MODELLING OF RAIN TRIGGERED LANDSLIDE USING SINMAP: A CASE STUDY IN RATHNAPURA AREA, SRI LANKA

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ABSTRACT: Landslide is one of the most destructive and very common natural hazards in mountainous terrain in Rathnapura, Sri Lanka. This study attempted to simulate the rain-triggered slope instability phenomena in this area by deterministic GIS based, hydrology coupled infinite slope stability model, namely the SINMAP model.
Results of SINMAP initial run were compared with landslide inventory map and found that 90% of landslide initiation locations fall in the unstable zone. The default six stability classes of the model were reclassified into four classes for easy comparison with National Building Research Organization (NBRO) hazard zonation map. SINMAP model predicts 90% of the known landslide initiation points within the very high hazard and high hazard zones whilst, NBRO's method indicate 80% of them within the same instability regions. Above results indicate that the SINMAP model can be utilized as a tool for identification of landslide hazard zones in this area. Having established the SINMAP model for the area, several recharge scenarios were modeled to arrive at a threshold rainfall leading to full saturation and placing the area under worst conditions with regard to slope instability. It is identified as 75 mm per day rainfall and it is in close correspondence with the rainfall threshold reported by Bhandari and Thayalan (1994), 200 mm per 3 days, as that trigger landslides in the hilly and mountainous terrains of Sri Lanka.

1. INTRODUCTION

Landslide is one of the geological hazards very common in many countries in the world. It is the most common natural hazard in hilly terrains. Landslide is a significant hazard which has serious impact on the economy and humans through the loss of properties, infrastructure, and human life.

Landslides are single hazardous events which may cause localized and minor damage compared to events such as earthquakes and floods. However, with the increase of human population and the occupation of the land surface, mass movement events have a greater potential to affect humans. Human interruption of landuse/landcover affects the slope stability of mountainous terrains. Landuse and landcover changes affect the effective precipitation that reaches the earth surface and runoff, as well as the soil cohesion and root cohesion provided by vegetation cover. The degradation of vegetation cover by overgrazing, fire or clear cutting alter the hydrological conditions of a slope and promotes rapid runoff, erosion and increases the possibility of slides and debris flows (Varnes, 1984).

Landslide hazard analysis is a very costly and time consuming process that requires a large number of input parameters, technical knowledge and techniques of analysis. Geographical Information System (GIS) based slope stability models can overcome this problem. It has been well established that GIS is a powerful tool for handling spatial data such as topography, geology, landuse and rainfall, which are associated with landslide hazard.

Sri Lanka is an island nation with an elevation range up to 2524 meters above the sea level. Mountainous terrain of Sri Lanka consists of approximately 14,000 sq.km out of the 65,525 sq.km total land area. Landslide is the most destructive hazard in the mountainous terrain in Sri Lanka. Therefore, examination of slope instability has become a highly demanding topic, particularly with the increase in development and expansion of human settlements and transportation facilities.

Natural factors such as earthquakes, rainfall, weathering of bedrock, formation of underground caverns, erosion, development of tension and shrinkage cracks followed by water intrusion can be described as factors that affect the slope equilibrium. Rainfall induced landslide are very common in the mountainous areas of Sri Lanka. Most of the slope failures are due to changes in hydro static and hydro dynamic conditions, along with the raising the water table by protracted and heavy rainfall, and the development of a wetting front. Human induced factors such as removal of vegetation, removal of vegetation root structure, steepening of slopes by cuts, loading a slope near its crest, removal of earth below the toe, and construction of water retaining structures upstream of a slope, changes the equilibrium of the slope.

With population growth, there is an increasing demand for land that is suitable for housing, necessary infrastructure and other services such as health care and education. Therefore, in a country where 20% of the total land area is mountainous, utilization of land on hill slopes is unavoidable. Therefore, it is extremely important to map the landslide potential of hilly terrain in order to delineate the land that is unsuitable for development.

National Building Research Organisation (NBRO), Sri Lanka has performed extensive studies on slope failures in Nuwara Eliya and Badulla administrative districts during the past two decades, and has established a probabilistic methodology for landslide hazard zonation mapping (NBRO User Manual, 1995).

2. STUDY AREA

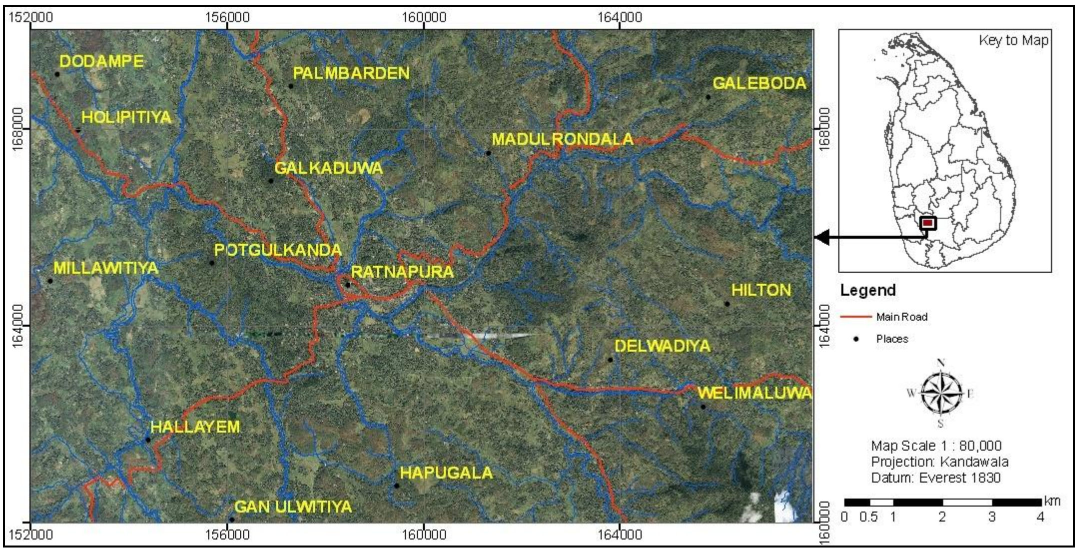

Figure 1 Location map of study area- Rathnapura, Sri Lanka

A 160 sq. km area surrounding the Rathnapura town, which is located towards the southern part of the hilly terrain, was selected as the study area. This region is world famous for gems such as Sapphires, Rubies, Cat's eye and Tourmaline. Due to the abundance of wealth from gem mining, this area is becoming highly populated. Unfortunately, the same area has a recorded history of many landslides within the past few decades, as well as annual incidents of flooding. Growth in the population, which forces the establishment of settlements towards the highlands, as well as inappropriate land use practices have a significant influence in increasing the frequency of landslides in this area.

3. METHODOLOGY

3.1 Digital Elevation Model

In a GIS environment, a DEM is represented and visualized using two main data structures: Rectangular grid (GRID) and Triangulated Irregular Network (TIN). The GRID DEM is typically stored as a raster dataset, where each pixel represents the elevation. The requisite DEM was therefore had to be created using the 1:10,000 scale contour data and spot heights collected from the Survey Department of Sri Lanka.

There are several interpolation techniques available to generate a DEM from such data. However, it has been found that a DEM with a well-connected drainage structure and realistic representation of streams and ridges can be produced using Topo to Raster command in the ArcGIS software package (Hutchinson, 1989). Therefore, this study made use of that functionality in the generation of the DEM. In this process, the first and foremost task is to define the most suitable grid resolution which depends on the inherent properties of input datasets. This aspect has been the research object of Tomislav Hengl (2005) who, based on empirical and analytical rules, has come to the conclusion that in the case of contour data, a suitable pixel size can be derived based on the complexity of the terrain; in quantitative terms, the suitable pixel (x) is to be calculated using the following equation; $x=(A/2*\sum L)$ where, A is the total size of the study area and L is the total cumulative length of all contours. With a total area of 160,004,949 m^2 and 5,122,535 m of contour lines in total, the value for the suitable pixel size for this case turns out to be 16 m and was used.

3.2 SINMAP Model

Stability INdex MAPping (SINMAP) is a raster based infinite slope stability model coupled with a hydrologic model. It does not, thus, applicable to deep-seated slope instability phenomena, including deep earth flows and rotational slumps (Pack, Tarboton and Goodwin 1998). Figure 2 shows in a nutshell, the data requirements of the SINMAP models together with the steps involved in its execution towards arriving at a landslide hazard map.

Being deterministic, the SINMAP model characterizes the study area in question through geotechnical and hydrological parameters acknowledging the fact that they are attributed with a spatial variability. This variability of geotechnical and hydrological parameters are taken into account by imposing a uniform probability distribution with lower and upper bounds.

The factor of safety, FS, is defined conventionally following geotechnical engineering practice, as is the ratio between the shear strength and the mobilized shear stress at the surface in question. With the incorporation of the probability distribution functions for the geotechnical and hydrological parameters, the stability index, SI, is defined as the probability that FS is greater than unity. Five stability classes have, arbitrarily, been assigned for the SI values, 0, 0-0.5, 0.5-1.0, 1.0-1.25, 1.25-1.5, and >1.5 and referred to as defended, upper-threshold, lower-threshold, quasi-stable, moderately stable, and stable.

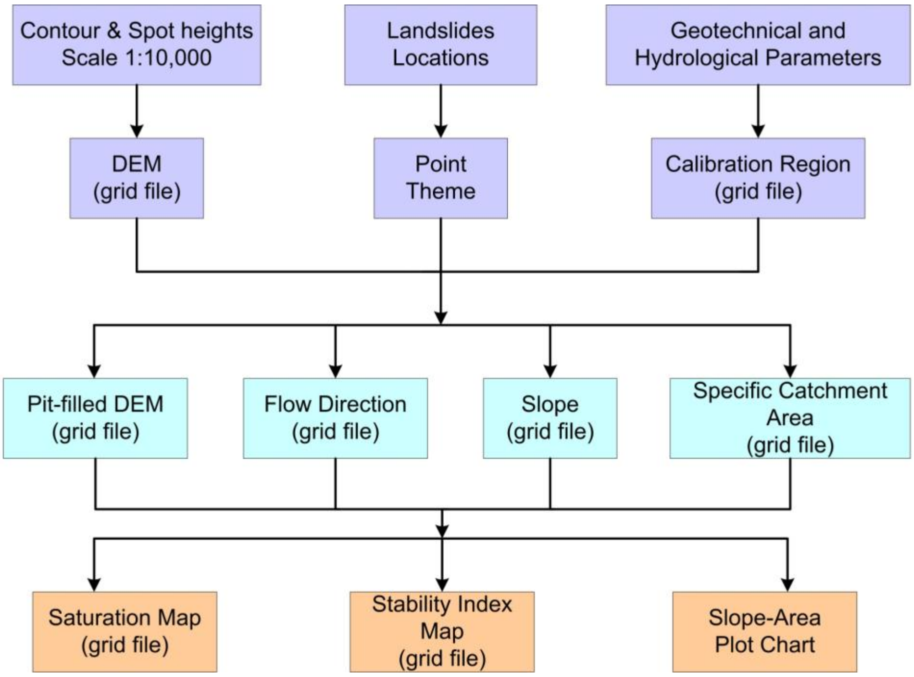

Figure 2 Flow diagram of methodology

3.3 SINMAP Model Parameterization and Execution

Geotechnical parameters; Soil cohesion (C), internal fiction angle (φ'), density of the soil (ρ_s) and hydrological parameters; hydraulic conductivity (k_s), rainfall are required for the model. Parameters were gathered from a previous project entitled "Detailed Assessment of Unsupported Earth Cuttings in the Residual Soils and Colluviums at the Rathnapura Municipal Council Area" (SLUMDMP, 1998), except rainfall. Daily rainfall records from 1996 to 2005 were collected from the Meteorology Department of Sri Lanka which was further incorporated to obtain the wetness index parameter, ratio between transmissivity (k_s*soil depth) and rainfall. The study area was divided into 6 calibration regions based on soil type, soil depth and geotechnical parameters. i.e. areas having similar geotechnical and hydrological parameters were grouped together. The model was calibrated by varying geotechnical parameters and analyzing sensitivity of stability index values. The historical landslide location gathered from NBRO were used validate the model.

After the model execution, the stability index map produced by SINMAP (6 classes) was further reclassified into 4 classes by combining quasi-stable and moderately stable classes into low to medium level hazard, and upper threshold and defended classes into very high hazard to compare the result with existing NBRO landslide hazard map. Then a number of rainfall scenarios including 'no-rainfall' and 'historical maximum' were modeled in the intention of determining the minimum value of recharge leading to an unstable condition with full saturation.

4. RESULTS AND DISCUSSION

Figure 3 shows slope stability index map, out of 20 landslide points 4 were observed in defended class, 7 in upper threshold, 7 in lower threshold class that mean 90% of landslides were observed unstable regions where FS less than 1. Other 2 landslides were observed marginal stable class.

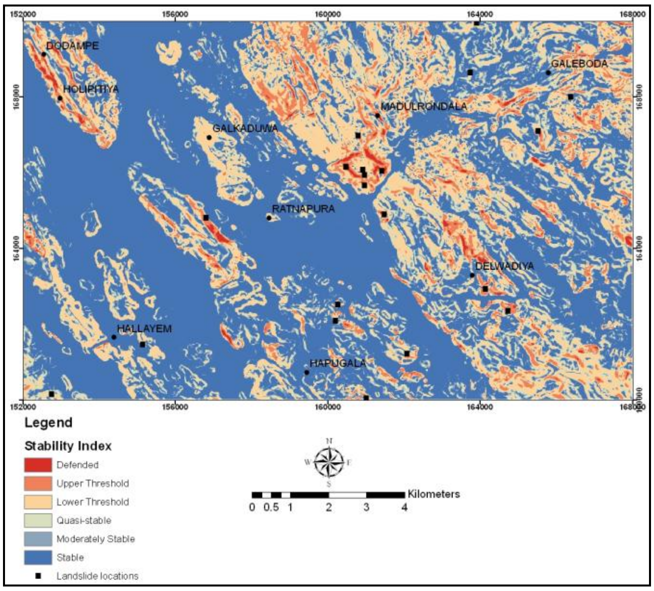

Figure 3 Stability Index map overlaid with landslide locations

Figure 4 and 5 show reclassified stability index map and NBRO landslide map respectively. Table 1 shows the comparison between landslide susceptibility modeled by SINMAP and susceptibility map produced by NBRO. When the results compared combining high hazard and very high hazard classes together, 25% (18 landslide points out of 20) and 11% (16 landslide points out of 20) out of total study area fallen in SINMAP result and NBRO map respectively.

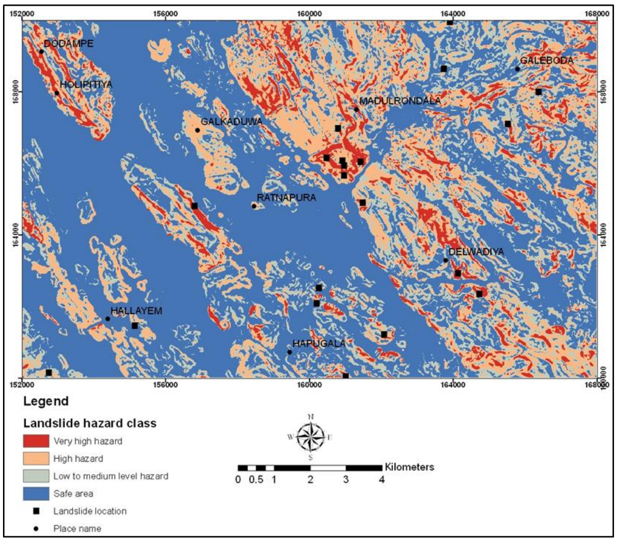

Figure 4 Reclassified SINMAP SI map

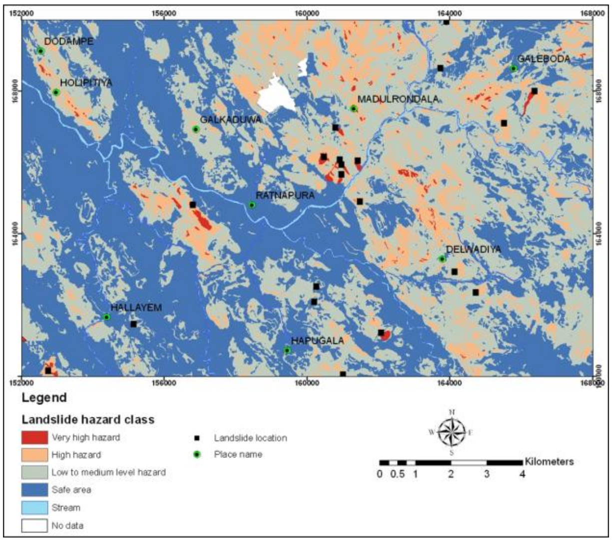

Figure 5 NBRO map

Having established the SINMAP model for the area in question with acceptable accuracy as discussed above, several recharges scenarios were modeled to arrive at threshold rainfall leading to full saturation and placing the area under worst conditions with regard to slope instability. Results indicate that total saturation of the area is reached at a steady state rainfall rate of slightly greater 75mm per day. Therefore, the daily threshold rainfall value for maximum susceptibility scenario could extracted as 75 mm. This is in close correspondence with the rainfall threshold reported by Bhandari, 200 mm per 3 days, as that trigger landslides in the hilly and mountainous terrains of Sri Lanka.

Susceptibility Class	Landslides in different stability classes		Area found in different stability classes			
	SINMAP	NBRO	SINMAP		NBRO	
			Km^2	%	Km^2	%
Safe area	0	0	91.2	57	75.2	47
Low to medium level hazard	2	4	28.8	18	67.2	42
High hazard	7	3	30.4	19	16	10
Very high hazard	11	13	9.6	6	1.6	1
Total	20	20	160	100	160	100

Table 1 Comparison between landslide susceptibility modeled by SINMAP and NBRO map

5. CONCLUSION

SINMAP, deterministic slope stability model was successfully utilized for delineating the landslide hazard zones in Rathnapura area, Sri Lanka. Modeling of different scenarios towards identifying the threshold rainfall for fully saturation and placing the area under worst condition was successful, and it is identified as 75 mm per day. MapWindow GIS and SINMAP 2.0 for MapWindow software packages are downloadable at free of cost. Therefore, implementation of the above model for landslide susceptibility mapping is viable for any individual or an agency with data availability.

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