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Landslide Susceptibility Mapping Using Frequency Ratio and Certainty Factors models in central Zab basin

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Abstract: Preparation of landslide susceptibility mapping is one of the most important stages in landslide hazard mitigation. The aim of the research was landslide susceptibility mapping by Frequency Ratio (FR) and Certainty Factors (CF) with aide of remote sensing data processing and GIS spatial analysis. The area study in research is central Zab basin in west Azerbaijan province, Iran. In this research, through geological maps and field studies, we primarily prepared a map for landslide distributions in central Zab basin. Then, applying other information sources such as the existing thematic maps, we studied and defined the 10 factors such as: slope, aspect, elevation, land cover, NDVI, distance to drainage, distance to fault, distance to road and precipitation. To get more precision, speed and facility in our analysis all descriptive and spatial information was entered into GIS system. The landslide susceptibility maps were classified into four classes: low, moderate, high and very high. The results shows that more than 70 percent of landslides have happened in two classes, high hazard and very high hazard and showed that the FR model is better in prediction than the CF model in study area.
[Himan Shahabi, Baharin Bin Ahmad, and Saeed Khezri. **Landslide Susceptibility Mapping Using Frequency Ratio and Certainty Factors models in central Zab basin**. *World Rural Observ* 2021;13(2):6-10]. ISSN:1944-6543(Print);ISSN:1944-6551(Online).http://www.sciencepub.net/rural 2. doi:10.7537/marswro130221.02.

KEYWORDS: **LANDSLIDE SUSCEPTIBILITY MAPPING; SATELLITE IMAGES; FREQUENCY RATIO, CERTAINTY FACTORS, CENTRAL ZAB BASIN.**

Introduction

Preparation of landslide inventory and susceptibility maps is one of the most important stages in landslide hazard mitigation. These maps provide important information to support decisions for urban development and land use planning (Fell et al., 2008). Also, effective utilization of these maps can considerably reduce damage potential and other cost effects of landslides. However, landslides and their consequences are still a great problem for many countries, particularly those in the developing world (Guzzetti et al., 1999). During the past few years, quantitative methods have been implemented for landslide susceptibility mapping studies in different regions (Kanungo et al., 2006; Süzen and Doyuran, 2004). More sophisticated assessments involved, for example, FR and CF (Lee and Sambath, 2006; Shahabi et al., 2012c; Shahabi et al., 2012d; Van Westen, 1994; Zêzere, 2002; Shahabi et al., 2012b). Nowadays, statistical methods are more applicable for prediction and classification of environmental problems in various regions.

This investigation performs in central Zab basin in the southwest mountainsides of West-Azerbaijan province. This investigation research is want that identification the sensitive landslide area by using of FR and CF models until by identification this region, performance measures for control rationale in the region and prevent of capital and energy waste (Gruber et al., 2009). Landslide susceptibility processing and practical verification of the methodology can provide a basis for

urbanism, land use planning and for public administration offices and insurance companies (Lee and Min, 2001). The methodical procedure in preliminary geological investigation stages presents low cost research, especially for larger areas and lined structures which are endangered both by extremely slow landslides and by rapid debris flows (Makropoulos et al., 2006).

2. CASE STUDY

Zab basin occupies southwestern section of West Azerbaijan and northwestern part of Kurdistan. The area under present study covers parts of mountains and slopes in southwestern West Azerbaijan in the central portion of Zab basin between the latitudes of (36° 8' 25") N and (36° 26' 27") N and the longitudes of (45° 21' 21") E and (45° 40' 44") E (Shahabi et al., 2012a).

Central Zab basin has a north-south orientation and stretches almost 30km in east-west direction. The study area covers some 520km^2 of its total area (Figure 1). It is one of the settled geographical basins including a city, three towns or small cities, and over 80 villages (Khezri et al., 2013b). Here, a north-west extension branches off from the east-west oriented ridges of Zab valley, creating a different landscape from that of the internal sections of Azerbaijan and Kurdistan. The major part of the study area is located in the Sanandaj- Sirjan zone and its east and eastern north parts locate in the Mahabad- Khoy zone (Khezri et al., 2013a).

In aspect of tectonic since the region is located in major Zagros thrust direction and faults are the main causes of pit formation. The region morphology strongly affected by tectonic forces.

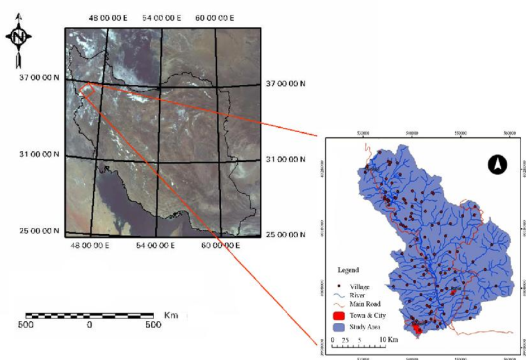

Figure 1. Geographical posation of study area

3. Material and Methods

In landslide hazard susceptibility, the instable regional factors that their fluctuations were accompanied by differing frequencies of landslide events were defined as controlling factors in susceptibility. They include geology (lithology), geomorphology (elevation, slope, and aspect), distance to roads, distance to fault, land use, NDVI, Precipitation, and distance to drainage network. Each thematic factor was subdivided into different classes by its value or feature. All causative factors were converted into thematic maps. The thematic map represents large quantities of spatial data. A vector-to-raster conversion of the above thematic layers were undertaken to provide raster data of landslide areas with 15 m ×15 m pixels. The study area covers 35,840 pixels and total number of landslide inventory points is pixels. The preparation of a landslide susceptibility map involves, manipulations, analysis by using frequency ratio model and validation by R-Index method. The flow chart shows the methodology.

Geological paper maps at 1:10000- scale covering the study area were digitized and the geologic formations were identified. The two largest datasets were topographical parameters that were collected from the 1:50000-scale paper topographic maps. A digital elevation model (DEM) was generated from a triangulated irregular network (TIN) model that was derived from digitized contours with a contour interval of 25 m by using surface analysis tool in Arc GIS 9.3 software. The elevation, slope angle, aspect, and shape of the slope parameters were obtained from the DEM. The elevation, slope angle, aspect, and shape of the slope parameters were obtained from the DEM.

Another dataset was land use, which was interpreted from Landsat ETM$^+$ image on the 21 April 2009, it was calibrated using field observations. Because of significant cloud coverage, results of the classification were edited and simplified by manual digitization. The interpreted images were then digitally processed to further modify the boundaries by supervision classification with ERDAS (Earth Resource Data Analysis System) software. landslide-inventory map of the study area was identified by SPOT 5 satellite on the 25 May 2008 Extensive field studies were used to check the size and shape of landslides, to identify the type of movements and the materials involved, and to determine the state of activity (active, dormant, etc.) of the landslides. A total of 85 landslides were identified in the study area (Figure 2).

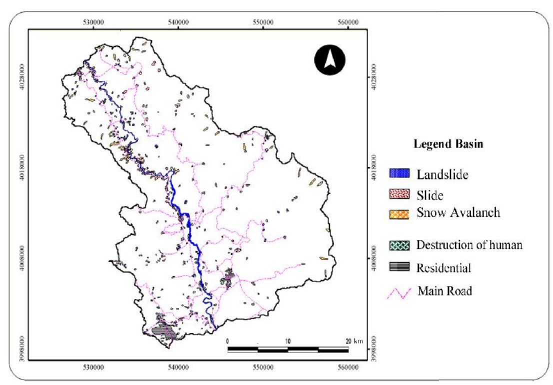

Figure 2. Landslide Inventory map of central Zab Basin

After preparation of the needed information layers by influential parameters on landslides, we drew the susceptibility maps of slide hazard using the following two methods and frequency ratio (FR) and certainty factors (CF) incorporating and evaluate their performance.

3.1 Frequency ratio method (FR)

The spatial relationship between all landslides and each related factor were derived using the frequency ratio. The frequency ratio is the ration between the landslides in the class as a percentage of all landslides and the area of the class as a percentage of the entire map (Lee and Pradhan, 2007) (See Eq. 1). When evaluating the probability of landsliding within a specific period of time and within a certain area, it is of major importance to recognize the conditions that can cause the landslide and the process that could trigger the movement (Yalcin et al., 2011). The correlation between landslide areas and associated factors that cause landslides can be allocated from the connections between areas without past landslides and the landslide-related parameters (Bednarik et al., 2012). In order to prepare the landslide susceptibility map quantitatively, the frequency ratio method was implemented using GIS techniques.

Therefore, the frequency ratios of each factor's type or range will calculate from their relationship with landslide events. The frequency ratio was calculated for sub-criteria of parameter, and then the frequency ratios were summed to calculate the landslide susceptibility index (LSI) (Eq. 1) (Lee and Sambath, 2006).

$$LSI = Fr1 + Fr2 + Fr3 + \ldots + Frn \quad (1)$$

Where, *Fr* is rating of each factor's type or range, *n* is number of factor.

According to the frequency ratio method, the ratio is that of the area where the landslide occurred, to the total area, so that a value of 1 is an average value. If the value is >1, it means the percentage of the landslide is higher than the area and refers to a higher correlation, whereas values lower than 1 mean a lower correlation (Akgün and Bulut, 2007). In general, to predict landslides in central Zab basin, it was necessary to assume that landslide occurrence was determined by landslide-related factors, and that future landslides will occur under the same conditions as past landslides. In order to construct the landslide susceptibility map quantitatively, the frequency ratio model was first used by means of GIS (Shahabi et al., 2012d).

3.2 Certainty factors method (CF)

Direct methods essentially consist of the Geomorphological mapping. Among the indirect-methods, the heuristic (index) and the statistical approaches have been more frequently applied in mapping hazard over wide regions with the aid of GIS related techniques. In the heuristic approach, instability factors are ranked and weighted according to their assumed or expected importance in causing mass-movement. The statistical approach is based on the observed relationships between each factor and the past and present landslide distribution. Among the commonly used GIS analysis models for landslide hazard, Certainty Factors (CF) have been experimentally investigated (Binaghi et al., 1998). The CF, defined as a function of probability, was originally proposed by Shortliffe and Bu-chanan and later modified by Heckerman (See Eq 2):

$$CF = \begin{cases} \dfrac{ppa - pps}{ppa(1 - pps)} if ppa \geq pps \\ \dfrac{ppa(1 - pps)}{pps(1 - ppa)} if ppa < pps \end{cases} \quad (2)$$

Where, *ppa* is the conditional probability of a number of landslide events occurring in class a and *pps* is the prior probability of the total number of landslide events occurring in the study area.

The *CF* value varies between -1 and 1, a positive value means an increasing certainty in landslide occurrence, while a negative value corresponds to a decreasing certainty (Heckerman 2013).

The favorability values (*ppa*, *pps*) have been derived by overlaying (3) each data layer with the land slide inventory layer in Arc GIS and calculating the landslide occurrence frequency. Morphology is shown to be the major controlling factor for land sliding.

4. Results and Discussion

4.1 Landslide susceptibility analyses using Frequency ratio method

In general, to predict landslides, it is necessary to assume that landslide occurrence is determined by landslide related factors, and that future landslides will occur under the same conditions as past landslides (Akgün and Bulut, 2007). In order to construct the landslide susceptibility map quantitatively, the frequency ratio model was first used by means of GIS. The comparison between the spatial distribution of landslides and landslide susceptibility map shows that the causative factors selected are relevant and model performs successfully. The analysis shows important ability of some variables in causing landslides. If the value is greater than one, then there is a high correlation, and a value of less than one means a lower correlation. A landslide susceptibility map (Figure 3) was constructed using the LSI value for interpretation.

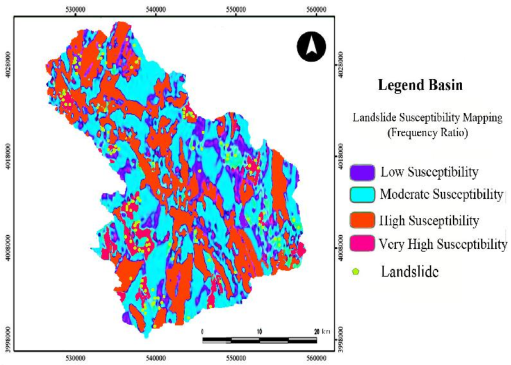

Figure 3. The landslide susceptibility map produced by FR

4.2 Landslide susceptibility analyses using Certainty factors method

The overall estimation of the landslide susceptibility for an area results from the combination of the susceptibility levels of the individual factors. In particular, the maps have been first re-classed according to the *CF* value; then the data layers have been combined using the *CF* integration rule in Arc GIS (Raster Calculator Tool – Spatial Analyst).

The integrated *CF* values have been classified into five hazard classes on the base of the threshold criterion in accordance with the methodology. According to this criterion, we produced the final map reclassifying the areas by means of these five different landslide susceptibility levels (Figure 4). Finally, the active landslide map was posed on the layer of re-classed *CF* value (Susceptibility class). We can observe that most landslides happen in the low susceptibility class.

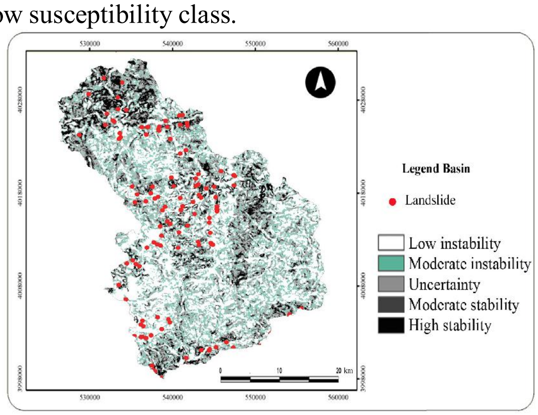

Figure 4. Landslide susceptibility map segmented by threshold criteria

The second classification seems to perform better, with 33% of the area in a medium level of instability (Figure 5) and 42% of landslides in the medium susceptibility class.

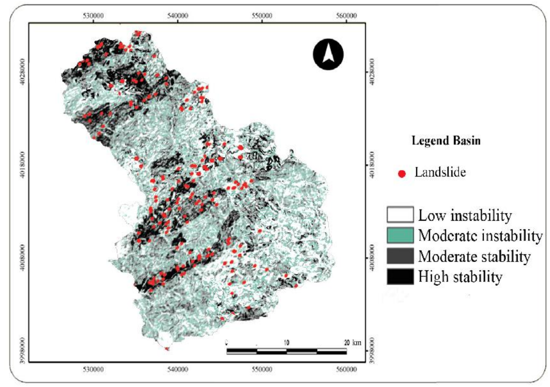

Figure 5. Landslide susceptibility map segmented by statistical analysis of the distribution of values

5. Conclusion

The distribution of the landslide density among different susceptibility levels is coherent. The results are showing that susceptibility accuracy by using of frequency ratio and certainty factors methods are very important in because of attend to membership value of per operative in final susceptibility landslide in done disasters of landslide predict. Therefore, the study area is sensitive to landslide. More than 70 percent of landslides have happened in two classes, high risk and very high risk. This agrees with the real world condition. From assess of all hazard classes view, frequency ratio is more exactly than certainty factors method. As quoted from landslide susceptibility maps are of great help to planners and engineers for choosing suitable locations to implement developments. The information provided by this landslide susceptibility map could be the basis for decisions making, planners and engineers to reduce losses caused by existing and future landslides by means of prevention, mitigation and avoidance.

Acknowledgment

We are thankful to the Department of Geo information in Universiti Teknologi Malaysia (UTM) and International Doctorial Fellowship (IDF) for providing the facilities for this investigation.

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