Multiple Models for Landslide Hazard Zonation

Nafuti, M.H.
Assistant Professor
e-mail: hasanzadeh.m@gmail.com

Natural Resources Faculty, Islamic Azad University Maybod Branch, Yazd, Iran

ABSTRACT

In recent years, damages arising from mass movement have been increasing in northern region of Iran. This can be due to human destructive activities and abusing of natural resources. The occurrence of landslides in these regions is increasing as a consequence of changing forests into roads and tea farms. The investigation of phenomenon and factors contributing to its occurrence is vital and finding susceptible zones for the purpose of preventing and avoiding its harmful consequences is necessary. There are qualitative methods and quantitative ones. In this research, the statistical method of multiple regression was used for landslide hazard zonation of accuracy of the proposed model, the method was used for the neighboring basin. The results of the investigation showed that most recorded landslides in the area have occurred in the zone which is marked as susceptible Zone by the offered model.

1. INTRODUCTION

Landslides like other natural disasters cause many economical and corporal damages all over the world, annually. Iran due to special geological, physiographic and climate conditions is susceptible to landslides. Hitherto, in different province of Iran 3250 landslide has been reported and thought that number of incident landslide is double of this value.

Considering high amount of landslide damages, expenditures of studying and investigation such phenomenon for better understanding and planning to avoid or decreasing the damages are lower than these detriments. Therefore, understanding effective factors in landslide and identifying different area from incident susceptibility point of view is one of significant and essential practice for reducing or prevention from such damages of landslides.

There are various methods for landslide hazard zonation such as Anbalagan, Moura and Warson, Brab, Nilson, in which most of them are empirical and are used in areas with special conditions. In recent years, methods recede from empirical and qualitative states and move towards more quantitative and statistical methods. One of these methods is bivariate statistical method that was used by Campus et al. (2000), Marhaento (2006) and Magliulo et al. (2008) for landslide hazard zonation. For instance, Magliulo et al. (2008) prepare susceptibility map to landslides for north of Italy by bivariate statistical method. In these methods, based on available evidences in area and distribution of landslides, a relation between effective factors and incidence of landslide has been found and that region has been partitioned based on obtained relation from susceptibility point of view into dangerous zones. Another statistical method is multi-variable regression approach that was used in this study. In this method, mutual relationship between influential factors and effectiveness of each of them in landslides is explained, quantitatively.

Research Area

Shalmanrood watershed (Case study area) and Kiarood watershed (area for testing model) in east of Guilan province (North of Iran) that are located between 49° 55′15″ and 50° 18′30″ eastern longitude and 36° 54′55″ and 37° 13′ 25″ northern latitude (Fig. 1). Area of Shalmanrood is 495.5 square kilometers, its average height 523.5 meters and its climate is very humid. Average annual rainfall rate of region is 1302.9 mm.

Fig. 1: Location of Shalmanrood Watershed on Guilan Province and Iran Map
Material and Methods
The first stage of landslide hazard zonation is recognition and data gathering that are related to effective factors. Recognition and selection of significant factors have great role in precision and reliability of hazard zonation. Selection of best variables has great significance. For identifying effective parameters in landslide incidence, field observation has been conducted and during this period four parameters rain falling, steepness, petrology and landuse recognized as effective parameters.

Also, during this investigation by GPS, exact location of landslides was determined and after preparation of distribution map, this map entered into geographical information system. As mentioned above, four parameters identified as most effective factor for incidence of landslides and related maps prepared like below.

Slope Map
For preparation slope map, first of all, lines with 100 meters height have been digitized. After that, digital elevation model (DEM) has been prepared and then slope map prepared. Slope map of region divided into 5 classes (Table 1).

<table>
<thead>
<tr>
<th>Slope (%)</th>
<th>Class 0-15</th>
<th>16-30</th>
<th>31-45</th>
<th>46-60</th>
<th>60+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landuse</td>
<td>farmlands</td>
<td>Tea farms</td>
<td>forest</td>
<td>Road buffer</td>
<td></td>
</tr>
<tr>
<td>litology</td>
<td>Other litologies</td>
<td>k2V</td>
<td>Cph</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>1200-1400</td>
<td>1000-1200</td>
<td>&lt;1000</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Rainfall Map
For provision rainfall map, relation between rainfall and height has been applied on DEM and then three rainfall classes for region was definite (Table 1).

Landuse Map
Landuse map provides from Iran landuse map which provision from SPOT satellite images. Then landuse map validated by field observation. Different landuse classes showed in Table 1.

Litology Map
For providing litology map, geological map were used and then by field investigation were controlled and some correction has been done over them. It is noteworthy that since just in two of petrologic maps (Cph, k2V) landslide has been occurred, so each of them considered as a distinct class and other units (without landslide) considered as a class (Table 1).

Preparation of Homogeneous Map
After preparation various slope, landuse, litology and rainfall maps and from overlay all of them, homogeneous map were obtained. Homogeneous unit are those unit that have common properties such as slope, rainfall, litology and landuse and because of some difference with adjacent units (from one of mentioned above influential factors) are distinct from them.

Statistical Analysis
For statistical analysis multivariate regression approach was used. Before regression implementation considered parameters were quantified. Because some factors like litology and landuse composed of lexical units, couldn’t use them for analysis. Also, other parameters like that have quantitative units, have no linear relationship with landslides and up to a limit have reverse relation. Therefore, it is necessary to quantify all parameters and deduce meaningful and weight for all classes. For this purpose, at first homogeneous units map and landslide distribution map merge together and area of landslides of each homogenous map were calculated. Ratio of this area with respect to homogeneous unit area is considered as Y. Then, homogenous units that are similar to other units from three parameters and are differ from each other just by classes of one factor, have been considered and then Y value of them were compared. For example, Comparison Y value in class 1 & 2 for rainfall factor showed in Table 2.

<table>
<thead>
<tr>
<th>Homogenous Units</th>
<th>Y Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope mm</td>
<td>Landuse mm</td>
</tr>
<tr>
<td>class 2</td>
<td>class 2</td>
</tr>
<tr>
<td>class 3</td>
<td>class 2</td>
</tr>
<tr>
<td>class 4</td>
<td>class 2</td>
</tr>
<tr>
<td>class 3</td>
<td>class 3</td>
</tr>
<tr>
<td>class 4</td>
<td>class 3</td>
</tr>
<tr>
<td>class 4</td>
<td>class 4</td>
</tr>
</tbody>
</table>

Thereafter, relations between different classes of rainfall factor obtained. Eq. (1) shows linear relation between classes 1 and 2 for rainfall.

\[ Y = 0.4804 X + 0.0145 \]  
\[ r = 0.89 \]

Based on this relation and with assignment of weight 10 for class 1 of rainfall, weight 4.8 for class 2 of rainfall was obtained. For class 3 that no landslide was occurred, weight 0 was determined. This procedure was followed and
following linear relations between class 2&3 and 2&4 of landuse factor (Eq. 2 and Eq. 3 respectively); class 2&3 of litology (Eq. 4); class 2&3 and 3&4 of slope (Eq. 5 and Eq. 6 respectively) were concluded.

\[
Y = 0.0657 X + 0.023 \quad (2)
\]

\[
r = 0.85
\]

\[
Y = 3.203 X - 0.037 \quad (3)
\]

\[
r = 0.97
\]

\[
Y = 0.0158 X + 0.058 \quad (4)
\]

\[
r = 0.93
\]

\[
Y = 1.6828 X + 0.577 \quad (5)
\]

\[
r = 0.95
\]

\[
Y = 0.5036 X - 0.0595 \quad (6)
\]

\[
r = 0.99
\]

Based on obtained relations, weights that are associated with classes of each effective factor in landslide were calculated that are shown in Table 3.

2. RESULTS

After obtaining related weight of each effective factor, this data for homogeneous units as 51 iterations and four treatments R, G, L, and S in which are associated to rainfall, litology, landuse and slope has been transmitted into SPSS software. For multivariable regression, step by step approach was used. After statistical analysis, Eq. (7) was obtained for region.

\[
Y = 0.0211 G + 0.0651 L + 0.0261 S - 0.2453 \quad (7)
\]

Values of 0.775 and 0.601 obtained for multivariate and \( R^2 \) correlation coefficients, respectively.

According this equation, parameter R that is associates to rainfall has been omitted from model due to poor correlation. Due to lack of data about rain intensity, annual average rainfall was used. If there exist data about rain intensity this region, probably rainfall factor shows stronger correlation and this relation change to another form.

General Eq. (7) and each of variable S, L and G have meaningfulness of more than 99 %. Therefore, result of multivariate regression is acceptable.

After concluding above relation, we use it for all of homogeneous units and calculate Y value for each of them and then landslide susceptibility map was generated as shown in Figure 2.

![Landslide Susceptibility Map of Shalmanrood Watershed](image)

**Evaluation of Landslide Hazard Zonation Reliability**

Although reasonable correlation coefficient was obtained for this model, but for more confidence about reliability of landslide hazard zonation, evaluation has been conducted.

For this purpose, Kiarood watershed that is in the vicinity of Shalmanrood watershed and has similar climate, litology, slope and landuse properties like shalmanrood watershed was used as model test region. Thus, firstly, distribution map of landslide was prepared by field investigation and digitized for Kiarood watershed. Then

<table>
<thead>
<tr>
<th>Table 3: The Weight Value of Each Class of Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class Number</strong></td>
</tr>
<tr>
<td><strong>Factor</strong></td>
</tr>
<tr>
<td>Slope</td>
</tr>
<tr>
<td>weight</td>
</tr>
<tr>
<td>Landuse</td>
</tr>
<tr>
<td>weight</td>
</tr>
<tr>
<td>Litology</td>
</tr>
<tr>
<td>weight</td>
</tr>
<tr>
<td>Rainfall</td>
</tr>
<tr>
<td>weight</td>
</tr>
</tbody>
</table>
effective factor maps for Kiaroood watershed were concluded as method that was conducted for Shalmanrood watershed and from overlay all of them, homogeneous map were obtained.

Then obtained model of Shalmanrood watershed (Eq. 7) was applied on this map and susceptibility classes like Shalmanrood watershed was defined and landslide susceptibility map for Kiaroood watershed were obtained (Fig. 3).

Fig. 3: Landslide Susceptibility Map of Shalmanrood Watershed

Finally, this map was merged with distribution map of landslide and number of incident landslides in each susceptibility class was calculated (Table 4).

Table 4: Comparison Number of Incident Landslides in Different Landslide Susceptibility Class in Kiaroood Watershed

<table>
<thead>
<tr>
<th>Susceptibility Class</th>
<th>Number of Observed Landslide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td>moderate</td>
<td>1</td>
</tr>
<tr>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Very high</td>
<td>25</td>
</tr>
</tbody>
</table>

As shown in Table 4, this model can distinguish different classes susceptible to landslide incidence, well.

Also, one could observed that majority of landslides in this watershed had occurred in very high susceptibility zones, in which, determined by this model. Therefore, reliability of obtained map is valid.

Since this model obtained from Shalmanrood watershed and was used for determining hazard zonation of both watersheds in this model, one could conclude that map of landslide susceptibility for Shalmanrood watershed has reasonable validity.

3. DISCUSSIONS AND CONCLUSIONS

Based on obtained model, following results was obtained:

Applied method is a quantitative method and has some advantages with respect to other empirical and qualitative methods such as considering mutual relation between independent variables (effective factor) and dependent variable (landslide) and also express effectiveness of each of them quantitatively.

Land use factor is the most important element in incidence of landslide of this area. Landuse change from forest to tea farms (has short roots than forest tree) and non-standard road construction is major cause for landslide of the mentioned watershed.

Second important factor in this area is litology. Volcanic ash (k2V) and filet (Cph) due to alteration and clayey fine-grained soil with argillaceous minerals that is susceptible to moving and providing that other conditions play its role in landslide.

The third important factor in incidence landslide is steep. Majority of landslide of this region is steep and occur at 30-50 degree.

REFERENCES


