Application of Satellite remote sensing for detailed landslide inventories using Frequency ratio model and GIS

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Abstract

This paper presents landslide susceptibility analysis in central Zab basin in the southwest mountainsides of West-Azerbaijan province in Iran using remotely sensed data and Geographic Information System. Landslide database was generated using satellite imagery and aerial photographs accompanied by field investigations using Differential Global Positioning System to generate a landslide inventory map. Digital elevation model (DEM) was first constructed using GIS software. Nine landslide inducing factors were used for landslide vulnerability analysis: slope, slope aspect, distance to road, distance to drainage network, distance to fault, land use, Precipitation, Elevation, and geological factors. This study demonstrates the synergistic use of medium resolution, multitemporal Satellite pour l'Observation de la Terre (SPOT), for prepare of landslide-inventory map and Landsat ETM^+ for prepare of Land use. The post-classification comparison method using the Maximum Likelihood classifier with SPOT images was able to detect approximately 70% of landslides. Frequency ratio of each factor was computed using the above thematic factors with past landslide locations. It employs the landslide events as dependant variable and data layers as independent variable, and makes use of the correlation between these two factors in landslide zonation. Given the employed model and the variables, signification tests were implemented on each independent variable, and the degree of fitness of zonation map was estimated Landslide susceptibility map was produced using raster analysis. The landslide susceptibility map was classified into four classes: low, moderate, high and very high. The model is validated using the Relative landslide density index (R-index method). The final, landslide low hazard susceptibility map was drawn using frequency ratio. As a result, showed that the identified landslides were located in the class (51.37%), moderate (29.35%), high (11.10%) and very high (8.18%) in Susceptibility zones.

Key words: *Landslide susceptibility, GIS, Frequency ratio model, Validation, Zab basin.*

1. Introduction

Landslide is one of the natural disasters that create social – economic damages. Although absolutely economic damages rate resulted in landslides higher in the development countries, but by made researchers from UNDRC for almost developing countries, these damages are one or two percent of their national gross production [2]. Therefore, it is able tell that the developing countries relating tolerate the high damages both economic and body security aspects. This matter is confirmed the emergency of management of natural disasters in these countries. In Iran take place several natural disasters such as earthquake, flood and landslide by reasons such as litho logy, topography and climate reasons. Approximately half of this country area is mountains and it have rapid slopes, shaking, existing active faults and rainfall caused that every year. In the mountains regions take place various landslides and create interesting considerable damages to human and natural environment. 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 use of Frequency ratio model until by identification this region, performance measures for control rationale in the region. And prevent of capital and energy waste. Landslide susceptibility mapping of an areas can be assessed and predicted through scientific investigation of landslides, and thus landslide damage can be reduced through suitable mitigation measures. Many methods and techniques have been proposed to evaluate landslide prone area using GIS and/or remote sensing [11, 9, 8, 18, 5, 27, 28, 31, 4, 10, 16, 20, 21].

Frequency ratio model, a simple probabilistic model with an acceptable accuracy, was applied for the deduced thematic layers [14]. Frequency ratio can be evaluated by the ratio of the area where landslides occurred to the total study area for a given factor‘s attribute. Landslide vulnerability map was validated using R-Index.

2. Geographical location of study area

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. 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 (Fig. 1). It is one of the settled geographical basins including a city, three towns or small cities, and over 80 villages [23]. 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. 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 [24].

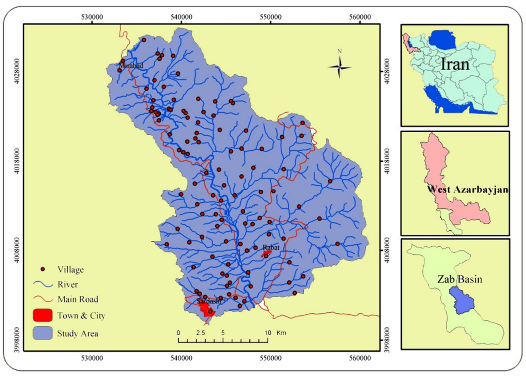

Fig. 1 Geographical location of study area

3. Material and Methods

In landslide hazard zonation, the instable regional factors that their fluctuations were accompanied by differing frequencies of landslide events were defined as controlling factors in zonation. They include geology (lithology), geomorphology (elevation, slope, and aspect), distance to roads, distance to fault, land use, 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 (Fig. 2).

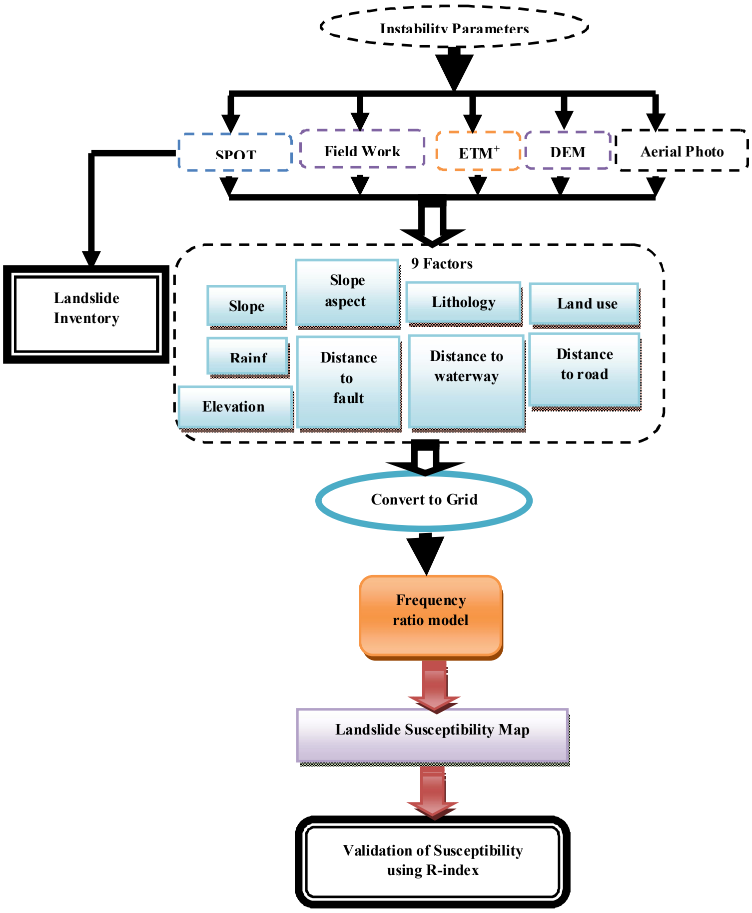

Fig. 4 flow chart stages of study

Geological paper maps at 1:10 000- 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 1:50 000-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 9.2 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 (Fig. 3).

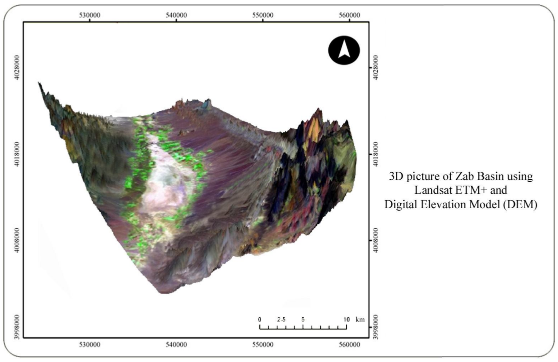

Fig. 3 3D picture of Zab Basin using Landsat ETM + satellite photos and Digital Elevation Model of it

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 23 landslides were identified in the study area (Fig. 4).

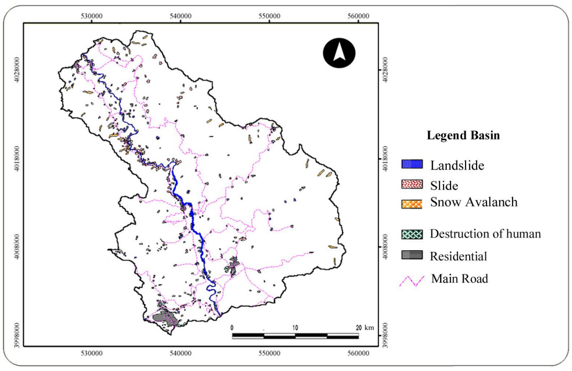

Fig. 4 Landslide Inventory map of Zab Basin

3.1 Probabilistic likelihood ratio

For the application of the probabilistic model, frequency ratio was used to identify future landslides using the similarity of past history of landslides [28, 26, 7] Frequency ratio is based on relationship between distribution of landslides and causative factor, to make known the correlation between landslide locations and the factors in the study area [25]. To apply this model, a spatial database of landslide-related factors, was constructed. All data layers were transformed to GIS system and geo-referenced in the Universal Transverse Mercator (UTM) coordinate system. Then maps of the various factors were classified under different classes. The data layers obtained 212 are square-grid matrices with lines by columns and each pixel represented 15 x 15 m area on the ground. Using the overlay of training subset of landslide location map and different predisposing factor's ranges, the spatial relationship between landslide locations and each factor's range was extracted. The numbers of landslide occurrence pixels in each class was evaluated, and then the Frequency Ratio value (FR) for each factor was calculated.

4. Results and Discussion

The SPOT imagery is mainly composed of green, red, and near-infrared wavebands. In the green and red wavebands, the landslide has a stronger reflectance than other land covers.
However, in the near-infrared waveband, vegetation reflects the near-infrared more strongly than bare soil (landslide). In this study, in order to effectively extract landslides from multitemporal imageries, the image differencing algorithm was used to generate the differentiated image from pre- and post-quake images. The algorithm is based on a pair of coregistered images of the same area collected at different times. The process simply subtracts one digital image, pixel-by-pixel, from another, to generate a third image composed of the numerical differences between the pairs of pixels (Ridd and Liu 1998). The waveband combination (G_{dif}, R_{dif}, NIR_{dif}) for the differentiated image can be expressed as (Eq. (1)):

$$(G_{dif}, F_{dif}, NIR_{dif}) = (G_2-G_1, R_2-R_1, NIR_2-NIR_1) \quad (1)$$

Where G2 - G1 is the difference of the green waveband between pre- and post-quake images, R2 - R1 is the difference of the red waveband between pre- and post-quake images, and NIR2 - NIR1 is the difference of the near-infrared waveband between pre- and post-quake images.

The land use change types were categorized by the method of image subtraction, where the brightness value after hazard subtracts that before hazard. The three major change types are positive change, no change, and negative change. (1) Positive change is the differential brightness value greater than 0. Vegetation land cover has been substituted for the original bare land surface. In some areas vegetation work had been implemented and received a positive change value. (2) No change is the differential brightness value close to 0. These areas are not suffering from hazards such as undamaged buildings, unchanged vegetated areas and bare land. (3) Negative change is a differential brightness value less than 0 (Fig. 5).

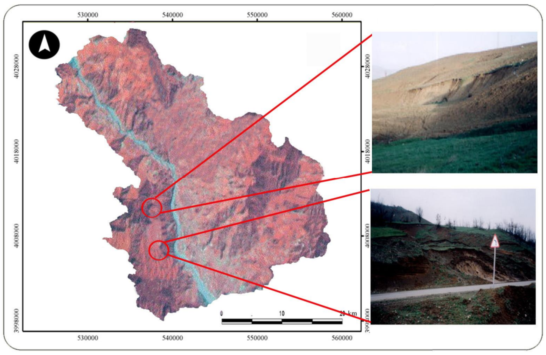

Fig. 5 SPOT satellite images at the central Zab basin landslide

4.1 Geology

Geological factor is considered as independent variable in landslide formation in that lithology and its varied structure tends to lead to a variation in stone stability and strength and also to a varied soil texture [17]. The layer was extracted from 1:100000 maps of the Iranian Geology Organization. It was quantified and then appended to the model since it proved to be statistically significant. It is important to note that the study area lacks lithographical consistence and uniformity, and lithological sequence and disruptions are clearly visible between different strata, which evidently suggest the role of dynamic tectonic forces. Most of slide events in the study area occurred in loose formations including fine-grained sediments in particular in alluvial terraces. Stones, homogenous phylite formations, marble, lime, green Andesite, dolomite and sandstone have the widest distribution in the region (Fig. 6).

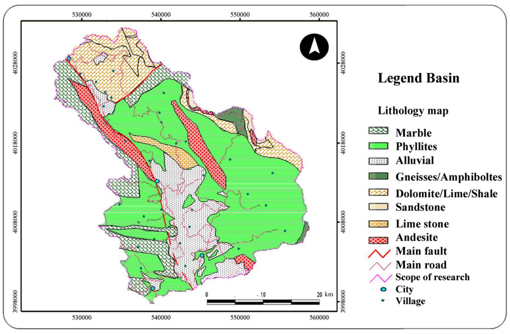

Fig. 6 Lithology map of study area

Proving statistically significant, the geological layer was classified in terms of stone stiffness (Table 1).

Table 1: Classification of geological strata

Lithology	***Value***
Sandstone, andesite	1
Lime (dolomite-orbitolina)	2
Lime and shale and sand	3
Phylite and gneiss	4
Shale	5
Alluvium	6

4.2 Elevation

While landslide occurs in a certain elevation accompanied with a certain gradient, the elevated height of a given region results in an increased gradient which in turn increases the shear forces in slopes. Further, the elevated height promote daily temperature variations which in turn, as a secondary factor, provide required debris for slide phenomenon through incurring weathering and Cryoclastie phenomenon. Thus, the hypsometric map or map of height variations is also regarded as an effective data layer in landslide analysis. The raster layer of Digital Elevation Model was prepared using 1:50000 maps of the Iranian Geology Organization and their interpolation (Fig. 7).

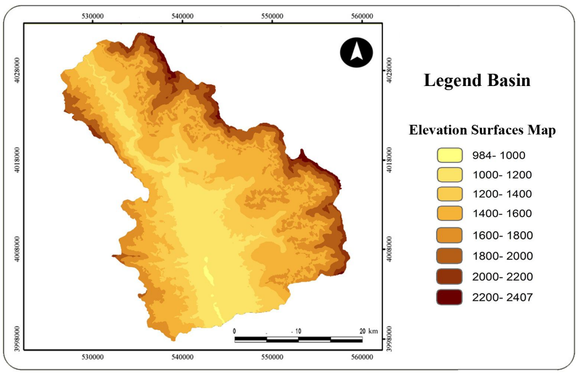

Fig. 7 Elevation surfaces map of study area

4.3 Distance to fault

Fault in itself does not act as a primary factor in landslide formation; higher distribution of faults, however, may contribute to a higher slope gradient which in turn results in increased gravity down the slope [13]. Several faults in the central Zab basin have created faces in different escarpments. As a consequence, discontinuities and interruptions are evident between different contexts (Fig 8).

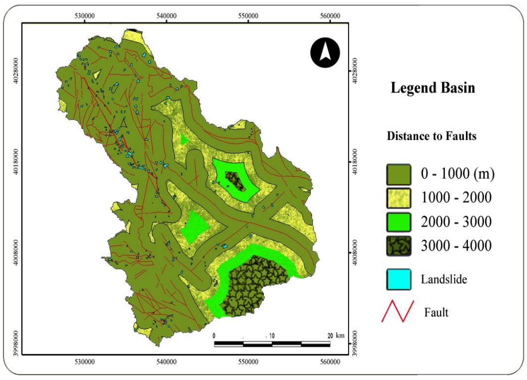

Fig. 8 Distance to fault lines map of study area

4.4 Slope

Slope is viewed as the major controlling factor in landslide formation. Critical slope intensifies the influence of the other factors. In a uniform slope, with homogenous lithological characteristics, increased slope has the major influence on creation of landslide [12]. While the maximum slope is not necessarily associated with maximum slide, there will be almost no chance of landslide without adequate slope angle. Accordingly, the slope map of the study area was prepared and this raster layer was directly incorporated into the model used in the study (Fig. 9).

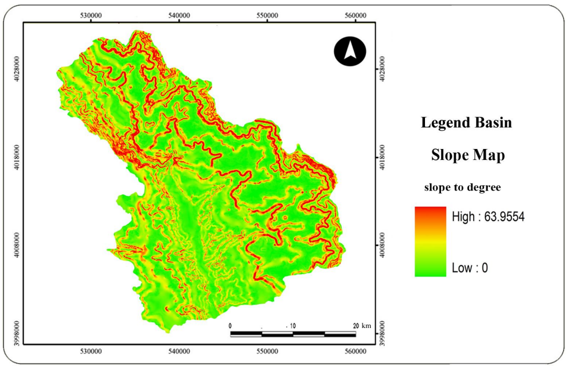

Fig. 9 Slope map of study area

4.5 Slope aspect

Slopes with a westerly aspect typically have excessive snow stability, and this is followed by increased moisture in such slopes. This justifies the selection of this important parameter as a determining factor in landslide formation. It is importance, however, does not match that of the slope gradient. In general, northern slopes are influential in creation of landslide due to snow durability and moisture, in particular during spring. Further, these slopes cause tectonic activities as a result of longer moisture durability during warm seasons, which is associated with creation of fine-grained deposits that have the highest susceptibility of landslide [22]. Given the importance of this factor, a map of slope aspect was also prepared for the study area, and was incorporated in regression model (Fig. 10).

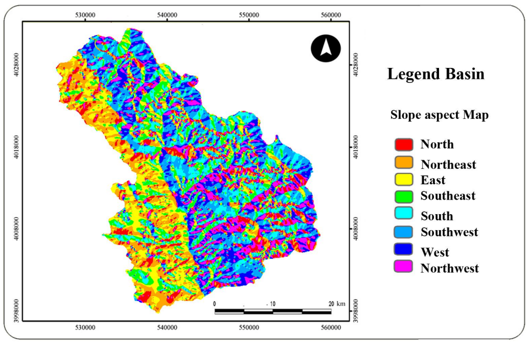

Fig. 10 Slope aspect map of study area

The layer proved qualitative; therefore, it was classified into three categories: northern; western and eastern; and southern, southwestern and southeastern (Table 2).

Table 2: Classification of slope aspects

Slope aspect	*Value*
N-NE-NW	3
E-W	2
S-SW-SE	1

4.6 Distance to road

Human usages and his activities have always played a decisive role in environmental changes. The site selection for these usages occasionally is such inappropriate that leads to disorganized and interrupted natural ecosystem. An instance of such inappropriate site selection concerns road construction in which any negligence during its prospective studies will amount to endangering human lives [6]. In sum, there is a significant correlation between the extent and frequency of landslide on one hand and distance to regional road system on the other. The parameter causes cuts in slopes and thereby destabilizing them (Fig. 11).

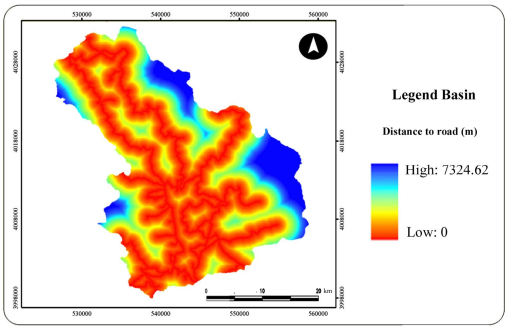

Fig. 11 Distance to road system map of study area

4.7 Density of drainage system

Drainage layer was selected so as to consider the roles of inappropriate drainage and undercutting of hydrographic system, simultaneously. Inappropriate drainage systems promote infiltration of water into slope. Higher number and density of drainage systems running on or along the base of slope will bring about more desirable situation for water infiltration [1]. Density of drainage system is among the controlling factors of landslide formation. In study area, localities with decreased slope gradients revealed increased density of watercourses. This has significantly affected creation of landslides. However, at the points with higher gradients, which are associated with stiffer formations and decreased deposition of fine-grained deposits, lower density of watercourses is recorded, which have been influential in undercutting, debris avalanches and rock falls. In flat areas such as plains, which include thick sedimentary strata, drainage density is lowered due to permeability of the ground and has resulted in heavier volume of fine-grained texture with heavy texture. However, the opposite scenario applies as well. In particular, occasionally points with higher density have provided desirable settings for even undercutting of the slopes. Density function of Arc GIS solution was used to measure the extent of drainage system. The function distributes the measured total length of watercourses in a given region thorough its area. The density and drainage density map of the study area were calculated and prepared as outlined above (Fig. 12).

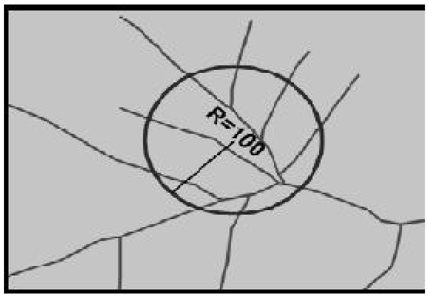

Fig. 12 Measuring the extent of drainage density based on determined radius over the basin

In this study, the assumed radius for in estimating the drainage system density was 100km. Very low density of hydrographic network in study area is indicative of intense infiltration of surface runoff into the textures of Zab basin, which provides desirable conditions for the phenomenon under consideration (Fig. 13).

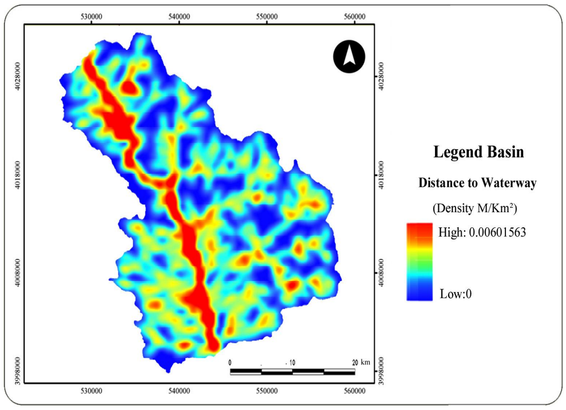

Fig. 13 Drainage density map prepared with 100km assumed radius over the basin

4.8 Precipitation

Precipitation, in particular sudden, intense rains, and snow melting is a controlling factor which trigger mass movements through providing water, increasing the underground hydrostatic level and pour water pressure. Of the factors leading to elevated pore water pressure in soils, in particular in fine-grained types which have lower permeability and are poorly drained, is sudden overloading of the soil which results in compacted soil. When the soil undergoes such pressure, waters within it will create a negative (upward) pressure as they cannot drain out quickly. When the pore pressure is equivalent to the upper pressure resulting from loading, the shearing resistance of the slope decreases and will lead to failure of the engaged mass. Since the study area is second only to the northern regions in Iranian territory in terms of precipitation rate, the regional precipitation distribution pattern was mapped and incorporated into the model (Fig. 14).

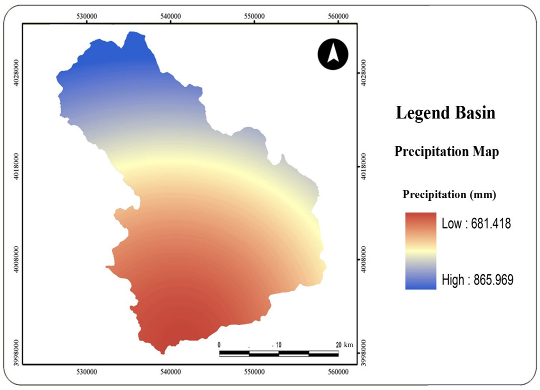

Fig. 14 Precipitation map of study area

4.9 Land use

Changes in ground surface has the potential to affect slope failure, given the presence of other relevant factors. The lack of appropriate coverage such as vegetation is influential in increased frequency of landslides. In addition, loading the slope, and in particular digging the base of slope and undercutting and injecting water into it are effective elements in landslide occurrence [19]. Land use map 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. Thus, plotting the slide layer against that of the land use reveals that the frequency and density of landslides in central portions of Zab basin is higher in arid landscapes (Fig. 15).

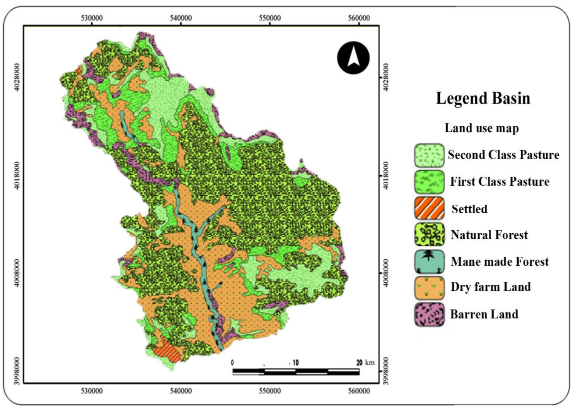

Fig. 15 Land use map of study area

This qualitative variable was also categorized by the relative importance of each usage (Table 3).

Table 3: Classification of land use with relative value of individual usages

Kind of land sue	*Natural forest*	*First-class pasture*	*Second-class pasture*	*Man-made forest*	*Dry farm land*	*Barren land*	*Settled*
Value	1	2	3	1	4	5	5

6. Discussion and conclusion

The spatial relationship between all landslides and each related factor were derived using the frequency ratio. The frequency ration 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. The frequency ratio method is very easy to apply, and results obtained by [26, 30, 29, 15] are very intelligible. The landslide susceptibility index (LSI), Eq. (2), was calculated by a summation of each factor ratio value [27]:

$$LSI = \sum Fr_a \qquad (2)$$

where Fr_a is the frequency ratio of each factor type or range. A Fr of 1means that the class has a density of landslides proportionally to the size of the class in the map. 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 (Fig. 16) was constructed using the LSI value for interpretation.

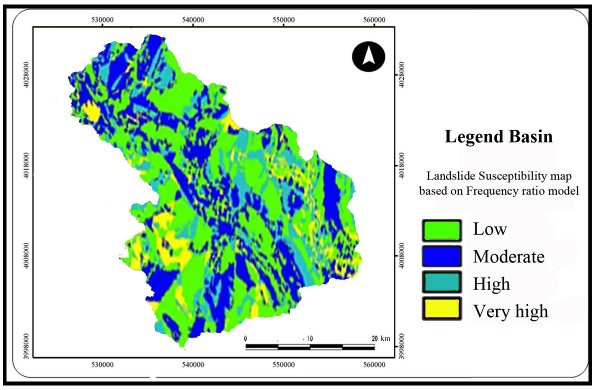

Fig. 16 Sensitivity map to landslide hazard of study area

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 [26]. 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. The landslides are the mostly spread in areas belonging to lower and moderate elevation classes. The 80% of landslides have occurred in 1000 – 1600 m elevation classes; have the highest frequency ratio value.

As a general aspect, shear stresses on the slope material increase with increasing of slope degree and it is expected that landslides will occur in the steepest slopes. On the other hand very low shear stresses are expected at gentle slopes. Slope angle is a most important factor contributing to slope instability. It is noticed that most of the landslides have occurred on slope of 20°-30°. Steep slopes are made of resistant hard rock and are stable and generally have less significant anthropogenic activities remaining relatively without interruption. The slope aspect play a major role in combination of slope gradient. The aspect of the slope can control landslide initiation. It can be seen that landslide mostly falls on facing N, NW, S, SW slopes.

The Sarasht-Piranshahr main road also has a strong relationship with landslide occurrence based on this study which can be because of disruption of natural profile, cut slope creations through road construction activities and the loads imposed by construction materials. Tension cracks may be created as a result of an increase in stress on the back of the slope because of changes in topography and the decrease of load [3]. The closer distance to the road 0 to 20m, the greater landslide probability has occurred. This is due to anthropogenic activities. Proximity to Drainage is one of the important factor for causing landslides. The 48% of landslide falls in the first, second and third order streams. Abundant landslides are observed in the drainage distance of 0-200m

and 2000-400m. Land use plays a most important role in causing landslides.

Dry farm land and mane made forest are much prone to slides due to very closely related to anthropogenic activities of intense agricultural plantation; increase the construction activities for built up land. Geology is a major controlling factor for landslide. The geology of the area, results of frequency ratio, it can be seen that highest in Alluvial and Marble classes. This class mainly including discontinuities of rock dipping outward the slope direction and easily weathered materials, these are the main reason for 79% of landslides have occurred in this class. The Rainfall is a triggering factor to causing landslides. It can be noticed that 61% of landslides occurs in the 800-900 class.

Distance to fault is another factor in generate slope instability. Although distance to the fault isn't as distance to the road from space effect for landslide occurs. About half of the landslides have occurred in Class 0-1000 m. Then can be found seismic and intense of active fault or lineament of inactive or dormant fault affected on occur of landslides. The results of the Susceptibility map have been validated with the landslide incidences located from the field studies. The distribution of the landslide density among different susceptibility levels is coherent. The results are showing that zonation accuracy by using of Frequency ration method is very important in because of attend to membership value of per operative in final zonation landslide in done disasters of landslide predict. So, proximity 51.37% of area lands is low hazard class, 29.35% it is moderate hazard class, 11.10% it is high hazard class and 8.18% it is very high hazard class.

5. Validation of susceptibility map

Susceptibility maps were validated by means of land- slide affected area corresponding to susceptibility classes.

Landslide susceptibility map generated in this study exploit the relative landslide density method (R-index) to assess the relationship between the landslide susceptibility map and landslide inventory points. The sample data were collected by field work and GPS. The number of landslide which is detected in filed observes were 29 landslides consequence heavy rain falls. Kinds of landslides from size occurred throughout the region. Frequency ratio model was evaluated. Although in the map of diagnostic analysis only a class of high hazard is fewer consistent, other classes are match with distribute of landslide occurred. Validation of susceptibility maps performed with a formula that defined as follows (Equation 2):

$$R = (ni / Ni) / \sum(ni / Ni)) \times 100$$
(2)

Where ni the number of landslides occurred in the sensitivity class i and Ni the number of pixel in the same sensitivity class i. The R-index sample data set in Low hazard class is 36%, Moderate hazard class is 62%, High hazard class is 129% and very-high hazard class is 171% in frequency ratio model (Table 4).

Table 4: Validation(R-index) of Frequency ratio model

Validation methods	*Sensitive class*	*Number of pixel*	*Area per cent*	*Number of landslide*	*Landslide percent*	*R-index*
Frequency ratio	Low hazard	126010	9.9	1	3.4	36
	Moderate hazard	506184	39.9	7	24.1	62.8
	High hazard	316945	25	9	31	129.1
	Very high hazard	318821	25.1	12	41.4	171.1

Unlikely, from assess of all classes view, weight of evidence is more exactly than other two classes (Fig. 17).

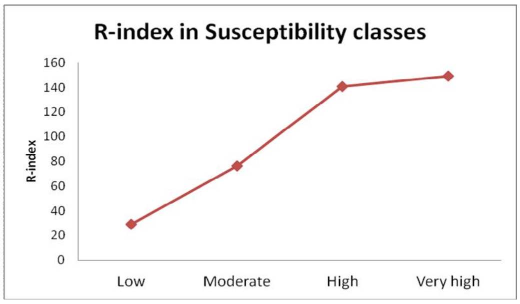

Fig. 17 R-index validation of Frequency ratio model for susceptibility mapping in the study area

As quoted from [27] landslide susceptibility maps are of great help to planners and engineers for choosing suitable locations to implement developments. These results can be used as basic data to assist slope management and landuse planning, but the methods used are valid for generalized planning and assessment pur- poses, although they may be less useful at the site specific scale where the local geological and geographic hetero- geneities may prevail.

Acknowledgements

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