IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

GIS-Based Landslide Susceptibility Mapping by AHP Method, A Case Study, Bamyan, Afghanistan

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Abstract: Landslides are one of the critical phenomena that frequently lead to loss of human life and property, as well as causing severe damage to natural resources and infrastructures. Bamyan province is a landslide prone zone because of its own characteristics including the rush topography, climate conditions, seismic potential and geology. Every year landslide in Bamyan resulting in significant economic and social losses (e.g., deaths, injuries, and property destruction).

This paper presents a landslide susceptibility analysis in Bamyan, Afghanistan using AHP (Analytic Hierarchy Process) method. To provide the landslide susceptibility, determination of the effective factors in landslide occurrence is very important. For this purpose, first the most important factors affecting the occurrence of landslides in this province were identified through ground observations and comparison of pervious research. Therefore, twelve factors which affect the landslide occurrence were selected as: including lithology, distance to drainage, slope, distance to fault, rainfall, land cover, distance to village, drainage density, elevation, aspect, distance to road and LST. According to the relation between the above factors and landslide distribution, the weight value and rating value of each factor were calculated using AHP. Finally, the susceptibility maps of the study area provided using Arc GIS software through weighted overlay method.

Key words: Landslide; Susceptibility map; GIS; Analytical hierarchy process.

1. INTRODUCTION

Landslide is one of the most damaging natural disaster phenomena that occurs every year across the world specifically on the mountainous area. Landslide occurs because of various natural and human factors on different scales around the world and causes human and financial losses (Aksaray et al., 2011). Occasionally, an enormous landslide buries a town or city, killing thousands of people. Landslides cause billions of dollars in damage every year, about equal to the damage caused by earthquakes in 20 years. Most of the time, the damage caused by landslides is due to the lack of awareness of the people(H. R. Pourghasemi et al., 2013).

A landslide is the movement of mass of rock, debris or earth down a slope. They result from the failure of the materials, which fall down the slope due to force of gravity. It is also known as slope failure slumps or landslips (Amir Yazdadi & Ghanavati, 2016). Outward and downward movement of mass consisting of rocks, slop instability and soils due to natural or manmade causes is termed as landslides. These events are associated with pre and post of earthquake, soil erosion, rainfall and anthropogenic activities (Koley et al, 2020). The term' landslide' comprises all varieties of mass movements of hill slopes. It can be defined as the inward and outward movement of slope forming materials composed of rock, earth, soil, mud and debris or combination of all these materials along surfaces of separation by sliding, flowing and falling, slowly or rapidly under the influence of gravity (Koley et al, 2020); (Amir Yazdadi & Ghanavati, 2016). Landslides cause adverse effects on human lives and economy worldwide. Steep slopes characterize mountainous terrains, fractured, folded and high relative relief weathered rocks. Expansion of urban and manmade structures into potentially hazardous area leads to extensive damage to infrastructure and occasionally results in loss of life every year (Kamp et al., 2008).

Landslide susceptibility mapping has greatly helped designers and engineers to select suitable locations for development projects, and the results of such studies can be used as basic information to assist managers and environmental planning. Finally, potential hazards can be avoided by identifying areas with high landslide potential (Hamid Reza Pourghasemi et al., 2012). The results of research conducted in different countries show that landslides occur under the influence of various human and natural factors, but the effect of every factor is different according to geomorphology, geology, climate and other factors in different regions (Saleem et al., 2019). There have been many studies conducted on landslide risk zoning some of them are as follow: (Naseri, 2016) (Kamp et al., 2008); (Kanwal et al., 2017); (Moradi et al., 2012); (Feizizadeh & Blaschke, 2013);(Hamid Reza Pourghasemi et al., 2012); (Koley et al, 2020);(Amir Yazdadi & Ghanavati, 2016); (DV.COM, 2014); (Alam, 2020); (Aksaray et al., 2011). The mentioned research, which conducted in different countries like Afghanistan, India, Pakistan, Iran, Korea, Italy, Bangladesh and Turkey the aim of all the research are to identify the effective factors, which cause landslide, and to specify the efficiency level of those factors.

In order to provide landslide susceptibility maps various methods such as fuzzy logic, statistic methods and Analytic Hierarchy Process (AHP) can be used (Amir Yazdadi & Ghanavati, 2016). Since 1970s, researchers have been searching for suitable methods to assess the spatial distribution of landslide hazards based on GIS techniques. During this period, various methods proposed by researchers to assess the landslide phenomenon, one of these methods is AHP. This method used by (Saaty, 1980); (Bernasconi et al., 2010); (Amir Yazdadi & Ghanavati, 2016); (Achour et al., 2017); (Abedini & Tulabi, 2018) and (Devara et al., 2021). AHP gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis (Ayalew et al., 2005). Using this method, each layer used in landslide susceptibility zoning is broken into smaller factors, then these factors are weighted based on their importance, and eventually the prepared layers are assembled and the final map is produced. It is based on three principles: decomposition, comparative judgment and synthesis of priorities (Malczewski, 2006). In this method, weight of each layer depends on the judgment of expert, so that the more precise is the judgment, the more compatible is the produced map with reality (Moradi et al., 2012).

The Bamyan province is a landslide prone zone because of its own characteristics including the mountainous topography, climate conditions, seismic potential, geology and geomorphology. Based on the report of "Afghanistan natural disaster incidents" in 2020 most landslides occur in the northern, central and western parts of Afghanistan. Landslides are one of the most frequent hazards in Bamyan, resulting in significant economic and social losses (e.g., deaths, injuries, and property destruction). Figure 1, 2, 3, 4,5 and 6 shows the occurrence of landslide in different time in different part of Afghanistan. For instance, the landslide, which occurred on September 23, 2018 in Shibar district of Bamyan, resulting in significant economic and social losses (e.g., deaths, injuries, and property destruction)(Shroder, 2016). Unfortunately, no comprehensive landslide research has been conducted in Afghanistan yet. Some few researches has been conducted but limited to a very small scale like in the level of a province or a district, which is not enough. Therefore, to date, statistics on the number of landslide events in terms of location and time and statistics of landslide damage are not available in the country. However, according to a survey conducted by the Afghanistan - Natural Disaster Incidents with the financial support of the OCHA in 2020, the number of families affected by natural disasters in Afghanistan is 16,446, the number of victims 109430 and the number of damaged homes 8303 and similarly the number of destroyed houses 2717 reported (OCHA, 2020).

Figure 1. photo of Dara Ali, Yakawalang, Bamyan landslide taken by local people in 22/09/2015.

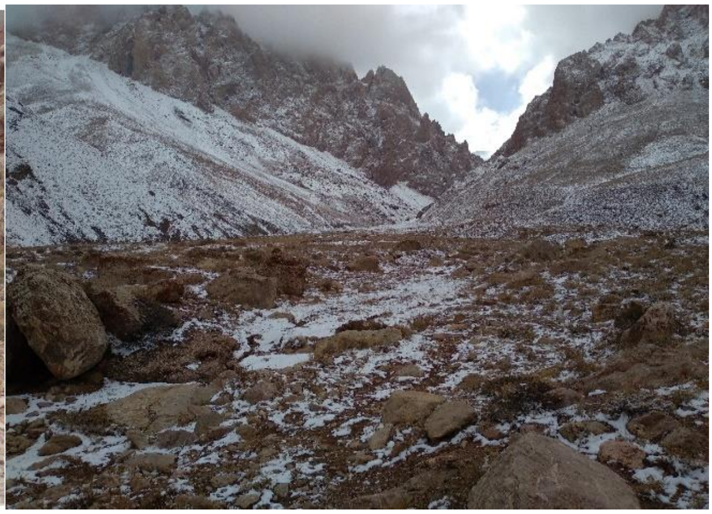


Figure 2. Same landslide but photo took in 5/09/2021.

Figure 3. photo of Kotal Surkhak, Yakawalang landslide took in 05/09/2021.

Figure 4. Photo of second landslide in Dara Ali, Bamyan took in 05/09/2021.

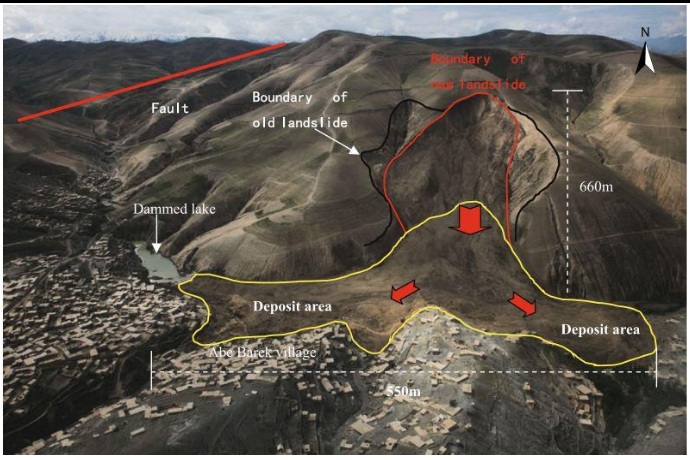


Figure 5. Photo of Abe Barek, Badakhshan landslide (photo: Fardin Waeze/UNAMA(UN,2014)).

Figure 6. Photo of Abe Barek, Badakhshan landslide (photo: Fardin Waezi/UNAMA (UN,2014))

Another landslide that occurred due to heavy rain in Barak district of Badakhshan province on May 2, 2014, attracted the attention of the world due to its great intensity and destruction. The human casualties of this event were between 300 and 2700 people. Furthermore, according the observation, which conducted through high-resolution satellite imagery, such as World View, between June 7, 2013 and May 5, 2014, about 78 infrastructures, damaged and destroyed(Zhang et al., 2015) and (Unitar, 2014). Similarly, according to a report published by Radio Azadi on February 11, 2015, it shows that all kinds of natural disasters occur annually in different parts of the country with different scales(Radio Azadi, 2015).

Identifying landslide prone areas is one of the first steps in natural resource management and development planning. Landslides occur under the influence of various natural and human factors, and evaluating the impact of each of these factors has a significant role in predicting the probability of their occurrence and zoning(Zhang et al., 2015). Identifying the effective factors in the occurrence of this phenomenon and its potential in the management of natural resources and reducing the damage caused by it is very important(Amir Yazdadi & Ghanavati, 2016).

The purposes of this study are the recognition of effective factors in susceptibility mapping of Bmayan in terms of the occurrence of this phenomenon using AHP model and GIS technique. Therefore, selection of criteria and standards, providing of factors raster layers, determining of relative and final weight of factors, overlaying of layers and preparing of landslide susceptibility map is the major objectives of this research to determine sensitive sites that have the maximum occurrence probability of landslide.

2. DESCRIPTION OF THE STUDY AREA

Bamyan is a historical site and one of the thirty-four provinces of Afghanistan, which located in the central part of Afghanistan figure 9. Geographically Bamyan province located between 34°49′17″ N latitude and 67°49′38″ E longitude. The average altitude of Bamyan province is 2600 meters from sea level. The total area of Bamyan province is 14148 square kilometers and the total population is 387,300 people. Bamyan has seven administrative unites Bamyan center, Yakawalang, Waras, Panjab, Shiber, Saighan, Kahmard (CSO, 2013).

Landslides in countries such as Afghanistan, Pakistan, India, Nepal, Bangladesh and Bhutan generally caused by the Hindu Kush and Himalayan mountain ranges(USAID, 2017). Based on USAID observation in 2017 northern and central part of Afghanistan experience most landslide hazard. According this observation Bamyan Province has the Landslide Susceptibility Index of 19.8K (population at landslide risk). The Bamyan province in Afghanistan is a landslide prone zone because of its own characteristics including the mountainous topography, climate conditions, seismic potential, geology and geomorphology. Apart from others factors the most important factor which cause landslide in Bamyan is rough topography of Bamyan. Altitude changes in this province range from 2000 to 5044 meters. Two popular mountains scenery of Afghanistan extended to Bamyan, which are Hindu Kush and Baba. These two mountains scenery most of the time are covered with snow and make source of surface and ground water in Bamyan. Main geographical characteristics of this region are steep rivers, valleys and mountains with high elevation. The climatic zone of alpine relief in Bamyan is characterized by a short cold summer and a long rigorous winter, with the most precipitation occurring as snow. Bamyan is covered with snow in the whole of winter. Bamyan province has a very complex geology. However, sedimentary rocks cover the most area of this province. Because of long winter and cold climate, the province has less vegetation coverage. Most area of this province covered by bare land. Together, these factors, in addition to human factors, cause landslides. Bamyan landslides are included loose soil, rock; organic material, water, and motion look like a slurry downslope ward. They include both fine and coarse grain particles. Causes of landslides here are heavy precipitation or quick snowmelt in the slopes with less vegetation. Most of the landslides are happen after heavy participation in spring or snow melting in summer. Although there are no exact statistics on the number landslide and its victims and financial losses.

Some local media have reported some of these disasters. According to a report published by Shia Association News on September 23, 2018 because of landslide in the Shibar district, Bamyan province, three members of a family killed and one injured. In addition to the casualties, about 40 sheep, 4 cows and 9 acres of agricultural land destroyed (Shia Association News, 2018). According to the report of Afghanistan Voice Agency on May 8, 2014 in Sorkh Juy village of Dara-e-Fooladi, which is 20 km away from Bayan centre, about 100 families fled their homes due to a possible landslide (AVA, 2014). According to a report provided by the Afghanistan natural disaster incidents with the financial support of the OCHA Office in 2020, due to natural disasters, four people killed, 19 people were injured, 1241 families affected and 79 houses were destroyed (OCHA, 2020). Photos of occurred landslide in Bamyan province are shown in figure 1, 2, 3 and 4. Therefore, for more detail the google earth photographs of occurred landslide in Bamyan province are shown in figures 7 and 8.

Figure 7. Google Earth photo of Dara Ali, Yakawalang landslide.

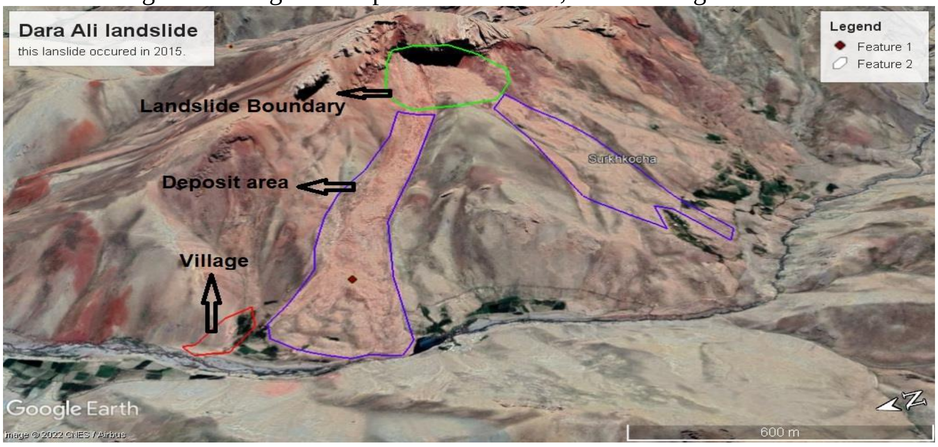


Figure 8. Google Earth photo of second occurred landslide in Dara Ali, Yakawalang

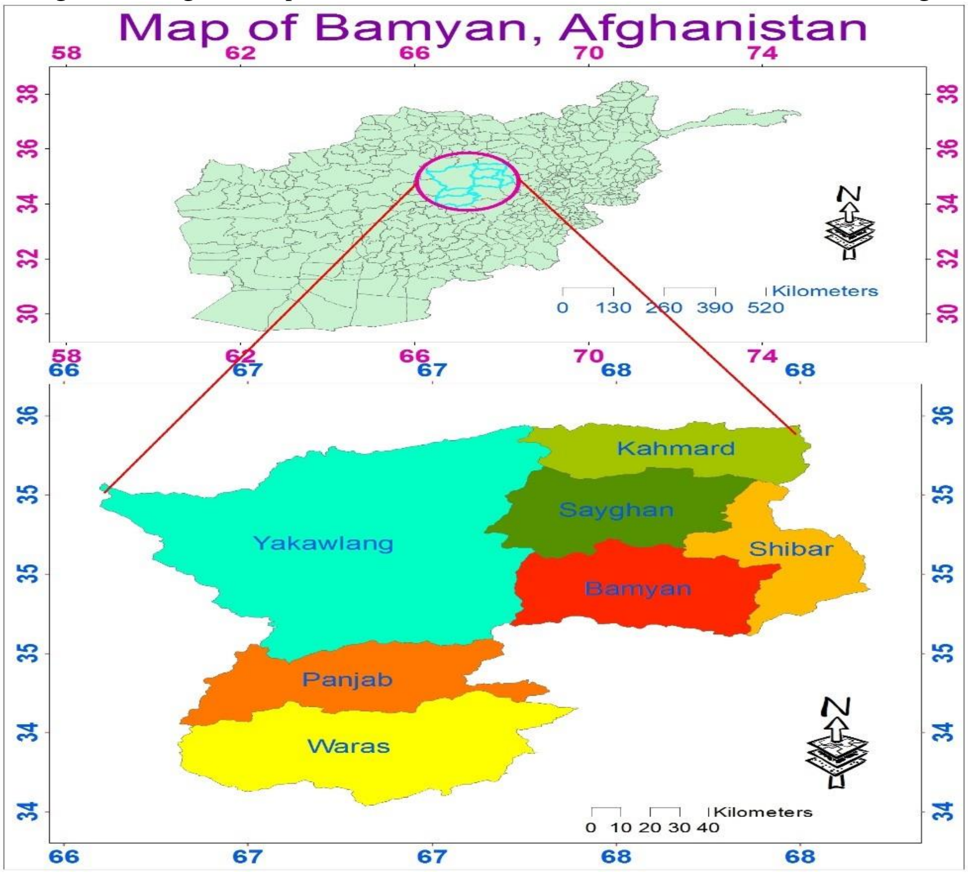


Figure 9. Bamyan, Afghanistan

3. OBJECTIVE OF THE RESEARCH

The overall objective of this research is to provide the landslide susceptibility map of Bamyan and contribute to mitigate landslide risk.

The Specific objectives are as follows:

- Preparation of landslide inventory map.
- To provide landslide susceptibility map of Bamyan province using AHP method and GIS techniques.
- Contribute to mitigate landslide risk by establishing reliable methods to determine the risk.

4. MATERIAL AND METHOD

In the first step, landslide prone areas explored through aerial photographs and Google Earth. Then, for better understanding of the landslide prone areas, a committee consisting of geologist, geodesist, environmentalist and geographer visited some areas. Since the study area is very large, the team visited locations where the landslide occurred. After a comprehensive review, the committee based on geological, geomorphological, hydrological, human and environmental characteristics of study area and using comparative studies and results of other researchers 5 criteria and 12 sub-criteria were identified to achieve the goal. Based on the selected criteria and sub-criteria, data collected from different sources, which is shown in table 1.

Table 1. Data source

Data	Description	Source
GDEM	Resolution (15m)	USGS Earth Explorer https://earthexplorer.usgs.gov/
Aspect	Extracted from GDEM	USGS Earth Explorer https://earthexplorer.usgs.gov/
Faults	Extracted from Geological	USGS Earth Explorer https://earthexplorer.usgs.gov/
Slope	Extracted from GDEM	USGS Earth Explorer https://earthexplorer.usgs.gov/
Drainage	Extracted from GDEM	USGS Earth Explorer https://earthexplorer.usgs.gov/
Lithology	FAO Map Catalog	https://data.apps.fao.org/map/catalog/srv/eng/catalog.search?fbclid=IwAR1vErVybmOh8ynaVcM04jfSdhqooFPc3VJQ43iGjfdox5vI4hK_yVBAh-A#/home
Rainfall	PERSIANN yearly Data Resolution 0.25×0.25 degree	CHRS Data: https://chrsdata.eng.uci.edu/?fbclid=IwAR1rr5o5qNfU_ZurS1t70hWqoo8AljGNQg3NBlcQ4XGzmX3Xpsr-V76VzCU
LU&LC	Spatial Resolution (10m) provided from Sentinel-2	Esri 10m Land Cover: https://livingatlas.arcgis.com/landcover/?fbclid=IwAR3kzwQiNMQ35VED6ie4BMX3wTtoK3Vtzchx47BfBalOkoyPDSX02N9yixA
Roads	Open Street Map (OSM)	Geoinformatics World: https://geoinformaticsworld.com/vector_data/?fbclid=IwAR3THZHGbsf47kcTC2gBbojjYhM4z8NE11Ql8skQ9DXKIb48jaTxcJhrVU0
LST	Extracted from Landsat 8	USGS Earth Explorer https://earthexplorer.usgs.gov/
Villages	Open Street Map (OSM)	https://extract.bbbike.org/
Boundary of study area	DIVA GIS	https://www.diva-gis.org/gdata
Location of active landslides	Field survey	The coordinates of active landslides collected using handheld GPS.

Afghanistan is one of the poorest countries in the world in terms of research database. Unfortunately, forty years civil war have left Afghanistan with no research database. All data used in this study are secondary data that collected from various Internet sources. Unfortunately, sometime this kind of data are not suitable for specific research in a small area. Because the global data have been, provide for the purpose of globally research. It mean that their scale and resolutions are not suitable for a small region. However, in this study, in addition to the collected secondary data, some primary data also collected through field visit. For example, some landslide occurred area visited in order to assess the geological, morphological, climatic, hydrological and environmental characteristics of the area. Handheld GPS used to take the coordinates. Camera used to take photos. Then all these information used for validation of secondary data and final landslide susceptible map.

Next, all the data pre-processed for next use. It mean that some function like clip, mosaic, vector to raster have been applied using Arc GIS 10.5 software. First, the digital elevation model of the region classified into 6 elevation classes based on the natural failures that exist in the heights of the region. Slope layers and slope direction were prepared from the digital elevation model of the area. Similarly, all others digital layers like lithology, land surface temperature, precipitation, LU&LC, distance to villages, distance to faults, distance to drainage, drainage density, distance road, distance to rivers have been prepared. Finally, all the vectors layers converted to raster layers. The next step is to assign weigh value for each criteria, sub-criteria and classes. This step performed according to the instructions of the AHP method. The AHP is a structured technique for dealing with complex decisions that was developed by Saaty in the 1980 year. This technique is based on pair-wise comparison of the contribution of different factors and gives various scenarios to the decision-makers. Since there is no linear relationship between the landslide and the factors influencing them, therefor the usual statistical approach cannot solve all the problems. In this respect AHP model provides conditions that can to determine the landslide susceptible map with more details (Ghanavati, 2012).

5. LANDSLIDE SUSCEPTIBILITY ANALYSIS

In this research, the AHP method used to specify the weight value of each involved criteria, sub criteria and classes for landslide zonation mapping in Bamyan province. In the first step, the hierarchical structure should be drawn figure 10. In this figure, we faced with a four level hierarchy including goal, criteria, sub-criteria and classes. Making the subject or problem into a hierarchical structure is the most important part of hierarchical analysis, because in this part, by analysing difficult and complex problems, the hierarchical analysis transforms it into a simple form that can be correspond to the human mind and nature. In other words, the process of hierarchical analysis simplifies complex problems by breaking them down into hierarchically interrelated elements whose relationship between the main purpose of the problem and the lowest level of the hierarchy is clear. AHP method breaks down complex problems into simple ones that are easy for users to understand. A comprehensive description about AHP can be found in (Saaty, 1980) and (Bernasconi et al., 2010).

1. The Goal, criteria, sub-criteria, alternative.
2. The Goal, criteria, factors, sub-factors, alternative.

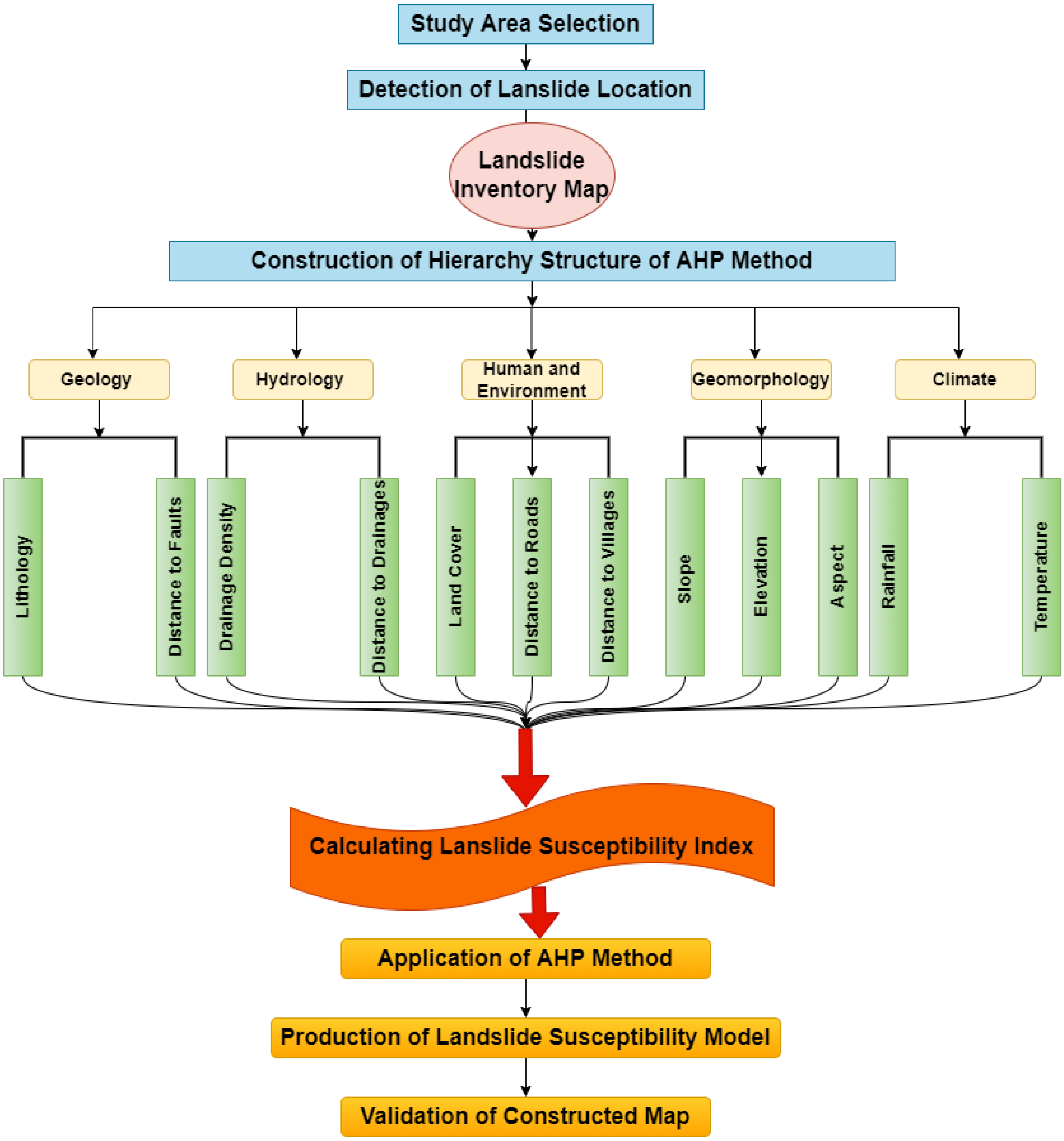


Figure 10. Hierarchical analysis process, constructing a hierarchy for landslide susceptibility mapping

The AHP gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis(Ayalew et al., 2005). It has been successfully employed in landslide susceptibility mapping by several researchers (Ayalew & Yamagishi, 2005); (Moradi et al., 2012); (Moradi et al., 2012); (Malczewski, 2006). AHP involves building a hierarchy of decision elements (factors) and then making comparisons between possible pairs in a matrix to give a weight for each factor and also a consistency ratio as described by (Devara et al., 2021). This will describe the importance of each factor relative to every other factor (Moradi et al., 2012). In AHP, each factor is rated against every other factor by assigning a value between 1 and 9, if the factors have a direct relationship. Conversely, the value varies between the reciprocals 1/2 and 1/9 (Table 1; Saaty 2000).

5.1. Preparation of landslide inventory map

In orde validate the result of the final map. The landslide inventory map was provided with the help of aerial photographs and ground surveys. Since the area of study area is very large and visit of evry single occurred landslide point is defficult. So, the location of 20 active landslide collected. Accordingly, The landslide inventory map has been prepared only for Yakawalang district of Bamyan province figure 11.

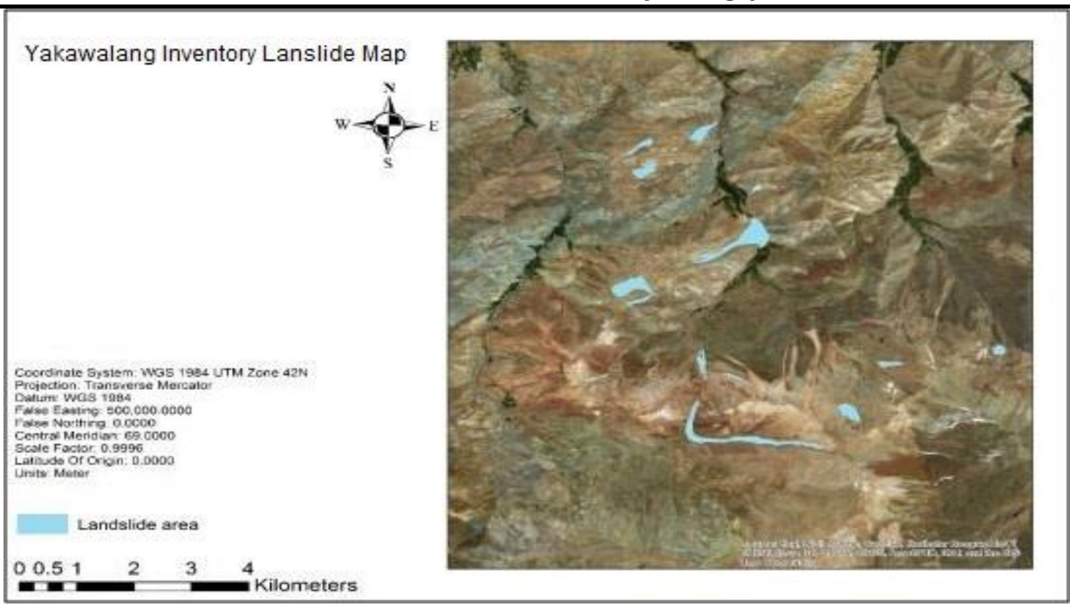


Figure 11. landslide inventory map of Yakawalang district.

5.2. Determining the weight value for factors, sub-factors and classes of sub-factors:

The important steps of the AHP process are (1) constructing a hierarchy structure, (2) defining the weight value of each criteria, and (3) combining the criteria. In the first step, factors and their spatial representation should be associated with a common scale to make comparisons possible. In the second step, a pairwise comparison matrix is constructed, and each factor is compared with the other factor, relative to its importance. For instance, in the current research, the lithology factor has the most effect and it will get the highest number caparison to all other factors. The basis for judging is Table 2, according to which the degree of superiority of one factor over another factor is determined by the degree of effectiveness of this factor to the goal. In the hierarchical analysis process, the most weight is given to the layers that have the greatest impact on goal. In order to estimate the weights of each factor and to show the effect of each factor on landslide, a committee consisting of experts in geology, geography, environmental science and geodesy formed. Then, according to the weighting and preference table presented by Saaty. Each factor and its preference over other factors were determined. The quality of the comparison was described by the consistency ratio (CR), which is calculated as the ratio of the (CI) and the random index (RI), as indicated in Eq.1.

$$CR = CI/RI \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Therefore, here the consistency index of a matrix of comparisons is calculated based on Eq.2.

$$CI = \frac{\lambda_{max} - n}{n - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Here, in Eq.2 λ_{max} is the average of (λ) and the (n) is the number of criteria. As in this research the number of criteria are 12 then the (n) will take the value of 12. A matrix with a satisfactory consistency level should yield a CR of less than 0.10. The low consistency ratio (<0.10) indicates that the computed weight for each factor is acceptable. Using a weighted linear combination (WLC), the landslide susceptibility map was derived. It is one of the most applicable function that can be used for decision making inside GIS. (Malczewski 1999). In WLC, the twelve factors layers are over lied and multiplied by their corresponding weight values. Finally, the overall score calculated using Eq.3.

$$V_H = \sum_{k=1}^{n} W_k (g_{i,j}) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In this formulaV_H, is the final weight, W_k is the weight of each criteria and $g_{i,j}$ is the weight of each related class of criteria.

Table 2. Scale of preference between two parameters in AHP (Saaty,2000)

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

Table 3. Pairwise comparison matrix, factor weights and consistency ratio of landslide influencing factors

Criteria	Geology	Hydrology	Morphology	Manmade and Environmental	Climate	weight
Geology	1	3	4	6	8	0.481
Hydrology	0.333	1	3	4	7	0.265
Morphology	0.25	0.333	1	3	4	0.141
Manmade and Environmental	0.16	0.25	0.333	1	3	0.076
Climate	0.125	0.143	0.25	0.333	1	0.039
Consistency ratio= 0.04						

Table 4. Pairwise comparison matrix, sub-factors weights and consistency ratio of landslide influencing sub-factors

Criteria	Lithology	Distance to drainage	Slope	Distance to Fault	Rainfall	LU&LC	Distance to Village	Drainage Density	Elevation	Aspect	Distance to Road	LST	weight
Lithology	1	2	3	4	5	6	6	6	7	7	8	9	0.23
Distance to drainage	0.5	1	2	2	3	4	6	6	7	7	8	8	0.17
Slope	0.33	0.5	1	2	3	4	5	5	6	7	7	8	0.14
Distance to fault	0.25	0.25	0.5	1	2	3	5	5	7	7	7	8	0.12
Rainfall	0.2	0.33	0.33	0.5	1	2	2	3	4	5	6	6	0.08
LU&LC	0.16	0.25	0.25	0.33	0.5	1	2	2	4	4	5	6	0.06
Distance to Village	0.16	0.16	0.2	0.2	0.5	0.5	1	2	3	3	4	5	0.06
Drainage Density	0.16	0.16	0.2	0.2	0.33	0.5	0.5	1	2	2	3	3	0.04
Elevation	0.14	0.14	0.16	0.14	0.25	0.25	0.33	0.5	1	2	2	3	0.03
Aspect	0.14	0.14	0.14	0.14	0.2	0.25	0.33	0.5	0.5	1	2	2	0.02
Distance to Road	0.12	0.12	0.14	0.14	0.16	0.2	0.25	0.33	0.5	0.5	1	2	0.02
LST	0.11	0.12	0.12	0.12	0.16	0.16	0.2	0.33	0.33	0.5	0.5	1	0.02
Total	3.27	5.17	8.04	10.77	16.1	21.86	28.61	31.66	42.33	46	53.5	61	1.00
Consistency ratio=0.05													

Table 5. Weights and consistency ratio of landslide influencing classes.

Sub-factor	Sub-factor classes	Weight	Sub-factor	Sub-factor classes	Weight
Aspect	N	0.09	Lithology	Sedimentary	0.09
	N-E	0.08		Metamorphic	0.06
	w	0.07		Volcanic	0.03
	N-W	0.06	Distance to Fault	0-1000	0.09
	E	0.05		1000-2000	0.07
	S-E	0.04		2000-3500	0.05
	S	0.03		3500-5000	0.03
	N-W	0.02		5000-10500	0.01
	Flat	0.01	Rainfall	290-350	0.01
Land cover	Ice/snow	0.02		350-430	0.03
	Dense vegetation	0.04		430-510	0.05
	Sparse vegetation	0.06		510-600	0.07
	Built-up/Bare land	0.09		600-700	0.09
Distance to Village	0-2000	0.09	Distance to Road	0-2000	0.09
	2000-4000	0.07		2000-5000	0.07
	4000-8000	0.05		5000-10000	0.05
	8000-15000	0.03		10000-20000	0.01
	15000-30000	0.01		20000-33000	0.03
Distance to Drainage	30-600	0.09	Slope	0-9	0.03
	600-1500	0.07		9-.18	0.04
	1500-2500	0.05		18-35	0.02
	2500-3500	0.03		35-50	0.07
	3500-7100	0.01		50-74	0.09
Elevation	0-2500	0.01			
	2500-3000	0.03			
	3000-3500	0.05			
	3500-4000	0.07			
	4000-5044	0.09			

The resulting landslide susceptibility map generated through the AHP method is shown in Fig. 12. It was reclassified into four relative susceptibility zones: low risk, moderate risk, high risk and high risk. According to Fig. 12, the susceptibility condition is very high in Yakawalang district, Panjab district, some portion of Shiber, Saighan, Kahmart district. Landslides are active in all districts of Bamyan province, but the area of under risk are differents. For example, Yakawalang, Punjab and Bamyan center suffer most from landslides, but other districts such as waras, Shibar, Sighan and Kahmard are relatively less. Moderate landslide susceptible zones are shown to be widely distributed again in Yakawalang, Panjab, Kahmart, Saighan, Shiber and som part of Bamyan city. The low landslide susceptible areas are mainly in Waras, some portion of Bamyan city, Yakawalang and Shiber. From Table 6, it can be observed that 9.26% of the total area was found to be of low landslide susceptibility. 29.52% of the study area is under moderate risk, 58.34 percent is under the high risk and 2.88 percent is under the very high risk. The results of landslide zoning maps can be used as basic information to assist environmental management and planning.

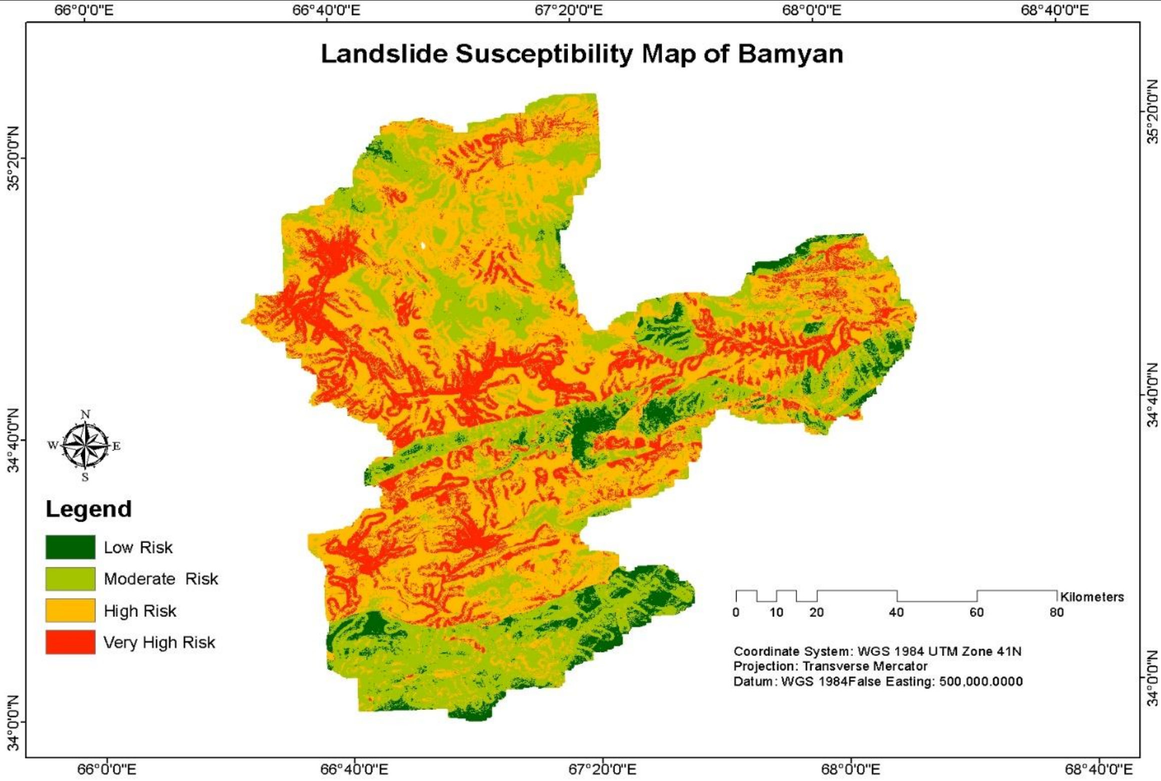


Figure 12. Landslide susceptibility map generated using analytic hierarchy process

Table 6. percentage and area of landslide risk areas

Landslide susceptibility zones	Area in square kilometer	Percent
low risk	1309.705	9.26
Moderate risk	4175.072	29.52
High risk	8251.572	58.34
Very high risk	407.638	2.88

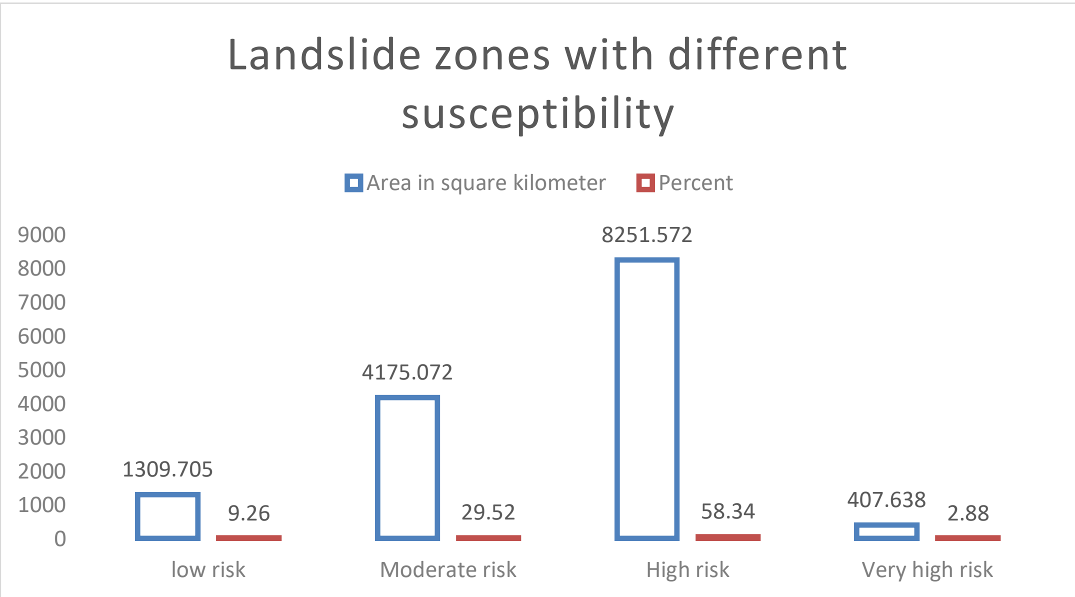


Figure 13. Area of landslide susceptibility zones in square km and percentage.

Rainfall plays a significant role in landslides due to raising the water level of groundwater, which in turn increases the static pressure and pore water pressure in slope materials. Most of the landslides occur after the heavy rain falls, thus the rainfall is one of the main parameters in producing landslide maps. Water infiltrates rapidly upon heavy rainfall and increases the degree of saturation and potential of landslide occurrence (Moradi et al., 2012). In this study, the yearly rainfall data with spatial resolution of 0.25×0.25 degree for year 2017, 2018 and 2019 acquired from Centre for Hydrometeorology and Remote Sensing data portal. Then the average of these three years calculated in Arc GIS and divided in 5 classes as shown in figure 14. The given weight for this factor is 0.08.

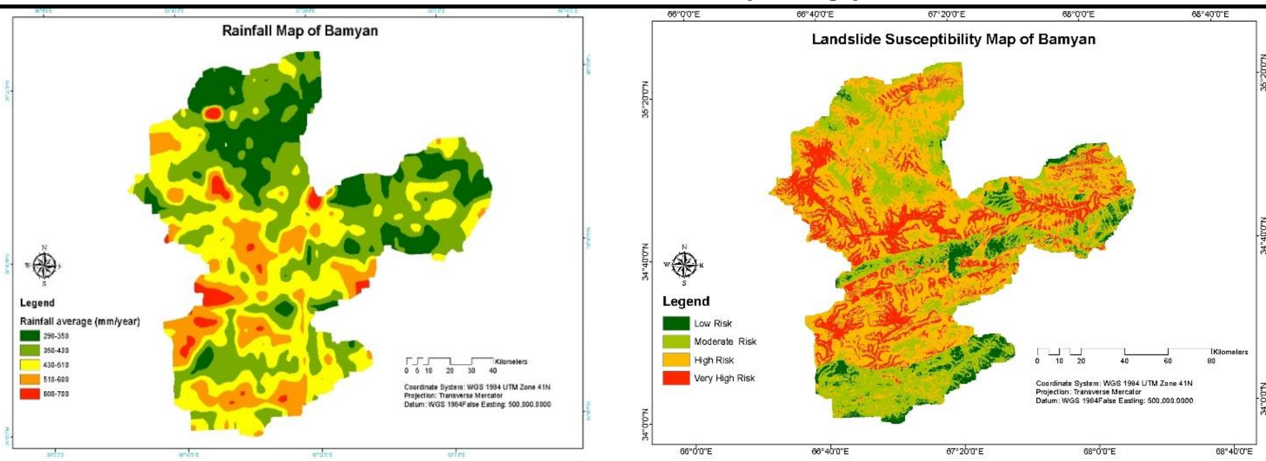


Figure 14. Rainfall map, landslide susceptibility map

Surface temperature plays an important role in melting refrigerators. Chips flowing from melting refrigerators; destroys geologically non-resistant materials and leads to landslide(Amir Yazdadi & Ghanavati, 2016). To find out about the effects of temperature on the occurrence of landslides, the temperature map of the study area has been extracted form Landsat 8 image using the formula figure 15. $LST = BT/(1 + \left(\lambda * \frac{BT}{C2}\right) * \ln(E))$. Where BT is the top of atmosphere brightness temperature, λ wavelength of emitted radiance and its value for landsat8 band 10 and band 11 respectively are 10.8 and 12. In this study for this factor, a weight of 0.02 assigned.

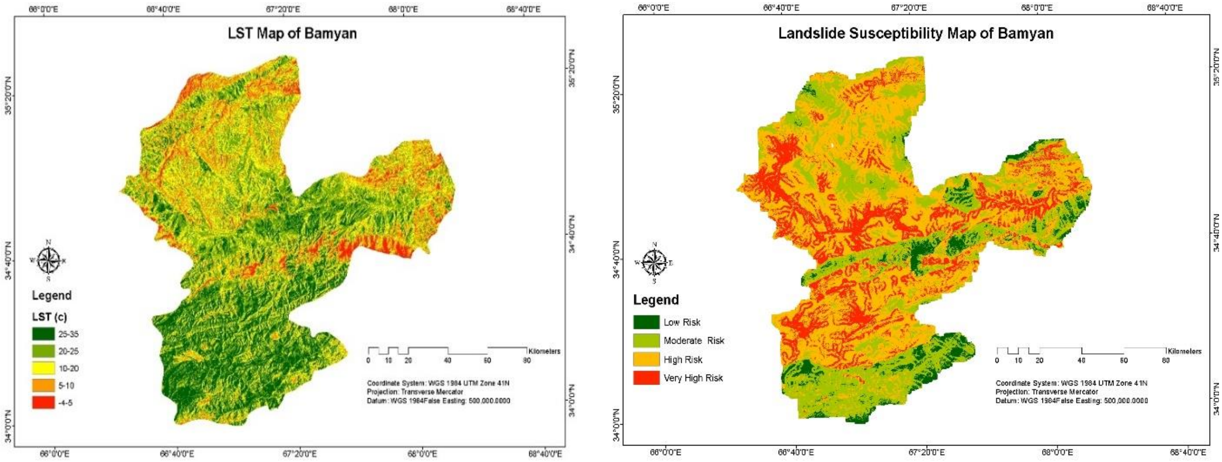


Figure 15. LST map, landslide susceptibility map

Elevation changes in each area considered as an effective factor in creating mass movements. This factor controls the direction of runoff and the density of the drainage network and has a significant effect on the amount of soil moisture (as an effective factor in mass movements). In addition, elevation changes play a significant role in making steep slope.(Schlagel et al., 2016). In this research, the Elevation data (GDEM) collected from USGS earth explorer. In this research, a weight of 0.03 assigned to this factor. Base on geological breaks the elevation classified in five classes figure 16.

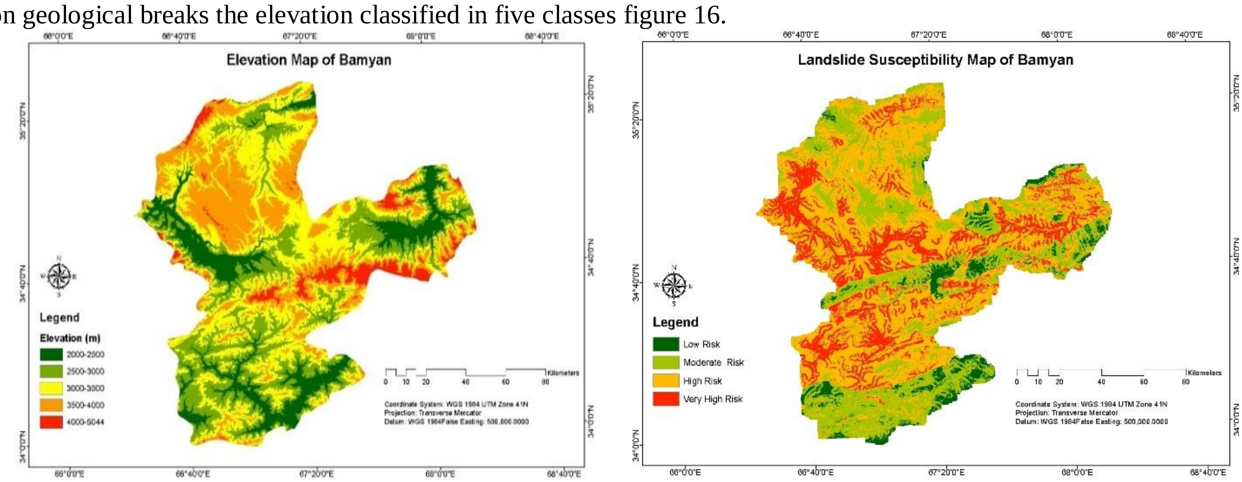


Figure 16. Elevation map, landslide susceptibility map

Investigation of slope status is important because the mechanism of many displacements related to surface materials and transport processes is a function of the slope. In this regard, it can be said that due to the very high altitude range, the highlands are very young and steep, so they have a severe and significant erosive appearance. Therefore, the most and most effective dynamic factors can be found in mountain axes (Schlagel et al., 2016) and (H. R. Pourghasemi et al., 2013). For preparing landslide susceptibility map, the slope map was divided into four slope categories and a weight of 0.14 assigned to this factor. According to the landslide inventory map, most landslides had occurred in 30-50 degree of slope ranges. Theoretically, landslides do not generally occur in areas less than 5 °figure 17.

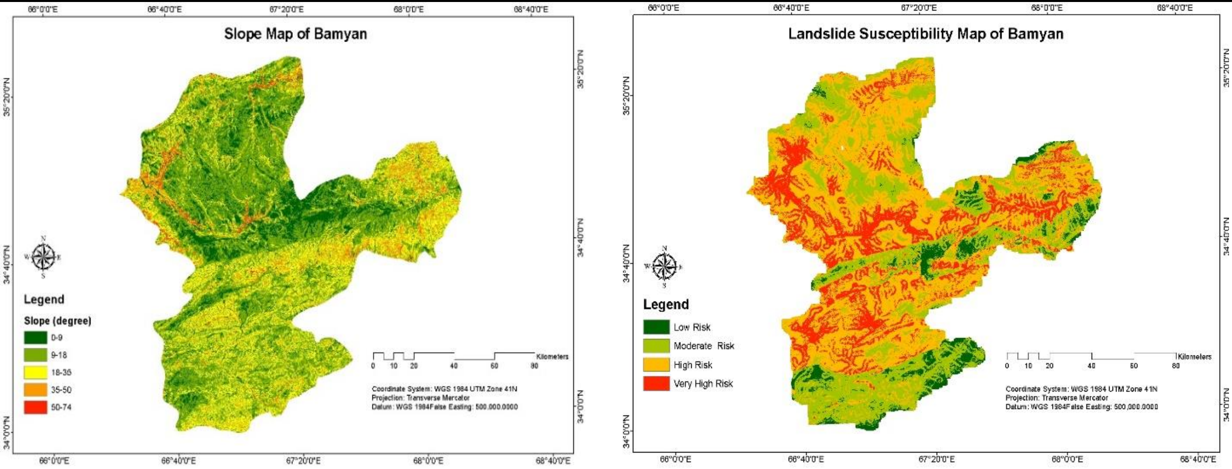


Figure 17. Slope map, landslide susceptibility map

Aspect was weighted most heavily to the southeast and northwest to account for higher failure rates observed by presumably due to fault-face orientation and moisture-microclimate regimes(Aksaray et al., 2011). Faults in crystalline rock and associated rock falls and slides were observed to most commonly be exposed to the southeast among ridges in the northeast Hindu Kush Mountains (Shroder et al., 2011b), and higher moisture content in orientations nearest to northwest-facing slopes contributed to instability in loess as discussed in ranking of lithology (Moradi et al., 2012). In this study, the aspect map generated from GDEM. For providing the landslide susceptibility map a weight of 0.02 assigned to this factor figure 18.

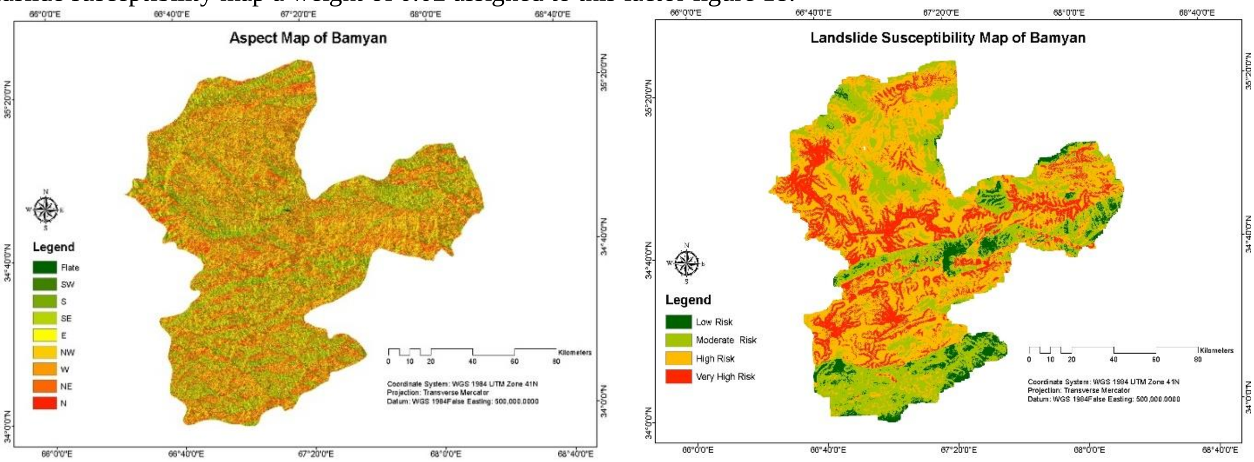


Figure 18. Aspect map, landslide susceptibility map

The land cover type is very important for landslide studies, especially the areas that are covered with intense vegetation. As in tea plantations, intensely vegetated areas exhibit more saturation and greater instabilities than forest. Land cover analyses showed that landslides commonly occurred in the barren area. Barren slopes are more prone to landslides. In contrast, vegetative areas tend to reduce the action of climatic agents such as rain (Amir Yazdadi & Ghanavati, 2016). In this study land cover data collected from Esri data portal with spatial resolution of 10m. For this purpose, the land cover map of the study area classified into 4 classes such as water, dense vegetation, sparse vegetation and built up, bare land as shown in figure 19. For providing the final susceptibility map of the study area a weight of 0.06 assigned to this factor.

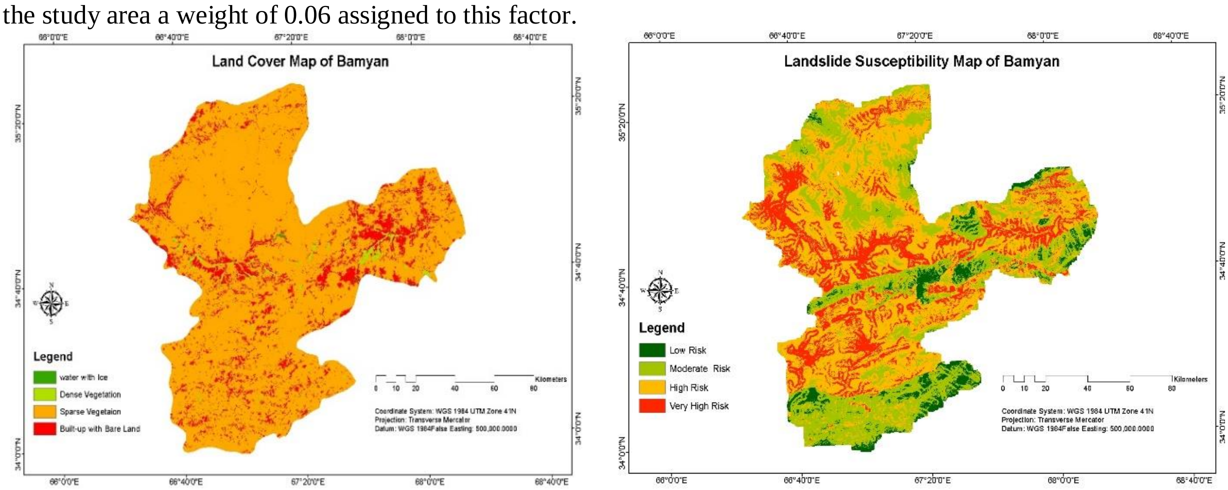
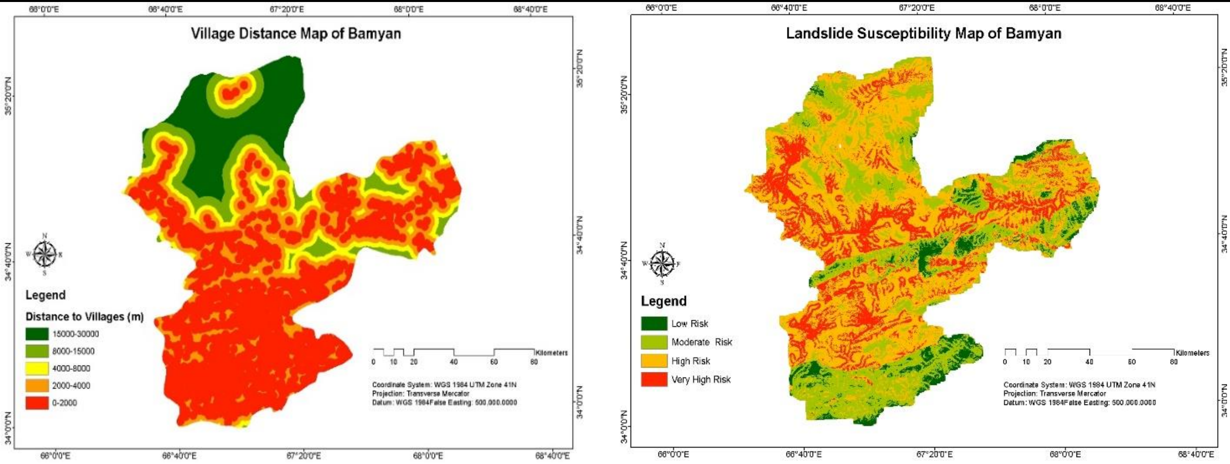


Figure 19. Land cover map, landslide susceptibility map

Human activities always play a critical role in environmental change. In many cases, the location of these land uses is so inadequate that it causes distraction in the natural ecosystem.(Aksaray et al., 2011). In this study, the village density or human activity considered as an effective factor in landslide susceptibility mapping. For this, factor a weight of 0.06 assigned. Figure 20 shows the village density map of Bamyan.



Figur 20. Village density map, landslide susceptibility map

The distance to road is one of the main parameters in preparing landslide susceptibility maps. Roads can be one of the reasons of occurring landslides. Roads change the nature of topography, decrease the shear strength of toe of slope, and cause the tensile stress. Naturally, slope may be stable, but after road construction, road can have undesirable effect on slope. The road causes infiltrating of water in slopes and enforces extra stresses due to traffic loads. In this region, many landslides have occurred because of unsystematic road construction in marl sediment alluvial(Aksaray et al., 2011). In this study, roads are classified into 5 classes based on specified distance as shown in figure 21. For the purpose, of making the landslide susceptibility map a weight of 0.02 assigned to this factor.

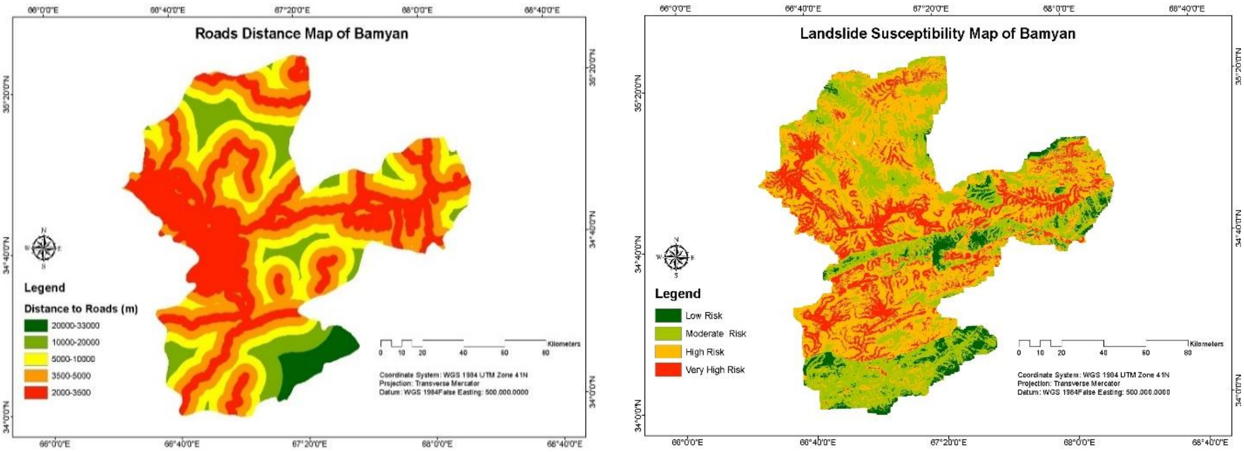


Figure 21. Road distance map, landslide susceptibility map

Distance to drainage is one of the effective factors for the stability of a slope. The saturation degrees of the materials directly affect slope stability. The proximity of the slopes to the drainage structures is also important factor in terms of constancy. Drainage may harmfully disturb stability by eroding the slopes or by saturating the lower part of material until the water level increases(Moradi et al., 2012). For the current purpose, distance to drainage with different buffer zones start from 30m to 3500m created and classified into five classes as shown in figure 22. For the purpose of creation of final landslide susceptibility map a weight of 0.17 assigned to this factor. Distance to drainage after the lithology factor is the second important factor that more effect on landslide occurrence.

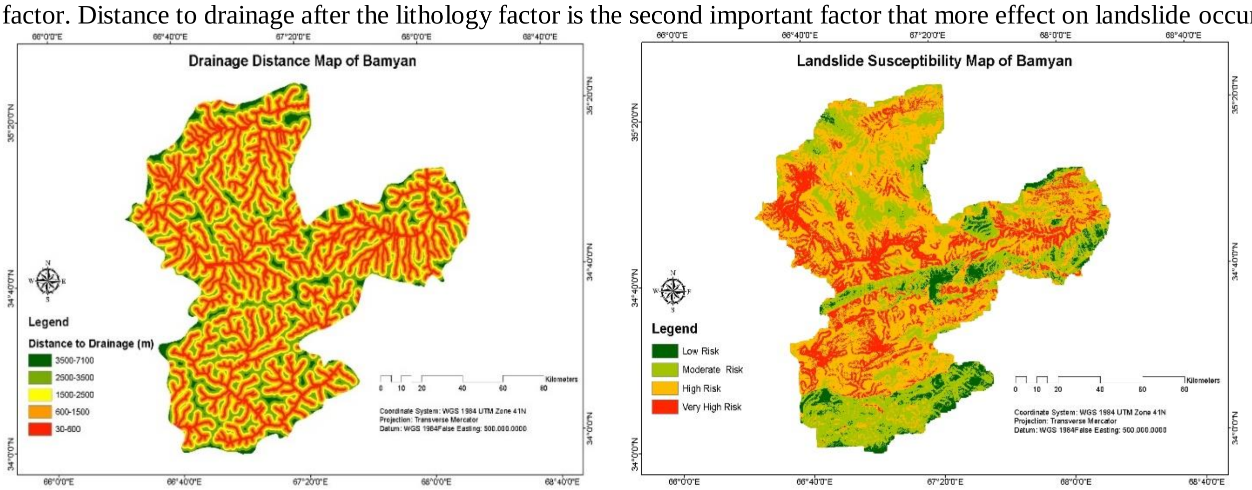


Figure 22. Drainage distance map, landslide susceptibility map

In general, water flows have a direct effect on landslide events in terms of their volume. The larger the volume of water, the greater the impact on geologically unstable materials such as soil, clay and silt. The drainage density calculated and classified into five classes. A weight of 0.04 considered for this factor. Therefore, groundwater exchanges directly the appearances of surface water by supporting drainage base flow. Groundwater disturbs surface water by providing moisture for riparian vegetation, and monitoring the trim strength of slope materials, thereby affecting slope stability and erosion processes. Most of the time the volume of the drainages increase because rainfall in the spring season and because glacier and snow melting in the summer season. In smaller, low-order streams, groundwater also provides much of increased discharge during and immediately following storms. The effect of streams to landslide increases all of these events(Amir Yazdadi & Ghanavati, 2016) and (Moradi et al., 2012). The drainage density classified into five classes as shown in figure 23. For providing the final landslide susceptibility map a weight of 0.04 assigned to this factor.

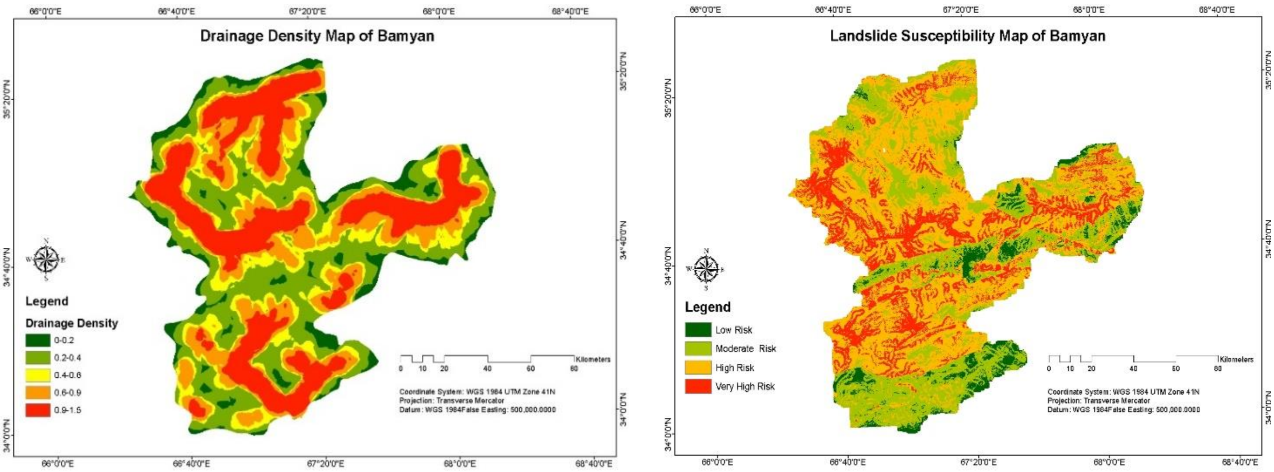


Figure 23. Drainage density map, landslide susceptibility map

The main cause of slippery mass movements is the layers of loose marl formation. If the aggregation is composed of clay, the clay causes these layers to absorb rainfall and become slippery after expansion and saturation. Lithology is one of the most important parameters in landslide studies because different lithological units have different degrees of susceptibility. Due to the lack of detailed geological data in this the study area, the lithological map of the study area divided into three major categories: sedimentary, volcanic and metamorphic. In this classification, the most score belong to Quaternary rocks and sediments and cover the big part of the study area, that is, Quaternary rocks and sediments are more reliable to land sliding. Because of the geologically reason Quaternary rocks and sediments are very young, not very stiff, and are unstable(H. R. Pourghasemi et al., 2013) and (Achour et al., 2017). As mentioned in this research because of lack of detailed geological data in the Afghanistan, the geology of the study area divided in three classis as shown in figure 24. Since, sedimentary rocks cover most area of the study area. On the other hand, the resistance of sedimentary rocks to external factors such as slope, moisture, etc. is low, the highest weight assigned to this factor.

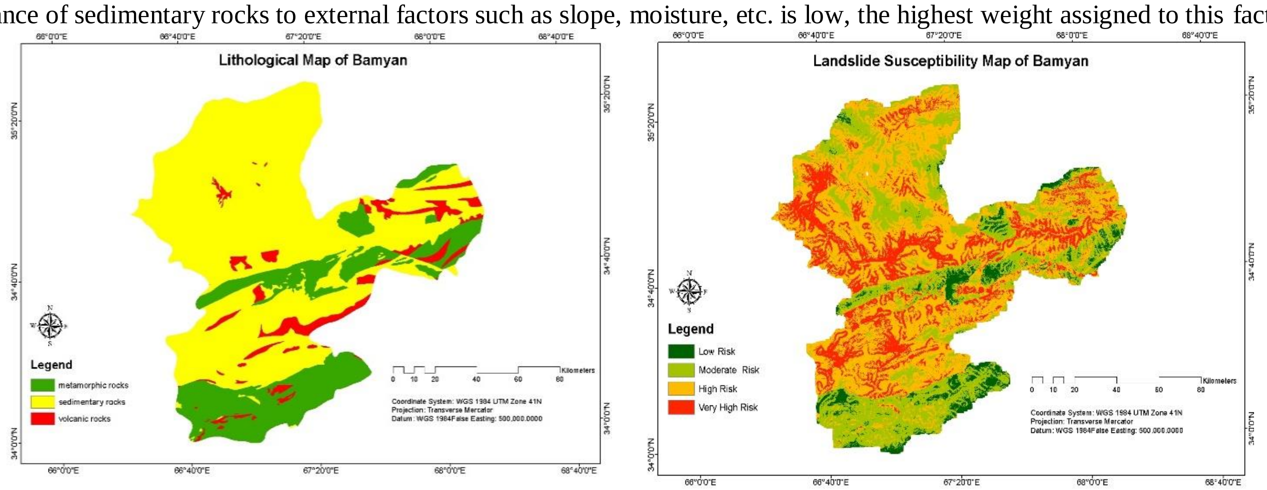


Figure 24. Lithology map, landslide susceptibility map

For the fault factor, different effects can be imagined in the occurrence of slips in the slopes. Fragmentation and shear in the fault zone, water infiltration from these areas into the slopes, discontinuities around faults and erosion differences in the slopes are some of the effects that can be mentioned. Fault movement act as a trigger for landslides occurrence in the region. Landslide occurrence after an earthquake proves how effective is geological faults in landslide occurrence. In fact, the movement of faults causes the movement threshold to reach the slope. Tectonic movements play an intensifying and accelerating role in the occurrence of landslides. To investigate the relationship between landslides and fault factor, a map of the distance from the fault and the density of the fault was prepared. As it known, the impact threshold of faults is often up to a radius of 2 km so that about 90 percent of landslides are located within this range. The fault extracted from the geological map and classified into five classes as shown in figure 25. The range of distance is from 1000m to 10500m. For providing the final susceptibility map a weight of 0.12 assigned to this factor.

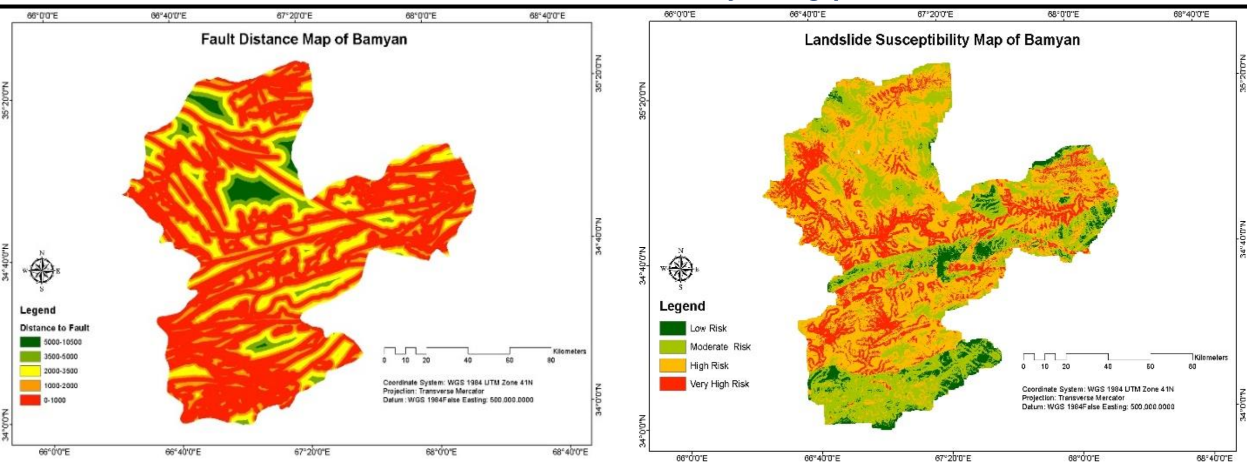


Figure 25. Fault distance map, landslide susceptibility map

To manage and minimize landslide hazards, research on landslide mapping is essential. Many methods have been proposed by researchers for providing of landslide susceptibility maps. In this research, the landslide susceptibility map of Bamyan province provided using AHP method.

Bamyan city is a landslide prone zone because of its physical appearance including the steep, topography, climate situations, located on earthquake zone, geology and geomorphology. In this research, using field survey, 20 landslides areas have been specified. Majority of these landslides occurred because of failure of geological materials, steep slope, erosion due to river, and unsystematic road construction in marl sediment deposited.

Finally, in order to validate the accuracy of the final landslide susceptibility map. The susceptibility map has been compared with the landslide inventory map of the study area. The results revealed that the active landslide zones had a high connection to the high and very high susceptibility class of map. The AHP map shows that approximately 80% of the active landslide zones located at high and very high susceptibility zones of map. High and very high susceptibility zones are commonly matched sedimentary rocks. These rocks are composed of marl rocks that are very sensitive near water. The low susceptibility zones are associated with metamorphic and volcanic rocks and dense vegetation coverage. In this area the failure of the geological material, steep slope, river erosion considerably increase the potential of land sliding. Based on this research, it presented that the high and very high susceptibility landslide zones identified by the AHP method, can calculate potential landslide areas in the reality. The result of this research shows that if the field accurately examined, then the HP method will give high accuracy results.

CONCLUSİON

Landslides are the most disastrous natural hazards in the across the world also in Afghanistan. Their assessment should been done before the construction of all types of engineering projects. A correct assessment of the probability of landslide occurrence is therefore required for road projects such as A1 highway. As can be seen, the economic value of landslide damage, even on a very small scale in a sensitive area, such as transit roads or residential, agricultural and industrial sites, is very significant and high if it occurs. Failure to pay attention to them in order to stabilize or relocate and lack of accurate and scientific studies during the construction of roads or residential and commercial places can inflict irreparable damage on the country's economy.Therefore, creating a regional strategy for the protection of human and natural resources and reducing the damage caused by its occurrence is very important and necessary, to achieve sustainable development goals, providing a suitable model and a suceptibile landslide map can be helpful for coresponding Environmental and urban development planner authorithies.

One of the advantages of the AHP method is that the factors affecting the occurrence of landslides are prioritized by comparing pairs between the given weight factors and the degree of impact of each factor on the landslide event, so this leads to a more reliable results. For these reasons, the AHP model is used by planners to solve the complex management problems that they face. On the other hand, GIS technique, due to its ability to manage large volumes of spatial information, is a powerful tool for this type of preliminary studies. Therefore, the combination of GIS technique and AHP model makes it possible for planners to choose the most appropriate option through pair wised comprison of influencing factors.

The study area was zoned in the form of different information layers based on the factor affecting the landslide event, and finally the occurrence of landslide zones was identified from a very low risk to very high table 3. Among the effective factors, lithological sub-criteria, distance to drainage, slope and distance from fault respectively with 0.23, 0.17, 0.14 and 0.12 have been identified as the most important factors in landslide formation in the study area. The role of others factors is reduced in relation to their impact on landslides and their weights are described in Table 2. The results of the final map shows that 9.26% of the study area is belongs to low risk, 29.52% belongs to moderate risk, 58.34% belongs to high risk and 2.88% of the study area is under the very high risk table 3.

The landslide susceptibility maps presented in this research constitute an important tool for decision maker, planners, and engineers. They can make rapid and well-grounded decisions to minimize and avoid the damage and losses caused by existing and future landslides, or avoid the highly susceptible zones, by suitable preventive measures and mitigation procedures.

ACKNOWLEDGEMENTS:

This research was supported by the 2021-22 Fellowship of the Coalition for Disaster Resilient Infrastructure (CDRI) organization. The authors would like to thank the CDRI organization and Bmayan University for their supports. The authors would like to express their sincere appreciation to Dr. Anwar Mohghy (Associated professor in Geology department, Bamyan University), Dr Sai Bhaskar Reddy (project advisor) Ms. Chanda Hada (project advisor) and Ms. Aishwarya Pillai (CDRI Fellowship Programme Team) for their constructive comments and helps.

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