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The Generation of Landslide Susceptibility Map Using Physical (Experimental)Method : A Case Study In Cheshme Kabud District, Iran

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Abstract

Landslide is a natural hazard and complicate phenomena that can cause damages to human and their properties in the world every year. Most of the landslide occurrences in Iran are shallow type. They occurred mostly in the North and West parts of Iran. Cheshme Kabud is a rural district that is located in the west of Iran has many landslides the consequence of the inherent and triggered parameters. The method used for landslide susceptibility in this research is physical (experimental) method. It is based on slope adjustment, that consider slope as the moderator factor. First, all classes of 9 parameters including aspect, soil, vegetation, land use, erosion, lithology, distance to road, distance to fault and distance to river are weighted and then, these weights are converted by with reference to the effect of slope classes. The final classes of the weighting generate landslide susceptibility map. The model is validated by using receiver operating characteristic (ROC) technique. The result shows the accuracy of the model is about 85%. It can be concluded that vulnerability surface that is determined by the model for landslide occurrence, is highly accurate.

Keywords: Landslide, Physical (Experimental), Susceptibility, Cheshme Kabud, Validation

1. Introduction

Landslide is the worlds' third largest natural disaster that causes many damages [36]. In the world scale, landslides cause billions of dollars in loss and thousands of deaths and injuries each year. Some countries suffer the most damage; they lose about 0.5% of the gross national product per annum due to landslides [4]. The single slope slide is generally not as remarkable or costly as other natural hazard like earthquakes, main floods, storms et cetera. However, they are extremely widespread, and over the years may cause more things loss than any other natural hazards. Besides, much of the destruction and sometimes a considerable proportion of the loss of life occurring with earthquakes and extreme storms are due to landslides [34].

In Jun 1990, earthquake is occurred in the north of Iran, and it took about 37000 lives, and so many people die in the landslide triggered by earthquake from Rudbar area that located in Gilan province. Even a village (Fatalak) were buried under thousands of ton soil, and all people live in this village were dead. Iran topography is mostly mountainous. Tectonic activity, high seismic, sensitive geology and climatic conditions are extremely susceptible for landslide occurrence. In most part of Iran, landslide is the common disaster. Based on preliminary study government estimated (2005) financial loss due to landslide is about $ 126 billion. This is an addition to loss of life, and injury occurred. The estimated numbers of landslides that occurred in Iran are about 32000 (government report, 2012).

Most of the landslides occurrences in Iran are of the shallow type (see Figure.1). Tectonics' landslides can also be seen in the zone of geology, which matches fault lineation. Close to the study area, (about 50 km distance) in the mid of April 2002, earthquake (5.2 MW) has triggered some landslides and rock falls which destroyed rural buildings, agriculture land and grassland. Nevertheless, in the study area, there is no landslide that occurred due to direct consequence effect of this earthquake. All of the landslides that they were investigated are shallow landslides with soil material. Thus, flow, topple and other types of mass movement are not study in this research.

"Cheshmeh Kabud" district is located on the west of Iran, which is part of Kermanshah province with 120-km2 area (see Figure.1). Cheshmeh Kabud rural district, because of its tribal structure and excessive pasturing land and stratum sensitive geology is extremely vulnerable to landslide (see Figure.2). It has an elevation average of 1500 m above sea level. The instability that cause landslides have damage road and natural resources (see Figure.1). Destroying jungles by human activity means preparing the area to landslide occurrence. (see Figure.3). Many villages and farms are located on unstable terrain, then identifying landslides would assist the government effort for moving some population from the hazard region. Figure 4, 5 shows effect of landslide on rural settlement.

Figure 1 here

Figure 2 here

Figure 3 here

Figure 4 here

Figure 5 here

Landslides need to be controlled and managed therefore, require proper plan. Landslide identification is the first step in landslide management. The detection of landslide is require knowledge about current and future occurrence. Landslide inventory records landslide occurrence which can be determined using many methods. In fact, date of the actual landslides that have occurred is difficult to determine. If the landslide is new, we can estimate about the date of occurrence, but difficult to determine time. Therefore, in general landslide's inventories map record the entire only type, new or old and size of landslide. Future prediction of landslide uses different names such as evaluation, assessment, zonation, sensitivity, vulnerability, susceptibility. There are various methods were used by different authors with the objective to predict or estimate location of landslide that would occur [30, 23,7,26, 11,16, 2, 15,1, 24,10, 32,25,19, 35,5, 3, 17].

Landslide susceptibility is usually can be divided into two categories: qualitative and quantitative or direct and indirect methods. Qualitative methods are subjective, and they portray the hazard levels in descriptive terms. Geomorphologic mapping is an example of a qualitative and direct method. Quantitative methods produce numerical estimates (probabilities) of the occurrence of landslide phenomena in any hazard zone. Direct landslide susceptibility mapping involves mapping landslides within a given region by means of field studies, aerial photography interpretation or other methods [31].

In this research, the landslide susceptibility map is generated by using a new algorithm, based on local condition. The first step involve with preparing a large scale landslide inventory map through very high resolution images and fieldwork, GPS, Aerial photograph (1:20,000 scale) with geomorphologic method (semi-automatic and automatic methods). The use of physical (experimental) method can help to assess for local environment compatibility, and to selected landslide susceptibility parameters. Figure. 1 shows the study area and satellite image.

In this study, methods and devices for mapping single landslides, or clusters of slope failures are not considered since the priority is on regional scale. Generally for single slope study always involve with monitoring or geotechnical survey. The methods and techniques used in this research is for mapping the surface characteristics of shallow landslides (soil slide). Other slides and topples include mud and rock fall and flow do not considered in this study.

2. Data and Methodology

This research utilized satellite images (Ikonos, Geoeye, Aster, IRS and Landsat) and maps (Soil, Lithology, Geology, Topography, Erosion and DEM). These data were acquired directly from government agencies and Geoeye company. North part of the study area (15 percent) was not covered with high-resolution satellite images (Ikonos, Geoeye); therefore, to detect landslide the area was investigated by aerial photograph (1:20000). In addition ,aerial photograph there are DEM (10 m) and IRS Cartosat-1(2.5 m) image which help to identify 15 percent of the area, this is located outside the study area. All the data mentioned above that involve images and maps are secondary (ancillary) data, which were acquired from government agencies.

Ikono's image (Multispectral bands 4 m and Pan band 0.8 m) was captured in the year 2000. Figure 1 shows Ikonos image which was acquired from Geoeye company because of the foundation. Most of this image does not need atmospheric correction but some parts of it (north and central parts) required the correction, which was carried out using Erdas software. Only north and west parts of the study area, are in the Ikonos images, while other part of the image, shows another rural district of Harsin county. Thus, this part was used for validation process through validation area technique. The year 2000 image requires control from fieldwork for updating landslide inventory map. Since, this part of the area is not hummocky and mountainous; therefore, fieldwork for ground control was easy to undertake.

Geoeye image of year 2009 (Multispectral 1.6 m and Pan 0.5 m) covers the central and south parts of the area, whilst, it covers most of the research area. This image is a very high-resolution image that allows researchers to investigate all aspect of a phenomenon ,factors and environments influence on it. Thus, researchers are able to investigate landslide ,condition and indication of parameters that lead to slope failure (geomorphology or indirect method). Some landslides, especially old landslides, were detected by this method by interpreter the image of the study area. Geomorphology indication in the image (stream shift, crack on the surface of the slope, spoon-shaped hollow with the accumulation of material at the toe, discontinuity along a layer, creation of the lake in mountainous area and etc.) is a good technique for identifying old and trees covered landslide (dormant) in the field and on the very high- resolution image. The number of landslides could be recognized in the Geoeye image directly while other landslides from the fieldwork. Geomorphology phenomena that appears on Geoeye image has a correlation to landslide occurrence (indirect method).

Remote sensing software (e.g. Erdas and Envi) and GIS software (ArcGIS) were used for interpretation and analysis of the images, and to produce maps. In addition, weighting of factors and factors classes are determined by two methods, manually (Thomas L. Saaty method) and software based (Expert Choice: see Figures 6 and 7). Therefore, quality factors and their classes (expert judge) are converted to quantity value.

Figure 6 ,7 here

Lithology map with a scale of 100,000 was prepared from government geology map (See Figure 8). This map was divided into three classes or types of rocks. The accuracy is suppose to be adequate to help for landslide susceptibility calculation. Geology map has symbols for formation and tectonic.

Lineament and fault lines are displayed by the indicators. Thus, map of fault can be extracted from geology map for evaluation of distance effect of the fault on landslide occurrence.

Figure 8 here

Area is divided into three classes by researchers who produced erosion map of the area. Landsat images soil map and fieldwork data were devices for determination of the erosion in the study area. Classes of erosion map include low, moderate and high erosion. South of the study area has high erosion, and with regard to landslide inventory this area has shown numerous landslides, particularly shallow landslides. Soil map have four classes, and most of landslides occurred in the classes of regosols (young soil). Fieldwork, sampling of soil, aerial photo and Landsat images were used to provide database by researchers who generate soil map in the study area (see Figure 9).

Figure 9 here

River and road are two parameters that have high influent on landslide, with regard to distance to these parameters. Since landslides are shallow, then river and road cut lower part of the slopes; therefore resistance power has been reduced which triggered slope to fall. River and road map were extracted from topography maps (1:25,000 scale). Figure 10.

Figure.10 here

Land use map has been generated from Landsat (ETM+) images, and it was divided into three classes of farming, range and combination of farming and garden. The study area is rural area; therefore, there is no variety of use of land. Vegetation is important index for all zonation and susceptibility landslide mapping. This map was extracted from ETM+ images, which were exploited to determine the number of vegetation types in Kermanshah province where Cheshme Kabud rural district is part of it. The area research was divided into 7 classes, which are mountainous, hummocky and plateau type of vegetation. The base of this project are vegetation map and the ETM+ images with sampling from fieldwork.

Digital elevation model (DEM) was extracted from topography map (1:25,000 scale) with 10 meters pixel size. Figure 1 shows most of the landslides were distributed in the study area . The average size of the landslides are 1000 m2. Therefore, pixel size of DEM is adequate for analysis of landslide detection (see Figure 11).

Figure.11 here

2.1. Physical (experimental) method

Physical method applied an algorithm which is based on new combination of factors influencing on landslide occurrence. The principle of this method is by considering slope as a mediator where slope classes will adjust moderator variable that effect the other parameters (weight), before they are used in the final analysis . Figure 12 shows how slope's classes are as moderate classes for other factors after they are weighted by Expert Choice software.

Figure .12 here

First, the slope classes (five) were normalized by expert judgment from 0 to 1 point (See Table 1). Second, 8 factors and their classes were given point from 1 to 100 points. Third, each classes were overlaid or combined with slope classes, and then every factor classes were converted to final point. At the end, the total points of the factors classes will be counted in each of slope class. This slope classes represent the sensitivity of the surface in the study area (see Table 1).

Table.1 here

For weighting the parameters (before being applied entered to slope adjustment) Thomas Saaty method (1977) that is an analytic hierarchy process (AHP) method is used. This method determine incompatible between parameters, and then assess several coefficient to evaluate the significance and rank of parameters in the landslide occurrence .

Furthermore, factors are calculated and weighted by Expert Choice software. It is to assign ranks to the factors and alternatives by expert's opinion. A pair-wise comparison method/matrix is carried out to get relative weights from expert's opinion. Then, gathered weights were computed in the multi-criteria evaluation process tool using Expert Choice software (ECS) keeping view consistency ratio (CR). If CR is satisfactory, the computed weights will be recorded for further processing. Finally, sensitivity analysis can be conducted in ECS that validates the decision making weights because of uncertainties in decision weighting [28]. This analysis and weighting for factors is similar to Saaty manual method. Then, the best output weighting is selected between two methods by expert judgment. Factors that are entered into two systems include vegetation, soil, aspect, landuse, distance to road, distance to fault, distance to river, erosion and lithology. (see Figures 13).

Figure. 13 here

2.2. Validation

The validation of the predicted data is one of the most important parts of a probability-based map production process. In landslide susceptibility literature, although several methods are available for this, the area under the curve obtained from the ROC (receiver operating characteristics) plot is the most preferred and applicable type of statistical assessment. The ROC curve is a graphical representation of the trade-off between false negative and false positive rates for every possible cut-off, i.e., the trade-off between sensitivity and specificity. By tradition, the plot shows the false positive rate, or specificity, on the X axis and 1 minus the false negative rate, or sensitivity, on the Y axis. Table 2. shows the calculation methods for sensitivity, specificity, correct percentage, and hit ratio for each cut-off value. The detail information are shown in Table 2 and Equations 1 to 4.

$$\text{Sensitivity} = TPF\ (\text{True Positive Fraction}) = \frac{TP}{TP + FN} \qquad \text{(Eq 1)}$$

$$\text{Specificity} = 1 - FPF\ (\text{False Positive Fraction}) = 1 - \frac{FP}{FP + TN} \qquad \text{(Eq 2)}$$

$$\textit{Correct Percentage} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{FN} + \text{FP} + \text{TN}} \times 100\ \% \qquad \text{(Eq 3)}$$

$$HitRatio = \frac{TP}{TP + FN} \times 100\ \% \qquad \text{(Eq 4)}$$

TP= true positive

FN= false negative

FP= false positive

TN= true negative

Table.2 here

An ideal model presents an AUC value close to 0.1 where as a value close to 0.5indicates inaccuracy in the model [11]. The score value of each pixel, calculated by the physical (experimental) models and analyzed by the ROC curve method to select the best-fitting model for predicting the potential distribution of shallow landslides.

3. Result and discussion

Recently, most of methods used for landslide susceptibility, are statistical and data mining (neural network) [6, 27, 21,35, 28, 8, 9, 23, 29, 18, 20,33, 14, 37, 22, 13, 12]. These methods are not depending on subjectivity of experts, and they can assess variables independently; therefore, they do not have limitations as physical methods. Although they are general models in world scale, and are used in all environments and conditions. Thus, their results can be affected by different conditions because it is right when we are using general models and techniques. In fact, local factors are varying and different; therefore, constants and correlations cannot show the relationship between the independents and the dependent's variables.

In this study slope is considered as moderate variable (see Figure 14), and it is an important role for adjustment of the other factors. In fact, slope in all environments and condition is unique factor for landslide occurring, for example a shallow landslide (except flow, solifluction, creep and rockfall) cannot occur in slope below 5 degree, even if all conditions are available such as sensitive lithology, soil wetness, high precipitation, lack of vegetation, changing landuse and earthquake triggering. Where gravity is weak (slope under 5 degree) soil and debris cannot fall, and then a landslide will not occur.

Landslide susceptibility map is generated by experimental method that consider a accurate highly map because it is produced by primary weight (expert opinion), and then it moderate by slope classes (see figure 15). Receiver Operating Characteristic (ROC) is used for Validating of method that showed area under curve is about 85%. Thus, it can be stated, susceptibility of landslide in the model is acceptably accurate (see Figures.15, 16). Landslides and their conditions are considered in this study like geomorphologic environment. Parameters is selected with regard to model and data availability. Weight of slope classes is determined by Expert Choice software; therefore, it is less error compare to manually calculated. Then , All factor classes adjusted with slope classes and final map was generated. Validation of method is performed by Receiver Operating Characteristic (ROC) curve and result shows area under the curve is about 85%, consequently, landslide susceptibility is acceptably accurate.

Figure .14, 15 and 16 here

4. Conclusion

The aim of this study was to evaluate landslide susceptibility with experimental method. The main conclusion to be drawn from this study was experimental method is acceptable way to assess landslide sensitivity. The most obvious finding to emerge from this study was that slope factor as moderator can be adjusted other influencing factor to assess more accurate landslide susceptibility. It was also shown that some part of the area is stable for landslide occurrence; therefore, they are not requiring any project to prevent of landslide damage in future. Although, further investigation and experimentation into experimental method integrated statistical and data mining is strongly recommended for future study.

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5. References

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Caption

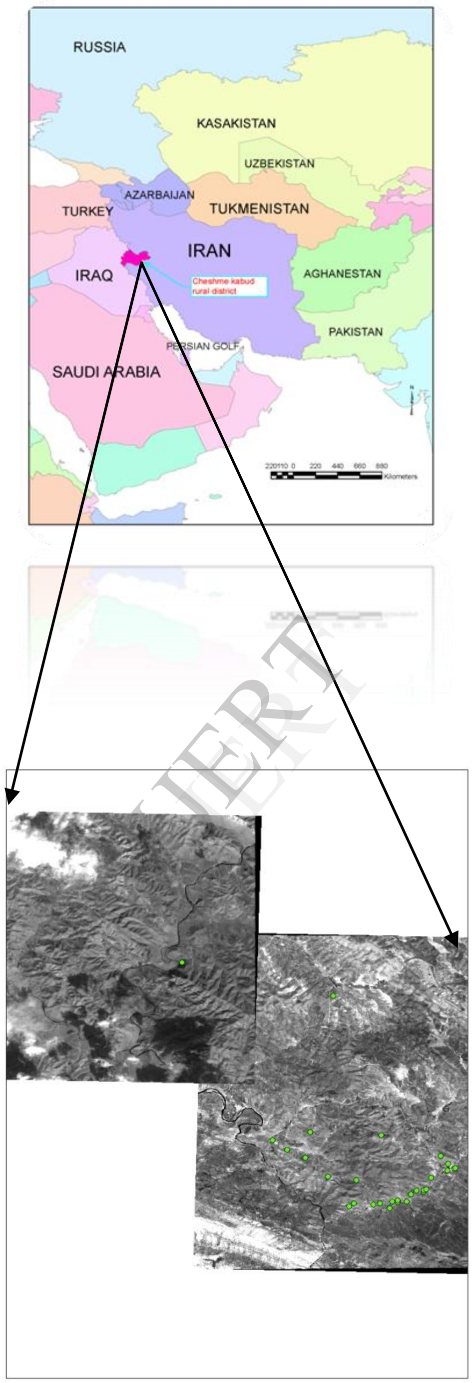

Figure.1 Map of the study area and distribution of shallow landslide (inventory) in the area that show on Ikonos (above) and Geoeye (low) images (courtesy from Geoeye Company)

Figure. 2 Effect of landuse on shallow landslide

Figure.3 Landslide damage to pasture in Cheshme Kabud rural district (Google earth image)

Figure.4 The Mirmengeh village lied on the landslide

Figure.5 Landslide occurred above the village settlement (Cheshme Kabud)

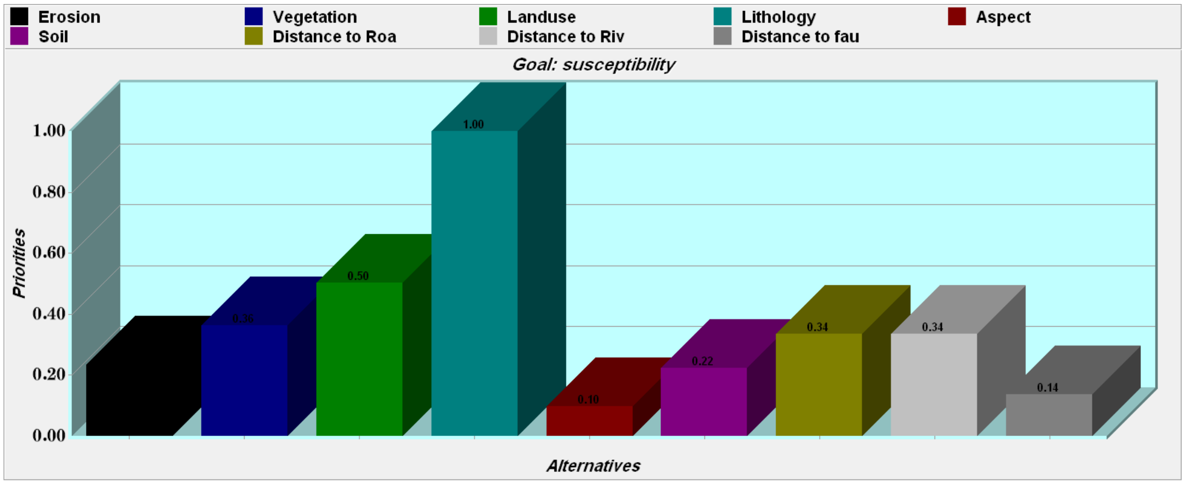

Figure. 6 Hierarchy of influence parameters by expert judgment (Expert Choice software)

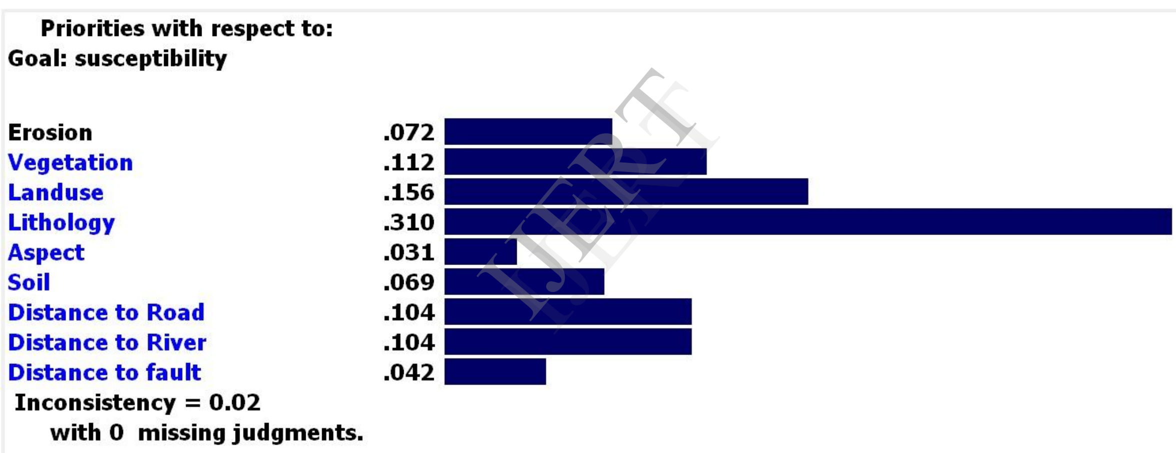

Figure.7 Weight results of the influence factors (Expert Choice software)

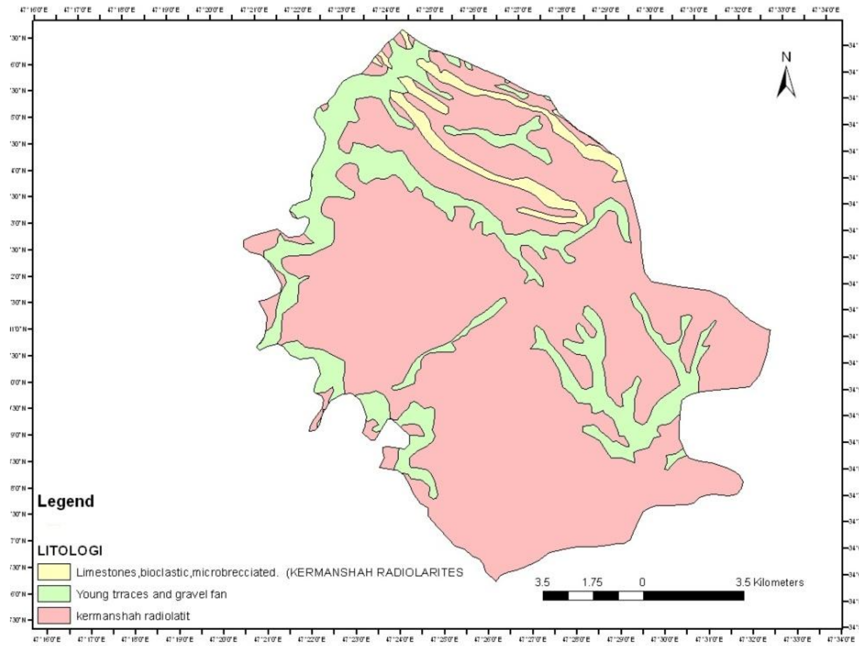

Figure.8 Lithology map of Cheshme Kabud

Figure 9 : Soil map of the Cheshme Kabud

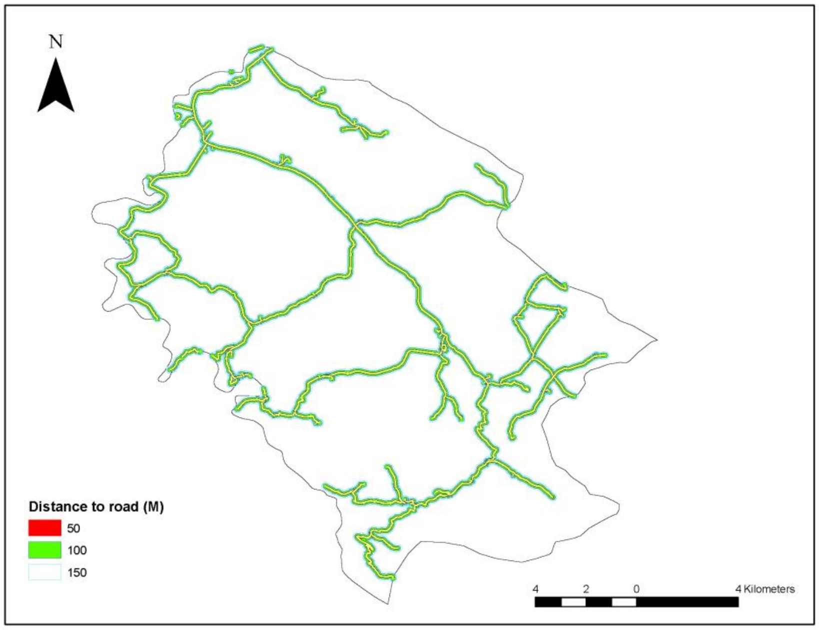

Figure.10 Cheshme Kabud distance to road map

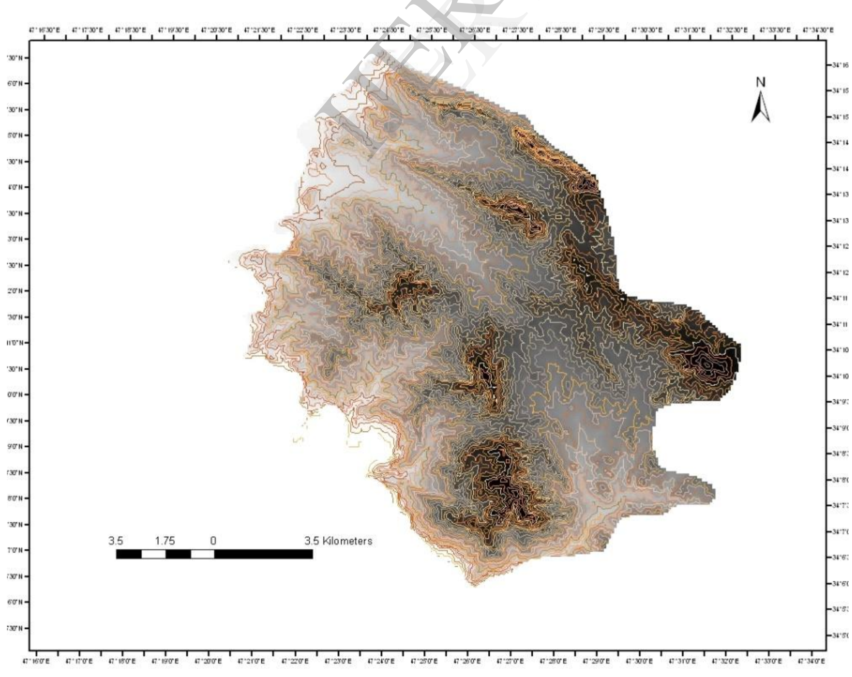

Figure.11 DEM and counter line of Cheshme Kabud map

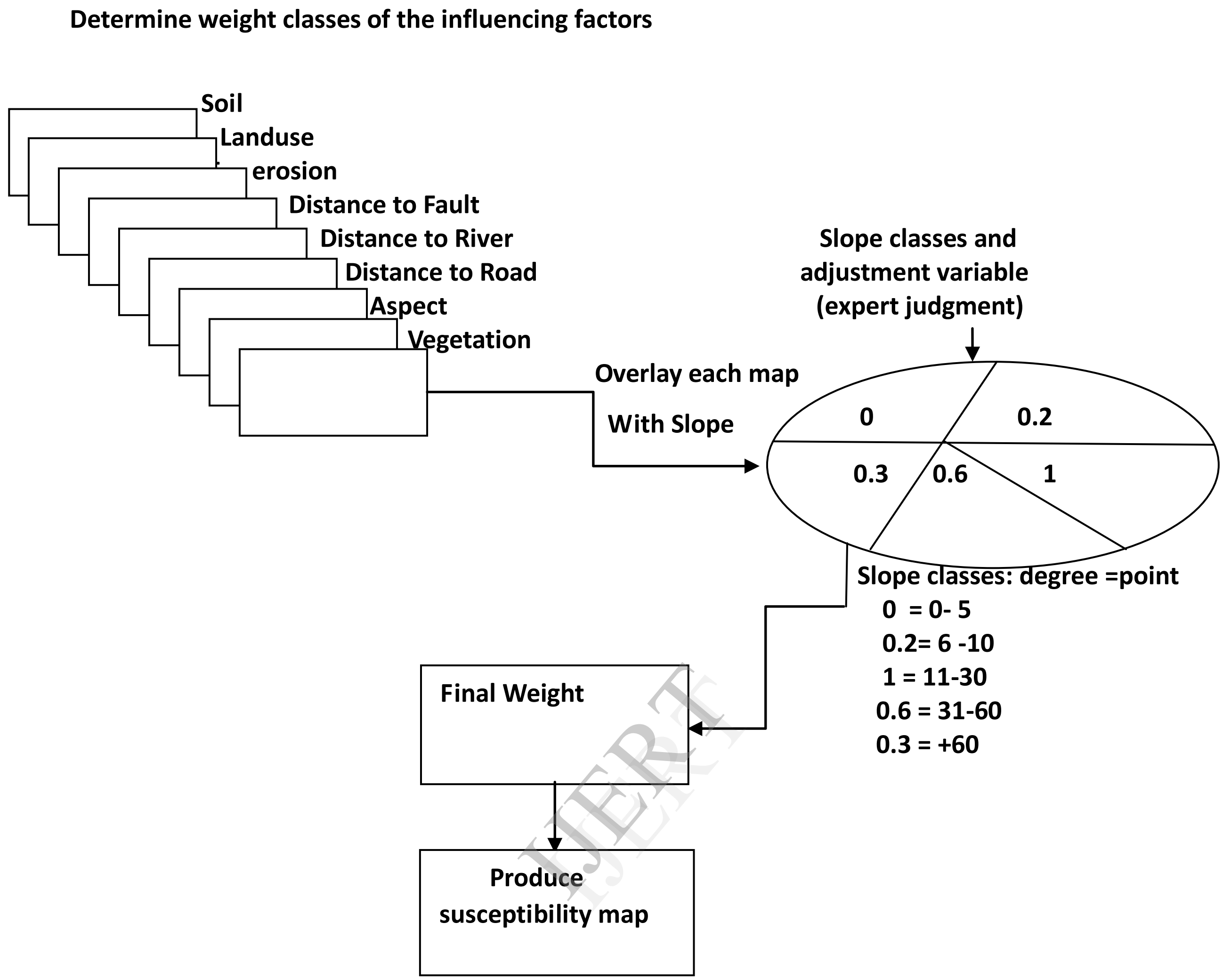

Figure.12 Flowchart stage of the physical (experimental) map

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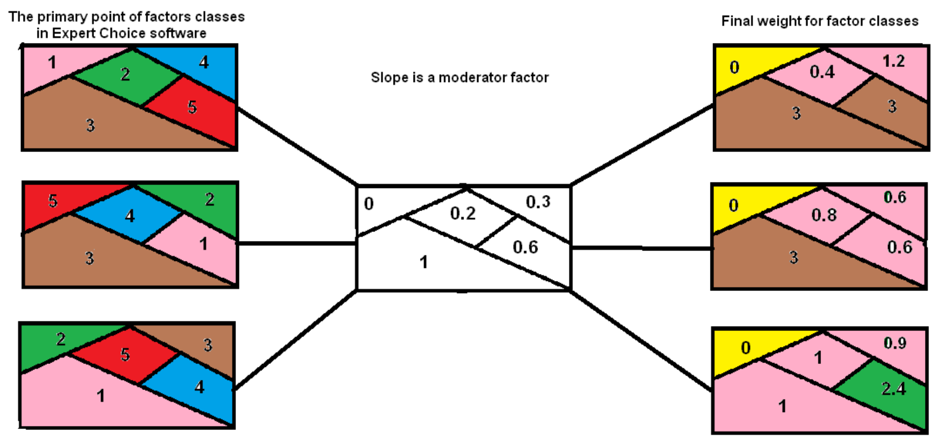

Figure .13 Flowchart shows how slope classes as moderator factor influence on weights of other factor classes after primary weighting determination.

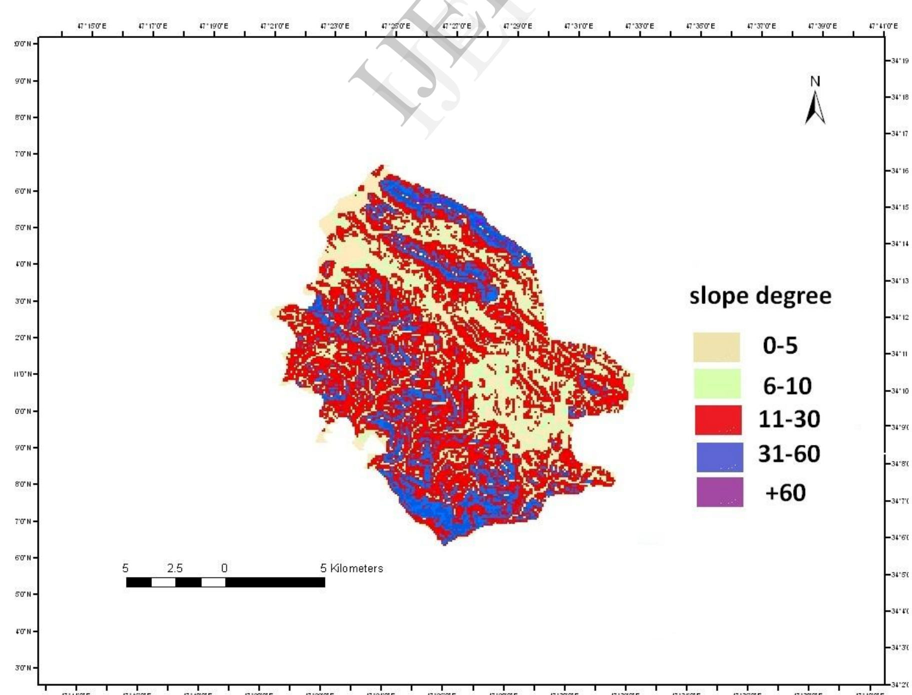

Figure.14 Slope map of Cheshme Kabud

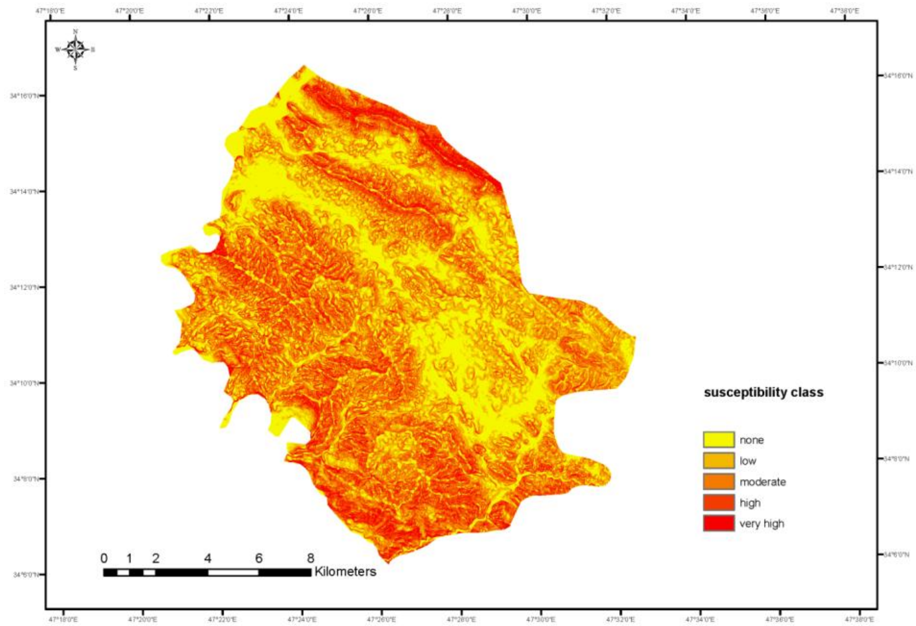

Figure.15 Landslide susceptibility map generated from physical (experimental) method

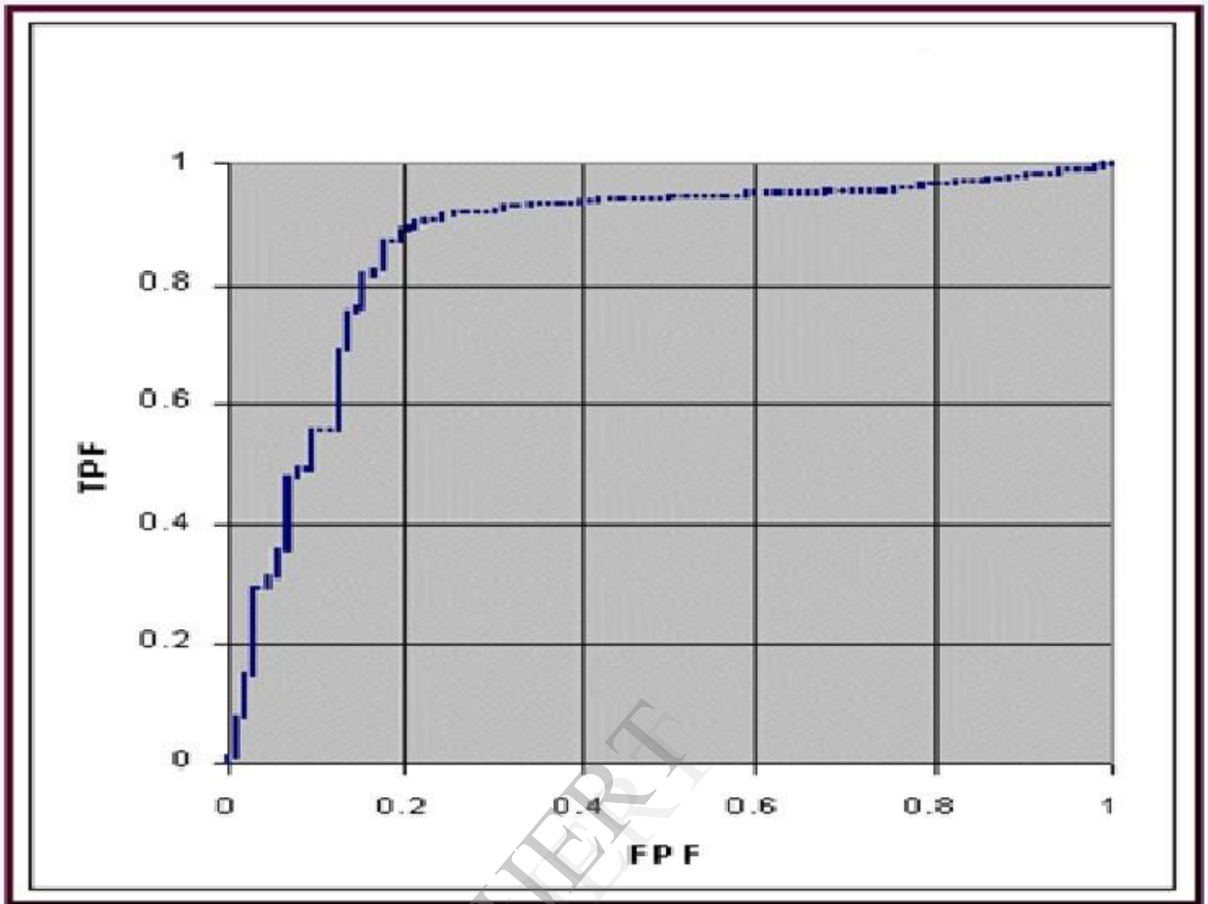

Figure.16 Graph of the validation of physical (experimental) model using ROC curve method

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Caption

Table.1 points of the slope classes to moderate (adjusted) factors classes

Slope classes (degree)	point
0-5	0
6-10	0.2
11-30	1
30-60	0.6
+60	0.3

Table.2 Scheme of the receive operation curve used to construct the formulas

	Positive	Negative	
Test positive	TP (True positive)	FP (False positive)	
Test negative	FN (False negative)	TN (True negative)