Remittances Review
May 2023
Volume: 8, No: 2, pp. 91 - 121
ISSN: 2059-6588 (Print) | ISSN: 2059-6596 (Online)

Received: 18 November 2022 Accepted: 18 March 2023
DOI: https://doi.org/10.33182/rr.v8i2.08

GIS-based landslide susceptibility mapping along the railway using analytical hierarchy process in southwest of Iran

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Abstract

Landslide problems are abundant in the mountainous areas of Iran due to a different geological conditions, abundant rainfall and anthropogenic factors, which leads to enormous loss of life and property every year. To control such problems, systematic studies of landslides are necessary, including inventory mapping and risk assessment. This study applies the analytical hierarchy process method in the south west of Iran. A landslide susceptibility map is prepared on the basis of available digital data and remote sensing imagery. The landslide susceptibility map is produced through physical and statistical methods. The results reveal that the predicted susceptibility levels are found to be in good agreement with the past landslide occurrences, and, hence, the map is trustworthy for future land-use planning.

Keywords: *Landslide susceptibility, Geographic information system (GIS), Analytical hierarchy process*

Introduction

Starting

Landslides are one of the natural phenomena that have serious effects in different parts of the world. It causes tens of billions of dollars of financial losses annually and more than 4,300 deaths (Frood and Patley, 2018; Inter et al., 2019). Out of about 43 natural hazards caused by human beings, about 38 natural hazards have been identified and registered in Iran. Due to the multiplicity, diversity, frequency and severity of landslides, Iran is ranked tenth in the world (Mohammadi et al., 2008). Slip refers to instabilities with specific dimensions that a mass of soil or rock moves downward on the rupture surface (Hafezi Moqaddas and Ghafouri, 2009). Today, with the advancement of science and technology, suitable grounds have been provided for recognizing and reducing this natural disaster. In this regard, GIS can be used along with decision support tools to assess landslide risk (Rahimi-Shahid and Rahimi, 2015). Investigation and evaluation of landslides is very important due to increasing awareness of their social and

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economic effects and the spread of urbanization in mountainous areas. According to the Center for Supernatural Epidemiology Research, landslides cause at least 17% of natural disaster deaths worldwide, and this trend is predicted due to increasing urbanization, deforestation and change. In rainfall, landslides continue in prone areas (Gotz et al., 2011). Today, one of the most important pillars of economic development are roads or linear structures with appropriate efficiency, which due to their length and crossing areas with different geological characteristics, more than concentrated structures, are affected by hazards. They are located in the environment and cause a lot of human and financial losses. In recent years, road management and maintenance has become a specialized profession, and in this regard, the zoning of potential hazards and identification of high-risk areas has become necessary (Roustaei and Ahmadzadeh, 2012). Communication networks and roads are an important part of any country's capital. Along with this issue, the maintenance of these huge communication networks and the development process of the road construction process as one of the factors of destruction of natural areas are very important (Talebi and Motavi, 2016). Preparation of landslide zoning maps to identify and separate landslide prone areas and safe places for future economic development of an area in a seismic country with high geological and topographic diversity such as Iran is very sensitive (Adinehvand et al., 2017). Remote sensing techniques are powerful tools for identifying, describing and tracking landslides, especially in mountainous areas (Vasowski and Boonga, 2014; Garcia-Davalillo et al., 2014). Artificial aperture radar techniques, which measure dimensions and motion along the ground and thrust, measure slow thrusts only by recording sequential thrusts (Herrera et al., 2013). Various studies have been conducted in this field, including Adinehvand et al. (2017) to study the effective factors in landslide occurrence from statistical models to prepare a landslide susceptibility map in Baghmalek-Izeh area by rare logistic regression method (Rler) paid. Assessing the quality of landslide susceptibility zoning maps showed that it can be used in crisis management and cost reduction programs in more detailed landslide surveys in the region. Armin et al. (2017) to landslide risk zoning in Kohgiluyeh and Boyer-Ahmad Provinces using Haeri-Samiei experimental model (Haeri and Samei, 1997) and combining thematic maps of lithology, slope angle, fault length, road length And the river, rainfall, rainfall intensity and earthquake at a scale of 1: 1500000. The results showed that after combining the numerical score of thematic maps of Haeri-Samiee model, landslide hazard map in 4 classes without risk, very low, low and medium risk with area distribution of 26.3, 33.8, / 9, respectively. 36 and 2% were prepared. Zheng et al. (2020) proposed a new method, combining experimental modeling with a series of artificial aperture radar data, to provide an estimate of the volume and area of a potential landslide on the Yellow River Terrace in Gansu Central Province. Northwest Zagros is one of the landslide prone areas in Iran due to its geographical and geological conditions. Due to the high population density and high potential of the natural environment in these areas, landslide hazard zoning with the aim of risk management in these areas is of great importance (Moghimi et al., 2012). The aim of this study was to investigate the effect of landslides on the rail

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transportation system of the south-west of the country using geographic information system and spatial variables, which consist of overlapping railway layer and hazard zoning map to study Andimeshk-Dorod railway line. Be paid. For this purpose, Landsat sensor images and ground sampling points will be used to increase the accuracy and map the landslide area in the area.

Materials and methods

Study area

The study area is bounded by Longitude 47 º 58' 1.42" - 49º 18' 50.63" E and Latitude 32º 21' 40.94" – 34º 29.10" N from LANDSAT imagery-9-Nov-2002, with Path/Row number 166/037 (Figure 1). The temperature varies between -2 to about 50 degree centigrade.

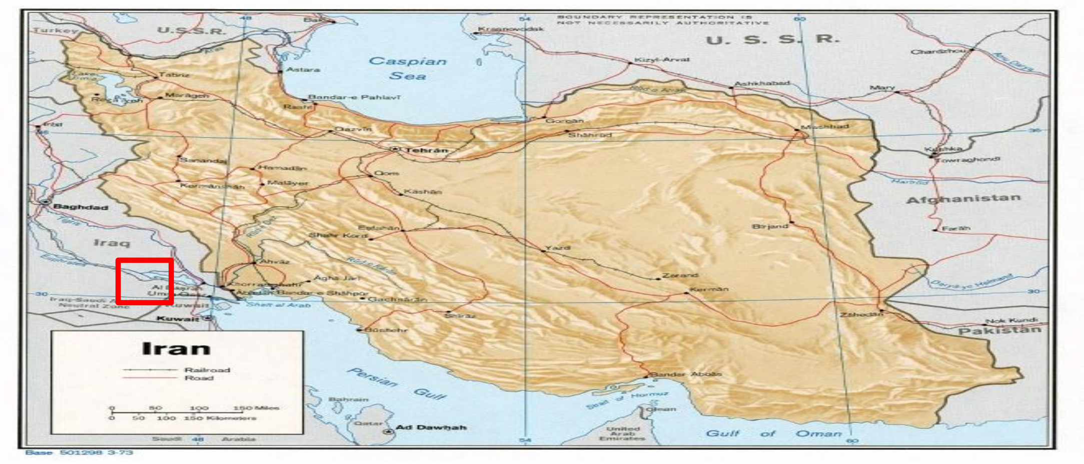

Figure 1: The location map of study area. (Iranian highway and transportation ministry)

Iran is a vast county that has four seasons at the same time. Depending on the geographical areas, there are different kinds of problems. Khuzestan and Lorestan provinces have an altitude ranging (vary in elevation) from about 142 to 4400 meters. The study area extends from Andimeshk in north of Khuzestan province to Khorramabad, Dorud and Azna in north of Lurestan (Lorestan) province. Administratively the study area will be in parts of Khuzestan and Lorestan provinces of the Islamic Republic of Iran. The important cities in the study area are Andimeshk, Pule-Dukhtar, Sefiddasht, Khorramabad, Dorud, and Azna. These two provinces are very important from Geohazard and geological point of views. They belong to Zagros Structural Belt; both the provinces have different structural and tectonics setting. It is a mountainous area, which is usually snow-covered during winter. Sometimes, due to the heavy snow, the Railway signs are invisible. The railway is often slippery during spring. They are even dangerous during spring till the beginning of summer, because they are winding and attractive enough to distract drivers.

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These two provinces are very important from railway transportation point of view; because it connects south to north of Iran. It has also become the main concern of researchers geologically. It is because of the complexity that has been found in Zagros Structural Belt. Both the provinces have different litho-stratigraphy and geomorphological setting.

Relevant Data

In order to get geohazards map, different thematic and spatial data were collected and used for the study area. The existing geological map of the area in scale of 1:100,000 were compiled to generate the GIS geological map of the area. Iranian Surveying Organization (ISO) also provided the digital topographic data in scale of 1: 25,000. The digital topography maps are used to generate Digital Elevation Model (DEM) of the study area. LANDSAT-7 Enhanced Thematic Mapper (ETM+) dated 2002 data was provided by the Iranian Remote Sensing Center (IRSC) with path/row 166/037 in spatial resolution of 28.5 meters. Several ground truth data were collected along the railway road and tunnels. Figure 2 using Global Positioning System (GPS) in order to increase the accuracy of the ground control points in the study area. Analog and attribute (i.e. non spatial) data such as previous geo hazards locations, number of existing tunnels, number of the trains travelling, number of the passengers and travelers has been collected form railway transportation ministry of transportation Iran.

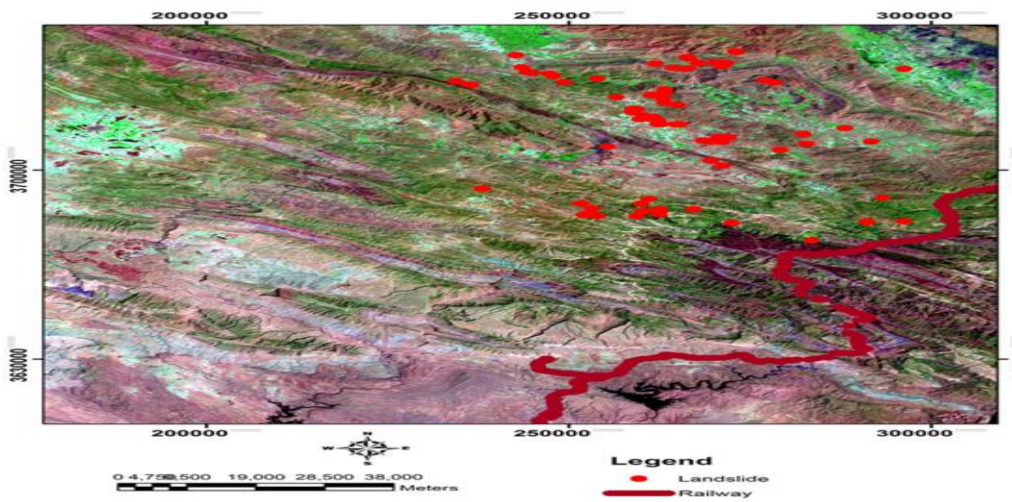

Figure 2: Railway road and Landslides on LANDSAT ETM+ image.

Image Geometric Correction

At this stage, the goal is to determine the size and location often pixel. Geo-reference Satellite images, are important steps in determining the quality of the images obtained from their combination. Therefore, the accuracy of this step is necessary. Reference to Geo-reference satellite imagery or In other words, the coordinates of selected control points in the images has been done. After geo-referencing data, the position of the image pixels in the image coordinates is needed to rewrite them in the new location. For ETM + geometric image correction, in 2002, The ETM + images have a precise coordinate system and the study area was covered used. Having selected the appropriate operation of ground control points, using software 4.8 ENVI, the ETM + images were taken. In order to do this, the complications defined as the intersection of roads, streets, buildings and networks of existing land. It was an attempt in which the ground control points are chosen so that the whole image can be fragmented. The appropriate numbers of 10 ground control points in the images were chosen after determining the degree of polynomial equations, evaluating the methods of DN interpolation degree is also necessary, and in order to rewrite them, the nearest neighbor test was used. Because of this method, it is better to keep the information in the original image.

The image was already radiometrically corrected by the Iranian Space Agency. These two aforementioned processes are called pre-processing. After pre-processing on the ETM+ 2002 image the post processing including enhancement and filtering have been attempted on the image to facilitate the potential of the analysts to interpret the objects needed in this research. Digital image processing has been processed based on techniques of digital enhances by 2% linear enhancement and sharpen filter within the environmental visualization image (ENVI) version 4.8 software.

Interpretation of the satellite image for the structural features and rock type discrimination were carried out using image elements such as tone, texture, erosion, drainage patterns and drainage density. It was accurate by the existing analogue geology map and several in-situ measurements. In order to identify the rock type the following steps were applied:

1- Discriminate rock types in term of igneous, sedimentary and metamorphic. The banded tone and textures were interpreted as bedding on the LANDSAT ETM+ image. Beddings are recognized as horizontal to sub horizontal strata on the image and were marked for sedimentary rocks.

2- Mechanically and chemically sedimentary rocks have been identified on the base of resistance to erosion, drainage density, drainage pattern and banded tone ratio. The study of this level indicated that the study area consists of chemically formed sedimentary rocks and some parts by mechanically formed sedimentary rocks.

3- This level tries to indicate what kind of rock it is. GPS was used in this level for about six locations in the study area through fields to check the determination of the lithological contacts. LANDSAT ETM+ data was calibrated by field data and then compiled with analog geology map of the study area to prepare the digital GIS geological map of the area. Lithological units were digitally processed within the ENVI4.8software. The digital divisions

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in terms of polygon vector type of lithological units were introduced to ArcGIS9.2 software in order to produce the topological relationships. Then the data was converted to the shape file format to generate digital GIS geological map of the area (Figure 3).

4- The final stage of identifying the rock type is mineralogy. The samples were taken to the mineralogy lab and the thin sections have been prepared to confirm the rock type identified by remotely sensed data. Samples have been collected from Shahbazan station, Mazou station, Tange-5 and Tange -7 stations and Olia village.

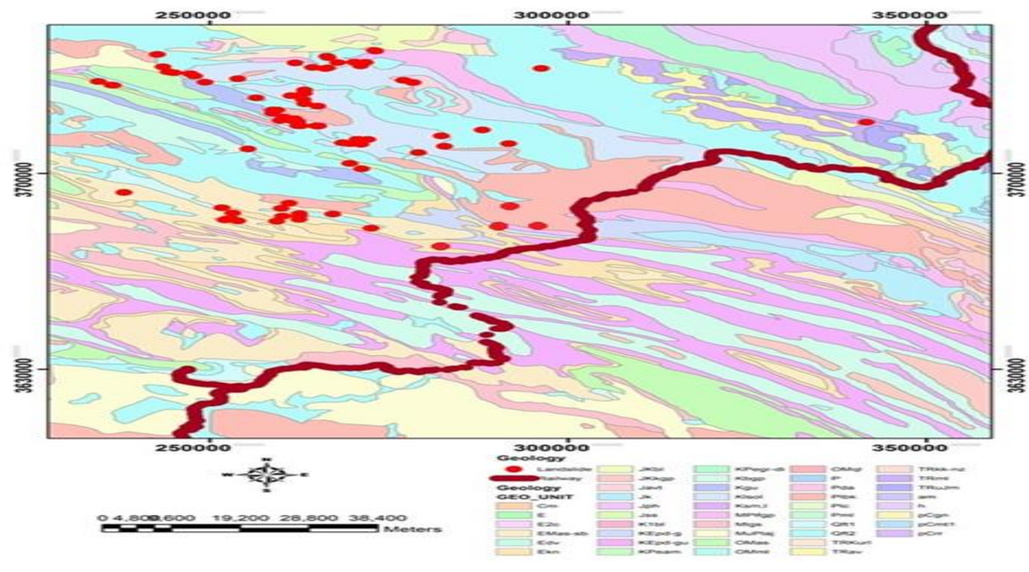

Figure 3: Geological map of study area, Zagros Mountain southwest of Iran

Extraction of geomorphology and structural effects

One of the advantages of remote sensing application in geological studies is coverage of large area that provides useful information from structural pattern. The use of remote sensing in geology to identify fractures, lineaments and their measurement is used to determine the orientation density, using this analysis; the size of a regional tectonic lineament can be realized. Land surface lineaments are linear or curved Phenomena in Crust that are broken and show Faults, fractures, joints and dykes that can be detected by satellite digital data processing and should be differentiated with artificial lineaments. Lineament analysis for the study of geological structures and for recognizing faults and limits in oil exploration, are very useful. Based on the information of lineaments of information, we can even analyze geological structures and geological history. Lineaments analysis is structural and tectonic studies on a regional basis.

Earth scientists use remote sensing data, including satellite imagery, aerial photos, digital elevation models, Earth digital elevation model and a shadowing model, to follow the extraction and determination of fracture geometry. Determining the geometric relationship between phenomena and structures can be studied to identify temporal relationships between the structures in the studied areas. The results of remote sensing techniques as applied to structural analysis of Studies are used. Having achieved the data from these studies, a thorough analysis should be supplemented by information from the field impressions. In general, the various methods of extracting structural effects information from remote sensing and geomorphology are used. Types of geological structures such as folds, domes, joints, fractures and general faults or lineaments, unconformity and so on are recognized in satellite images using ENVI software, that can be pronounced more clearly (Gupta, 2003; Prast 2001). In general, there are two methods for extracting information from satellite images: extracting of geomorphologic patterns and geometric designs by using patterns derived from spectral irradiance measurements, which utilizes the unique spectral characteristics by corresponding the types of rocks. The visual image interpretation method is the most practical method for extracting geological data from satellite images. In the visual interpretation of images thorough knowledge, experience and ability to identify problems in the interpretation of these data, particular ability to use the technology of remote sensing and satellite data resolution, is important.

The interpreter at this stage uses the principles of interpretation, which include the dominant tone or color, the texture image including rough and coarse model, include drainage, habitat networks that have significant effects in the extraction and digitization of maps. In the first stage, researcher extracts explicit forms in visual interpretation method by using knowledge experience, remote sensing technology, and enhances visibility and better diagnosis in the satellite events, started the fusion one or the combination of black and white PAN image, and the color image which increases the quality of the color, density and land cover drainage for more extensive and comprehensive analysis.

Joint use of remote sensing data with digital elevation model has facilitated the solution of many problems in geological studies. Remote sensing data, in particular, have certain advantages such as easiness in working in large areas, ability to display ground features in colors by recording different reflectance values, availability of synoptic vision, mapping possibility of inaccessible areas and the ability to process obtained data by means of computers.

Remote sensing data are images obtained multi spectrally, by which they display the morphological structure of the surface characteristics very well. By looking at this morphological structure, evaluation of the structural characteristics among the surface formations can be done. The present study, for indicating and extracting geomorphological and structural complications both raster data (image ETM + and DEM) were used.

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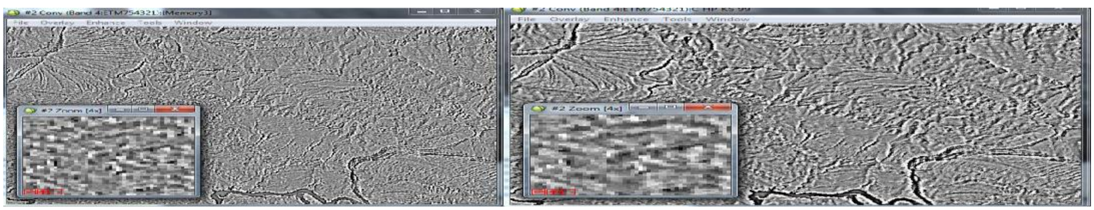
Generate Filter

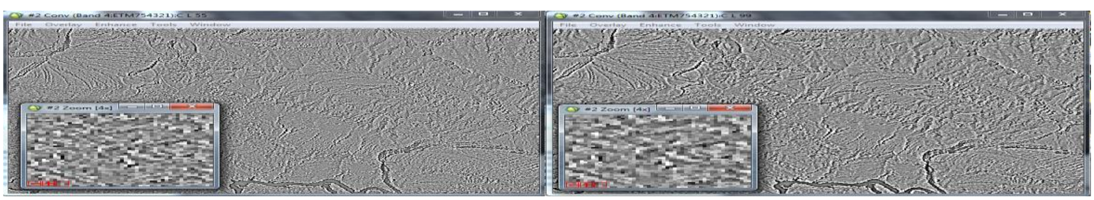
The contrasts of six bands are enhanced. The images of all the bands are compared in terms of contrast and definition of structural and geomorphological features. As a result of visual evaluation, LANDSAT ETM+ band-4 data which record the information at the wave-length between 0.75-0.90 micrometers were selected for this study that shows good contrast and display structural features like folds, faults and lineaments as compared to the other bands.

After choosing the bands for the image of ETM + for the filter, various filters such as Filtered Convolution High Pass (with Kernel Size of 9*9, 11*11,7*7, 5*5, and 3*3) and filter Convolution Laplacian (with Kernel Size different 9*9, 7*7, 5*5, 3*3, and 11*11) were applied to extract geomorphology and structural effects (Figures 4 and 5).



a)7*7 b) 9*9

Figure 4: Filter of Convolution High Pass with different Kernel size.



a)7*7 b) 9*9

Figure 5: Filter of Convolution Laplacian with different Kernel Size.

Generation of Principal Component Analysis (PCA)

Image Data have been analyzed at various band combinations. Images have been enhanced by using Principal Components Analysis (Figure 6). Enhanced remote sensing data have been used with digital elevation model which express the features of earth's surface three-dimensionally. This makes it possible to analyze the geo morphological characteristics (Kaya and Muftuoglu, 2000).

Principal Component Analysis is often used as a method of data compression. In an n-dimension all histogram, an ellipse (2 dimensions), ellipsoid (3dimensions) or hyper-ellipsoid (more than 3 dimensions) is formed if the distributions of each input band are normal or near normal. The

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PCA has the following advantages: (1)most of the variance in a multi-spectral data set is compressed into one or two PC images; (2) noise may be relegated to the less-correlated PC images; and (3) spectral differences between materials maybe more apparent in PC images than in individual bands (Sabins, 1987). In addition, the principal component analysis can be used for the following applications: Effective classification of land use with multi band data, color representation or visual interpretation with multi band data, Change detection with multi temporal data.

Recently, some researchers were using the principal component analysis to determine lineaments in the remote sensing literature. For instance, Ghosh and Viswanatham (1991).

In this study, The Principal Component Analysis was applied to all six ETM+ Bands and generated six different Principal Component images. First three highest eigenvalues were selected. These are bands1, 2 and 3. The false color composite image was generated by layer merging with these selected bands1, 2 and 3 (Figure 6).

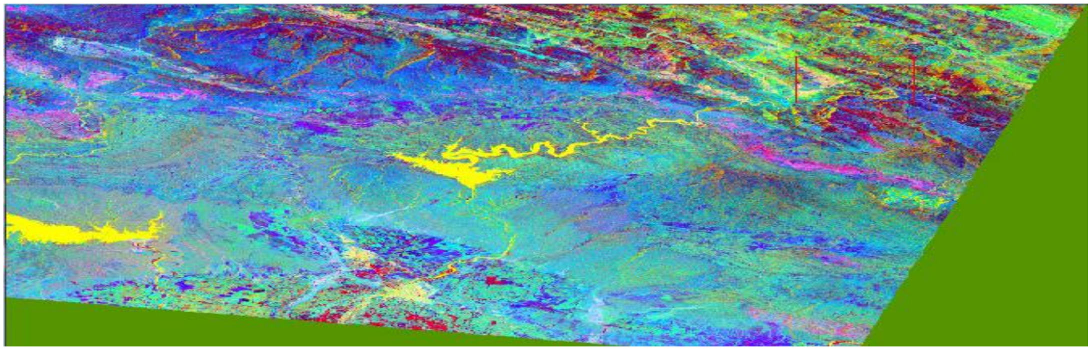

Figure 6: Principal component analysis (231) on image ETM+

Digital Elevation Model

Digital Elevation Model is the digital elevation map of the topography of land represents a cellular network. Each cell (pixels) of the grid with a digit code that represents the actual height of the point is to be clear and to identify geological features and structure is substantial.

DEM plays an important role for geo hazards mapping. It is considered as the conceptual layer in GIS to extract the landslide and rock fall prone areas. This helps to do morphometric analysis of drainages, structural geology and further geo hazards and disaster management study. The spatial resolution established for DEM was 28.5 meters agreement with the satellite image. To create the DEM of the study area, the digital topography map in the scale 1:25,000 was converted in to the text format using Micro station J software. Text format was introduced to River Tools 2.4 software to produce the shaded relief (DEM) (Figure 7) for the study area.

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The DEM has been produced by using River tools software with text format extracted from aerial photographs and later generated digital topography map by Iranian Survey Organization (ISO). Preprocessing, which is designed to remove any undesirable raster characteristics is produced by the initial processing of the raw data, remove noise, and correct geometric distortions.

For a last decade, geologists are interested in tracing lineaments from satellite images for studying the geo hazards and mapping the area prone to landslides. Faults, folds and lineaments can easily be traced on the image using different bands. Faults, folds and thrusts are digitally mapped based on the photographic and geotechnical elements such as tone and vegetation respectively. Structural map is created using field data and input data.

Generally, different enhancements are applied on the image to extract the geo structural features information (Lee 2005, Giacintoand et al., 2000). Based on it, a new development method has been applied in this research as one of the contributions of the research thesis. It is filtering and convoluting high pass technique on the satellite image like ETM+ LANDSAT and DEM. For ETM+ satellite image, the contrasts of six bands data are digitally enhanced.

The images of all the bands are compared in terms of contrast and definition of structural features. As a result of visual evaluation, LANDSAT ETM+ band-4 data which record the information at the wave-length between 0.75- 0.90 micrometers were selected for this study, since it shows a good contrast and display structural features like folds, faults and lineaments as compared to the other bands. The infrared band 4 of ETM+ LANDSAT image has been considered for filtering convolution kernel size too. The both directional and Laplacian convolution filter has been attempted within ENVI version 4.8 software environment on ETM+ satellite image as well as on DEM. Figures8, 9and 10 illustrates the both filters kernel size and matrix applied on the ETM+ satellite image.

Types of filters for the obvious complications and structural geomorphology of the area on the DEM and ETM + band 4 images have been used that under fully described.

Figure 7: Digital Elevation Model (DEM)

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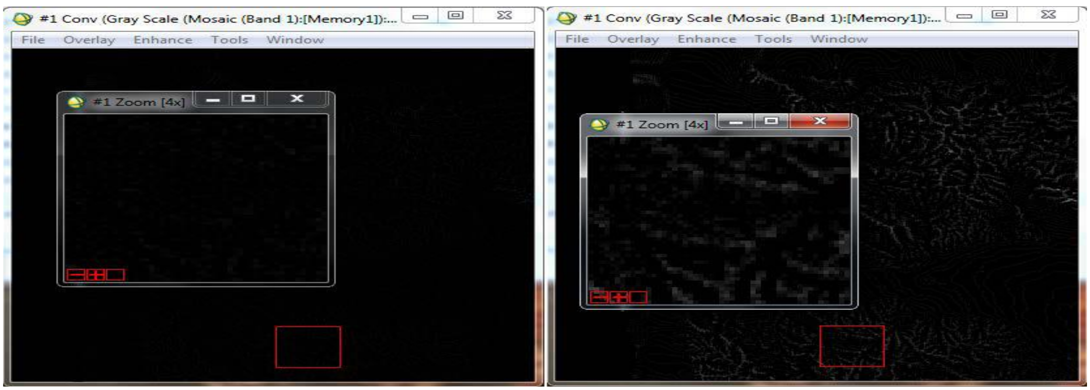
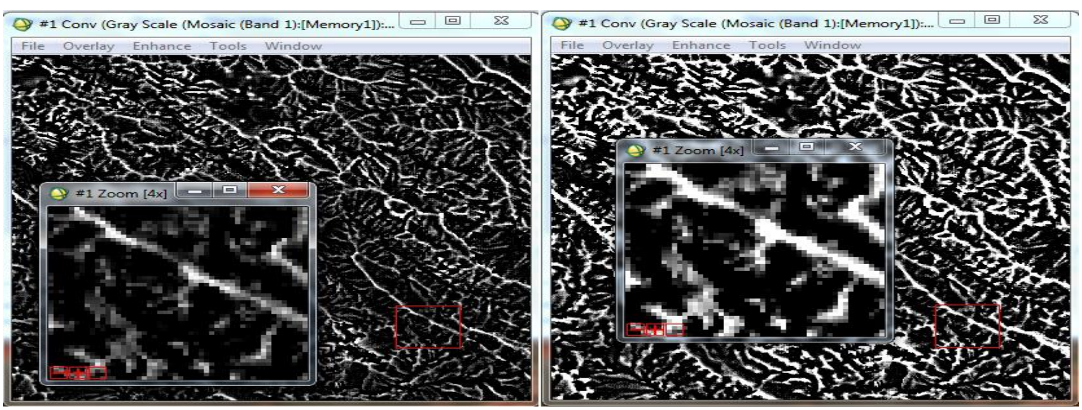
Digital image processing filtering convolution techniques have been applied on the DEM by which different images are produced. The high pass technique has been applied on DEM with 3*3, 5*5, 7*7, 9*9 and 11*11 matrix convolution kernel size, by which the lineaments and geomorphology features are enhanced (Figure 3-11).

The Convolution Laplacian technique with Kernel Size 7*7, 5*5, 9*9, and 3*3 was used to extract geomorphology and structural effects on the digital elevation model (Figure 3-12).

Finally, the directional technique with zero angle with kernel size 3*3, 5*5, 7*7, 9*9 and 11*11 have been carried out to produce the images with better enhancement and ability in order to interpret the objects (Figure 3-13).



a) 3*3 b) 5*5



a) 7*7 b) 9*9

Figure 8: Convolution High Pass with different Kernel Size on the digital elevation model

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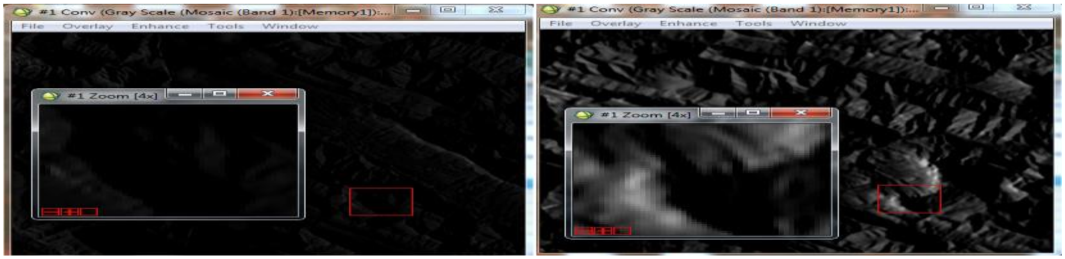
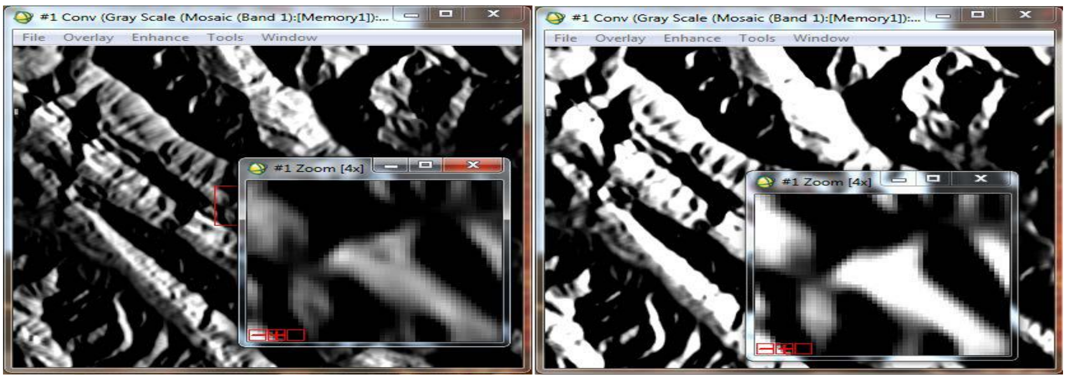
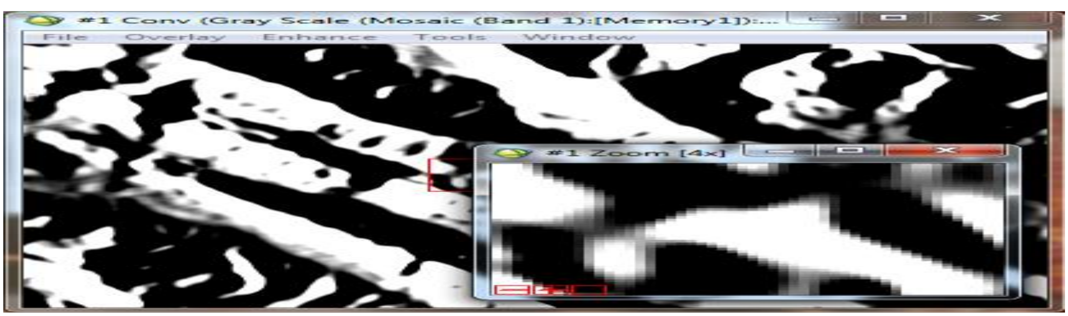


a)3*3 b)5*5



c)7*7 d)9*9

Figure 9: The show convolution High Pass with Kernel Size different on the digital elevation model



e)11*11

Figure 10: Convolution directional with different Kernel Size on the digital elevation model

Landslide and rock fall Record

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After initial studies on satellite images, topographic, and geologic maps, the study area was visited and historical landslides and rock falls registered by a Garmin GPS device. The data were transferred to ArcGIS software by using Map Source.

Effects, relationship, and weights of the variables

At this stage, the relationship between the different affecting variables on landslides, were studied to assign weights. To do this, at first, the variables are classified and different criteria for any of the variables were extracted. Then, the various classes of criteria with scattering layers recorded in the landslides study area were overlaid.

All levels of overlaying and assigning weight to the following criteria were performed using the Arc GIS9.3 software.

Slope

Slope, has a huge impact on the occurrence of landslides phenomenon. Convex, concave and straight play an important role in the frequency of occurrence of this phenomenon. Convex surface topography due to the geometry of the slope has fewer movements. Steepening slopes increase the destructive power and cause slope instability and rupture. A slope increase level intensifies the incidence of mass movement to a certain level. Table 1 class 15-30 and 5-15 grade have allocated the highest amount of landslide respectively. This rule follows the general relationship between slope and landslide. Meanwhile, the class of 0-5 degree has allocated the third rank to itself and the classes 30-45 and above 45 has allocated a small number of the occurred landslides that this issue is in contrast to the general rule of the relationship of the slope variables with the occurrence of landslide. To clarify this issue, attempts were done to investigate the relationship between these variables and other variables were in this regard (Figure 11).

Table 1: Scattering phenomenon landslide slope classes

Number	Slope	Weight	landslide%	area (km2)
1	0 - 5	3	20	5291.01
2	5 -15	5	35	6931.35
3	15 - 30	6	43.75	7559.09
4	30 - 45	2	2.5	3200.5
5	>45	1	1.25	562.13

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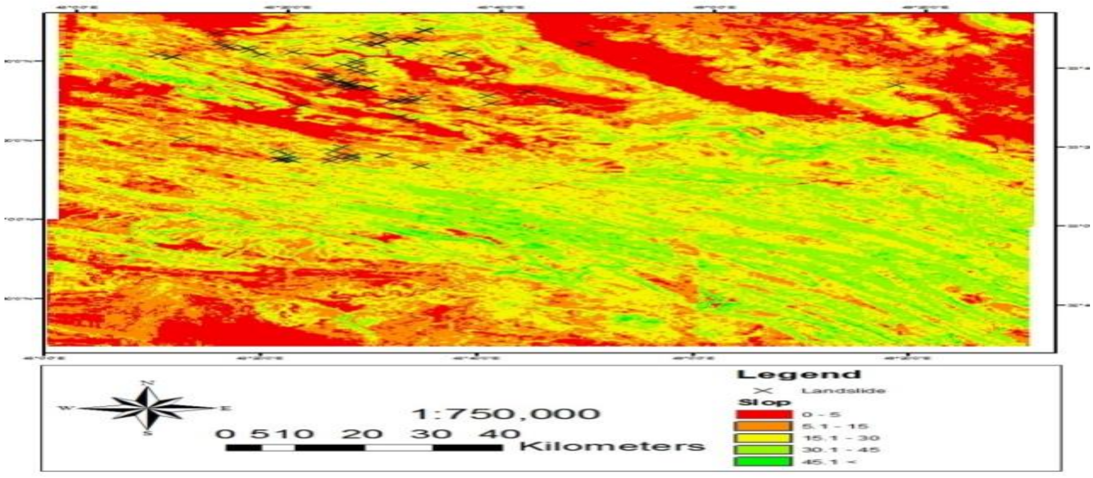

Figure 11: Slope map and distribution of landslides in study area.

Lithological units

Using 1:100,000 geological map of the area made of stone blocks in Khorramabad and Khuzestan province map, Lithological characteristics in a range of sensitivity to movements in the area of distribution of this movement has been displayed. In this regard, the most critical lithological units were assigned to units QFT2 and KLSOL and Emas-sb (Figure 12). Kpeam unit has the third rank in landslide. This phenomenon is due to the landslide susceptibility of these units. Other geologic units in the study area in terms of landslide shall have the same ranges.

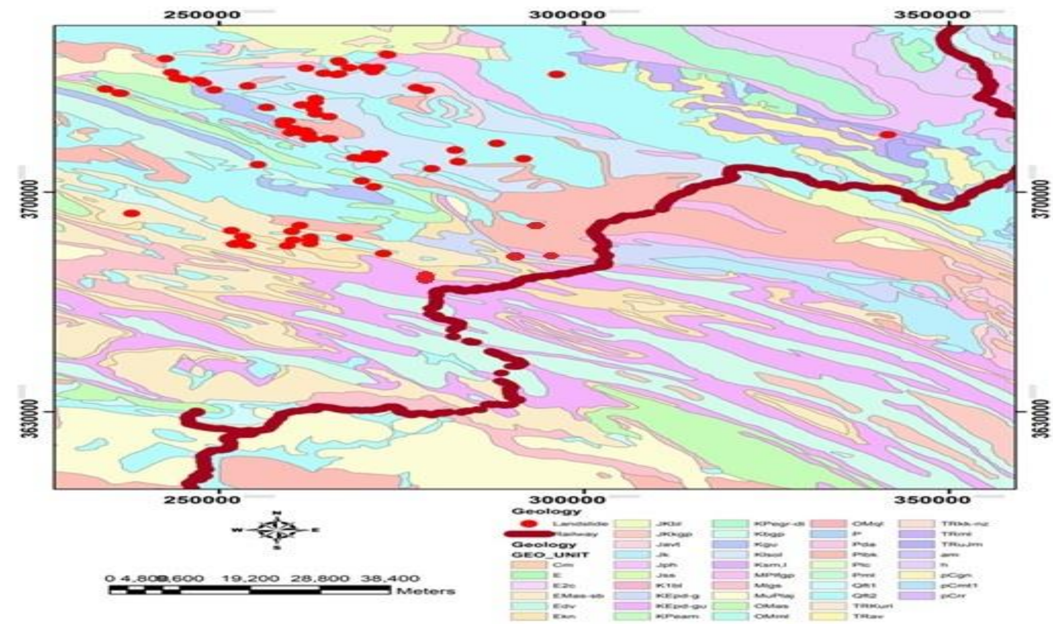

Figure 12: Distribution of landslides in different geological layers.

Rainfall

The water that moves through a range of motion is one of the most important factors in accelerating mass movement. Water increase means the increase of the hillside's weight or the apparent density of it that was effective in reducing the amplitude stability and was affected by many factors such as latitude, elevation, roughness, the geographical distance and the air mass is close to the sea. Water is one of the most important factors in accelerating the mass movement**.** If the soil can`t become dense due to the water between the soil particles, and increasing the density happens quickly, a little extra weight is transferred to the water and due to pressure, water between particles will increase and this reduces friction and as a result, downstream movement will occur. In this connection, as shown in the table, five floors of precipitation basin are obtained (Figure 13). The Classes of 300 to 400 and 400 to 600 mm are highest ranked for landslide. After that the class 800-100 mm, has the second grade (Table 2). This observation shows that in this field there is no clear relationship between the amount of precipitation, which is received annually, and the Range of motion. Most of the movements occurred in the second and third intervals of rain.

Table 2: Distribution of landslide in rainfall levels

Number	Weight	Landslide%	Area (km2)	Rainfall

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1	1	1.25	1460.93	300-400
2	6	42.5	7772.58	400 600
3	6	42.5	6295.64	600 800
4	2	16.25	4503.88	800 1000
5	1	1.25	2890.81	1000 1200

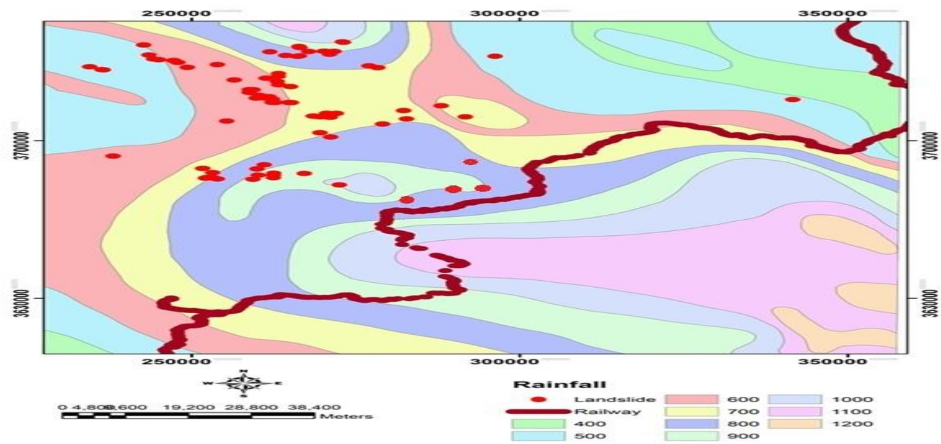

Figure 13: Distribution of landslides in rainfall classes.

Landuse and Land Cover

Land use is one of the main indicators of the stability of slopes and hazard zonation in a region. So that these parameters can affect the surface properties, so that the parameters of the Earth's surface properties, are affected. The land-use changes in natural environment must suit human needs. The severity of this vulnerability is directly related to the type of change (Ahmadi, 1988). the conversion of sloping forest land to agricultural land and pasture areas is a good example. Forest plants with roots disconnect network and Shear strength that results in mass slope, to the extent that the changes in this parameter by human factor has broken the relationship between the common law and the control parameters in a range of motion. Table 3 and Figure 14 can be used to get the Forest highest grades in landslide. Barren land class ranks are in second and third range, respectively. Generally, class of forest and agricultural lands should be a small percentage of landslides in their place, but what has happened in the region is opposite to the principle.

Table 3: Scattering phenomenon landslide in userclasses

Number	Weight	landslide%	area (km2)	Land use
1	4	31.25	3853.18	Dry Farming

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2	5	40	10468.69	forest
3	1	7.5	1626.32	Irrigated Farming
4	3	28.75	6113.82	range
5	1	1.25	828.54	rock

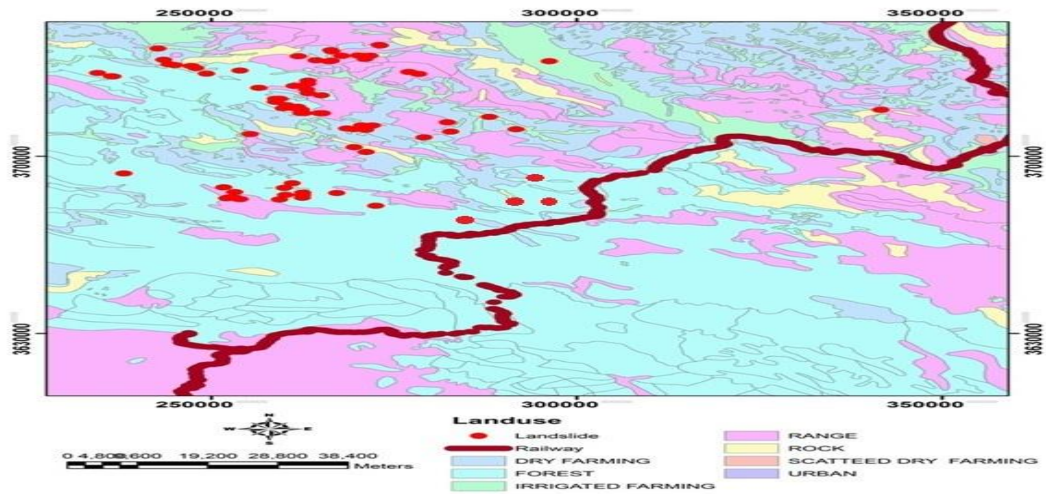

Figure 14: Landslides distribution and landuse of study area.

Vegetation density

Among the important factors that are involved in determining the role of the natural environment in the area, is the Vegetation of the area. Therefore, geomorphologic review, citing local plant information and many geographical issues such as height and angle of radiation is justified. Vegetation due to its close relationship with soil can also answer questions that arise in any area of geology. Plants have a variety of special functions, as its root is caused by playing back the soil strength. On the other hand, too much weight on the variability range of components provides assistance to Unstable slopes. Seeking to eliminate excessive vegetation, increased soil erosion rates are always a subject of major branches of natural resources and watershed management. Generally, vegetation evaporation destroys plants water storage power.

Neglecting Destruction of forests, may lead to Gradual loss of organic matter and gradual changes of vegetation into hard lands. Lack of vegetation restoration, Failure to implement conservation programs, and the Lack of drainage system along the road, causes soil erosion and mass movements. In studied region, for generating the vegetation map, ETM + satellite imagery by the use of remote sensing, and with using NDVI and formula of (3-1)

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$$\text{NDVI}=\frac{band\ 4-band3}{band4+band3}, \qquad (1)$$

in ENVI4.8 software was used to map vegetation in relation to the return value of -1(minus one) to +1(plus one).In this period, the number of 1 + indicates complete vegetation, -1 at last, the recognition of four story vegetation map of the study area classes were classified as: without vegetation, low vegetation density, dense vegetation, semi dense vegetation. Each of the above-mentioned classifications allocated a certain numerical value classes and in addition, the final vegetation map that was prepared in this way is shown in Figure 15The relationship between vegetation density and landslide indicates that classes without vegetation and low density vegetation, with very little difference, allocated first and second rank respectively in the occurrence of landslide. Afterwards, vegetation classes with average density are also placed in the third rank. Meanwhile, very dense vegetation classes occupy the last rank in the landslide.

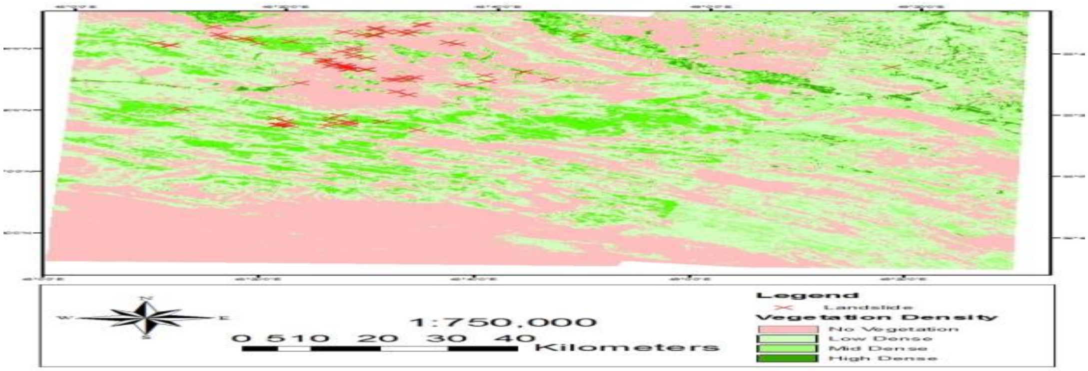

Figure 15: Scattering of landslide in vegetation density classes

Distance from network

Road construction in mountainous areas usually follows the topography and geo morphemic conditions. The most appropriate paths predicted for the design, and along the river is more in depth line. In this way, as usual, the alignment of the road is a few feet above the river. At intervals along the way, for road construction, shortening of the distance, widening of the railway roads, digging mountains, construction of trenches, tunnels and bridges are inevitable. Thus in those parts of the road that the mountains and trenches are constructed, the maintenance factor is removed from the footing of the slopes and the harmonized condition of slope stress toward the road becomes unstable. As a result, the potentials of happening landslides, rock fall, rock sliding and overturning rocks increases. During the intervals of first rank mountainous railway roads, for stabilizing the mountain slopes after constructing the trenches and digging mountains, attempts are done to build a retaining wall that is very expensive. Construction of retaining walls (Gabion package), drained and so on have potential instability in many cases have been reduced and in some cases due to the wring implementation of plans are not very effective (Haeri and

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Samimi,1988) Assessments on the variables and parameters of the network suggests that with increasing distance from the network, the landslide has decreased. This is to confirm the rules governing the relationship between the network and the landslide variables. Meanwhile, Class No. 5 also has the greatest distance from the network and frequency of landslides. This is undoubtedly a relationship between these variables and other variables, on the landslide phenomena (Table 4 and Figure 16).

Table 4: Distribution of landslide in the classes of networks

Number	Road	Weight	landslide%	area (km2)
1	0- 200	5	37.5	6295.07
2	200 -400	3	25	3756.87
3	400- 600	2	12.5	2582.07
4	600- 800	1	7.5	1978.27
5	>800	2	18.75	9312.84

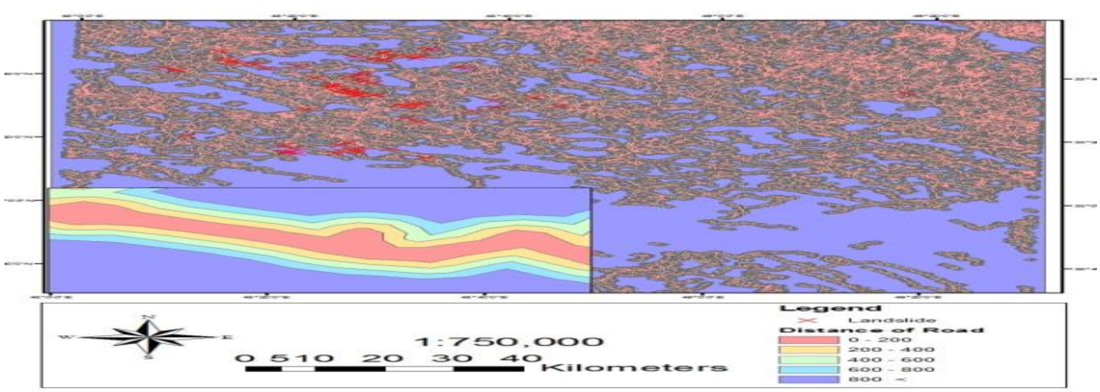

Figure 16: Distribution of landslide in the classes of networks

Distance from river

Foot washing and erosion on steep slopes and high flow rate by flood or surface runoff and river flows, is a Process that causes many slip phenomena. Foot slope erosion over time, caused by the flow of water destroys the harmonizing powers of the mass movement. This action increases the destructive effect of shear forces and eventually causes slope instability. The onset of instability is usually in the range of a series of tensile cracks that begin to fall or slip over time and lead to a mass (Jafari, 1996) According to the table 5, we found a clear relationship between grades 1-4 and landslides phenomenon in the study area. Thus, with increasing distance from the river, the landslide has been reduced. Meanwhile, Class Number 5 is 800 meters above the highest landslide in the study area. Contrary to the general rule, there is relationship between distance from rivers

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and landslides. For this reason, the relationship between these variables and other variables that influence landslide occurrence were investigated (Table 5 and Figure 17).

Table 5: Distribution of river distance and landslides

Number	River	Weight	landslide%	area (km2)
1	0 -200	2	7.5	1146.14
2	200-	2	6.25	972.39
3	400 -	1	3.75	927.89
4	600 -	1	1.25	949.7
5	>800	9	82.5	19929

Distance from Fault

The dominant weathering agent and crushed rocks, faults can act as a factor in the instability domain. The fault performance can be direct (moving the power Fault) and indirect (effects of lithology and slope). Therefore, the need to consider this factor as one of the factors involved in the occurrence of a range of motion is felt. In this regard, the fault map that was obtained in the first part of the thesis was used and according to the achieved results the distances of 500 meters was considered for this variable.

Table 6 shows that the class Number 5 has allocated the most landslides to itself. The class of 500-1000 meter has allotted the second rank and classes of 0-500, 1000-1500, and 1500-2000 have allocated subsequent ranks to themselves with minor differences.

This led to the study of the relationship between various parameters affecting landslide (Figure 18).

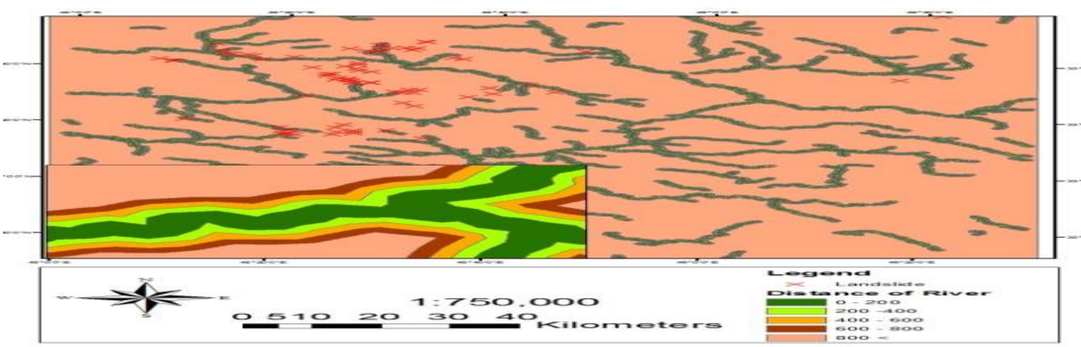

Figure 17: Distance from rivers and landslides.

Table 6: Scattering landslides in the faults classes

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Number	Fault (range, meter)	Weight	Landslide%	Area (km2)
1	0 -500	2	11.25	1990.14
2	500 -1000	3	15	1974.16
3	1000 -1500	1	8.75	1748.96
4	1500 -2000	2	10	1487.4
5	>2000	7	55	15725.08

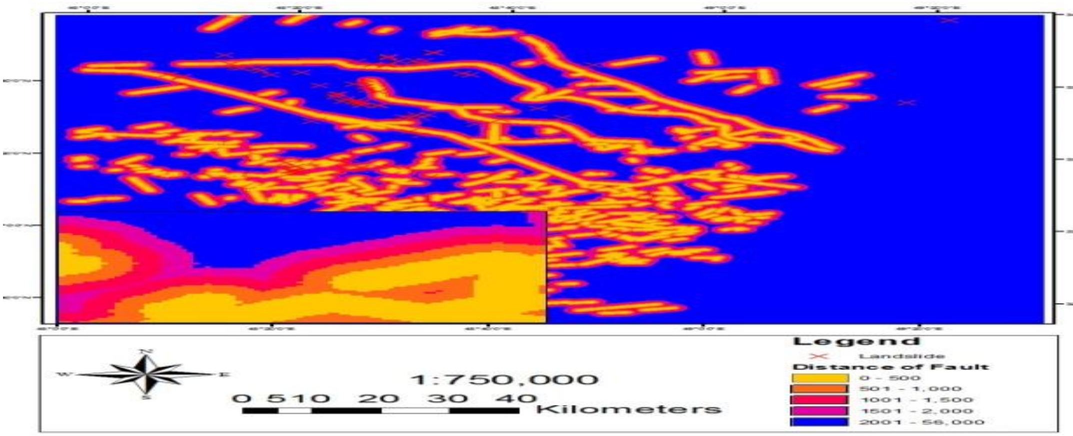

Figure 18: Scattering landslides in the faults classes

Methodology

Analytical Hierarchy Process (AHP) is flexible, powerful and easy to decide where conflicting decision criteria makes it difficult to choose among alternatives. Multi-criteria evaluation method first proposed in 1980 by Thomas L. hours already has numerous applications in various sciences. The method was chosen according to the following benefits for a range of selected movements' hazard zonation:

1. Using a combination of statistical features and GIS amenities
2. Easy Zoning by this method
3. Implementing of weights for all classes of effective variables with two different methods, or use of large number of influential variables.
4. Allowing different output maps, the ability to compare them with each other. In this way, one of the variables is landslide and rock fall, which is the dependent variable. The second variable can be any of the variables in the development of this movement, which plays the role of an independent variable. In this way, using the relationship that exists, the weight of each class is obtained. The weights are obtained, the final plan will be prepared for each of

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the variables as weight, and then all maps have the same weight that are associated with each pixel of the map. Finally, a plan is prepared for each pixel of this map equal to the sum of the pixels in different plans. After all these steps and mathematical and statistical calculations, the final maps of zonation are achieved. Then, the chosen maps are divided into safe, low-risk, medium risk, high risk and very dangerous classes. For this work, the pixel value is used in front of the frequency curve and by using slope break points, the borders of each class are obtained.

Classification using the hierarchical model (AHP)

Some of the used variables in examining the phenomenon of mass movement are qualitative. The decision, in terms of statistical analysis, becomes difficult. Therefore, to quantify these parameters, the AHP method is used. In both decisions are continuous or discrete (Mohammad, 2001). AHP is one of the most comprehensive systems that have been designed for multi-criteria decision. This process enables sensitivity analysis on the criteria and sub-criteria. In addition, it has been based on the paired comparison that simplifies the calculations and analyses. It also shows the compatibility to incompatibility rate that is a perfect advantage of this technique in multi-criteria decision-making. Furthermore, it has a strong theoretical basis and is based on clear principles (Ghodsi poor, 2006)

Point 1

Reciprocal condition

If preference of element A on element B is equal to N, preference of element B on element A is equal to 1/n.

Point 2

Principle of homogeneity

Element A and element B are the most Homogeneous and comparable elements. After all, preference of element A on element B cannot be zero or extreme.

Point 3

Dependency

Each hierarchical element can be associated with a higher level and this dependency can continue to a higher level in a linear way.

Point 4

Exception

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Whenever a change happens in the structure of hierarchy, the assessment process should be done again.

Weight Measurement

In the process of hierarchical analysis, the elements of each level are compared to a higher level and their weights are calculated the relative weight of the elements which are the relative weight of these elements. Then, by combining the relative weights the final weight of each element is called the absolute weight. All these comparisons in the hierarchical process are done in pairs. For measuring the variables, they must be compared in pairs or two by two. In this comparative issue, the basis of analysis is a 9-quantity table that has been designed from equal to infinite preferences, in a way that if the element of A is compared with the element of B, the decision-maker will say that the following features are important.

Judging by the small amount of time to convert 1 to 9 in Table 7 has been identified. When paired comparison matrix was formed, we can calculate the weight of all the variables. There are several ways to calculate the weight of each item as well as the paired comparison matrix (relative weight). The most important ways are:

- The method of ordinary least squares

- Logarithmic least squares method

Table 7: Preference values for paired comparisons

Numeric value	Preferences (oral assessment)	
9	Extremely preferred	Wholly preference or absolutely more important or wholly more desire
7	Very Strongly preferred	Preference or importance or very strong desire
5	Strongly preferred	Preference or importance or powerful desire
3	Moderately preferred	A little bit preference or slightly importance or slightly more desire
1	Equally Preferred	Preference or importance or Same desire
2,4,6,8		Preferences between above intervals

In the study, an approximate method (arithmetic mean) is used, which consists of three steps:

First step: should add the all amounts in columns.

Second step: Each element in the matrix of paired comparisons, the collection itself, is divided into columns that paired comparison matrix is normalized.

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Third step: the average value of the elements is calculated in each row of normalized matrix.

Therefore, the priority of each of the effective factors that caused mass movement within a range is based on the weighted average of the study. In the hierarchical model, after weighing all the classes of variables and the weights obtained for each class, we prepared the weighting map of each variable and multiplied this map to the obtained weighted coefficient (a1,…, a9) and then we achieved the results that led us to the final map. According to weight classes, the more number goes towards zero, the lower potential you will have for the occurrence of mass movements. In addition, the more it moves towards one, the basin will be more risky due to occurrences of these incidents.

The results of these steps were fully discussed in chapter four.

How to determine the relative importance of factors that influence the variability

According to different studies for each variable, specific weight or factor can be considered. There are three variables affecting overall weight of the landslide.

A) Blind Weight: This method is based on expert judgment and experience, weight or score is given to every effective factor. It is clear that this kind of weight does not have much credibility.

B) Weighted with the insight or vision: results and analyses of this method indicate that the statistical or mathematical foundations and the empirical studies have been done.

C) Weighting after the event: in this method after doing the necessary tests on the effective variables in stimulating or causing mass movements, an appropriate weight is given to every effective parameter. Obviously, this method requires special tools, because all the elements normally are not present in the method that is not accurate (Jaafari, 2007)

Zoning with GIS

GIS is a computer system for managing spatial data. The term indicates that the geographical locations based on geographic coordinates (longitude, latitude) are known or can be known. The term GIS system shows that it is connected to several parts with different functions. Thus, GIS is responsible for information systems, working capabilities, collecting, entering, processing, transformation, the image capture, composition, search, analysis, modeling, and data output. A geographic information system includes the cost of a bundle of letters on a computer with a working interface that provides access to special functions (Bonham, 24, 2000). GIS has many capabilities in zonation of the environmental phenomena that the other systems do not have. These features include analytic functions and systems integration.

In other words, the capability of the system, in combining spatial data with descriptive information in an integrated environment enables spatial analysis of geographic data. The

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geographic information systems are at the heart of the system. It can feed data and combine information; the new information is in the form of maps and tables, which are available to users.

Landslide hazard zonation

As human activities cause mass movements, they can also reduce or eliminate the occurrence of such phenomena effectively. Strategies, plans and implementations of civil projects should reduce the mass movements and limit the enhancement and development in the areas considering these movements. Also, a successful program in decreasing the danger is possible only by the active participation of people and the government. The first step to reduce its impact is to provide access to maps of potential land survey that show the occurrence of mass movements. The purpose of zoning is to divide the study area into regions and classify it according to the degree of stability of motion. The ultimate goal of the assessment and zoning of mass movements is to predict the future location of the occurrence of this phenomenon. Zoning of natural hazards depending on the objectives and risks occurs at different scales that measure macro and micro areas. So far, hundreds of natural hazards zoning maps have been prepared by using different techniques. The simplest type of zoning land is to divide it into two parts, secure and insecure. Complete and accurate zoning shows varying degrees of risk as negligible, low, medium, high and very high.

Zonation results using AHP Model

Zonation results by using AHP model consists of several stages. All of the steps described in Chapter 3 were conducted. Below, the results of each stage are shown.

Result of weights

The relative weight of each parameter has been calculated and priorities of each of the factors affecting the mass movement based on the weighted average of the study area were achieved. Full description is described as below (Tables 8 and 9).

Table 8: Paired comparisons between the factors influencing landslides in the city of Andimeshk and Doroud

Parameters affecting landslide	Distance to Fault	Distance from river	Network	Precipitation	Land	Vegetation	Geological formations	Slope
Distance to Fault	1	1/3	1/4	1/5	1/6	1/7	1/8	1/9
Distance from	2	1	1/3	1/4	1/5	1/6	1/8	1/9
Network	3	3	1	1/3	1/5	1/7	1/8	1/9
Precipitation	4	4	3	1	1/3	1/5	1/7	1/8
Land	5	5	5	3	1	1/3	1/5	1/7
Vegetation	6	6	7	5	3	1	1/3	1/5

Geological	7	8	8	7	5	3	1	1/3
Slope	8	9	9	8	7	5	3	1

Table 9: Relative weight of each of the parameters of the paired matrix

	Distance to Fault	Distance from river	Network	Precipitation	Land	Vegetation	Geological formations	Slope	Total	The relative weight
Distance	0.023	0.009	0.007	0.008	0.010	0.014	0.025	0.052	0.14	0.019
Distance from river	0.070	0.028	0.010	0.010	0.012	0.017	0.025	0.052	0.22 3	0.028
Network	0.093	0.083	0.030	0.013	0.012	0.014	0.025	0.052	0.37 2	0.046
Precipitati	0.116	0.110	0.089	0.040	0.020	0.020	0.028	0.059	0.48	0.060
Land	0.140	0.138	0.149	0.121	0.05	0.033	0.040	0.067	0.74	0.093
Vegetatio	0.163	0.165	0.208	0.202	0.17	0.100	0.066	0.094	1.17	0.147
Geologic	0.186	0.220	0.238	0.282	0.29	0.300	0.198	0.156	1.87	0.235
Slope	0.209	0.248	0.268	0.323	0.41	0.501	0.594	0.468	3.02	0.378

Slope = 378/0, geological constructions = 235/0, Vegetation = 147/0, landuse = 093/0, rainfall = 060/0, distance from the network = 046/0, 028 = distance from the river. / 0, distance from fault = 019/0.

The results of the weight map of each variable

By using scattering layer landslides and falling rocks that were incorporated in fieldwork, weight was given to all classes of effective variables and then the weighted map of each variable was weighted (Figures 19-26).

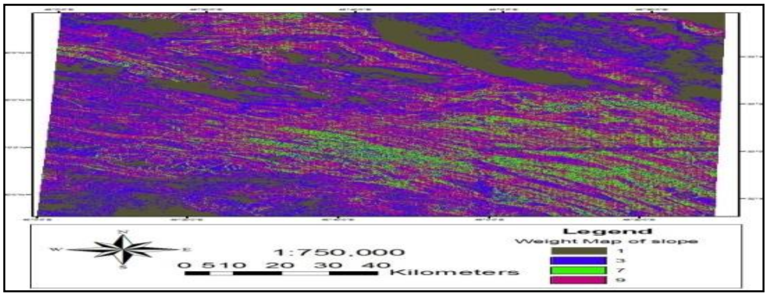

Figure 19: Weighted slop map

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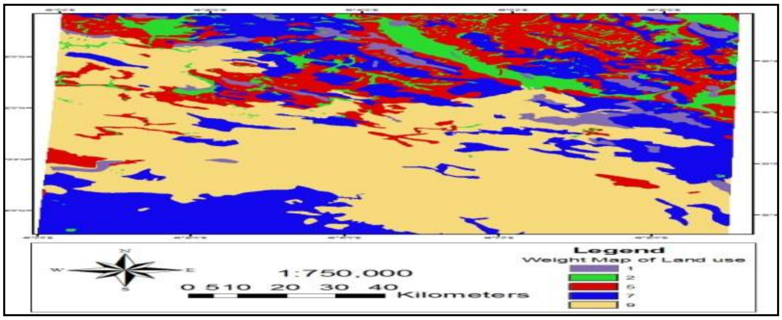

Figure 20: Land Use Map weights

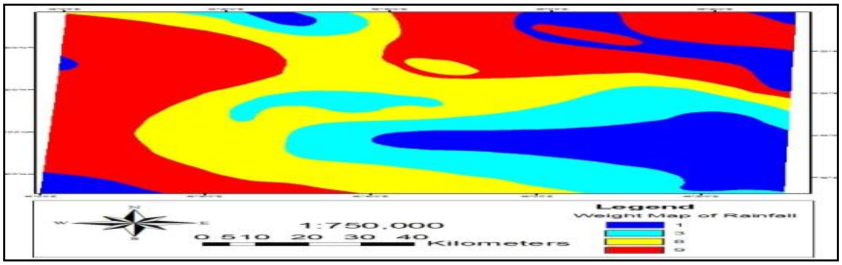

Figure 21: Weighted Rainfall Map

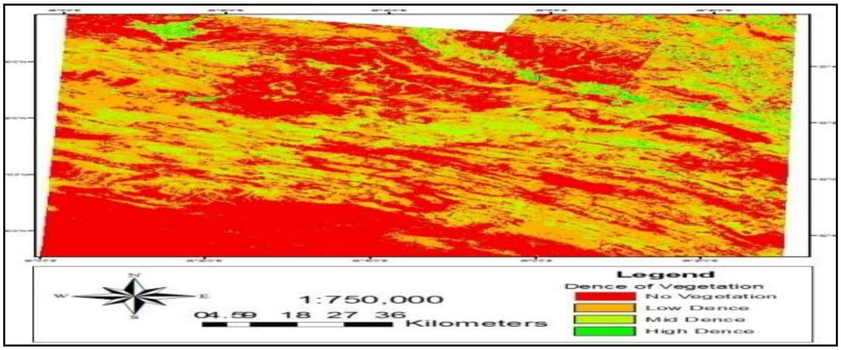

Figure 22: Weighted distance from vegetation density

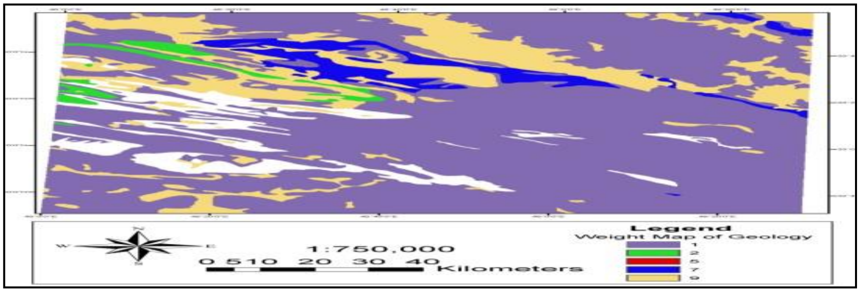

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Figure 23: Weighted geological map.

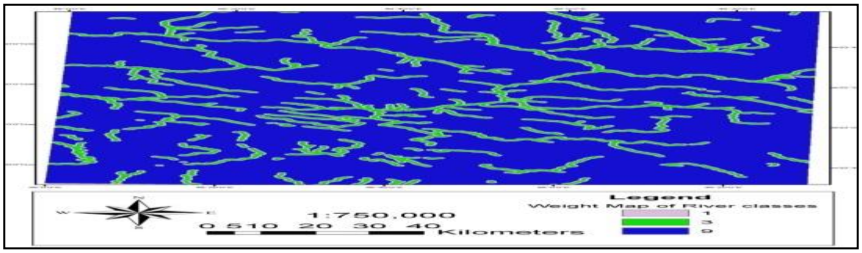

Figure 24: weighted distance from river

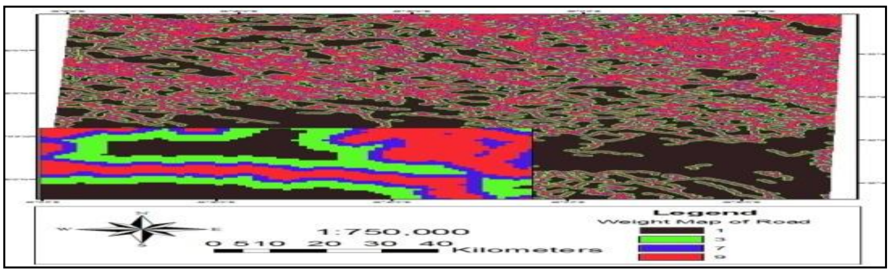

Figure 25: Map distances from road classes

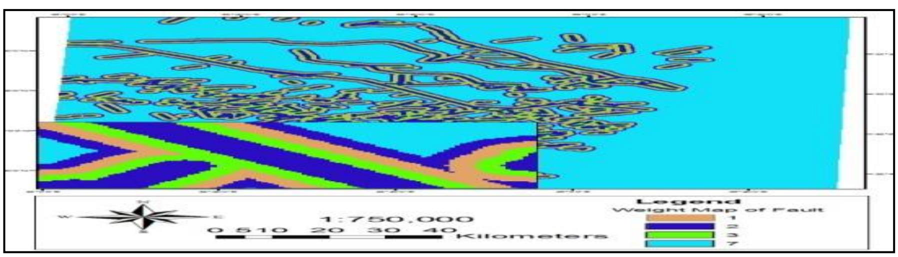

Figure 26: Weighted Map distance from fault

The weighting map of each parameter was multiplied in the relative weight of that variable. Consequently, the final map was achieved. Final Map = (weighted gradient map × 0.378) + (weighted map of geological formations × 0.235) + (weighted map of rainfall × 0.147) + (weighted map of land use × 0.093) + (weighted map of vegetation × 0.06) + (weighted map of distance networking × 0.46) + (× 0.028 weighted distance map of the river) + (weighted map of fault distance × 0.019). The final map of landslide hazard zonation (Figure 27) was prepared for the study area. These maps have been divided into five classes: no risk, low risk, medium risk, high risk and very dangerous.

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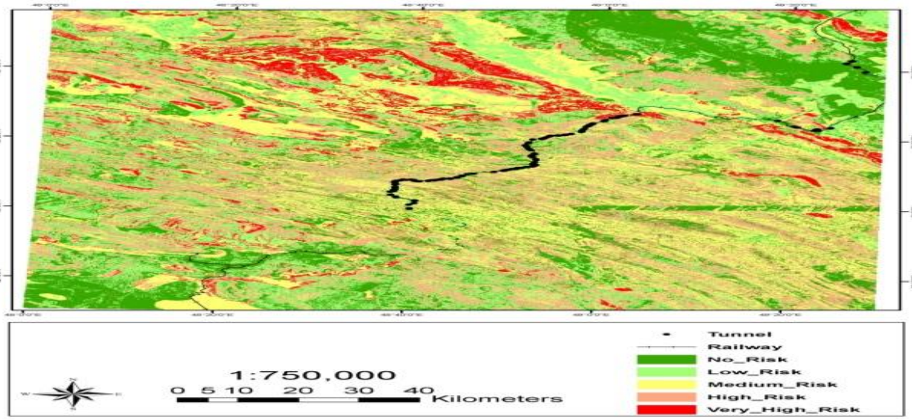

Figure 27: Landslide hazard zonation mapping scheme

Overlaying of the landslide risk zoning map and the railway

After preparing the final map of the landslide risk, we investigated the Andimeshk-Doroud railway line overlapping the railway layer and using risk-zoning map.

As table 10 illustrates, the total length of Andimeshk-Doroud railway lines in the study area was 443.58 km that the maximum length of this value in term of landslide is located in a safe area, and low risk and medium risk classes respectively allocated shorter length to themselves.

High risk and very high-risk classes respectively encompassed 32.87 km and 6.68km from railway lines length that totally is 39.55km or 8.92 percent of the total length of the Andimeshk-Doroud railway lines.

If we consider the length of railway lines in no risk and low risk areas, they have entirely allocated 63.33 percent to themselves that these values include more than half of the railway lines length.

However, the remaining 31.67 percent respectively has been allocated to medium risk, high risk and very high risk classes. In the other words for this amount of the railways, considerations should be taken.

Table 10: The length of railway lines in the various parts of the landslides risk zoning

Region	Zonation	Zonation (km2)	Length of railway	Length of railway(km)	Number of tunnel
No risk	21.32	4884.8	41.94	186.03	40
Low risk	22.39	5128.7	26.39	117.07	14

Medium risk	26.05	5966.66	22.18	98.38	64
High risk	24.99	5723.36	7.41	32.87	52
Very high risk	5.25	1203.61	1.51	6.68	8
Total	100	22907.13	100	443.58	178

Discussion and conclusion

This study addressed the design of spatial landslide model using the convolution kernel size technique on Digital Elevation Model (DEM) and LANDSAT ETM+, and Analytical Hierarchy Process (AHP) methods in the southwest of Iran. A few landslide causative factors were used in former studies in the area. Other causes of landslides were ignored by most of the researchers. In order to plan for landslides hazard mitigating, these methodologies have limitations. These new techniques and causative factors were developed and integrated with GIS in study area. Hence, the thematic data layers for the most important landslide causative factors, namely, Slope, Lithologic units, Rainfall, Distance from river, Vegetation density, Distance from network, Land Cover/Land use, Distance from the fault were used. These factors were selected according to knowledge acquisition from literature review and previous research, and field study. The relevant thematic layers were generated by using GIS and RS tools.

The raw data and thematic layers were processed and classified. The results were fed to GIS to determine the landslide hazardous areas. The following section presents the findings and contribution of the thesis.

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Volume: 8, No: 2, pp. 91 - 121
ISSN: 2059-6588 (Print) | ISSN: 2059-6596 (Online)

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