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# Landslide and Rockfall Susceptibility Mapping in Kabul-Jalalabad Road by Analytic Hierarchy Process (AHP) & Weighted Overly Mapping (WOM) Method in GIS

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## Abstract

*Landside and Rock falls are known as the most destructive natural hazards that threaten the inviolability of Human communities and infrastructures such as houses, Dames, Tunnels, Roads, etc. Roads in the mountainous area are known more vulnerable because of different factors like route cute disturbing and mass imbalances. Kabul-Jalalabad highway is a major part of Afghanistan's transitional route that connects the central regions to the eastern part of the country. The transportation system of this route is threatened by mass movement and rockfall events.* This *study used nine conditional factors including slope, lithology, (TWI), road distances, LU/LC, Curvatures, slope direction (aspect), precipitation, and fault distance. two modules (Analytic hierarchical process (AHP) and Weighted overly mapping (WOM)) are used in this study, Finally, the Landslide Susceptibility Map(LSM) of both modules is Classified into five zones(very high, high, moderate, low and very low ) of susceptibility in Arc GIS 10.8; after pairwise comparison in spice-logic 4.1.4 software; slope, lithology, slope direction, precipitation, and fault distance respectively identified as effective factors in landslides and rock fall susceptibility, final (LSM) of both methods shows that high and very high levels sensitivity zones Covers 21.35%, 8.43% for AHP and 40.16%, 10.72% for WOM modules respectively, Accuracy assessment of both module done based on 101 locational denoted landslides, (ROC) curve and AUC index are used to classifiers accuracy evaluation; finally AHP module known as much better than (WOM) one because of its (AUC) value that shows 0.923(Excellent) greater than 0.845(very good) (AUC) index of (WOM) module.*

**Keywords**: Landslide, rock fall, susceptibility, AHP, WOM, Kabul-Jalalabad highway, ROC.

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## 1. Introduction

Landslides and rock falls are known as one of the most common Natural hazards that threaten human civilization and welfare in many parts of the world.[1]. These phenomena are defined as mass (soil and rocks) movement in an unstable condition which often led massive damage to humanity as much as economic loss, financial cries even injuries or Causalities [2]. In human civilization, roads are one of the most important infrastructures which bring facilities for transportation and as well as economic trades that play a great role in the welfare of society, economic growth, and development of communities. The financial budget spent for the construction of roads in different geographical locations depends on the variety of environmental, climatic, and other natural conditions that requires for its construction, as well as its maintenance and safety. At the same time, the majority of landslides occur along the roads [3].it means protection of this national capital is necessary for the long-term suitable use of them.

Kabul-Jalalabad highway is one of the busiest and most important routes in Afghanistan; this route is characterized by a large exposure to slope instabilities and landslides, rock fall threatening roads according to climatic and physiographic conditions. The dominant topographic features result from active tectonic events; they are mainly high in its western parts and extend to, depressions, and deep valleys in the central (Laghman province) and eastern (Nangarhar province) parts. Landslide susceptibility mapping is a novel attempt in Afghanistan; it can be used as an efficient tool that gives additional efforts in landslide mitigation in a different part of the country. This phenomenon also causes a lot of damage and many problems, and along with that, that increases the cost of road construction, the cost of maintenance, repairs, and reconstruction, meanwhile such unexpected accidents disrupt transportation and increase traffic risks; therefore Identifying the effective factors in the occurrence of landslides in an area and zoning its risk is one of the basic tools to achieve solutions to control this phenomenon and select the most appropriate and practical option.

Landslide and rockfall mitigation are one of the contemporary attempts in the survey, construction, and maintenance of roads, and its potential susceptibility mapping is accomplished by different methods all across the world. Landslide susceptibility methods and modules are developed by researchers and experimented accord to various conditions in different parts and points of the earth; one of the much more sophisticated and more advised modules for different natural hazards mitigating like flood hazard and areal potential sensitivity evaluating method that based on probabilistic approach is analytic hierarchy process (AHP) that widely used and experimented at different causes by researchers like C Other methods have also been recommended and used including the

frequency ratio logistic Regression (LR)by researchers like [4,5] and weights of evidence (WoE) used by [6,7].

This study aimed to provide and develop a probabilistic-based approach that was completed on landslide and rock fall susceptibility assessment along the Kabul- Jalalabad highway by applying two methods. The first one is the analytic hierarchy process which is a multi-parametric method that was originally developed [7]. The second one is Completely GIS-based methods that call weighted overly mapping (WOM) algorithms, that widely used by many researchers all across the world and produce landslide susceptibility maps in a quite unpretentious manner [8,9,10].

## 2. Geographic and Natural Characteristics of Rout of interest (ROI)

The studied route was the Kabul-Jalalabad highway. This highway with a length of 104 km was put into operation in 2010. A large part of the route passes through mountainous areas with a narrow structure and is located in parts close and parallel to the Kabul and Alingar rivers. Often the road is built as a trench in the heart of the mountain and in some places, it is accompanied by tunnels and passes over embankments or bridges at the valley's intersection points. The project starts from the center of Kabul city, crosses the Mahipar and its heights, and faces the soroby plains. Crossing the vicinity of Daronta Dam, it leads to Jalalabad city. The highest height of the studied route is 2514.76 meters above sea level.

The western part of the road specified with high elevation, steep slope, and mountainous physiography mainly surrounded by different types of sedimentary (polyester calcites and Dolomites, conglomerate, etc.) and highly jointed and fractured metamorphic and igneous (schist, Gneiss, marble, Amphibolite, Granite Diorite, etc.) Rocks. At the area near the soroby suburb area of Kabul, this road passes from hill shaped and relatively plate area containing Cenozoic Clastic sedimentary rocks. After that road extends to a valley continued parallel to the Kabul river, which is familiarly known by the name of Silk valley, that is characterized by a steep slope and highly faulted and fractured metamorphic and igneous rocks that end in the patented area mainly composed by sedimentary fasces.

The studying portions of the road end at approximately 1 km extended with a steep slope and unstable state jointed Granodioritic rocks which causes rock fall events often more.

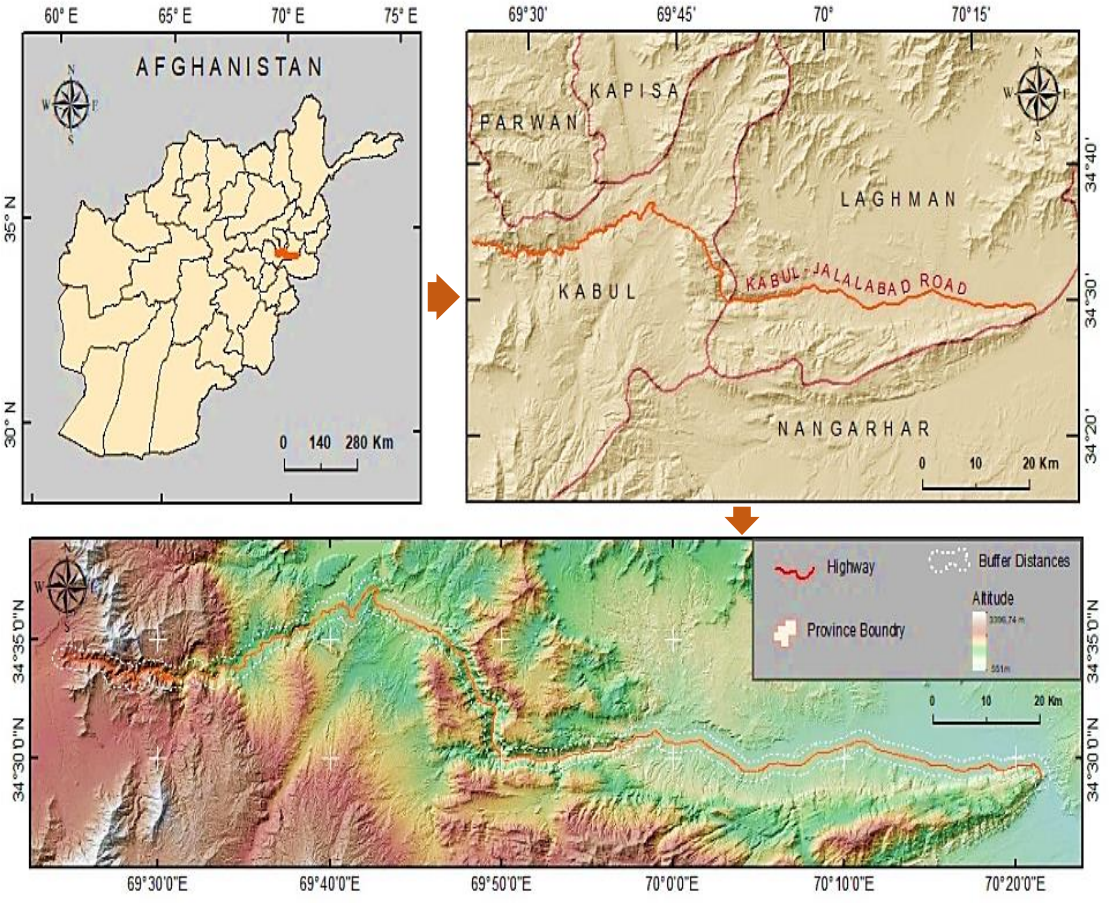



Fig. 1: Map of studying Road.

The eastern point of the road is ended at the Daronta subarea of Jalalabad city. Due to the difference in height, which can be seen in the studied route, from (586m) to (2514.76m) with different climatic varieties. As in the western parts of this route, the rainfall amount and temperature are relatively high than the temperature during the year in the eastern regions. The beginning of the route has a latitude of 34˚ 34′ 02″ North and a longitude of 64˚ 24′ 17″ East, and the end of the route passes through the latitude of 34˚ 29′ 08″ north and a longitude of 71˚ 21′ 34″ east (Fig.1).

## 3. Materials and Methods

Landslide is the result of static imbalances, especially in man-made disrupted areas. The stability of slopes is controlled by various natural and human interrupting factors. Recognition of these factors is so important for determining the affecting causes of the occurrence of landslides [9]. Therefore, in the first stage, spatial information was collected, according to a similar previously conducted Approaches, based on reviewed

literature at all (9) factors are considered for preparing a landslide sensitivity map in the area the selected factors including the type of lithology, land use, and Land cover, road distances, faults distance, Curvatures, topographic wetness index (TWI), precipitation, aspect (Slope direction), which described respectively as follows and concluded in the table (1).

### 3.1.Lithology:

The lithology is the most important factor in the analysis of natural hazards and many morphological features of lands and land surface characteristics depend on its type [10]. The lithological information used in this research was extracted from the 1: 100000 scale map of Afghanistan lithology shape file and after experimental interpretation, classified in to (6) classes as Class_1, 2 ,3 ,4,5,6 which Categorized respectively like ;Class_1(Mica, biotite, biotite-amphibole, garnet-biotite, garnet-sillimanite-biotite, pyroxene-amphibole gneiss, plagiogneiss, and schist, migmatite, quartzite, marble, amphibolite; Class_2 (Limestone, dolomite, marl, Mica, biotite, biotite-amphibole, and garnet-biotite gneiss, plagiogneiss, migmatite, quartzite, marble, amphibolite, Granodiorite, Alas kite, Granosyenite, Granite, Granite), Class_3 (Limestone, marble, quartzite, metasandstone, mica chist), Class_4 (Dunite, Peridotite, Serpentinite Limestone, dolomite, marl, conglomerate, sandstone, siltstone, shale, bauxite and bauxite-bearing rocks Sandstone, siltstone, mudstone, carbonaceous shale marl, conglomerate, weathered acid and mafic volcanic rocks), Class_5 (Gray conglomerate, gravel stone, sandstone, siltstone, clay, limestone, marl, gypsum, salt, acid and mafic volcanic rocks Shale, phyllite, mafic volcanic rocks, limestone ), Class_6 (Conglomerate, shingly sediments, gravel, sand, siltstone, breccia, limestone, gypsum, clay, loam; andesite, dacite and their tuffs (Dashtinovar Group); phonolite and soevite) which thematically Spatial extend shown in (Fig.2b) and table (2 & 5).

### 3.2. Tectonic Fault distances:

The fault distance layer from tectonic failures is also considered one of the potential factors for landslide occurrence and mass movement phenomenon. This issue is considered significant because of its localization in a new and relatively active tectonic setting of Afghanistan which is characterized as areas with strong topographical relief, which know as a result of continuous fractures in this route and the erosion of the Kabul River. Tectonic liniments were extracted from the 1:100,000 tectonic map of Afghanistan and after the essential correction Zoned in 5 Buffering distances as shown in, Table (5) and (Fig .2d).

### 3.3.Land cover and land use

**(Lc/Lu**: Land use and land cover (Lc/Lu) are crucial factors in the occurrence of landslides because they considerable impact on slope stability [11]. The importance of this component is determined by the amount of rainfall and the slope of the ground. Landslides are more likely to occur naturally in areas with steep slopes, moderate vegetation, and heavy rainfall [12]. ; land use and land cover map along the studded route was taken from a 1: 100000 scale Shapefile of Afghanistan's land cover map, which was divided into five Classes as Class_1 (Guardian and fruit trees,) Class_2 (Plate irrigational and Cultivation area), Class_3 (Marshland Permanently inundated lands), Class_4 (Rangeland) and Class_5 which contain Rock Outcrop and Bare Soil that represented in (Fig. 2c) and table (5).

### 3.4.Slope:

The slope has an essential role in controlling material slippage by increasing the Slope angle, the instability of materials (soil and rock) also increases. To extract this variable DEM data with a spatial resolution of (30m*30m) was used and its thematic map was provided by the use of the Slope algorithm under the Spatial Analysis tools of ArcGIS10.8 program. The slope of the study area varies from (0) degrees to (>72.4) degrees and was classified into (5) equal interval-based division Classes as shown in table (5) and (Fig.2g) .This factor is considered as one of the most important indicators in the study of hazards and natural processes (landslides, rock fall, soil erosion, groundwater potentiality detection, location of agricultural areas, etc.).For landslide risk zoning slope used widely by researchers like [12, 13] that Slope factor has been considered the most important one.

### 3.5.Aspect:

Aspect or slope direction is also considered a very important factor in the analysis of environmental hazards and the preparation of landslide susceptibility maps [13, 14]. which controls the amount of humidity and diversity of vegetation with the proportional absorption of light and solar energy [15] aspect classification is done in ArcGIS 10.8 software environment by using a Digital elevation model (DEM) (with a cell size of 30m x 30m) table (1) which used for other factors like Slope and curvature, Aspect of studying road classified into five Classes ( Plate area, North, East, south, and west) as mentioned in Table (5) and (Fig. 2f) thematic layer.

### 3.6.Topographic Curvature:

The Topographic Curvature provides influential information about the land surface stability its role in landslides is its ability to concentrate and disperse surface water currents, which therefore plays a key role in water infiltrations and their extent [16]. The Topographic Curvature is the convexity and concavity of a surface using consecutive topographic distances, this factor is produced in Arc GIS10.8 by the use of DEM data with similar resolution as slope and aspect, Curvatures done by the Curvature algorithm of Spatial Analyze tools, Curvature values vary from (-22.3 to +22.4) so that the positive values represent a convex and the negative values concaves and areas with zero values shows flat areas this variable were classified into 3 Classes based on the above characteristics. (Fig 2e).

### 3.7.Topographic wetness Index (TWI):

This index is one of the important factors in landslide risk assessment analyses. TWI is introduced by Beven and Kirkby [17] and is considered in most landslide research. The topographic wetness index is defined by (Eq.1).

$$TWI = \ln\left(\frac{S}{tan \propto}\right) \qquad \text{(Eq. 1)}$$

Where, S; is the specific area of the water basin, α; is the Slope of the area. This index was analyzed using (30m*30m) resolution DEM data in the ArcGIS10.8 program, and values vary from (3.75 to 24.3) and classified into 4 classes with manual intervals as shown in Table. (5).and (Fig. 2h).

### 3.8.Annual precipitation:

rainfall is the most important factor in natural disaster assessment such as landslides, rock Falls, mass movements, vegetation varieties and distribution, plant type and density, lithology (type of rocks), and know one of the most important factors in landslide occurrences, it is considered that it would be wrong to address issues such as landslides without considering it. The role of rainfall is mentioned in the works of [18,19] specified as an important and effective factor, which is more diagnostic and important. The average rainfall information of the study area, after being found from the site [20] and then interpolated with IDW method converted to Raster format, which shows the difference between the average rainfall in the study area from (572.01 to 701.17) mm/year, which was classified into 4 classes by manually interval manner in Arc GIS 10.8 as mentioned in Table (5) and (Fig. 2a).

### 3.9.Road distances:

The road distance is one of the most important human interrupt factors of natural hazards that leads to the instability of the slopes and leads to slipping and crawling of the slopes, which is due to the extension of the road from high to low slopes due to disturbance of the static balance of areas, and vibrations caused by crossing heavy vehicles and trucks which considered as a potential cause of landslides; The distance from the road factor can be mentioned in the works [21]. The road used in this study includes the main portion of (Kabul-Jalalabad road) which after its geometric correction by equidistance's algorithm under the Spatial Analysis tools road distance zoned in <150m,(150-300)m, (300-450)m,(450-600)m,(600-750)m that mentioned in Table (5) and (Fig. 2i).

Table 1: Data sources and their resolutions.

| Data type | Sours | Scale / Resolution |
|---|---|---|
| Lithology | Afghanistan Geology Map<br>Shapefile from. USGS spatial Data catalog. | 1:100000 |
| Land use and land cover | Afghanistan Geology Map<br>Shapefile from. USGS spatial Data catalog. | 1:100000 |
| Fault distances | Afghanistan Geology Map<br>Shapefile from. USGS spatial Data catalog. | 1:100000 |
| Road distances | Extracted on Google earth. | |
| Precipitation | https://pps.gsfc.nasa.gov | |
| Slope | Based on DEM data received from the Earth Explorer site. | 30m*30m |
| Aspect | | |
| Curvatures | | |
| Topographic wetness index (TWI) | | |

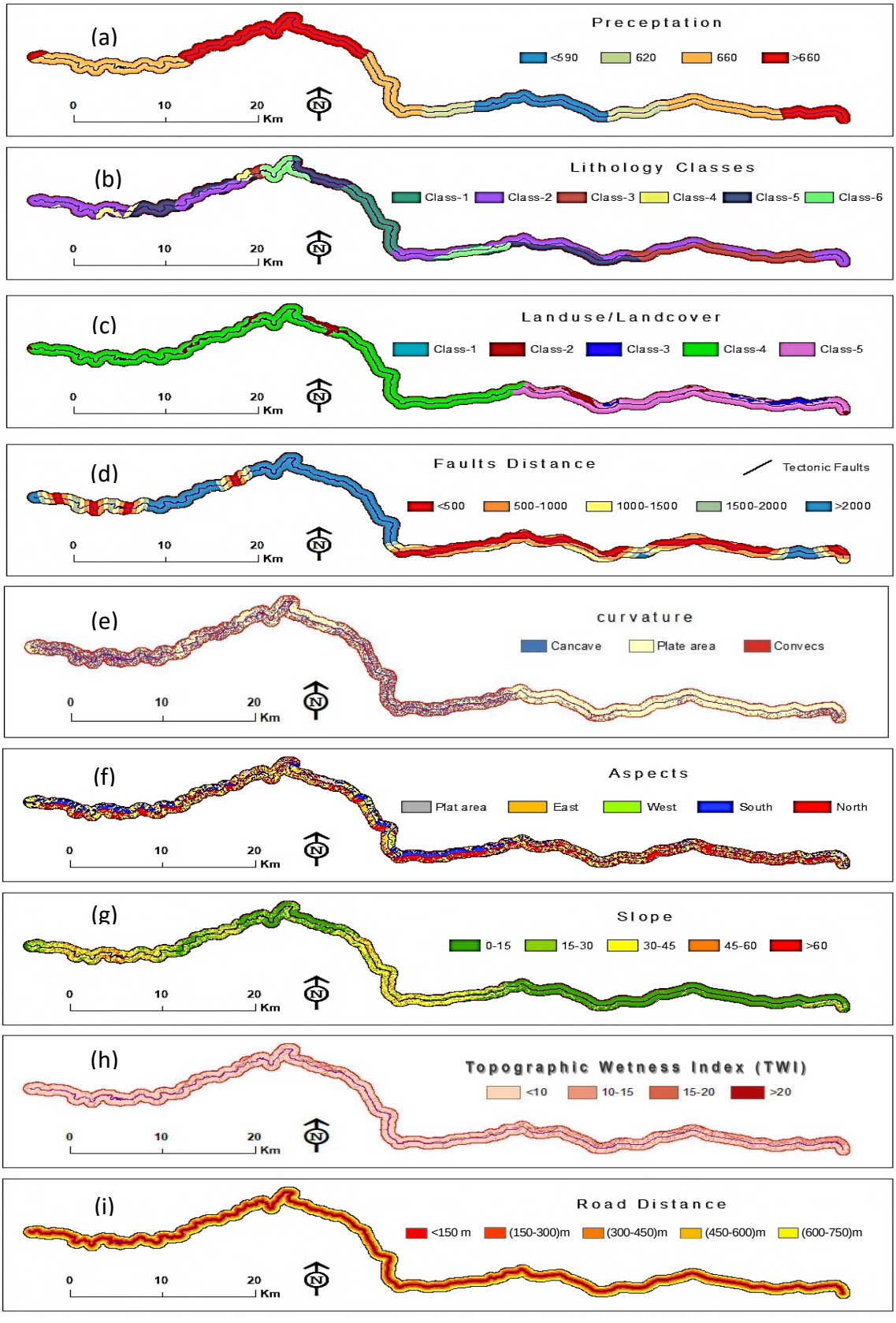



**Fig. 2**: Classified thematic map of all criteria; (a) precipitation, (b) Lithology, (c) Land cover and Land use, (d) Fault distance. (e) General Curvature, (f) Slope Aspect, (g) Slope (h) Topographic Wetness Index (TWI), (i) Road distances.

## 4. Methodology

A natural disaster like landslides, flood hazards, and rock falls Susceptibility analysis depends on several factors, identifying the influence role of factors that affect the occurrence of such a natural disaster is the first essential step to their assessments. In this study, to receive the most influential factors and phenomenon, by reviewing the necessary sources and references, formal and valuable information bases such as Afghanistan Natural Disaster Management (ANDM), land transport service departments, and scientific sources of landslide information were collected.

To enrich the spatial information sources, landslides, and rock fall along the studied route field visits and interviews with professionals and people living in the nearby area of the study route have been done and all this information is stored in a suitable database stored in a GIS environment. to identify the role of influence factor of landslide, referred to similar works of researches through Google Scholar, research gate, Science direct, and after receiving information and selecting the decision-making method and identifying the facility of ArcGIS to weight overly mapping (WOM) after all over special judgment carried out in Arc GIS 10.8 and also used analysis hierarchy Process (AHP) method. After analyzing the role of risk factors for landslides and rock falls susceptibility along the Kabul-Jalalabad route in the GIS environment, spatial analysis was performed with overlay and Raster calculator function of spatial analysis tools; overall configuration and essential steps of this research are shown in (Fig .3).

Table 2: Pairwise Comparison table of main factors.

| | (X1) | (X2) | (X3) | (X4) | (X5) | (X6) | (X7) | (X8) | (X9) | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| Lithology(X1) | 1 | 1/2 | 5 | 3 | 5 | 3 | 5 | 5 | 1/2 | **0.191** |
| Slope(X2) | 2 | 1 | 7 | 5 | 3 | 3 | 5 | 6 | 2 | **0.276** |
| land cover(X3) | 1/5 | 1/7 | 1 | 1/3 | 1/2 | 2 | 2 | 3 | 1/3 | **0.056** |
| Precipitation(X4) | 1/3 | 1/5 | 3 | 1 | 4 | 2 | 3 | 2 | 1/2 | **0.106** |
| Fault distances(X5) | 1/5 | 1/3 | 2 | 1/4 | 1 | 2 | 2 | 2 | 1/2 | **0.069** |
| Road distances(X6) | 1/3 | 1/3 | 1/2 | 1/2 | 1/2 | 1 | 2 | 2 | 1/4 | **0.052** |
| TWI(X7) | 1/5 | 1/5 | 1/2 | 1/3 | 1/2 | 1/2 | 1 | 1/3 | 1/6 | **0.030** |
| Curvatures(X8) | 1/5 | 1/6 | 1/3 | 1/2 | 1/2 | 1/2 | 3 | 1 | 1/4 | **0.040** |
| Aspects(X9) | 2 | 1/2 | 3 | 2 | 2 | 4 | 6 | 4 | 1 | **0.181** |
| * Consistency Ratio | 0.066 | | | | | | | | | |

Form of this study is divided into three main stages; First stage is defining the length and wide range of the studding route in this case long portion of the Kabul-Jalalabad road is considered as long as 104 km and buffered by 750m for each side road's center line second stage is the selection of criteria and sub-criteria that have influence role on the occurrence of landslides and rock falls. In the third stage, the pairwise comparison is done based on the analytic hierarchy process (AHP) due to more flexibility and facilitates The spice-logic 4.1.4 software is used to extract the weight of criteria and in the third stage weight of all criteria and sub-criteria defined for their relevant thematic layers, finally according to (Eq.7) AHP method defined to graphic form of statistic representation and spatial distribution.

### 4.1. AHP Method

The analytic hierarchy process (AHP) is a method for prioritizing criteria that extracts scaled weight of influence factors through the expert judgment of the problem and pairwise judgment of criteria and sub-criteria [21].

This module uses in hierarchically organized decision-making issues that contain a limited number of elements at different levels [22] (Fig.3). The hierarchical structure measures and combines different factors in complex decision-making processes and simplifies the combination of different components of factors into a common whole matrix of rational values [23].

AHP is considered a decision-making and forecasting method that plays the role of decision factors and criteria in terms of the factors that affect it, which can be used if the decision hierarchy is defined [24]. In performing pairwise comparisons, factors (criteria) preference intensity assessment or relative importance which extract after pairwise comparison by numerical values scaled from 0 to 9 (Table .3)

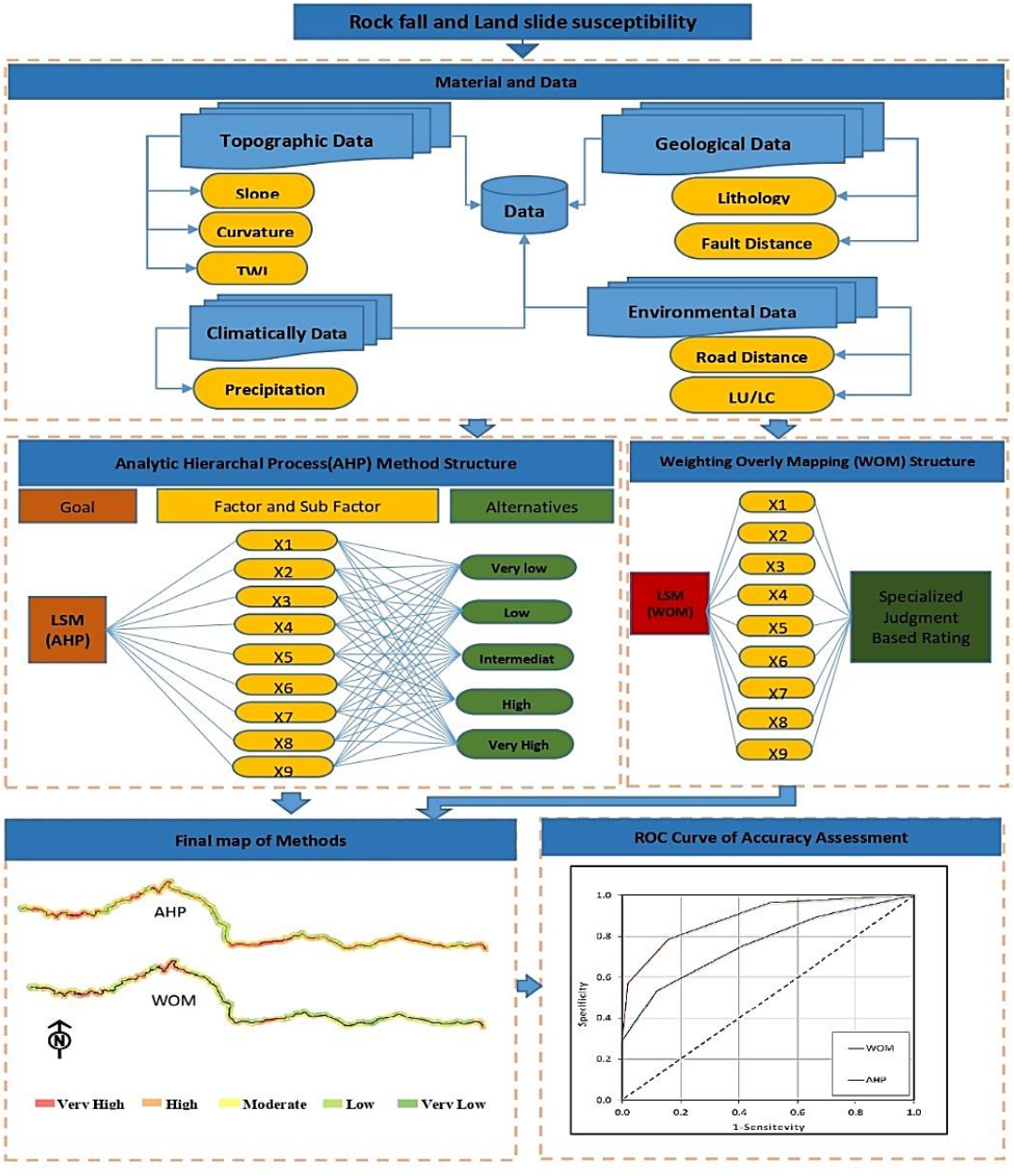



**Fig. 3**: Flow chart and essential steps of conducted research methods.

Table 3: Numerical scaled value for pairwise comparison [25].

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

A comparison matrix like Table (2) is then constructed with the results of the preferred intensity evaluation and the values are compared accordingly to solve the principal eigenvalue λ therefore, the total information value in a grid cell j is computed using (Eq. 2)

$$\lambda_* = \sum_{i,j=1}^{n} C_i \, v_j \qquad \text{(Eq. 2)}$$

Where $\lambda_*$ is the matrix values of compatibility vectors obtained from the sum of the multiplication between each specific vector element and the normalized relative weight considered parameters; $C_i$ is the normalized weight of I Criterion; $v_j$ is the standardized score of j Criterion; i and j are consecutive digit numbers (1, 2, 3…n ) [26].

An important condition in a hierarchical decision-making problem is to avoid inconsistencies that should be avoided in the decision-making process using the AHP method. Despite this inconsistency should not exceed a certain threshold that defines as (Eq.3) [27].

$$CR = \frac{C\,I}{RI} \qquad \text{(Eq .3)}$$

Where CR is the consistency Ratio; CI is the consistency Index which obtains from (Eq.4).and RI is the Random consistency index that depends on the degree of comparison matrix and is obtained from the table (4).

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad \text{(Eq. 4)}$$

Table 4: Degree of matrixes-based incontinency ratio determination [24].

| n | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.51 |

The Consistency Index will be equal to the number of comparisons considered (n), so the CI will be equal to zero to ensure the compatibility ratio (CR) ensures that the original preferential ratings are consistent. In calculating CI, the normalized relative weights and the normalized principal vector, and the principal specific value (λ) is first calculated. λ is simply the mean of the eigenvalues of the comparison matrix [28]. According to [29].The Nature of AHP is a solution to an eigenvalue problem that involves cross-matrix comparisons.

The above processes are run to extract prioritizing values for each factor this method can be summarized in the main steps as follows:

1. Problem recognition for decision
2. Creating a hierarchical structure of the problem at the three levels of purpose, criteria, and options.
3. Perform pairwise comparisons between criteria using the intensity scale and determine the weight of the criteria in order.
4. Calculate the maximum specific weight, compatibility ratio, and normalized values for each criterion/alternative.
5. For an unacceptable CR value, i.e. > 0.10, the comparison must repeat his judgment in pairwise comparisons until the CR value is at an acceptable level [30].
6. Defining the weighted value of each class suitably, and running conclusive formula of module like (Eq.5)

AHP gained its importance, especially in decision-making, due to its interactive graphical user interfaces, automatic calculation of priorities and variables, and sensitivity analysis [31]. Perhaps one of its main advantages is that it provides the ability to measure the consistency of decision-makers preferences and to manipulate quantitative and qualitative criteria [32]. However, the final decision made using the AHP method is based on subjective assessments, especially during pairwise comparisons [33]. In this manner rock fall and landslide susceptibility map (LSM) was finalized by the use of all already weighed criteria and sub-criteria in (Eq.5)

$$LSM = \sum_{i=1}^{n} R_i \times W_i \qquad \text{(Eq. 5)}$$

Where $R_i$ is the rating score of each layer and $W_i$ is the weights for each of the landslide conditioning factors [34].

These observations are confirmed by [35] that decision-makers in any decision problem can be subjective and uncertain about their level of priority, mainly due to incomplete and uncertain knowledge or information in the decision environment. Therefore, their preferences are subjective and their choices are influenced by sufficient information. In addition, in a decision-making process [36] described the term “mental uncertainty" as scientific ignorance, measurement uncertainty, inability to verify or observe, censorship, or other knowledge deficiencies.

### 4.2.Weighted Overlay Mapping (WOM) Method

The weighted overlay mapping (WOM) method is a simple and direct tool of Arc GIS to produce a susceptibility map [37, 38]. Many researchers used WOM to produce landslide susceptibility maps [39,40,41]. We used an overlay of raster layers of all controlling factors to prepare a susceptibility map. Raster layers of each controlling factor were reclassified and weighted according to their importance determined by AHP (Table 2 & 5). The cumulative weight of all 9 inputting layers was maintained at a total of 100. All layers were combined by using a weighted overlay tool based on the following (Eq.5).

$$S = \sum W_i S_{ij} / \sum W_i \qquad \text{(Eq. 6)}$$

Where $W_i$ is the weight of the $i^{th}$ factor, $S_{ij}$ represents the subclass weight of the $j^{th}$ factor and S is the spatial unit of the final map. The completion of this process resulted in the ultimate production of a landslide susceptibility map of the Highway (Fig. 4a).

Table 5: Overall and individual weight of criteria and sub-criteria.

| Factors | Classes | Caparison matrix | | | | | | Weight |
|---|---|---|---|---|---|---|---|---|
| | | Class_1 | Class_2 | Class_3 | Class_4 | Class_5 | Class_6 | |
| Lithology | Class_1 | 1 | 1/2 | 1/4 | 1/4 | 1/9 | 1/9 | 0.033 |
| | Class_2 | 2 | 1 | 1/2 | 1/3 | 1/4 | 1/3 | 0.069 |
| | Class_3 | 4 | 2 | 1 | 1/3 | 1/3 | 1/3 | 0.102 |
| | Class_4 | 4 | 3 | 3 | 1 | 1/2 | 1/3 | 0.172 |
| | Class_5 | 9 | 4 | 3 | 2 | 1 | 1/2 | 0.268 |
| | Class_6 | 9 | 3 | 3 | 3 | 2 | 1 | 0.356 |
| CR = 0.037 | | | | | | | | |
| | | 0-15 | 15-30 | 30-45 | 45-60 | >60 | | |
| Slope | 0-15 | 1 | 1/3 | 1/4 | 1/7 | 1/9 | | 0.040 |
| | 15-30 | 3 | 1 | 1/2 | 1/3 | 1/4 | | 0.099 |
| | 30-45 | 4 | 2 | 1 | 1/2 | 1/2 | | 0.173 |
| | 45-60 | 7 | 3 | 2 | 1 | 1/2 | | 0.278 |
| | >60 | 9 | 4 | 2 | 2 | 1 | | 0.409 |
| CR = 0.011 | | | | | | | | |
| | | Class_L1 | Class_L2 | Class_L3 | Class_L4 | Class_L5 | | |
| Landover | Class_L1 | 1 | 1/3 | 1/2 | 1/6 | 1/9 | | 0.045 |
| | Class_L2 | 3 | 1 | 1/2 | 1/2 | 1/4 | | 0.104 |
| | Class_L3 | 2 | 2 | 1 | 1/2 | 1/7 | | 0.117 |
| | Class_L4 | 6 | 2 | 2 | 1 | 1/2 | | 0.231 |
| | Class_L5 | 9 | 4 | 7 | 2 | 1 | | 0.503 |
| CR = 0.038 | | | | | | | | |
| | | <590 | 590-620 | 620-660 | >660 | | | |
| Precipitation | <590 | 1 | 1/3 | 1/3 | 1/5 | | | 0.078 |
| | 590-620 | 3 | 1 | 1/3 | 1/3 | | | 0.156 |
| | 620-660 | 3 | 3 | 1 | 1/2 | | | 0.299 |
| | >660 | 5 | 3 | 2 | 1 | | | 0.466 |
| CR = 0.049 | | | | | | | | |
| | | Concave | Plat area | Convex | | | | |
| Curvatures | Concave | 1 | 2 | 1 | | | | 0.376 |
| | Plat area | 1/2 | 1 | 1/4 | | | | 0.149 |
| | Convex | 1 | 4 | 1 | | | | 0.474 |
| CR = 0.046 | | | | | | | | |

Continue of Table 5

| | | <500m | 500m-1000m | 1000m-1500m | 1500m-2000m | >2000m | Weight |
|---|---|---|---|---|---|---|---|
| Fault distances | <500m | 1 | 6 | 2 | 4 | 9 | 0.517 |
| | 500m-1000m | 1/6 | 1 | 2 | 2 | 2 | 0.167 |
| | 1000m-1500m | 1/2 | 1/2 | 1 | 2 | 3 | 0.164 |
| | 1500m-2000m | 1/4 | 1/2 | 1/2 | 1 | 2 | 0.095 |
| | >2000m | 1/9 | 1/2 | 1/3 | 1/2 | 1 | 0.057 |
| CR = 0.065 | | | | | | | |
| | | <10 | 10-15 | 15-20 | >20 | | Weight |
| TWI | <10 | 1 | 1/3 | 1/3 | 1/4 | | 0.090 |
| | 10/15/2022 | 3 | 1 | 1/2 | 1/2 | | 0.204 |
| | 15-20 | 3 | 2 | 1 | 1 | | 0.342 |
| | >20 | 4 | 2 | 1 | 1 | | 0.364 |
| CR = 0.017 | | | | | | | |
| | | <150 | 150m-300m | 300m-450m | 450m-600m | >600m | Weight |
| Road distances | <150 | 1 | 2 | 4 | 5 | 3 | 0.402 |
| | 150m-300m | 1/2 | 1 | 3 | 6 | 6 | 0.326 |
| | 300m-450m | 1/4 | 1/3 | 1 | 3 | 3 | 0.140 |
| | 450m-600m | 1/5 | 1/6 | 1/3 | 1 | 2 | 0.070 |
| | >600m | 1/3 | 1/6 | 1/3 | 1/2 | 1 | 0.062 |
| CR = 0.077 | | | | | | | |
| | | Plate Area | North | South | West | East | Weight |
| Aspects | Plate Area | 1 | 1/6 | 1/3 | 1/3 | 1/9 | 0.048 |
| | North | 6 | 1 | 2 | 3 | 2 | 0.369 |
| | South | 3 | 1/2 | 1 | 2 | 2 | 0.239 |
| | West | 3 | 1/3 | 1/2 | 1 | 1/2 | 0.117 |
| | East | 9 | 1/2 | 1/2 | 2 | 1 | 0.228 |
| CR = 0.06 | | | | | | | |

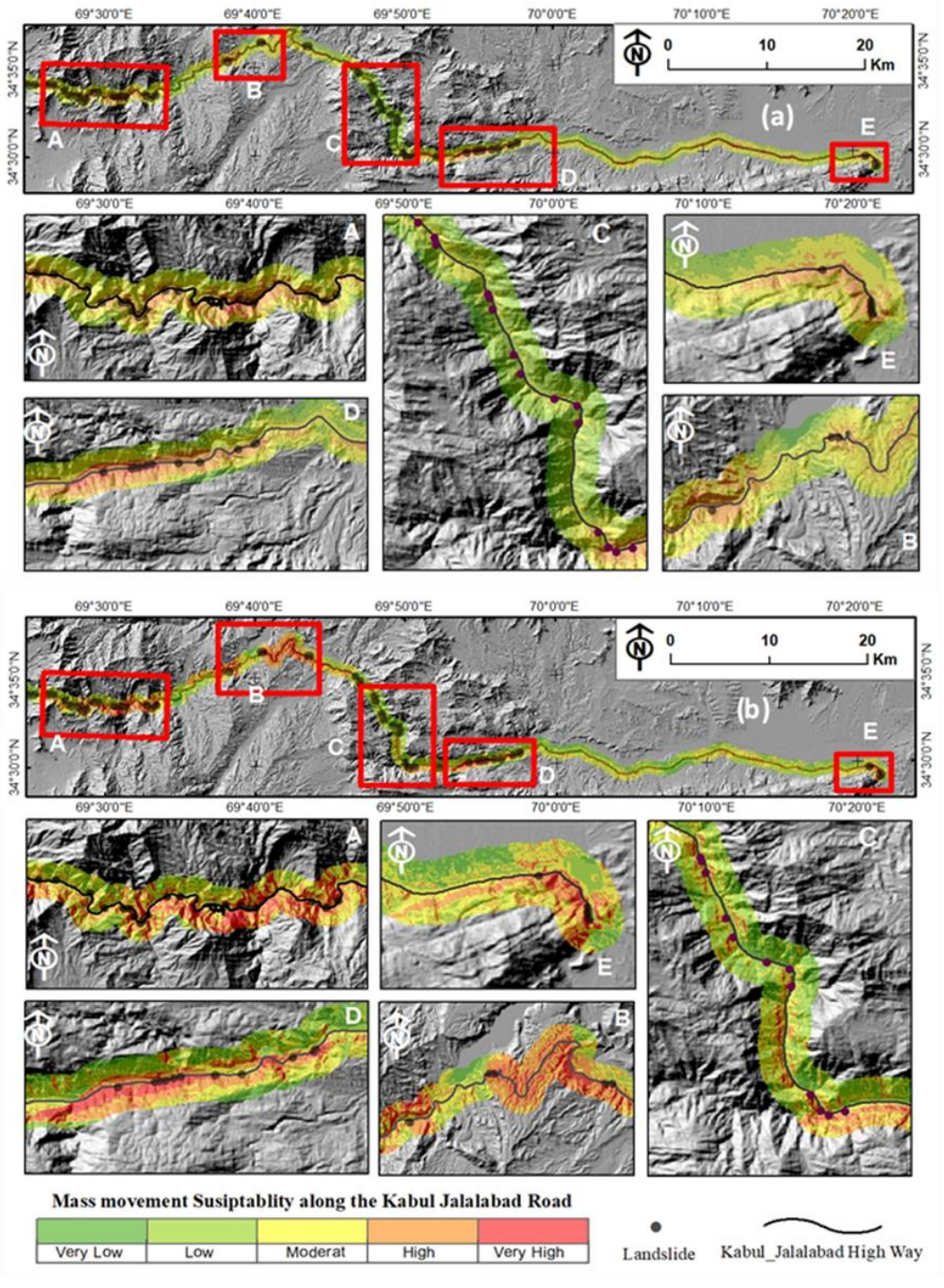



Fig. 4: Rockfall and landslide susceptibility map of Kabul –Jalalabad road; the (a) weight of Overly Mapping (WOM), (b) Analytic hierarchy process (AHP) method approaches.

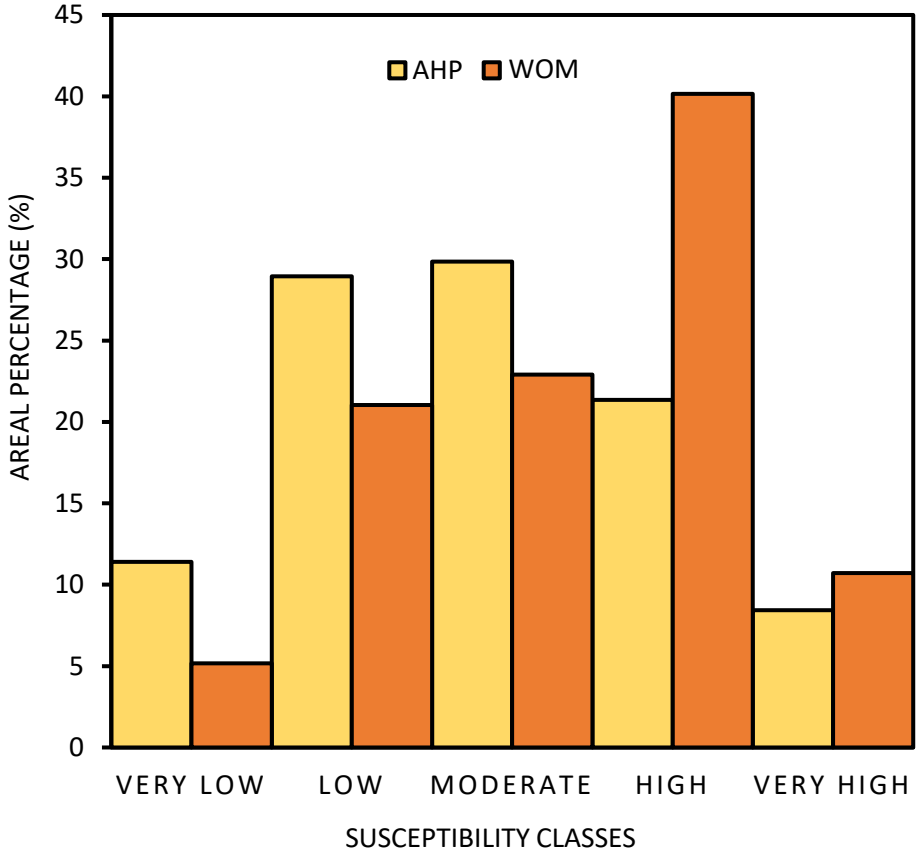



Fig. 5: Areal percentage of rock fall and landslide susceptibility for Kabul –Jalalabad road.

## 5. Evaluation of research results

Accuracy evaluation of natural disaster susceptibility mapping is one of the basic steps in assessing the susceptibility of the module that overlaps with the landslide sensitivity map and its distribution in this cause receiver operating characteristic curve (ROC) is used to evaluate and compare the accuracy of results. Because of the non-influence rule landslides occurred Rock falls which were detected by different methods mentioned in the methodology were denoted around 101 points of landslide and rock fall evidence all across the studied portion of Kabul-Jalalabad highway as a consequence of filed observation and Google Earth traces. The receiver operating characteristic (ROC) curve is one of the most desirable tools for graphically assessing the accuracy of classifiers for rock fall and landslide susceptibility zoning [42]. In addition, the area under the curve (AUC) index indicates the precision of classifiers, it is quantitative values vary from 0 to 1, that (0.9-1) is excellent, (0.9 - 0.8) very good, (0.8-0.7) good, (0.7 - 0.6) average and

(0.6 - 0.5) is weak [43].The closer area under the curve to 1, represents the best accuracy of classifiers. After finalizing the susceptibility map of methods characterized the accuracy of either and (AUC) index values gain in Microsoft Excel that shows 0.923 and 0.845 for AHP and WOM respectively with graphical representation in (Fig.6)

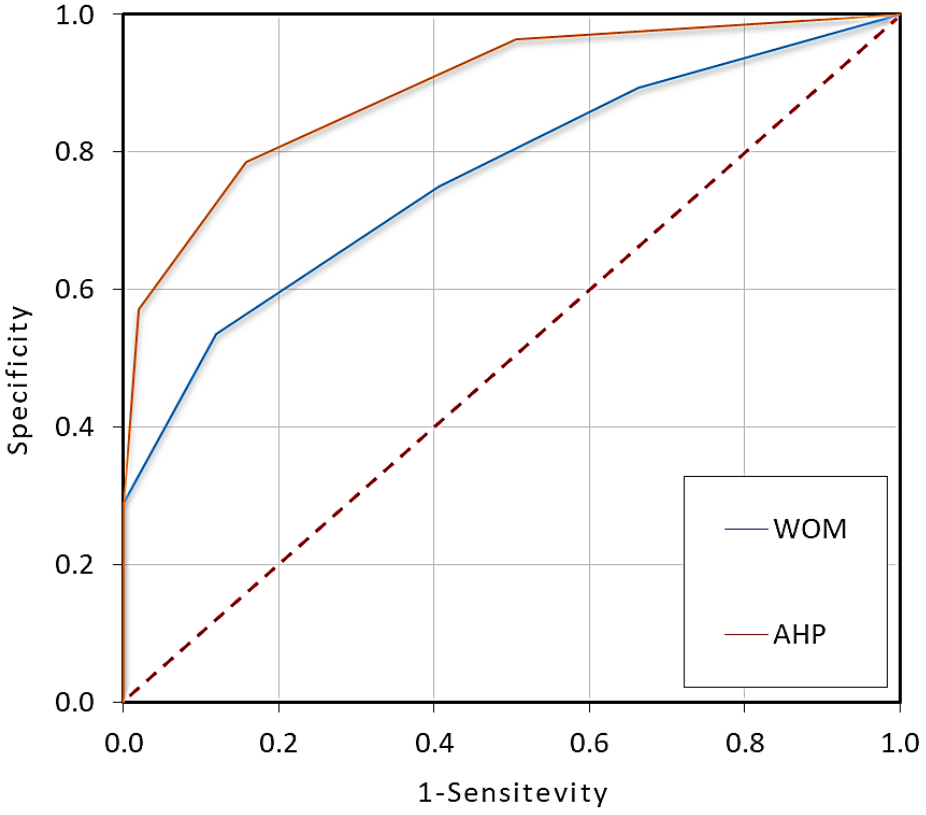



Fig. 6: Graphical Represent of methods accuracy assessment by (ROC) curve.

## 6. Discussion and results

Respectively after applying (Eq.5 &.6) landslide susceptibility of the area obtained for both studying methods of studying as a form of susceptibility maps which is known as a good tool for recognition of areas prone to landslides of rock fall, these maps are also known as a good source of information in the management of natural disasters like issues titled in this study. Landslide susceptibility zoning maps also show the spatial distribution that confirms all the factors involved in the potential risk of landslides and rock fall. However, this map is not able to predict the amount of displacing materials and its exact time. Nevertheless, predictive models can be valued for regional planning for landslide risk reduction and prevention assistance [44,45]. In this study to Clarify the relationship

between landslide impact factors and their influence role after a Specialistic in judgments and pair wised comparison for main and sub-criteria shown in table (2, 5) weight of all Criteria and their relevant classes vary from (0.033 of lithology's Class_1 to 0.517 of Fault distances <500m Class ), Slope, lithology, slope aspects, precipitation, fault distances, and land cover defined as a most influenced factor with 0.276,0.191, 0.181,0.106,0.069 and 0.056 influence weight respectively. The influence weight of slope classes increases continually with an increase of slope gradient then the highs value of slope class is obtained for >60 degrees, and the high value of influence weight of lithology is defined for Class_6 which is shown in table (5) contains Conglomerate, shingly sediments, gravel, sand, siltstone, breccia, limestone, gypsum, clay, loam; andesite, decide and their tuffs, and For aspect classes, North, south, and east has more high values than others as shown in table (5). The AHP module was finalized by defining the main Criteria values as an implication of (Eq.5), which define in expanded form in (Eq.7) Susceptibility map of both methods (AHP and WOM) classified into five Sensitivity and susceptibility levels as (Very low, Low, Medium, High and very high) that frequency of all zones for both methods are represented in (Fig .5), High and very high levels sensitivity zones Covers 21.35%, 8.43% for AHP and 40.16%, 10.72% for WOM respectively. Both methods related (LSM) shows five regions as much more susceptible than another area along the Kabul Jalalabad road and similarly has a high correlation with occurred Landslide and rock fall detected point, which indicates the rational accuracy of methods that five areas recognized with high, slope, positive relief and much weathered and sensitive Rock types. landslide susceptibility map (LSM) of (WOM) produced by the user of (Eq.6) and as shown in (Fig.4a) and areal percentage of each one shown in (Fig.5), which shows many similarities for Very Low, Low and Very High zone of susceptibility With (AHP), that means this method has more relatively high uncertainty than (AHP) modules, because of un running pairwise comparison to priorities all influencing factors. to evaluate the accuracy of each classifier receiver operating Characteristic (ROC) curve and AUC index used to assess the precision of each module Finally AHP module is known as a much better tool than (WOM) one because of their (AUC) value which shows 0.923 for (AHP) that is greater than 0.845 (AUC) of (WOM) module and specified in Excellent and very good Classes respectively. AHP module this ability of prediction is known as high-level experiment judgments between Criteria and their relevant classes, which depends on the level of experts' applicable experience and knowledge to comparing judgments.

$$LSM = 0.867 * X1 + 0.269 * X2 + 0.059 * X3 + 0.104 * X4 + 0.071 * X5 + 0.054 * X6 + 0.030 * X7 + 0.042 * X8 + 0.181 * X9 \quad \text{(Eq.7)}$$

## 7. Conclusion

This study is based on the probabilistic method as analytic Hierarchy processed (AHP) and weighted overly mapping (WOM). AHP is one of the hierarchy comparison influences of parameters and their prioritizing method for zoning the risk of landslides and other natural disasters, which has recently been used widely by researchers in various parts of the world and denoted with high interest by many researchers. advantages of this method are the use of a small amount of information (influence factors), spatial independence of information in estimating the weight of each factor (variable) on the occurrence of landslides; Non-generalizability, uniqueness of the event, the accuracy of preconditioned information on pre-existing landslides and inflexibility in small geographical constraints are the main disadvantages of the method. Weight of the event; Understanding the factors contributing to landslides is very complex and sometimes unconventional, while the underlying factors contributing to landslides can be identified even in field visits to aerial photography facilities, in which case some factors are neglected to be. Also, in this research, the weighted overlay mapping (WOM) method is used to increase the accuracy of the final results to detect the most susceptible locations, accordingly, the final similarity between the results of these two methods that have a close relation to that. Occurred landslides events distribution and more sensitive influence Factors, the factors affecting the occurrence of Rockfall and landslides in Kabul-Jalalabad road in this research by considering (9) criteria and their thematic maps were provided by the use of ArcGIS10.8 facilities. This study shows about the 5 portions of the road has high association and spatial coordination for rock fall and landslide susceptibility. Spatial distribution of high and very high sensitivity for the AHP method from very high and high potential is (8.43%) and (21.36%) of the study area, respectively, which shows (10.72%) and (40.16%) in WOM; both of these methods have a close relationship between more susceptible area and invented points of Rockfall and landslides. Slope changes, lithological varieties, annual average precipitation, and slope aspect were determined as the most effective factors.

The accuracy of approaches comparatively Assessed by the use of ROC curves shows that AHP is much more valid because of its high (0.923) value of the (AUC) index than the (0.845) of the WOM method.

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