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Application of Analytical Hierarchy Process (AHP) to Landslide Susceptibility Mapping at Korek Anticline, Northeast of Iraq

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Abstract: ***Landslide problems are abundant in the korek anticline due to a unique combination of adverse geological conditions. To control such problems, systematic studies of landslides are necessary, including inventory mapping and risk assessment. The purpose of this study is to produce landslide susceptibility maps by using analytical hierarchy process(AHP). At first, landslide locations were identified by aerial photographs and field surveys. seven parameters were used in the AHP method gives value from 1 to 9 according the most important factor and each one was separated into five categories ranging from 1 to 9, representing their specific conditions derived from the investigation of the landslides. Lithology, Slope angle, TPI, lineament Density, TRMM, drainage density and Curvature of the study area are considered as the landslide conditioning parameters. This procedure helps in the produce of the final susceptibility map. five levels of relative hazard are defined on a landslide susceptibility map: (1) very low; (2) low; (3) moderate; (4) high; and (5) very high hazard. From the field observation of the study area ,18 stations were selected and this station were represented on maps of study area, some of them suffer from different type of failure and after studying and preparing the model it appears that this stations lies within high risk classification to very high risk. The hazard increase toward the top of korek anticline limb and decrease toward the edges of limbs.***

Keywords: Landslide, korek, anticline, lineament, hazard, failure.

1. Introduction

Landslides are dangerous natural hazards that occur suddenly and cause considerable damage. (Guzzetti al. 1999).

Several different methods and techniques for landslide susceptibility mapping have been proposed and applied. Landslides in the study area, which occur frequently, often result in significant damages to people and property.

GIS softwares (10.4) were used as a basic analytical tool for space management and data manipulation. Parameters such as lithology, slope, TPI, Lineament density, TRMM, Drainage density and curvature.

This study is focused on the landslide hazard assessment in Korek Anticline, North of Iraq, used a Remote Sensing and a Geographic Information System (GIS).Landslide-conditioning parameter maps are produced from Digital Elevation Model (DEM) and from existing thematic maps such as lithology and slope angle of the study area.

Landslide susceptibility maps are produced to help humans to recognize, avoid, or otherwise adapt to landslide hazard mitigation procedures.

2. Location of the Study Area

The study area is located in the north eastern part of Iraq. It is laid within the High Folded Zone (HFZ), which is a part of the unstable shelf of Arabian Plate. lying between the following geographical coordinates: 36° 59´- 36° 63´ N; 44° 41´ - 44° 49´ E .It is one of the relatively complex geological structures within the foreland fold belts or the Zagros Fold-Thrust Belt (ZFTB) of the Zagros orogenic belt, which is a part of the Alpine–Himalayan mountain chain (Alavi, 1994). (Figure 2).

Figure 1: field investigation of Stations(7,9,15)for the study area

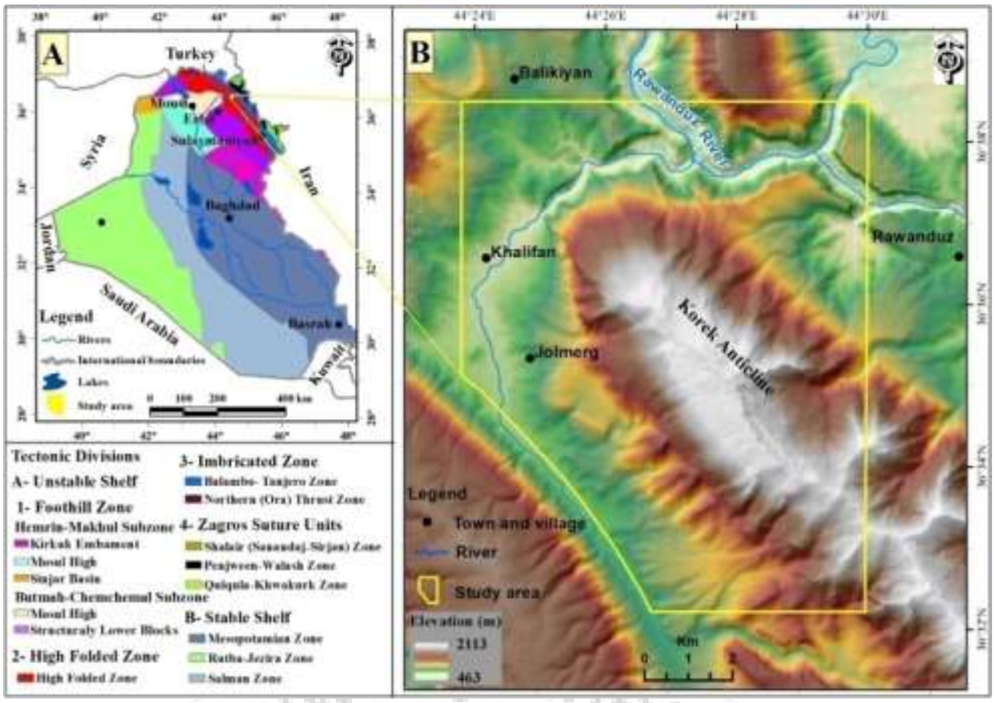

Figure 2: Location map of the study area in the HFZ. **(A):** tectonic zones of Iraq after (Jassim and Goff, 2006). **(B):** color coded of DEMs adopted fromShuttle Radar Topography Mission (SRTM)

3. Geology of Study Area

3.1 Geologic setting

Korek Anticline it is the highest mountain ranges in the study area. It is a wide anticline, trending NW-SE direction . This anticline can be divided into three domes (Al-Kadhimi *et al.*, 1996). The plunge of the northwestern dome is located within the study area. The Lower Jurassic rocks are exposed in the core of this dome. It is a complex structure, which is affected by many thrust faults. These faults have a different trend and plunge. It is dominated by propagation of thrust faults plunging northeastward. While, the opposite plunge of thrust fault is less propagation. In addition to the plunging area is truncated by thrust fault. Thus, it is a box-shaped type folding and complex structure.

3.2 Stratigraphy

More than one formations are exposed in the study area as show in the Geological map (figure 3) but some of them are exposed with very restricted area on the rim ,so that the stations that taken are located on some of this formation not for all.this formations from oldest to young are:

1-Sargalu, Naokelekan, Barsarin, and Chia-Gara Formation:
Represents the U- Jurassic. The age of this formation ranges from Late Jurassic to Early Cretaceous. It consists of well-bedded limestone and marly limestone, which contain a large amount of Ammonite fossils. The thickness is about 150m.(Omer, 2005).

2-Balambo – Sarmord Formation: The age of this formation is Early Cretaceous . It consists of dolomitic limestone and marly limestone(Sissakian, 1998). the thickness is about 80m.(Omer, 2005).

3-Qamchuqa Formation: it comprises thick bedded limestones (often strongly dolomitised) of Hauterivian to albian age. Chatton and Hart(1960) divided the Qamchuqa into a lower unit of Barremian-Aptian age and an upper unit of Albian age. The qamchuqa formation comprises organodetrial and detrial and locally argillaceous limestones with variable degrees of dolomitisation (Bellen et al., 1959).(Figure 3)

4. Aqra-Bekhma Formation: The age of this formation is Late Cretaceous. It consists mainly of limestone and dolomite. The limestone is light gray and grayish brown in color, hard to very hard, well bedded to massive. Its thickness is about 400m. (Sissakian, 1998).

5-Shiranish Formation: The shiranish formation was defined by Henson(1951) from the high folded zone of N Iraq near the village of shiranish Islam NE of Zakho. the shiranish formation in it is type area comprises thin bedded argillaceous (locally dolomitic) overlain by blue pelagic marls (Bellen et al.,1959).(figure 3)

6-Tanjero Formation : The age of the formation is Late Campanian – Maastrichtian (Jassim and Goff, 2006). Lithologically, the formation is composed of sandstones, claystones, Shales, and beds of conglomerates with common lateral and vertical variation (Omar, 2005).

7-Kolosh formation: The age of the formation is Middle Palaeocene – Early Eocene (Jassim and Goff, 2006). The formation consists of fine clastics which are characterised by their black color, like sandstone, siltstone, claystone with rare conglomerate lenses and shales. (Sissakian, 1998).

8-Quaternary sediments: in the high folded zone ,quaternary deposits are restricted to depressions such as the halabja and qalatdizeh depressions where the present day dokan and derbendikhan lakes are situated(Jassim and Goff, 2006).

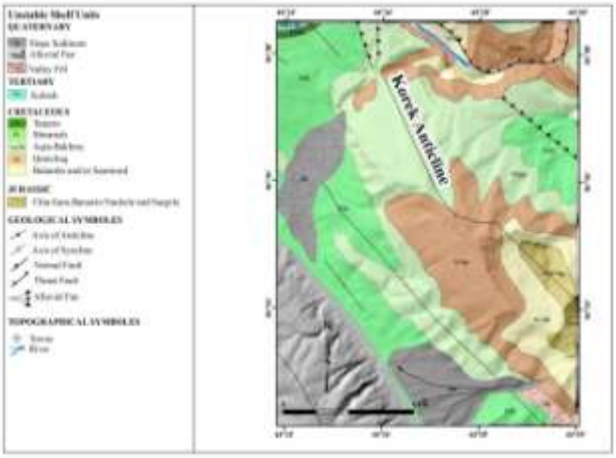

Figure 3: Geologic Map of study area

4. Using Of Analytical hierarchy process (AHP) for Analysis Landslide Hazard

The analytical hierarchy process (AHP) defined as a semi-quantitative method in which decisions are taken using weights through pair- wise relative comparisons without inconsistencies in the decision process .The AHP consists of following five steps:

1) Break down a decision problem into component factors.
2) Arrangement of these factors in a hierarchic order.
3) Assignment of numerical values (table 1, saaty, 1977) to determine the relative importance of each factor according to their subjective relevance.
4) Set up of a comparison matrix.
5) Computation of the normalized principal eigenvector, which gives the weight of each factor (saaty and vargas, 2001).

The main advantages of using AHP as an expert based method in landslide susceptibility analysis are :

1) All types of information related to landslides can be included in the discussion process.
2) judgment is structured so that all information is taken into account.
3) Discussion rules are based on expert's knowledge and experiences.
4) When a consensus is reached, weights for each relevant factor are obtained automatically by eigenvector calculation of the comparison matrix.
5) In consistencies a in the decision process can be detected using consistency index values. Yalcin (2008),(kayastha et al., 2013).

The main disadvantage of this method is that subjective preference in the ranking of factors may differ from one expert to another. (Table 1) explain preference between parameters in AHP method.

While table (2) and (3) show respectively, the Classification of landslide hazard criteria, and the Pair-wise comparison matrix and normalized principal eigenvector for landslide causative factors.

Table 1: Scale of preference between two parameters in AHP (Saaty, 1977)

Preference factor	Degree of Preference	Explanation
1	Equally	Two factors contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one factor over another
5	Strongly	Experience and judgment strongly or essentially favor one factor over another
7	Very strongly	A factor is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one factor over another is of the highest degree possible of an affirmation
2,4,6,8	Intermediate	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

5. Production of the thematic data layers

Various thematic data layers representing landslide Causative factors namely lithology ,slope degree, TPI, lineament Density, TRMM, drainage density and Curvature.

5.1 Landslide Causative factors

1. Lithology: Geology plays an important role in slope stability. Soft rocks are found on the Quaternary deposits, Hard rocks are found on the Qamchuqa Formation, and partly on the Aqra- Bakhme Formation.

According to the lithological units, most landslides are located within Limestone, and Dolomitic limestone. Lithology is important factor that influence on landslide it gives (value 9) (table 2) in AHP method.Then reclassified the map into 5 classes (1-3-5-7-9) according the scale that used in the causative factors in AHP method (Figure 4).

2. Slope angle: The slope angle play a very important role in the the landslides susceptibility (Rozos et al. 2008). Because the slope angle is directly related to the landslides so it is used in preparing landslide susceptibility maps**.** The slope is important factor so it gives (7 value)(table 2) in AHP method and reclassify the slope map classes as follows :(1,3,5,7,9) according the scale that used in the causative factors in AHP method (Figure 5).

Table 2: Classification of landslide hazard criteria for the study area

Criteria	Score				
	9	7	5	3	1
Lithology	Qamchuqa	Aqra-Bakhme	Balambo-Sarmord	Chia-Gara, Barsarin, Naokelekan and Sargelu	Shiranish
Slope angle (degree)	43-more than 75	30-43	21-30	11-21	0-11
TPI	170 – 449	-57 - 170	-36 - -57	-130 - -36	-130- -349
Density of lineament	9-7	7-5	5-3	3-1	1-0
Curvature	4.41-35.62	-0.65 - 4.41	-1.08- -0.65	-4.55- -1.08	-38.08 - -4.55
Drainage Density	0.011-0.014	0.008-0.011	0.005-0.008	0.002-0.005	0-0.002
TRMM	665.1-730.7	599.6-665.1	534.0-599.6	468.4-534.0	402.8-468.4

Table 3: Pair-wise comparison matrix and normalized principal eigenvector for landslide causative factors .

	Lithology	Slope angle	TPI	Density of lineament	Curvature	Drainage Density	TRMM
Lithology	1	0.777	0.555	0.555	0.111	0.333	0.333
Slope angle	0.777	1	0.714	0.714	0.142	0.428	0.428
TPI	0.555	0.714	1	1	0.2	0.6	0.6
Density of lineament	0.555	0.714	1	1	0.2	0.6	0.6
Curvature	0.111	0.142	0.2	0.2	1	0.333	0.333
Drainage Density	0.333	0.428	0.6	0.6	3	1	1
TRMM	0.333	0.428	0.6	0.6	3	1	1

3. TPI : Topographic position index (TPI) compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell (Weiss, 2001; Zinko et al., 2005);TPI is important factor that influence on landslide it gives (5 value) in AHP method then it was reclassified in 5 natural break classes (1,3,5,7,9)according the scale that used in the causative factors in AHP method(table 2) (Figure 6).

4. Lineament Density: In the study area the active tectonics plays an important role in the landslide susceptibility. (Rozos, 1989) include All tectonic lineaments (faults, fracture, etc.). lineament density is important factor that influence on landslide it gives (5 value) in AHP method then it was reclassified in 5 natural break classes (1,3,5,7,9) according the scale that used in the causative factors in AHP(table 2) (Figure 7).

5. Drainage Density: A drainage pattern is the pianimetric arrangement o f streams etched into the land surface by a drainage system. There are two types of the drainage pattern in study area: dendritic and Parallel patterns. (Argialas,1985) Drainage density is important factor that influence on landslide it gives (3 value) in AHP method then it was reclassified in 5 natural break classes (1,3,5,7,9)according the scale that used in the causative factors in AHP(table 2) (Figure 8).

6. Rain Fall(TRMM) : Precipitation is among the most usual Influential factors for landslide appearance (Rozos,2010) .it works by monthly mean of last 10 years from (2007 to 2017) of the study area from the world data (TRMM). this factor gives (value 3) in AHP method. Then reclassify the map into 5 classes (1-3-5-7-9) according the scale that used in the causative factors in AHP method(table 2). Landslide density percentage is higher as the precipitation increases and thus the higher the precipitation (Figure 9)**.**

7. Curvature: The influence of plan curvature on the slope erosion processes is the convergence or divergence of water during downhill flow. For this reason, this parameter constitutes one of the conditioning factors controlling landslide occurrence (Pourghasemi ,2012). Curvature is factor that influence on landslide it gives (1 value) in AHP method .The plan curvature map was prepared consist of five classes and then reclassified into five classes (1,3,5,7,9) (table 2)(Figure 10).

5.2 Landslide susceptibility maps

After the interaction of the principal parameters for AHP method. In AHP, the comparison of factors is made using a scale from 1 to 9 if the factors have a direct relationship and a scale from 1/2 to 1/9 if the factors have an inverse relationship. This procedure helps in the compilation of the final susceptibility map. five levels of relative hazard are defined on a landslide susceptibility map: (1) very low; (2) low; (3) moderate; (4) high; and (5)very high hazard. the stations in study area lies between high and very high hazard .the hazard increase toward the top of limb and decrease toward the edges of limbs.(Figure 11).

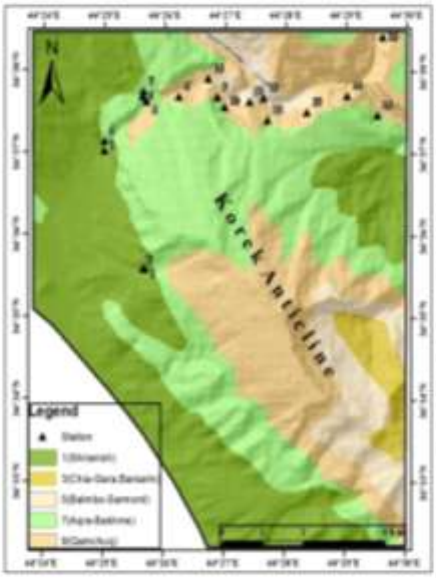

Figure 4: Reclassified Lithology Map

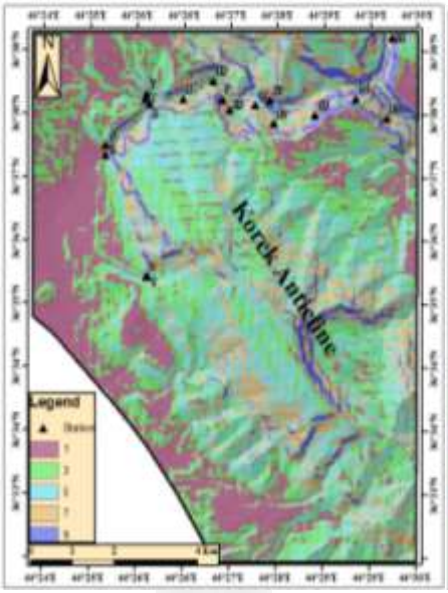

Figure 5: Reclassified Slope Map

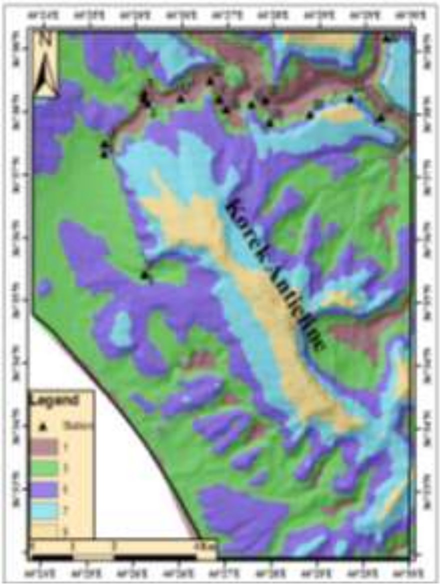

Figure 6: Reclassified TPI

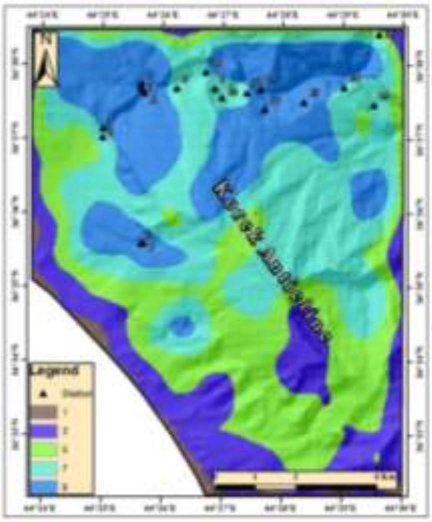

Figure 7: Reclassified Lineament Density

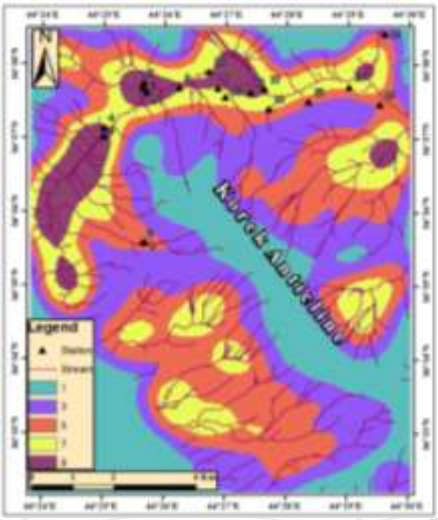

Figure 8: Reclassified Drainage Density

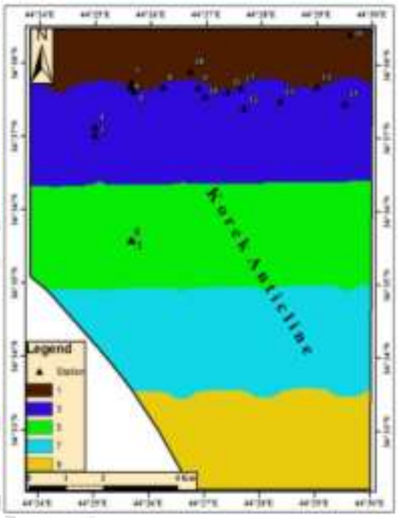

Figure 9: Reclassified TRMM

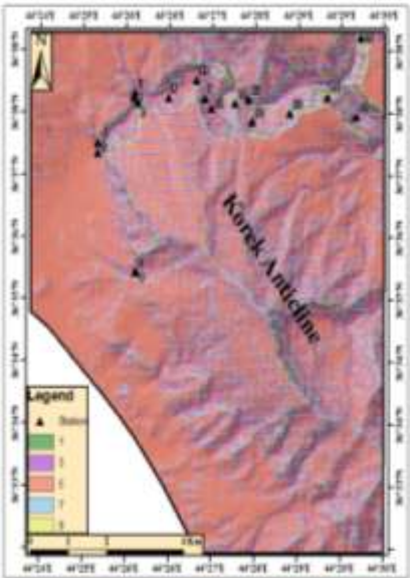

Figure 10: Reclassified curvature

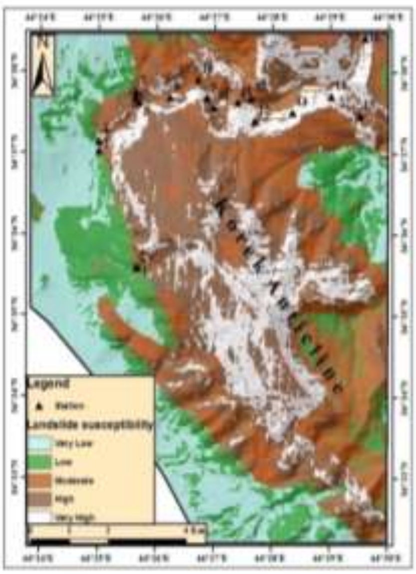

Figure 11: Landslide susceptibility maps

6. Conclusions

There are many studies of landslide susceptibility using GIS-based modeling. In this study AHP model and GIS were used for landslide susceptibility assessment as attempt to reduce the hazard of landslide if the zone of this hazard predicted. In this model seven parameters used for landslide susceptibility assessment (lithology ,slope degree, TPI, lineament Density, TRMM, drainage density and Curvature)and this parameters arrangement according the most important parameter that influence on landslide susceptibility ,the values of these parameters arrangement according to experience of the researcher. Then the landslide susceptibility map was prepared and it is classified the study area into five classes (very low ,low ,moderate ,high and very high).

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