Low	5.4
83-151	Low	13.6
152-221	Moderate	6.3
222-290	High	2.2

Table 02: Extents of Susceptibility Classes

In this study area, only one landslide has been occurred (Puwakgahawea in 2002) in the past. The area affected by it is including in the "**moderate**" category of the susceptibility map (Figure 14).

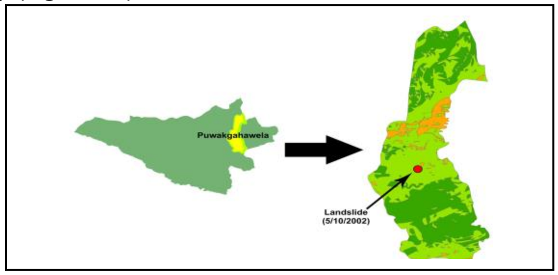

Figure 14: Previous Landslide Occurrences

IV CONCLUSIONS AND RECOMMENDATIONS

The landslide susceptibility zonation map for Imbulpe DS Division was produced as a result of this within a GIS. Even though it is better to consider rainfall as a major factor for this type of mapping, but it was not considered here since the study area is very small in size where the rainfall pattern was same for the whole area. Because the landslide contributing factors vary from region to region, the numerical rating scheme used here may not be suitable for other parts of the country. The result of this analysis in the form of a landslide susceptibility map, is a valuable tool in decision making, for implementing future development projects in the terrain and for mitigation projects. It is always better to avoid the highly susceptible zones but, if not possible, corrective measures must be worked out to minimize the probability of landslide hazard occurrence.

The final output of this study can be differed from another output from another model, because the factors which consider for another study can be changed. Further it can be recommended that the results of this study must be compared with the different model results. Since there is no any theoretical background to compare different models, the study recommends that it can get a better result through a field verification process. And also, another limitation of this study is the limit of data availability. In this study, it was not considered about the landslide triggering factors such as weather conditions, rainfall amount, etc. The data on lithology were extracted from a 1:250,000 scaled map. This could impact badly to the final results.

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