Landslide hazard zonation using GIS techniques - A case study at Diyadawa, Deniyaya

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Abstract

Haphazard development activities on hill slopes and inadequate attention to construction aspects have led to the increase of landslide and consequently property damage and loss of life. Most landslides or potential failures can be predicted fairly accurately if proper investigations are performed in time. Studies carried out in several areas in Sri Lanka by the NBRO (National Building Research Organization) suggest that small landslides could be easily avoided by paying a little more attention in land usage, slope and other important governing factors. This paper discusses mapping efforts carried out on PC based platforms with commercially available GIS software and discusses the methodology of mapping, predicting landslide prone areas by incorporating land-use and surface topography (relative slopes) which are the major contributing factors for landslides. In the process, paper maps of land-use and contours were digitized and analyzed using a software tool to create a composite map. Then the software illustrated vulnerable areas were validated by visiting the study area, where landslides had occurred already in the recent past. In this study only two major causative factors were included in the analysis because of many limitations available in acquiring the data. Nevertheless, the study outputs are matching reasonably well with actual landslides happened in the study area. By incorporating other major triggering factors for landslides such as hydrology & drainage and bedrock geology more accurate results could be obtained in producing the composite map for landslide vulnerable areas.

Keywords: Landslide, GIS, Hazard zonation

Background

Late evening on 17th May 2003 severe flash floods and landslides hit villages in south and southwest of Sri Lanka. It is identified as the greatest disaster in more than 50 years. According to the latest official figures, the calamity killed 248 people and affected 145,891 families in 6 districts. Approximately 10,000 houses were completely destroyed and additional 30,000 houses damaged. 4,815 persons are currently living in 42 evacuation centers in Matara, Ratnapura and Galle districts. While the numbers of affected and displaced families are highest in Matara District, Ratnapura District had the highest mortality rate. Available evidence suggests that the frequency and magnitudes of landslides have increased in recent years causing serious damage to life and property (De Silva, and Chandrasekera, 2000). However, records before 1970 appear sketchy and many landslides have gone unrecorded, like the Kothmale landslide of 1947. Specially small landslides that do not cause much damage to life and property are not recorded. There were 136 landslides during the 1986-1987 period (NBRO, 1991-1994). In early June 1988, Sri Lanka experienced a devastating landslide damage, which caused over 300 deaths. According to Parliament reports approximately 225,000 people in ten districts were affected by floods and landslides that destroyed over 15,00 homes. Cost for rehabilitating was estimated at about 120 million rupees at 1988 prices. It must be noted that in the year 2003, there were nearly 500 landslides and cutting edge failures occurred within the southwestern slope of the country claming nearly 200 human lives along with colossal amount of property damage.

Introduction

Landslides take place on slopes and generally but not always, on steep slopes where there is already some degree of instability. There is no doubt that rainfall especially intensity of the rainfall is a triggering factor in bringing about the occurrence of landslide and other mass movements. Furthermore the density of population, proportion of the land occupied by estates, forests, grasslands, other reserves and barren lands sparing very little land for human settlements. Therefore identification of landslide risk areas will be beneficial for mitigation measures and future human settlements. Increasing damage to life and property from landslides obviously related to the spread of human settlements into unsuitable areas which are prone to landslides. Needs for mapping and identification of hazardous areas is a high priority and the activity is in progress. Most of the vulnerable areas have been mapped at 1:10,000 scale by the National Building Research Organization (NBRO) which is the mandated institute for landslide hazard assessments. These maps have been submitted for relevant authorities for the implementation through relocation of
settlements. However the implementation needs collaboration of stakeholders and should be lead by Provincial Administration where the progress is not agreeable.

Objective of the study
The main objective of the study is to identify landslide prone areas and producing a visual interpretation of zonation with risk levels by combining minimum number of causative factors for landslide occurrence.

Study area
Study area was located in Deniyaya, which is a mountainous terrain in the North West part of Matara district, and covers a part of Kotapola and Pasgoda secretarial divisions. It is geographically located between (175000, 177000) E and (124000, 126240) N. The study area falls under the Survey of Sri Lanka toposheet No: 81 & 87 on scale 1:10,000. The origin of the projection is 200,000 meters south and 200,000 meters west of Pidurutalagala (7° 00' 01.729" N, 80° 46' 18.160" E) – Transverse Mercator projection.

Causative factors
The National Building Research Organization (NBRO) has proposed six causative factors after studying around 1700 landslides occurred in all around Sri Lanka. The contribution or weightages of each of the six factor as a percentage are given in Table 1.

Table 1 Causative factors and their weightages

<table>
<thead>
<tr>
<th>Causative factors</th>
<th>Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock geology and geological structures</td>
<td>20</td>
</tr>
<tr>
<td>Surface deposits</td>
<td>10</td>
</tr>
<tr>
<td>Slope range</td>
<td>25</td>
</tr>
<tr>
<td>Hydrology and drainage</td>
<td>20</td>
</tr>
<tr>
<td>Land use and management</td>
<td>15</td>
</tr>
<tr>
<td>Landform</td>
<td>10</td>
</tr>
</tbody>
</table>

Data Collection

Contour Map
Landslides usually occur in sloping or hilly terrain, hence it could be assumed that slope of the terrain will have a bearing on landslides. Thus, in the context of predicting landslide prone areas, mapping and investigation of slopes in landslide prone areas would become imperative.

The slope of the land varies from place to place and thus, in the process of mapping slopes of a large land mass, classification of slopes in to suitable ranges or categories become a practical necessity. In generating slope maps, 10 m interval (1:10000 scale) contour paper maps have been used. Using the Arc view 3D analyst, the TIN model (Triangulated Irregular Network) given in Figure 2 for the study area is created from the digitized contour map (Figure 1). From the TIN model, slope map was generated.

Figure 1 Contour map
Figure 2 Perspective view of the area
Land use map
Land use map (Year 2001) has been prepared on 1:10000 scale using paper maps. The land use and management system is grouping of similar land uses and different land uses, under various management categories in pursuit of some predetermined purpose. The multiplicity nature and the extent of diversity in the number of land use categories and management systems pose a real problem to scientists engaged in this field of mapping. As such it is essential to decide and adopt a classification system covering all aspects of mapping to achieve the desired end result.

Rainfall data
Rainfall has both direct and indirect effect on the landslide of the hill slopes. Direct effect includes saturation of soil and rock mass, seepage through the slopes, generation of excess pore pressure and erosion of surface soil. Indirect effect includes gradual removal of fine particles by subsurface flow and facilitating weathering both physical and chemical means. However, since the spatial distribution of the rainfall intensity is not a variable for the whole study area, rainfall has been taken as a driving factor for the occurrence of landslides rather than a causative factor. The National Building Research Organization (NBRO) have proposed a thumb rule of rainfall dependant early warning, that is “72 hrs cumulative rainfall exceeds 200mm, and if rains continue, the probability of a landslide occurring is substantially increased”.

Data analysis
In order to generate the landslide hazard zonation for the study area, a model has been developed in a GIS environment. Data in the form of thematic maps (slope and land use) were input into GIS.

Contribution / Weighting factors Slope
In the study area slope varied from 0° to greater than 40°. Table 2 illustrates five different clustered slope ranges and their respective weightages. Figure 3 shows the corresponding slope distribution.

<table>
<thead>
<tr>
<th>Slope range (deg.)</th>
<th>Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;40</td>
<td>25</td>
</tr>
<tr>
<td>31 - 40</td>
<td>16</td>
</tr>
<tr>
<td>17 - 31</td>
<td>13</td>
</tr>
<tr>
<td>11 - 17</td>
<td>7</td>
</tr>
<tr>
<td>0 - 11</td>
<td>5</td>
</tr>
</tbody>
</table>

(Source: NBRO)

Land use
Different types of land use features that are identified in the study area (Figure 4) and their respective weightages are given in Table 3.

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Weightage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tea</td>
<td>15</td>
</tr>
<tr>
<td>Dense forest</td>
<td>3</td>
</tr>
<tr>
<td>Terrace paddy</td>
<td>8</td>
</tr>
<tr>
<td>Home garden</td>
<td>15</td>
</tr>
<tr>
<td>Scrubland</td>
<td>8</td>
</tr>
<tr>
<td>Other plantations</td>
<td>3</td>
</tr>
<tr>
<td>Waterways</td>
<td>0</td>
</tr>
</tbody>
</table>

(Source: NBRO)
Producing the compose map

Overlaying

The methodology is a weighted overlaying process of the relevant maps, which can be performed with the raster calculation in Arc View 8.3.

The Raster Calculator

The Raster Calculator provides a powerful tool for performing multiple tasks. Mathematical calculations can be performed using operators and functions, set up selection queries, or type in Map Algebra syntax. Inputs can be raster layers, coverage's, shape files, tables, constants, and numbers.

Mathematical operators of Spatial Analyst

Operators and functions evaluate the expression only for input cells that are spatially coincident with the output cell. Mathematical operators apply a mathematical operation to the values in two or more input rasters. Three groups of mathematical operators are available in the Raster Calculator: Arithmetic, Boolean, and Relational. All operators (including Bitwise, Combinatorial, and Logical) can be typed into "The Raster Calculator".

Arithmetic operators

Arithmetic operators allow for the addition, subtraction, multiplication, and division of two rasters or numbers or a combination of the two. For example, the result of [Inlayer1] + [Inlayer2] results in an output grid displaying the summation value for every cell (Figure 5).

Figure 5 Example of Raster Calculation

Figure 6 The Raster Calculator for the project
Therefore in the present analysis the compose map can be created using the following expression.

\[(\text{Slope map}) + (\text{Land use map}) \rightarrow (\text{Compose map})\]

![Diagram of the compose map](image)

**Figure 7 Compose map**

**Results and Discussion**

In order to validate the results produced, predicted landslide prone areas were compared with the actual landslide locations, for the year 2003 as shown in Figure 7. The scale of risk levels given in Figure 7 depends upon number of causative factors considered and their corresponding weightages. The prone areas predicted are reasonably close to the real locations. Nevertheless, some areas having high risk (according to the predicted hazard zonation map) are not representing actual landslides. These deviations may be due to number of causative factors considered being less, accuracy of the input data... etc. and the accuracy of the predicted zonation map could be greatly improved incorporating few other causative factors.

With the close evaluation of the actual landslide locations, it is evident that the hydrology and drainage could be the next important parameter to be incorporated in to the model. Depending on the accuracy of the contour data layer it is possible to create very accurate drainage density map and by incorporating in to the model the predictions will be more accurate.

**Conclusions and recommendations**

Prediction of landslide prone areas presented herein is compatible for use as a computerized system up to some extent. The current methodology using in a real world scenario for the time being is not recommended, without a proper analysis of the other major causative factors. This method is recommended for quantification of landslide hazard zonation as a result of causative factors outlined previously. Then comes the question, Is the number of causative factors used in the analysis enough? Is there any other factor/s, which might affect an occurrence of a landslide? These are some of the important aspects that should further be investigated, for the successful completion of the landslide prone area mapping.

Although designed for use in Deniyaya, the system has the required resilience for exploitation to cover other landslide predictions in Sri Lanka. And also it is recommended to use air photo-interpretation followed by field investigations, since it could be successfully used in identification, delineation and mapping of land use units in various management categories. It
also allows a large area of mapping in reasonably short time with great accuracy. Also regular liaison should be established with agencies involved in land use planning to collect whatever available information on recently completed and ongoing projects pertaining to the mapping in areas of project interest.

Acknowledgement
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References