APPLICATION OF SATELLITE IMAGES AND COMPARATIVE STUDY OF ANALYTICAL HIERARCHY PROCESS AND FREQUENCY RATIO METHODS TO LANDSLIDE SUSCEPTIBILITY MAPPING IN CENTRAL ZAB BASIN, NW IRAN

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ABSTRACT

Preparation of landslide susceptibility mapping is one of the most important stages in landslide hazard mitigation. This study considers landslide susceptibility mapping in central Zab basin in west Azerbaijan province, Iran. Seven factors were used for landslide vulnerability analysis include: slope, aspect, distance to road, distance to drainage, distance to road, land use and land cover, and geological factors. This study demonstrates the synergistic use of medium resolution of SPOT-5 Satellite, for prepare of landslide-inventory map and Landsat ETM$^+$ satellite for prepare of Land use map. After preparation of the needed information layers by influential parameters on landslides, we drew the zoning maps of slide hazard using the following two methods analytical hierarchy process (AHP) and frequency ratio (FR) incorporating and evaluate their performance. The landslide susceptibility map was classified into four classes: low, moderate, high and very high. The models are validated using the relative landslide density index (R-index method) that results shows that more than 80 percent of landslides have happened in two classes, high hazard and very high hazard and showed that the frequency ratio model is better in prediction than the AHP model in study area.

KEYWORDS: Susceptibility mapping, Satellite Images, analytical hierarchy process (AHP), Frequency ratio model (FR), Zab basin.

I. 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. 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 [21]. During the past few years, quantitative methods have been implemented for landslide susceptibility zonation studies in different regions [13, 2]. More sophisticated assessments involved, for example, AHP and FR [23, 30]. 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 AHP and FR models until by identification this region, performance measures for control rationale in the region and prevent of capital and energy waste [7, 5].

The aim of this study was to use widely-accepted models, a statistical methods include analytical hierarchy process (AHP) and frequency ratio (FR) their performances and comprehensive validation of landslide susceptibility mapping prepared through two different methods, analysis approach and landslide causative factor databases developed using Satellite images with the aid of GIS in Zab basin, while limiting the collection of landslide and thematic data. For the Zab Basin. Landslide vulnerability map was validated using R-Index.

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 [10, 25]. 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 [1, 14].

II.   GEOGRAPHICAL LOCATION OF STUDY AREA

The study area is located in the southwest mountainous area of West-Azerbaijan province along the Zab river basin in Sardasht 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 (Fig. 1). Central part of the Zab river basin stretching 30 km from north - to south and east – to west respectively, about 520 square kilometers (Figure 1). This basin is one of the residential most populated areas in the region which include one city, three townships, and more than eighty villages. This zone is quite susceptible to landslide due to its climatic conditions, geology, geomorphologic characteristics and human activities. It is one of the settled geographical basins including a city, three towns or small cities, and over 80 villages [26]. 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 [18].
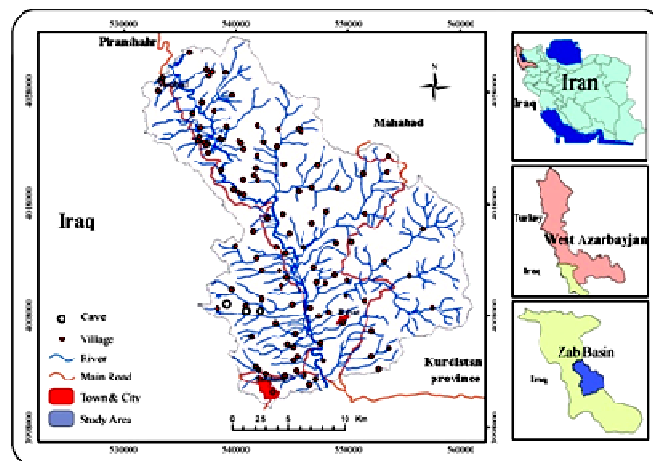

Figure1. Geographical position of study area (Source: Author generated).

III.   MATERIAL AND METHODS

The data entry and production were the most cumbersome and time-consuming steps of this study. First of all, a digital elevation model (DEM) of the study area was generated from a triangulated irregular network (TIN) model that was derived from digitized contours of four 1:50,000 scale topographical maps with a contour interval of 25 m. The slope, slope aspect parameters were obtained from the generated DEM.

The critical point was the selection of appropriate pixel size for positional accuracy and precision of susceptibility levels in the resultant map. The positional accuracy needed for 1:50000 scale maps must be 150 m. For this reason, a pixel size of 50 m was selected for our DEM. Fault lines were derived

from 1:100000 scale geology maps and the aerial orthogonal distance of all pixels to fault lines calculated. A similar process was carried out for road lines, and drainage networks. In addition, the kilometer square density of drainage networks, road and fault lines were also used to demonstrate the importance of the features in the whole study area.

The properties of the landslides were recorded on a standard landslide inventory data sheet, but the main purpose herein was to map only the boundaries of the landslides. A digitized map of landslide boundaries was produced, and these digitized maps were input into GIS. A vector-to-raster conversion was performed to provide a raster data of the landslide areas.

Waterways of zab basin were digitized and all the needed operations for using this information in Ilwis environment were carried out. The rasterized pixel size is considered to be 25×25 square meter. We drew the annual co-rainfall curves in Zab river basin by using 30 year statistics of the stations in the studied region, Interpolation technique and Krigging in GIS environment.

Another dataset used was land cover, 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. The accuracy of the land cover interpretation was checked by in the field work. After geo-referencing the resultant image, a combination of bands 1, 4 and 7 was used to make complex color pictures, and operational information layer created by the method of Categorization of Utmost Probability (Figure 2).
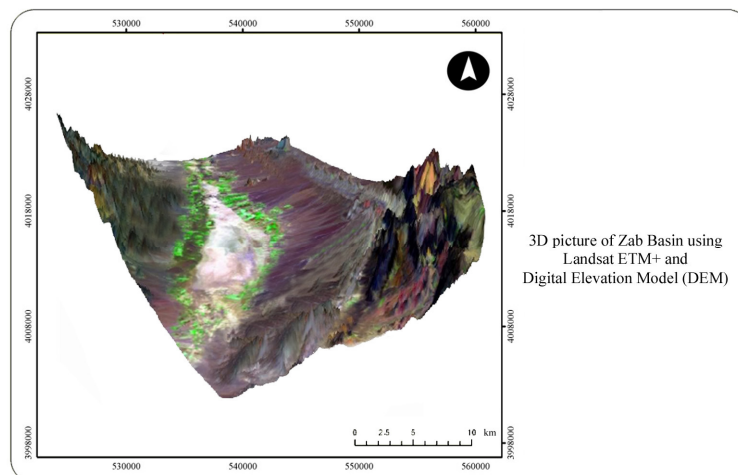

Figure 2. 3D image picture of Zab Basin, extracted using Landsat ETM + satellite photos and the relevant Digital Elevation Model (Source: Author generated).

After preparation of the needed information layers by influential parameters on landslides, we drew the zoning maps of slide hazard using the following two methods analytical hierarchy process (AHP) and frequency ratio (FR) incorporating and evaluate their performance.

3.1. Analytical hierarchy process (AHP)

The application of the AHP method, developed by Saaty (1977), for landslide susceptibility has been shown before [20, 29] and it was used to define the factors that govern landslide occurrence more transparently and to derive their weights. Where AHP was used, the CR (Consistency Ratio) was calculated. The models with the CR greater than 0.1 were automatically rejected. With the AHP method, the values of spatial factors weights were defined. Using a weighted linear sum procedure [16] the acquired weights were used to calculate the landslide susceptibility models.

Multiple criteria analysis (MCA) techniques are effective tools to survey complex phenomenon and extols programming. Combination of the two techniques, MCA (Multiple Criteria Analysis) and GIS, makes a technique referred to as spatial decision support system (SDSS). It is used generally to investigate location problems [12]. In Analytical hierarchy process (AHP) all criteria and factors are doubled up and are compared and result are registered in a weighting index matrix. There is nine

scales ranging from 1 to 9 that gradually show priority factors. One means equal values while 9 means the maximum priority (Table 1).

Table 1. Pair-wise comparison 9-point rating scale

Importance	Definition	Explanation
1	Equal importance	Contribution to objective is equal
3	Moderate importance	Attribute is slightly favored over another
5	Strong importance	Attribute is strongly favored over another
7	Very strong importance	Attribute is very strongly favored over another
9	Extreme importance	Evidence favoring one attribute is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

This study will make use of the AHP method because of its precision, ease of use, and because of its ready availability as a built-in tool within Expert Choice software. Factor weights for each criterion are determined by a pair-wise comparison matrix as described by Saaty (1990, 1994) and Saaty and Vargas (2001) [27]. The method employs an underlying 9-point recording scale to rate the relative preference on a one-to-one basis of each criteria [22].

In most susceptibility assessments, however, the state of knowledge about all event-controlling parameters is simply imperfect anyway. The numerical values are quantified translations useful for calculating factor weights and the validity of the numerical values may best be judged by the factor weights and the consistency of the calculation process [19]. Pair-wise comparison, however, is subjective and the quality of the results is highly dependent on the expert's judgment. In AHP, an index of consistency, known as the consistency ratio (CR) Eq. (1), is used to indicate the probability that the matrix judgments were randomly generated [28].

$$CR = CI = RI \tag{1}$$

where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty (1977) and CI is the consistency index and can be expressed as Eq. (2)

$$CI = \acute{\circ}(\lambda max - n) / (n-1) \tag{2}$$

where λmax is the largest or principal eigen value of the matrix and can be easily calculated from the matrix, and n is the order of the matrix.

For all the models, where the AHP was used, the CR (Consistency Ratio) was calculated. If the CR values were greater than 0.1, the models were automatically discarded. Using a weighted linear sum procedure [17] the acquired weights were used to calculate the landslide susceptibility models [3].

3.2. Frequency ratio method (FR)

When evaluating the probability of land sliding 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. 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. In order to prepare the landslide Susceptibility map quantitatively, the frequency ratio method was implemented using GIS techniques [9].

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 [17, 24] are very intelligible. The landslide susceptibility index (LSI), Eq. (3), was calculated by a summation of each factor ratio value:

$$LSI = \sum Fr_a \tag{3}$$

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.

IV. 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 [11]. The waveband combination (G_{dif}, R_{dif}, NIR_{dif}) for the differentiated image can be expressed as (Eq. (4)):

$$(G_{dif}, F_{dif}, NIR_{dif}) = (G_2-G_1, R_2-R_1, NIR_2-NIR_1) \qquad (4)$$

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 (Figure 3).
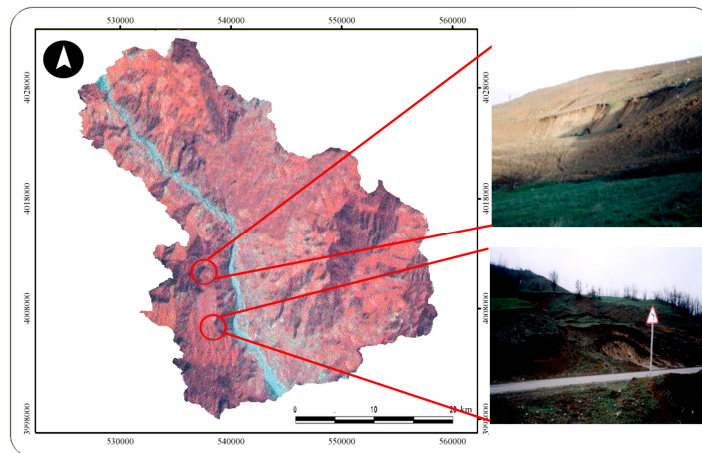

Figure 3. SPOT satellite images at the central Zab basin landslide (Source: Author generated).

4.1. Landslide susceptibility analyses using Analytical hierarchy process

In consistency matrix main diameter value is 1 and the elements of lower triangle are inverted at higher triangle elements. (aji = 1/aij). aji is the ratio of (A priority to B priority) [6]. The results of the pair-wise comparison matrix and the factor weights are shown in Table 2. The CR in our study is 0.05.

Table 2. Pair-wise comparison matrix and factor weights of the data layers

Factors	Slope	Geology	Land use	Distance to fault	Distance to drainage	Aspect	Distance to road	Weights

Slope	1	1/3	1	1	3	4	7	0.1706
Geology	3	1	2	3	4	5	7	0.3334
Land use	1	1/2	1	2	3	4	6	0.1951
Distance to fault	1	1/3	1/2	1	3	4	5	0.1497
Distance to drainage	1/3	1/4	1/4	1/3	1	2	4	0.4341
Aspect	1/4	1/5	1/4	1/4	1/2	1	3	0.2938
Distance to road	1/7	1/7	1/6	1/5	1/4	1/3	1	0.1589

After weighting each factor one has to multiply the resulting weights by each layer value. Using this equation, the final was determined [4]. As a result of the AHP analyses, the landslide susceptibility map was produced for central Zab basin (Figure 4)
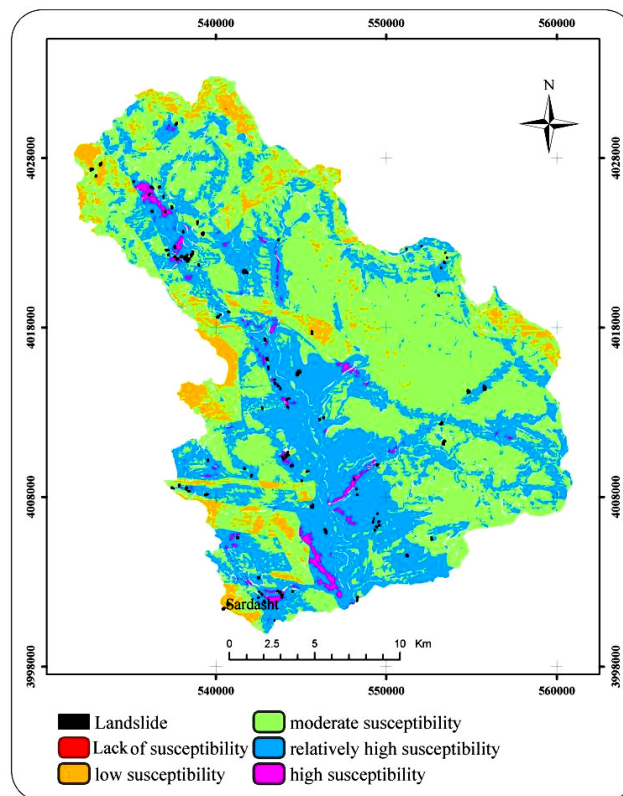

Figure 4. The landslide susceptibility map produced by AHP (Source: Author generated).

4.2. 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 [16]. 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 5) was constructed using the LSI value for interpretation.
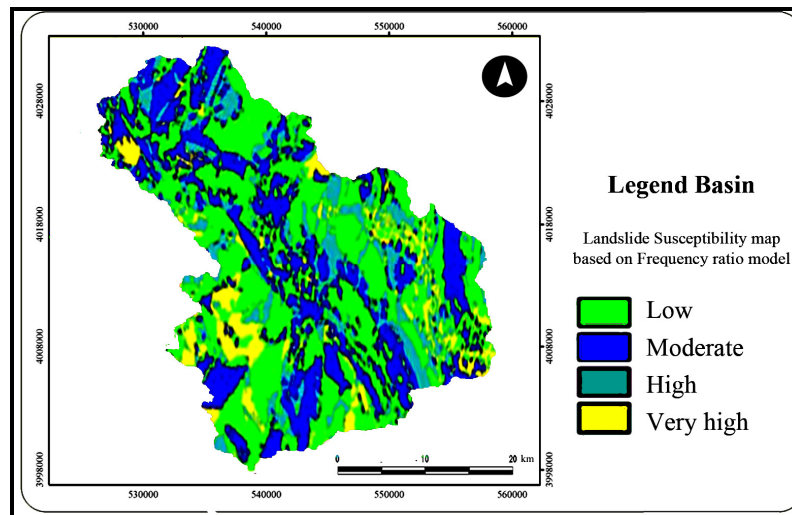
Figure 5. The landslide susceptibility map produced by FR (Source: Author generated).

4.3. Validation of susceptibility map

Susceptibility maps were validated by means of landslide 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. Analytical hierarchy process and frequency ratio model were evaluated. Although in the map of diagnostic analysis only a class of low 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 (Eq. 5):

$$R = (ni / Ni) / \sum (ni / Ni)) \times 100 \tag{5}$$

Where ni the number of landslides occurred in the sensitivity class i and Ni the number of pixel in the same sensitivity class i. from the classes with high and very-high hazard, frequency ratio method works better than Analytical hierarchy process method. The R-index sample data set in Very high hazard class for Analytical hierarchy process method is 139% but for frequency ratio method is 171% (Table 3).

Table 3. Validation (R-index) of Analytical hierarchy process and Frequency ratio

Validation methods	Sensitive class	Number of pixel	Area per cent	Number of landslide	Landslide percent	R-index
Analytical hierarchy process	Low hazard	125533	14.7	3	7.4	28.1
	Moderate hazard	227596	22.4	5	22.9	62.7
	High hazard	314671	30.1	9	27.1	128.4
	Very high hazard	248652	32.6	12	44.6	139.5
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

Finally, from assess of all classes view, frequency ratio is more exactly than other three classes in the Analytical hierarchy process method (Figure 6).
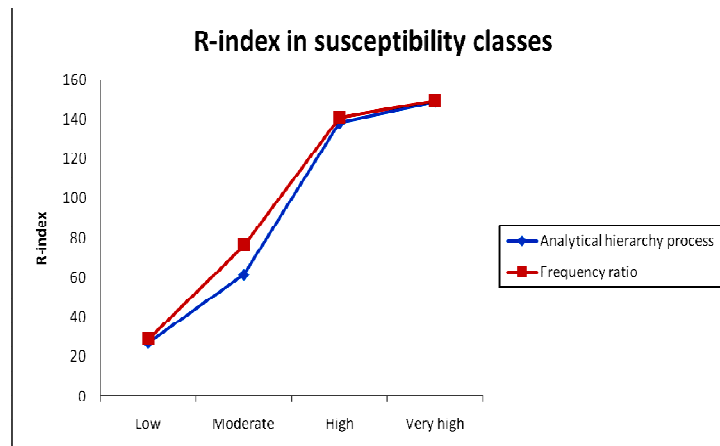
Figure 6. R-index validation of Analytical hierarchy process and Frequency ratio methods for susceptibility mapping in the study area (Source: Author generated).

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.

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 plays 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 [30]. The closer distance to the road 0 to 20 m, the greater landslide probability has occurred. Distance 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.

V. CONCLUSION

The distribution of the landslide density among different susceptibility levels is coherent. The results are showing that zonation accuracy by using of analytical hierarchy process and frequency ration methods are very important in because of attend to membership value of per operative in final zonation landslide in done disasters of landslide predict. Therefore, the study area is sensitive to

landslide. More than 90 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 analytical hierarchy process method. As quoted from 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 land use planning, but the methods used are valid for generalized planning and assessment purposes, although they may be less useful at the site specific scale where the local geological and geographic heterogeneities may prevail.

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