KPU International Journal of Engineering & Technology
Volume 3, Issue1, Sep. 2023
e-ISSN:2790-0819, p-ISSN:2790-0800

Date Received: 2022-08-07
Date Accepted: 2023-07-29
Date Published: 2023-09-15

Avalanche Susceptibility Mapping Using GIS-based Multi-Criteria Decision Analysis: The Case of Shighnan District

AHMAD SHEKIB IQBAL[1*], ABDULLAH NASER[2]

[1*]Assistant Professor, Department of Geographical Information Systems, Kabul Polytechnic University, KPU campus, 5th District, Kabul, Afghanistan. Email: shekibiqbal.si@kpu.edu.af

[2]Professor, Department of Engineering Geodesy, Kabul Polytechnic University, KPU campus, 5th District, Kabul, Afghanistan. Email: abdullah848032@gmail.com

Abstract

Avalanche is one of the most dangerous natural disaster phenomena, which causes heavy damage to properties and fatalities in most mountainous and inaccessible regions across the globe. In the present study, avalanche susceptibility map of the Shighnan district is prepared by applying GIS-based multi-criteria decision analysis-analytic hierarchy process method. The prominent avalanche occurrence terrain factors such as slope, elevation, aspect, curvature, and land cover are used in this method. Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) and Corine Land Cover data are used to generate considered terrain factors. The pairwise comparison matrix is used to calculate the weight values of terrain factors. Then, the weight values of each avalanche occurrence terrain factor are utilized in the AHP model to produce the avalanche susceptibility map. The results are classified into five zones of very high, high, moderate, low, and very low, which covers 13%, 35%, 28%, 23%, and 1% of the total area respectively. This avalanche susceptibility map will assist decision-makers in better planning and taking precaution while moving across the region.

Keywords: Snow avalanche, GIS, Remote Sensing, AHP model, MCDA

[*]Corresponding Author

1. Introduction

Avalanches are one of the most hazardous natural disaster incidents in Afghanistan, which are very destructive and unpreventable. Avalanche is a rapid, downward movement of a large mass of snow, ice, and rocks. An avalanche occurs when accumulated snowpack moves downside of a mountain under the influence of gravity. The flow speed of an avalanche may accelerate up to 200 km/h and put pressure up to 50 T/m^2 [1]. Due to high flow speed and pressure, the avalanches tend to destroy forests, human, property, road networks, and communication lines [1]. An avalanche is highly uncertain and hard to predict. Hence, it threatens the life of those who live in mountainous regions [2].

Normally, there are two main types of avalanches: loose avalanches and slab avalanches [1]. Loose avalanches initiate from a point or a single area and tend to collect masses of snow as it continues downside. Typically, this avalanche occurs due to poor connection between snow crystals and flow down a sloping surface in a triangular pattern [3]. In contrast, slab avalanches occurs due to failure in snow depth which take off from a large surface and hold more layers of organized snow [3]. This type of avalanche is more dangerous and cause most casualties and property damage [1]. In slab avalanches, the shear displacement depends on the slope angle and snow type. When the slope angel ranges between 25-90 degree, almost 90% of the total deformation is in shear displacement [3]. In slab avalanches the shear deformation will become more dominant when the density of snow increases. The chances of slab avalanches become rare when the slope angel reaches lower than 25 degrees. By increasing the slope angel, the frequency of slab avalanches also increase due to the higher shear stresses and deformation [3].

The occurrence of avalanches are affected by several factors such as topographical, metrological, snowpack structure, natural triggers, social activities, land cover, etc. [4], [5]. For avalanche susceptibility mapping of a region, it's difficult to consider all effective factors because, there are many contributing factors, and they are not homogenous. Indeed, there are two main types of factors, static terrain factors and dynamic metrological factors [6].

Prediction of avalanches are very difficult and challenging tasks as it involves dynamic meteorological factors i.e., snowfall, temperature, water content, wind speed, precipitation, rain fall and static terrain factors such as slope, aspect, elevation, curvature, and ground cover [6], [7]. Thus, an avalanche susceptibility map is an essential step for the evaluation of high-risk areas and very helpful to plan, manage and travel safely across the snow covered regions [6].

Various studies have been conducted to generate avalanche susceptibility maps using GIS, Remote Sensing, and multi-criteria decision analysis (MCDA) approaches. Several studies applied GIS-based AHP methods [5]–[8], Kumar et al. (2019), while producing avalanche susceptibility map, used probabilistic occurrence ratio (PRO). Many studies applied static factors such as slope, elevation, curvature, aspect, land cover, vegetation cover, and terrain roughness to generate susceptibility maps, since static factors are constant and can be used effectively for avalanche susceptibility mapping for long duration [1], [4], [5], [7]. Singh et al. (2019) integrated the static and dynamic factors to

produce avalanche susceptibility map. Dynamic factors like meteorological parameters and snowpack structures are changing in different times related to the weather conditions [7].

The present study attempted to produce an avalanche susceptibility map considering terrain and land cover parameters in Shignan district of Badakhshan province of Afghanistan by using GIS-based multi-criteria decision analysis Analytic Hierarchy Process (AHP) model that suggested by Saaty [10]. The key advantage of GIS in the assessment of natural hazard is its ability to integrate large heterogenous datasets, their management and analysis [6]. An important reason while using the AHP model is that it's easy to understand and has the strong capability in solving the complex decision problems [11] and this model can be implemented in GIS effortlessly.

2. Study area and dataset used

2.1 Study area

The study area is Shignan district of Badakhshan province, which is located in the mountainous northeast region of Afghanistan. It is bordered by Tajikistan in the east and northeast (Figure 1). Geographically, the study area lies between latitudes 37°15′22″ to 38°03′49″ N and longitude 70°44′41″ to 71°35′54″ E. The altitude of the study area extends from 1720 to 5150 m. The study area covers the area of 4486 km^2. Shighnan district has a relatively hot, dry, and short summers and cold and long winters. The region has a humid continental climate which is cold and temperate. The winters are rainier than the summers with an average annual precipitation of about 867mm. January is the coldest month with the average daily temperature of -3.3°C, and -17.5°C is the recorded lowest temperature. At the end of June, summer starts and ends in September. The average high temperature is 11.8 °C, and the highest recorded temperature is 16.6 °C has ever measured (Climate-data.org). Due to the high mountains, this district is very difficult to navigate, especially during the snowy winter where almost all the roads in this district are blocked, causing mobility difficulties for the inhabitants. The study area is characterized by cold temperatures, slight precipitation, and heavy snowfall that has led to an escalation of incidents including floods, avalanches, and landslides.

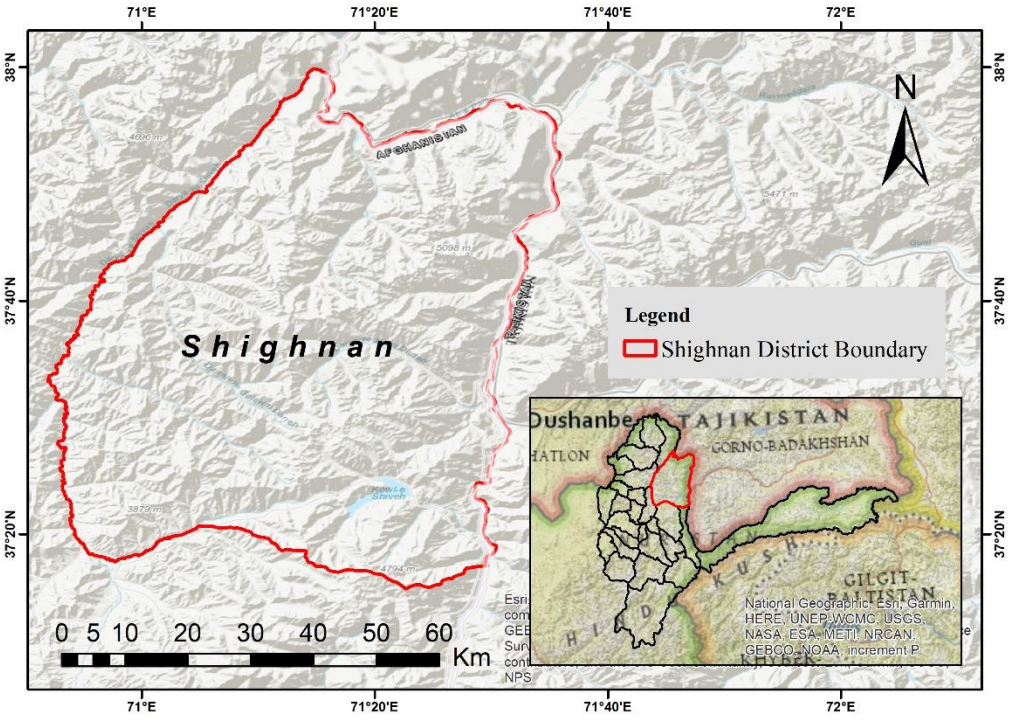


Fig. 1: Geographical position of the study area.

2.2 Dataset used

In the present study, the avalanche occurrence related factors are obtained from SRTM DEM and Copernicus. The avalanche occurrence terrain related factors, including slope, elevation, aspect, curvature, and land cover are considered as significant factors for generating avalanche susceptibility mapping [12]. The slope, elevation, aspect, and curvature are generated from SRTM DEM which was downloaded with a spatial resolution of 30m from USGS Earth Explored website (https://earthexplorer.usgs.gov/). The land cover data downloaded from Copernicus Global Land Service Portal (https://land.copernicus.eu/global/index.html). Each of them was considered a prominent avalanche occurrence factor and utilized for avalanche susceptibility mapping.

3. Methodology

The methodology adopted to generate the avalanche susceptibility map is illustrated in Fig. 2. and explained in the subsequent sections. The first part of the methodology was to collect the datasets used and proceeded to generate, analyze, rank, and reclassify the most significant avalanche occurrence terrain factors to acquire thematic layers. The next part was to generate pairwise comparison matrix between all terrain factors and calculate the weight values of thematic layers by applying analytic hierarchy process (AHP) method.

The final part was to integrate these thematic layers using a GIS-based AHP model to generate an avalanche susceptibility map. The methodology workflow is as follows:

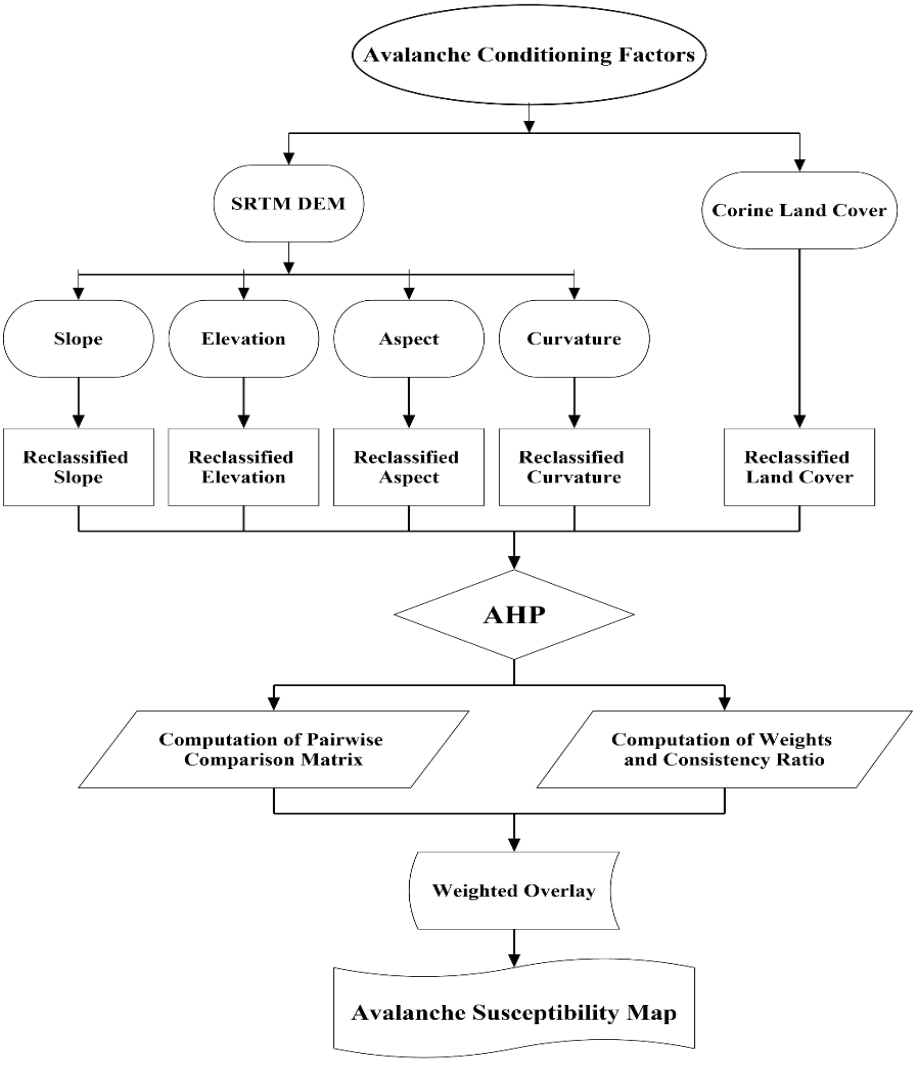


Fig. 2: Flowchart of the avalanche susceptibility mapping methodology.

3.1 Analysis of the factors and generation of thematic layers

The assessment of avalanche susceptibility mapping is a difficult and challenging task because there are several factors influencing an avalanche. Some factors that contribute to an avalanche susceptibility mapping are meteorological, snowpack structure, topographic characteristics, social activities, and natural triggers. The meteorological parameters incorporated in mapping avalanches are snowfall, wind speed, wind direction, precipitation, temperature, etc. Under meteorological conditions the snowpack structure rely upon successive snowfalls. The avalanches happen when the snowpack loses its

stability and becomes so weak or dislocated by natural triggers or social activities. The meteorological parameters and snowpack structure change continuously because they depend on weather conditions. Nevertheless, the topographical or terrain factors such as slope, elevation, aspect, curvature, and land cover are the constant factors for avalanche susceptibility mapping. Due to inadequate information about meteorological factors and short-term validity, the present study only considered the terrain factors. The details of each factor are summarized in the following subsections.

3.1.1 Slope

The slope is considered as a significant terrain factor for avalanche susceptibility mapping [7]. According to statistics, it is reported that most avalanche accidents occur where the slope angle is greater than 30° and less avalanches start on slope angle less than 25° [7], [12]. Though, the avalanches release from slope angle less than 25° when the snow has higher water content. Generally on such slopes, the shear stress is not large enough to initiate an avalanche [13]. Majority of avalanches release from slope angles between 28° and 45° [4], [6], [7], [14]. On steep slopes between 45°–55° very small avalanches can occur because the amount of snow deposition is limited. In the present study, the slope values were obtained from SRTM DEM and categorized into five classes (Figure 3).

3.1.2 Elevation

Elevation does not directly impact the initiation of avalanches. Nevertheless, meteorological factors such as snowfall, temperature, wind speed, and snow depth are directly connected to elevation, which in turn directly influence the occurrence of avalanches [7], [12]. Generally, at low elevations the chance of an avalanche occurring is low due to warm air. Likewise, snow that falls on lower elevation regions often melt and may change to rain when it reaches the ground. In the higher elevation regions, the snow can remain available for avalanche for a longer duration due to low temperatures [4], [6] . The present study area has the lowest elevation of 1719m and the highest elevation of 5148m, and most of the avalanches occur near regions with the highest elevations. The elevation ranges of the study area were categorized into six classes (Figure 3).

3.1.3 Aspect

Aspect is considered as a significant factor in evaluation of avalanche high risk zones [12]. Aspect does not directly influence the risk of avalanches; it is directly influenced by the sun radiation. The sun facing aspects receive more radiation from the sun with the snowpack structures becoming more stable than the shaded slopes. In addition, the windward slopes get stabilized due to less amount of snow while the leeward slopes increase the risk of avalanches because of extra snow loads [7]. According to Austrian and Swiss statistics report, 50% of all avalanches happen in the northern part (NW-N-NE) of the aspect [15]. Aspect map produced from SRTM DEM and categorized into 9 classes as illustrated in (Figure 3).

3.1.4 Curvature

Curvature is one of the significant parameter influencing avalanche susceptibility mapping [16]. Generally, avalanches happen on convex surfaces because of snowpack

instability compared to concave and flat surfaces that support stabilization [17]. Curvature map generated from SRTM DEM is categorized into 3 classes such as convex, concave, and flat, which are illustrated in (Figure 3).

3.1.5 Land cover

Land cover is also considered as a significant avalanche contributory factor. The land cover map provides information about the snow/ice, vegetation, build area, bare ground, and water body classes. Generally, dense vegetation cover such as forest has significant influence on avalanche activities. Dense vegetation cover is a greater shield against the avalanches which holds and reduces the amount of snow available for avalanche initiation [8], [18]. Snowpack structures are more stable in the forestry areas than the snow/ice and bare ground areas. Therefore, snow/ice cover and bare ground slopes are considered more susceptible to avalanches [16]. The land cover map of the study area is shown in Fig. 3.

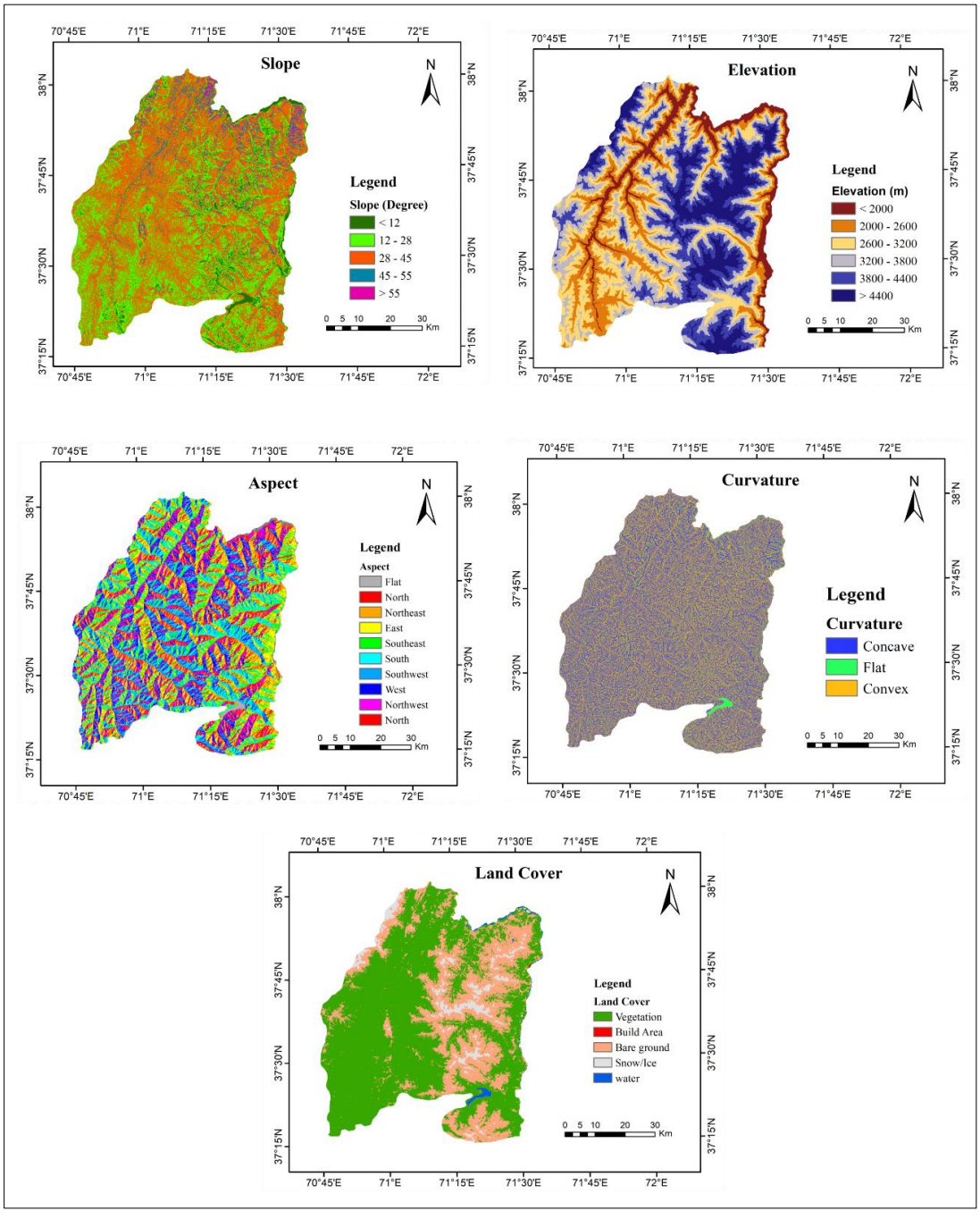


Fig. 3: GIS layers generated for avalanche susceptibility mapping.

3.2 Avalanche Susceptibility Mapping Using AHP Model

3.2.1 MCDA-AHP model

AHP is one of the Multi-Criteria-Decision-Making models that is broadly used in GIS-based decision-making problems. The concept of AHP was first proposed by Saaty [19]. AHP's wide use is because of its simplicity and does not need complex mathematics. In addition, it's possible to formulate the problems and consider qualitative and quantitative data simultaneously [19]. AHP model is widely and successfully used in various natural hazard studies such as avalanches [5], [7], [12], [18]. This technique is based on three main principles: decomposition of the problem, pair to pair comparison, and obtaining hierarchy of the priorities [19]. The principle of AHP is based on pairwise comparisons, which makes judgment easy and solve complex problems accurately. In the AHP technique, the problem is broken down into a hierarchical structure which makes the decision-makers to take the best decision. The judgment of this model is based on expert knowledge and the key concern is to create a hierarchy structure which splitting down the problem into a hierarchy of goal, criteria, and sub-criteria. In this study, the avalanche susceptibility mapping is the goal and the terrain factors which are described in section 3.1 are used as criteria.

The procedure for calculating the weights of parameters using AHP model can be summarized in the following steps [20]:

I. Generating pair to pair comparison matrix

In this step, we perform pair to pair comparison for each occurrence parameter. Each parameter must be at the same level, Saaty's importance value scale from 1 to 9 based on their relative importance (Table 1) were assigned and generated the pairwise comparison matrix for occurrence parameters which can be presented in Table 2.

Table 1: The importance value scale [19].

Importance	*Defining the relative importance*
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6,8	Intermediate judgement

Table 2: Pairwise comparison matrix and weight values of parameters.

Criteria / Criteria	Slope	Elevation	Aspect	Curvature	Land Cover	Weight Value
Slope	1	2	4	5	7	0.45
Elevation	1/2	1	3	4	5	0.29
Aspect	1/5	1/3	1	2	3	0.12
Curvature	1/5	1/4	1/2	1	3	0.09
Land cover	1/7	1/5	1/3	1/3	1	0.05

II. Calculation of weights

In this phase, at first the sum of each column is calculated in the pairwise comparison matrix. Afterward, each sum is divided into the matrix by summation of its column and the result demonstrates the normalized pairwise comparison matrix. The average of weights is estimated in each row of the normalized matrix and the results provide weight of each criterion (Table 2) [10].

III. Evaluation of consistency ratio

In this step, the consistency ratio (CR) of the n^{th} element is calculated. The CR calculation is used to check whether the pairwise comparison matrix is consistent or not. The following formula calculates CR:

$$CR = \frac{CI}{RI} \quad (1)$$

In the above formula, CI is a consistency index and RI represent the random index which is acquired from Table 3 based on the number of variables (n).

Table 3: Values of Random Index proposed by saaty [10].

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency index is derived using the following formula:

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

In the equation (2), λ_{max} is the maximum eigenvalue of the pairwise comparison matrix, and n is the number of criteria. The concept of the CR is designed in such a way that if the CR is less than 0.1 or 10% the matrix expresses inconsistency and requires reconsideration of pairwise comparison. If the CR is more than 0.1 or 10% the matrix expresses a validation of consistency [10]. The computed CI, λ max, RI, and CR of the matrix are illustrated in Table 4.

Table 4: Estimated consistency ratio and its variables.

CI	λ max	RI	CR
0.04	5.14	1.12	0.03

The weights of parameters have been computed based on their relative importance. The relative importance values were chosen based on avalanche-related published studies [5]–[9], [12], [18], [21], [22]. According to these studies, the relative importance of each criterion is carefully evaluated, and suitable relative importance values were assigned.

3.2.2 Avalanche Susceptibility Mapping

Th MCDA-AHP model is applied in GIS to produce an avalanche susceptibility map of the Shignan district. The avalanche occurrence terrain factors are reclassified as shown in Figure 3 and the ratings are assigned to each class using a scale range from 1 to 5 (Table 5). The reclassified avalanche terrain factors and the calculated weight values of corresponding terrain factors are used in equation 3 to produce an avalanche susceptibility map.

$$ASI = \sum_{i=1}^{n} (R_i \times W_i) \quad (3)$$

In the equation, *ASI* is avalanche susceptibility index, R_i is the rating value of reclassified class of the factors and W_i is the weight values for each avalanche terrain factor obtained from AHP technique.

The ASI map of the study area was then subdivided into the following five susceptible areas: very low, low, moderate, high, and very high susceptibility as illustrated in Fig. 4.

Table 5: Rating assignment to each factor.

Factors	*Categories (classes)*	*Ratings*
Slope	< 12°	0
	12° – 28°	1
	28° – 45°	5
	45° – 55°	3
	> 55°	1
Elevation	< 2000	1
	2000 – 2600	2
	2600 – 3200	3
	3200 – 3800	4
	3800 – 4400	4
	> 4400	5
Aspect	Flat	0
	North	5
	North-East	5
	East	2
	South-East	1
	South	1
	South-West	1
	West	2
	North-West	4
Curvature	Concave	1
	Flat	0
	Convex	5
Land cover	Vegetation	2
	Build Area	0
	Bare ground	4
	Snow/Ice	5
	Water	1

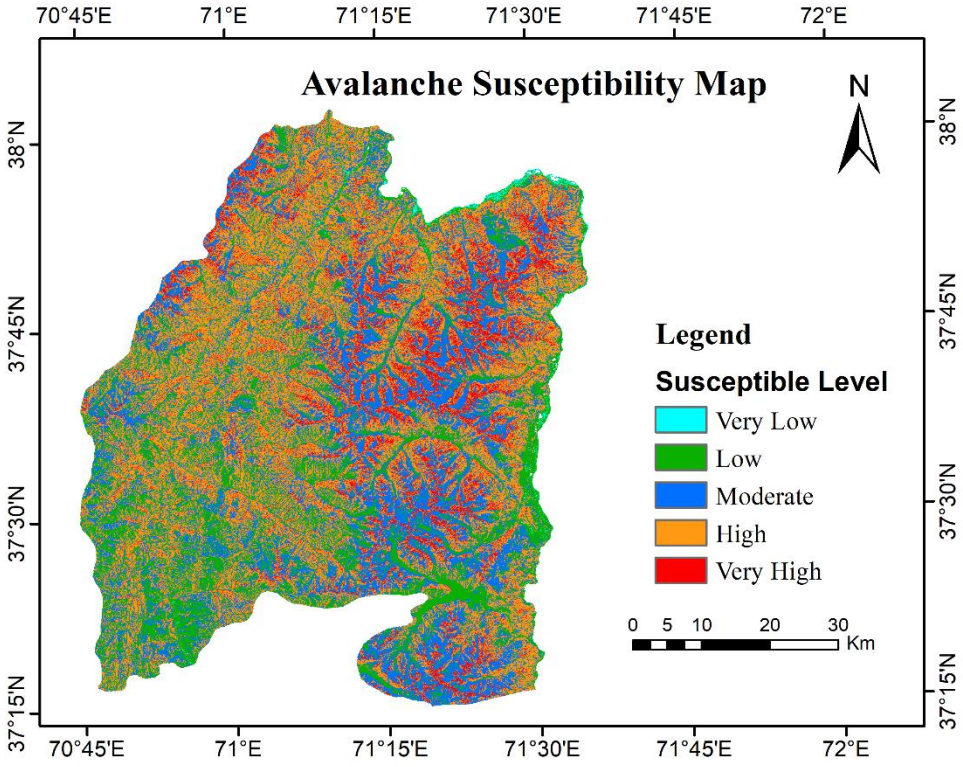


Fig. 4: Avalanche susceptibility map of the study area.

4. Results and discussion

Avalanches are one of the natural disaster incidents occurring due to terrain and meteorological factors. In this study, only terrain factors were applied to produce an avalanche susceptibility mapping due to their reliability, easy availability, and high dependency with avalanches. Avalanche occurrences are influenced by several factors such as slope, elevation, aspect, curvature, and land cover. For avalanche susceptibility mapping of Shighnan district, these factors were derived from the SRTM DEM and Copernicus portal. The slope was considered the most significant avalanche occurrence terrain factor. The slope layer was classified into five classes such as <12°, 12–28°, 28–45°, 45–55° and >55°. Those slope classes were rated, and maximum rating was assigned to the class ranges from 28–45° because this class was found to be the most prominent (Table 5).

The elevation layer was considered the second predominate terrain factor, which was classified into six classes such as <2000, 2000–2600, 2600–3200, 3200–3800, 3800–4400 and >4400. The maximum ratings were given to the elevation class of 3800–4400 and >4400 because of snow depth and heavy snowfall in these elevations (Table 5). Aspect layer was classified into nine classes; aspect classes of North, Northeast, and Northwest were assigned the maximum ratings because the snowpack is unstable in these zones (Table 5).

Curvature values were classified into concave, flat, and convex classes. The convex curvature values were considered more prone to avalanches than flat and concave. Thus, the maximum rating was given to the convex curvature values (Table 5). The land cover was generated from Copernicus and classified into five classes such as snow/ice, vegetation, bare ground, build area, and water. The maximum rating was assigned to snow/ice cover regions due to snowpack instability and susceptible to avalanche formation and minimum rating was assigned to water and build areas (Table 5).

Pairwise comparison matrix was used to calculate the weight values of each avalanche occurrence factor. The comparison matrix is given in Table 2. The slope factor was given the highest weight value in the pairwise comparison matrix than other factors. The degree of importance for each factor was specified based on the 1 to 9 scale (Saaty, 1980) and is presented in Table 1. After generating pairwise comparison matrix, the weight values of avalanche occurrence factors were computed. The weight values of slope, elevation, aspect, curvature, and land cover were assigned as 0.45, 0.29, 0.12, 0.09, and 0.05, respectively (Table 2). Therefore, the highest weight value is given to slope and lowest for land cover. The consistency ratio is computed as 0.03. The weight values of factor and given score to each class of the factors were integrated with GIS using Equation 3 to acquire the ASI.

The resulting avalanche susceptibility map for Shighnan district was divided into five zones as: very low, low, moderate, high, and very high (Figure 4). According to the results, high and very high susceptible regions cover 35% (1595.19 km^2) and 13% (586.25 km^2) of the study area, while moderate, low, and very low susceptible regions contribute 28% (1249.38 km^2), 23% (1018.44 km^2), and 1% (22.37 km^2) of the study area respectively (Table 6).

Table 6: Regional distribution of avalanche susceptibility map.

Avalanche Susceptibility	*Area (km^2)*	*Percentage %*
Very low	22.37	1
Low	1018.44	23
Moderate	1249.38	28
High	1595.19	35
Very high	586.25	13

5. Conclusion

Avalanches are one of the most dangerous natural phenomena occurring every year and tend to destroy properties, homes, livestock, and causes loss of lives. Hence, avalanche susceptibility mapping is a vital step in identifying the risky zones. The Shighnan district is a very complex mountainous area, and harsh climatic conditions. Therefore, avalanche susceptibility mapping of such an area is a very challenging task. The GIS and remote sensing technology integrated with MCDA-AHP model are applied to generate the avalanche susceptibility map of the Shighnas district. AHP model is being applied for

solving many problems and widely used for solving natural hazard problems. This model can integrate large number of dataset and easily acquire the weight values of various numbers of criteria.

In the present study, five avalanche terrain factors such as slope, elevation, aspect, curvature, and land cover were used as an input to produce the avalanche susceptibility mapping of the study area. The procedure involved various steps such as creating and analyzing the avalanche occurrence terrain factors, generating pairwise comparison matrix, calculating weight values of terrain factors, and producing susceptibility mapping. The avalanche susceptibility map was divided into five susceptibility regions. The results demonstrate that 1% of the area is in very low susceptibility region and 13% of the area is in very high susceptibility region. The results show that GIS-based MCDA-AHP technique is suitable for detecting and locating the avalanche risky zones. This avalanche susceptibility map can help decision-makers and engineers in better planning of infrastructure development, taking precaution while moving across the region, and useful for authorities in disaster management. Considering the dynamic meteorological factors will be beneficial for more accurate and precise avalanche susceptibility mapping of the region.

6. Disclosure statement

The authors declare that there is no potential conflict of interests.

References

[1] S. Kumar, P. K. Srivastava, Snehmani, and S. Bhatiya, "Geospatial probabilistic modelling for release area mapping of snow avalanches," *Cold Reg. Sci. Technol.*, vol. 165, p. 102813, 2019, doi: 10.1016/j.coldregions.2019.102813.

[2] I. McCammon and P. Hägeli, "An evaluation of rule-based decision tools for travel in avalanche terrain," *cold Reg. Sci. Technol.*, vol. 47, no. 1–2, pp. 193–206, 2007, doi: 10.1016/j.coldregions.2006.08.007.

[3] D. . McClung and P. Schaerer, *The avalanche handbook*, 3rd ed. Seattle, WA, USA: The Mountaineers Books, 2006.

[4] V. Singh, P. K. Thakur, V. Garg, and S. P. Aggarwal, "ASSESSMENT OF SNOW AVALANCHE SUSCEPTIBILITY OF ROAD NETWORK - A CASE STUDY OF ALAKNANDA BASIN," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, no. December, 2018, doi: 10.5194/isprs-archives-XLII-5-461-2018.

[5] S. Nasery and K. Kalkan, "Snow avalanche risk mapping using GIS-based multi-criteria decision analysis: the case of Van, Turkey," *Arab. J. Geosci.*, vol. 14, no. 9, 2021, doi: 10.1007/s12517-021-07112-4.

[6] R. Parshad, P. K. Srivastva, S. Ganguly, S. Kumar, and A. Ganju, "Snow Avalanche Susceptibility Mapping using Remote Sensing and GIS in Nubra-Shyok Basin, Himalaya, India," *Indian J. Sci. Technol.*, vol. 10(31), no. August, pp. 1–19, 2017, doi: 10.17485/ijst/2017/v10i31/105647.

[7] S. Kumar, P. Kumar, S. Snehmani, L. Oli, and Á. A. Gdem, "Geospatial Modelling and Mapping of Snow Avalanche Susceptibility," *J. Indian Soc. Remote Sens.*, vol. 46, no. 1, pp. 109–119, 2018, doi: 10.1007/s12524-017-0672-z.

[8] S. Kumar, P. K. Srivastava, and Snehmani, "GIS-based MCDA–AHP modelling

for avalanche susceptibility mapping of Nubra valley region, Indian Himalaya," *Geocarto Int.*, vol. 6049, pp. 1–14, 2017, doi: 10.1080/10106049.2016.1206626.
[9] D. K. Singh, V. Dutta, M. Hemendra, S. Gusain, and N. Gupta, "Geo-spatial Modeling for Automated Demarcation of Snow Avalanche Hazard Areas Using Landsat-8 Satellite Images and In Situ Data," *J. Indian Soc. Remote Sens.*, vol. 47, no. 3, pp. 513–526, 2019, doi: 10.1007/s12524-018-00936-w.
[10] T. L. Saaty and L. G. Vargas, "HIERARCHICAL ANALYSIS OF BEHAVIOR IN COMPETITION: PREDICTION IN CHESS," *Behav. Sci.*, vol. 25, pp. 180–191, 1980.
[11] J. Malczewski, "GIS-based multicriteria decision analysis: A survey of the literature," *Int. J. Geogr. Inf. Sci.*, vol. 20, no. 7, pp. 703–726, 2006, doi: 10.1080/13658810600661508.
[12] L. Selçuk, "An avalanche hazard model for Bitlis Province , Turkey , using GIS based multicriteria decision analysis," *Turkish J. Earth Sci.*, vol. 22(4), pp. 523–535, 2013, doi: 10.3906/yer-1201-10.
[13] C. Ancey, "Snow Avalanches," in *B. Schrefler, P. Delage (Eds.), Environmental Geomechanics*, New York, 2013.
[14] T. Arumugam, S. K. Dewali, and A. Ganju, "Integration of terrain and AVHRR-derived multi-temporal snow cover data for statistical assessment of avalanches : case study of a part of NW Himalaya," *Arab. J. Geosci.*, 2019.
[15] J. Benedikt, "Risk Assessment of Avalanches - a Fuzzy Gis Application," in *Proceedings of 5th international FLINS conference*, 2002, pp. 395–402, doi: 10.1142/9789812777102_0048.
[16] A. Snehmani, A. Bhardwaj, A. Pendit, and A. Ganju, "Demarcation of potential avalanche sites using remote sensing and ground observations : a case study of Gangotri glacier," *Geocarto Int.*, vol. 29, no. 5, pp. 520–535, 2014, doi: 10.1080/10106049.2013.807304.
[17] R. Nagarajan, G. Venkataraman, and Snehmani, "Rule based classification of potential snow avalanche areas," *Nat. Resour. Conserv.*, vol. 2, no. 2, pp. 11–24, 2014.
[18] A. A. Mohammed, H. R. Naqvi, and Z. Firdouse, "An Assessment and Identification of Avalanche Hazard Sites in Uri Sector and its Surroundin on Himalayan Mountain," *J. Mt. Sci*, vol. 12, no. 2, pp. 1499–1510, 2015.
[19] T. Saaty, "The analytic hierarchy process," *New York: McGraw-Hill*. 1980.
[20] T. Saaty, "Decision making with the analytic hierarchy process," *Int J Serv Sci*, no. 1, pp. 83–98, 2008.
[21] D. K. Singh, H. S. Gusain, V. Mishra, N. Gupta, and R. K. Das, "Automated mapping of snow / ice surface temperature using Landsat-8 data in Beas River basin , India , and validation with wireless sensor network data," *Arab. J. Geosci.*, 2018, doi: 10.1007/s12517-018-3497-3.
[22] J. Schweizer, B. Jamieson, and M. Schneebeli, "Snow avalanche formation," *Rev. Geophys.*, 2003, doi: 10.1029/2002RG000123.

Authors Profile



Ahmad Shekib Iqbal received the B.S. degree in Engineering Geodesy from Kabul Polytechnic University in 2015 and M.Sc. degree in Geomatics Engineering, Geodesy and Geographic Information Technologies Program from Gebze Technical University, Turkey in 2020. Currently, he is working as an Assist. Professor in the Department of Geographical Information System, Kabul Polytechnic University, Kabul Afghanistan. His research interests are Geographic Information Systems/Technologies (GIS), Remote Sensing, GIS-Transportation and Surveying Engineering.



Abdullah Naser received an M.Sc. degree in Engineering Geodesy from Moscow Institute of Geodesy, Aerial Surveying and Cartography in 1987. Currently, he is working as a HOD and Professor in the Department of Engineering Geodesy, Kabul Polytechnic University, Kabul Afghanistan. His research interests are Surveying Engineering, Cartography, GPS, and Spherical Geodesy.