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Assessment and Zoning of Areas by Risk Level of Snow Avalanches in Sharr Mountains

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Abstract: In the past decades, snow avalanches on Shar mountain have occurred continuously, which in certain places have led to undesirable consequences. The assessment and zoning of the areas with a level of risk in the case of Shar Mountain was carried out by applying MDA-AHP and Fuzzy Logic methods, while the analysis of the accuracy of the final obtained results were performed by applying the ROC method. The study area was classified in five categories, as areas with very low ($Z = 0$), low ($0 < Z < 0.2$), moderate ($0.2 < Z < 0.5$), high ($0.5 < Z < 0.7$), and very high ($Z > 0.7$) avalanche release potential zones, recorded in a developed geodatabase, as well as shown in two maps with zoned areas by risk level of snow avalanches in Sharr Mountains area, that are intended to be used as an open geospatial database by all stakeholders.

Keywords: Analytic Hierarchy Process (AHP); Avalanche release potential; Fuzzy Logic (FL); Multicriteria Decision Analysis (MDA); Receiver Operating Characteristics method (ROC); Sharr Mountains; Snow avalanche

1 INTRODUCTION

Natural disasters are events that negatively affect human life and well-being. They are classified as natural as they are generally caused by climatic phenomena, biological factors, geomorphological processes, or spatial phenomena. Their cause can be directly or indirectly the man himself with his activities, but which are minor in relation to the above factors. Natural disasters are generally unpredictable, with varying intensities and effects, which can strike at any moment, causing significant loss of human, animal, and material life. The person in this situation can influence their warning and prevention if possible.

Avalanches are snow masses that are released and move from mountain slopes in the direction of falling terrain. Avalanches are a significant natural hazard that affects road infrastructure, settlements and threaten the lives of people and animals, mainly in mountainous terrain. They occur because of the interaction of the snow layer, meteorological conditions, and topographic surface. These three factors are referred to as the avalanche triangle [1]. The mean avalanche victims are 250 per year [2]. For the tendency of a snow avalanche, there must be favorable meteorological conditions and terrain which meets the characteristics for the release of a snow avalanche. With the interconnection of these factors which include the physical component (theory of friction and movement of bodies), comes the potential for the release of an avalanche. By defining a model of snow avalanche potential, geographic terrain zoning can be done. In environments with snow avalanche discharge potential, the most influential factor within the avalanche triangle is the terrain factor. Among the components that characterize the terrain factor are slope required for sliding, rugged terrain, ground cover, distances from ridges, presence of gorges, relief forms (concavity and convexity), slope orientation, altitude, and many factors others with lesser influence.

The extent of an avalanche is characterized by three spatial zones:

• Initial area – that represents the area in which the avalanche begins to detach from the body in which it is superimposed. If the avalanche is of the slab type, it initially creates the refractive line, which simultaneously forms the upper avalanche boundary line.

• Movement area - represents the area in which the avalanche develops the highest speed of movement, the route of which is mainly determined by the relief. The boundary can be limited or unlimited depending on the terrain, for example: if the avalanche moves along the gorges, then the boundary is easily defined, but if the avalanche moves along the open slopes, then the boundary is indefinable for longer periods and may change depending on the amount of snow, speed, current vegetation, and many other factors.

• Deposit area - represents the area in which the avalanche ends or is deposited, which are usually areas with a smaller slope where the terrain "opposes" the direction of movement of the avalanche.

A snow avalanche in its formation has three main components, which with the interconnection between them create favorable conditions for the initiation of a snow avalanche, and they are:

- Topographic component,
- Meteorological component, and
- Physical component.

The only parameter from the above which can be taken as immutable is the relief. We can take this as such from the broader point of view because even the relief can't be said to be immutable as we know that the relief undergoes constant changes, but which are not observed in the short term. However, for the analysis, we are dealing with, compared to other parameters that are constantly changing, but at different time intervals, the relief will be part of the static components and will be presented through the digital elevation model (DEM) integrated through DTA (Digital Terrain Analysis) in GIS software.

Determining meteorological conditions and their impact [3] on avalanches requires a statistical study covering a period of about 30 years, as well as a review of meteorological conditions of all avalanche activities from the past to the moment they occurred. If such statistical data exist, for each climatic factor can be defined the so-called "zero line", which means the most favorable conditions for avalanches. In every winter season, after every snowfall, the climatic conditions can be identified and compared to the "zero line". After that, actions can be taken in different parts of the world with experiences in avalanches, such as closing roads which are high risk, snowfall in areas which are identified as areas with high snow avalanche potential or other actions depending on the need of that area.

2 MATERIALS AND METHODS

2.1 Study Area

For the study of snow avalanches in the framework of this paper, the area has been selected, the parameters of which have the potential for snow avalanches. The selected area is the geographical area of the Sharr Mountains. These mountains are located in Southwestern Europe, specifically in the south-southeast of the Republic of Kosovo, northwest of North Macedonia, and northeast of the Republic of Albania. This study area occupies an area of 1162 km^2 in the territory of the Republic of Kosova and 841 km^2 in the territory of the Republic of North Macedonia, while the whole the study area of Sharr Mountains is 2003 km^2.

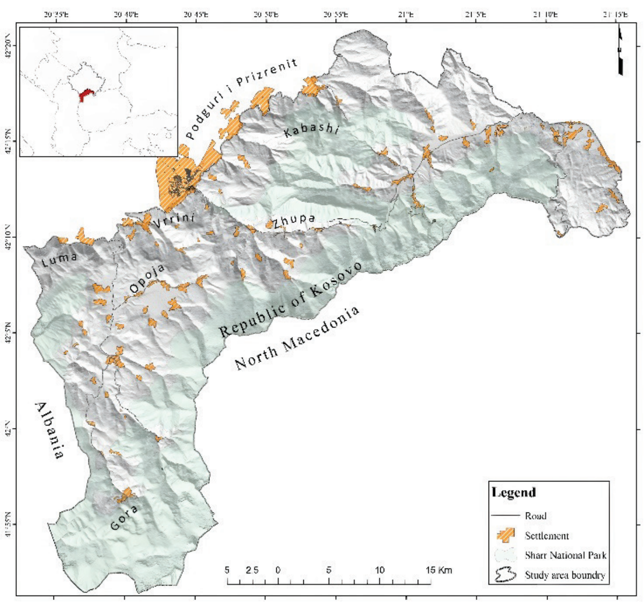

Figure 1 Map of the study area of Sharr Mountains in Kosova [4]

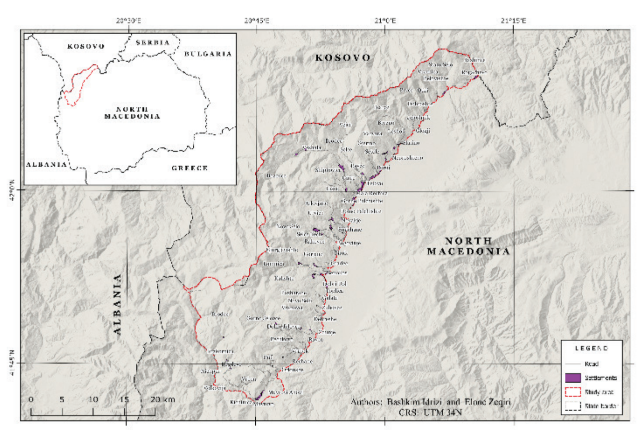

Figure 2 Map of the study area of Sharr Mountains in North Macedonia

Sharr Mountains in both side of border, in Kosovo and North Macedonia is already national park with special lows for its protection as natural heritage.

2.2 Topographic and Meteorological Conditions of Sharr Mountains

The altitude of the study area varies from 292 m in Kosovo side up to 2747 m in "Titov Vrv" highest point of Sharr Mountains in North Macedonia, which according to the classification of mountain by European Avalanche Warning Services – EAWS [5], Sharr Mountains are classified as high mountains, where the snow avalanches of all types can occur.

In the Kosovo side there are two meteorological stations, while in North Macedonia there are six meteorological stations of which one is in the center of area (in Popova Shapka / Kodra e diellit) and five are in the border between Sharr Mountain and the Pollog field.

Extreme recorded temperature value in the study area is –34 °C, the mean temperature in high areas with more than 1200 m is –3 °C, while the length of the period with low temperatures during winter season is up to 4 months. Sunny days in the study area range from 220 to 280 days, while winds reach speeds from 1 to 18 m/s with about 22% winds that comes from the northern direction.

The level of snow in mountainous areas reaches 1.6 m and 2 m in higher terrains, while the extreme recorded highest snow value is 3 m. The duration of maximal snowfall is 117 days.

The mean annual air humidity is 76%, in which the extremes range from 83% maximum in November and 64% minimum in August.

Such topographical and meteorological conditions are very suitable for generating a thick snow cover in the study area of Sharr Mountains, as very important precondition for snow avalanches.

2.3 Methods for Calculation of Potential Snow Avalanche Areas

2.3.1 Fuzzy Logic Method

During complex modeling, which are not defined according to a formula, and in which relations of diffuse categories prevail, due to large parameters number and the complex nature of the processing, a considerable degree of uncertainty expert decision-making contains. Such issues cannot be resolved through a classical approach. Zadeh on year 1965 [6] introduced a Fuzzy Logic methodology, in which the values in range from 0 to 1 reflect the degree of membership security. The process of transforming the initial input values on a scale of 0 to 1 is called the fuzzification process (μ).

$$\mu(C_{ij}) = \frac{FR_{ij} - Min(FR_{ij})}{Max(FR_{ij}) - Min(FR_{ij})} \cdot \left[Max\left(\mu(C_{ij})\right) - Min\left(\mu(C_{ij})\right) \right] + Min\left(\mu(C_{ij})\right) \quad (1)$$

where μ (C_{ij}) is the degree of class membership within the factor and FR is frequency of occurrence of the phenomenon.

2.3.2 Multicriteria Decision Analysis (MDA) - The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach that has been successfully implemented for a variety of decision-making situations and was introduced and developed by Thomas Saaty in 1980. It is the pairwise comparison method used for objective-related criteria. These pairwise comparisons are performed for all relevant factors within the analysis.

Estimates for each class of factors/criteria for spatial analysis of avalanches can be based on locations with avalanche activity as well as judgments of avalanche experts. After evaluating the classes for each factor, the weights for each factor are assigned hierarchically using the pairwise comparison matrix and the evaluation is done using the basic Saaty comparison scale ranging from 1 to 9. Value 1 expresses "equal importance" between a comparative pair and a value of 9 is given to those factors that are of much higher importance within the comparative factors.

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = \frac{\lambda_{\max} - N}{N - 1} \tag{3}$$

where: CR is consistency index, RI the common index of the AHP method, which has predefined values, but whose value depends on the size of the comparison matrix (Tab. 1), λ characteristic scalar value, and N the order of the matrix.

Table 1 Common Consistency Index [7]

N	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41
N	9	10	11	12	13	14	15	
RI	1.45	1.49	1.51	1.53	1.56	1.57	1.59	

In addition to the interrelated factors, the AHP method can be met with some strict criteria, for example in areas that are covered with dense forests, it is known that due to their existence in the same area there can be no snow avalanche potential and in these cases, we can operate with the elimination method through Boolean actions which strictly exclude these areas in the margin of areas with potential [8].

$$Z = \sum_{i=1}^{n} (w_i x_i) \prod c_j \tag{4}$$

2.4 Data for Determination of Avalanche Zones

Precise determination of avalanche zones for larger spatial areas is difficult to accomplish and therefore always tends to determine potential. It is divided into four phases, namely the input phase, the processing phase, the output phase, and the verification phase. The first phase is composed of input data, which are divided into two main parts, on the one hand, the data from the avalanche history, and on the other hand the data on the factors that are part of the second phase. In the second phase, all the important factors in defining the areas with avalanche a potential re determined. The third stage is obtaining results, and the last stage is verifying this result based on a comparative method.

<u>Terrain Slope</u> - Primary factor within the topographic component is the slope of the terrain. Theoretically, the release of an avalanche cannot begin without the presence of a terrain inclination angle, and according to Maggioni (2004) the areas with the potential to start an avalanche are those with a slope of 30°-60° [9].

<u>Terrain orientation (aspect) and solar radiation</u> - The orientation of the terrain, respectively the mountain slopes is directly related to the movement of winds and solar radiation. Knowing the geographical position of the study area, the positioning of the mountain slopes is a factor in the absorption of solar radiation from the earth's surface.

Topography is a key factor determining the spatial variability of irradiation. Latitude and longitude, slope and orientation of slopes, are elements that affect the amount of irradiation received in different places. Total solar irradiation can be determined based on direct sunlight on the surface, distorted radiation (due to obstructions such as clouds, smog, etc.), and reflected radiation (with albedo 0.9 for snow-covered surfaces), calculated with the formula:

$$\begin{aligned} {}_s g &= S_0 \tau^m \cos i + S_0 (0.271 - 0.294\tau^m) \sin\alpha \cdot \cos^2\left(\frac{\beta}{2}\right) + \\ &+ r S_0 (0.271 - 0.706\tau^m) \sin\alpha \cdot \sin^2\left(\frac{\beta}{2}\right) \end{aligned} \tag{5}$$

where: ${}_s g$ is the total irradiation on sloping surface ($\mathrm{Wm^{-2}}$), S_0 solar radiation (on certain days of the year), τ^m transmission of radiation from the atmosphere, i is the angle between the normal to the surface and the sunlight, a is the solar angle (solar altitude), and β is the terrain slope. Irradiation is calculated for the period of: beginning of February.

<u>The relief altitude</u> - The altitude factor as a geographical component has a great correlation with the meteorological factors because, with the increase of the relief altitude, the climatic conditions also change. The greater the amount of snow, the greater its deposition, which increases the possibility of avalanches, while the lower temperatures enable greater stability of the snow structure.

<u>The relief concavity and convexity</u> - The relief forms are very diverse where besides the canals, ridges, galleries, we also distinguish mainly rounded shapes in the form of valleys or hills. These shapes are otherwise called convex and concave. Within these two types, we distinguish many subtypes according to the transverse and longitudinal sides of the terrain. Transverse curvature is the degree of variability of terrain orientation along a contour lines, whereas longitudinal curvature is the degree of variability of terrain along a flow line. Gleason [11] and McClung [10] concluded

that avalanches are more common in initial areas with concave transverse curvature.

Mountain ridges - It is important to determine as they affect the movement of snow due to wind transport and its deposition behind the ridges. At the same time, the ridge plays the role of a shield from the solar radiation, as well as from the hot winds which hit the front part of the mountain. According to a study by Gauer [12] where measurements were made on both sides of the mountain ridge, it turned out that about 20-30% more snow was deposited on the side on which the ridge served as a shield against the wind than on the flat ground.

Land Cover - In general, avalanches can start on any slope with a certain inclination if a dense forest is not available to prevent the onset of the avalanche.

The terrain ruggedness - It plays an important role in the avalanche release potential, as terrains with greater ruggedness are obstacles or forces which counteract the pressure of the snow layer. The ruggedness of the terrain is affected by the layers of snow as well as its amount. If a terrain has a certain ruggedness, after the snowfall and the creation of a snow bed, that terrain will no longer have the same ruggedness after the formation of this snow bed. The topographic ruggedness index (*TRI*) express the amount of height difference between neighboring cells of a DEM and is determined based on the digital relief model and that according to the mathematical formula $TRI = (\sum(z_i - z_n)^2)^2$, where z_i represents the central cell for which it is defined TRI, and z_n represents the neighboring cell ($i = 1, 2, \ldots, 8$) [13].

The air and soil humidity - With the presence of humidity, the structure of snow undergoes deformations, the particles of which stick and create weight. We distinguish the presence of humidity at the top, bottom, and inside the snow space. When water penetrates under the snow layer due to melting or eventually due to rainfall that penetrates under it, it has the effect of reducing the frictional force between the snow layer and the layer in which this snow layer is located. The humidity of the soil surface depends on its very shape. Non-accumulative forms of relief always tend to be dry in terms of soil moisture, while the accumulative ones are to be wet, this is because the water streams that can form at the bottom of the snow bed target the latter. Index of soil moisture is not limited only by the topographic component, but since we do not have measurable data on soil moisture, we have limited its definition only to the topographic surface, which means that it is static and can be useless in cases when the soil moisture is assessed according to time variability. The wetness indexing is determined based on the formula $TWI = \ln(A/\tan\beta)$, where A represents the specific areas of the watershed, whereas β represents the terrain slope.

Exposure to the wind - Determining wind direction is a very important but quite delicate element, as wind dynamics are quite large. The two key wind elements that are important to this study are its ability to carry snow particles, as well as its strength to help initiate a snow avalanche. The first and most important element can be evidenced in the newly fallen snow which is compact and dry. Usually, the areas most exposed to the wind are mountain slopes, where the nearest pits or concave areas are subject to the accumulation of that snow carried by the wind. Snow deposition in the part of the ridge located behind the exposed slope, increase of up to four times [14]. In these positions, the snow depth marks the highest values of 2 up to 40 m distance from the ridgeline.

Snowfall - Snowfall in the existing snow layer is quite essential as it increases the weight of the snow slab, which can lead to a critical and favorable phase to increase the avalanche potential of the volatile layers. For large (catastrophic) avalanches, new snow is the main predictor [15]. Accumulation (layering) of new snow with a depth of 1 m during 3 days of rainfall is considered critical for the onset of an extreme avalanche, while with a depth of 30-50 cm, critical for the release of an ordinary avalanche [16]. If the snow load is larger than 2.5 cm/h, it will affect the instability of the weak layer which is expressed according to the stability index [17].

Air temperature - It effects on snow stability in different ways, where the degree of change is significant. Rising temperatures during snowfall and at fast intervals immediately after rainfall, contribute to instability. Time changes in air temperature has direct influence on the surface layers, while the weak layer is relatively unaffected by the air temperature due to the low thermal conductivity of snow [18].

2.5 Data Classification and Contribution to Snow Avalanches

Bucaj [4] in his master thesis research supervised by prof Bashkim Idrizi, has adopted the special methodology and standards for spatial modeling of areas with avalanche potential in Sharr Mountains, based on criteria of Fuzzy Logic and MDA/AHP methods, previous similar analyses for other cases of avalanches in other areas, as well as the specific topographic and meteorological conditions of Sharr Mountain. In next diagram (Fig. 3), the methodology with data classification and classes contribution to snow avalanches in a case of Sharr Mountains study area is given.

At the top of Fig. 3 are shown six datasets as contents of developed geodatabase within this research study. Three of them (orthophotos, topographic maps and photos) are part of the historical avalanche inventory, as necessary input data for output results evaluation. Other datasets (DEM, landcover and winds) are part of the data to be used for performing spatial analysis for detecting potential snow release areas. Based on the list of criteria for spatial analyses, core data from three datasets were used for processing necessary layers of terrain slope, terrain orientation (aspect), hypsometry (elevation), plan curvature, profile curvature, topographic wetness, topographic roughness, solar radiation and land cover.

Developed data stored in nine layers needs to be reclassified to be able for use in both Fuzzy Logic and MDA/AHP methods. For this reason, slope data was classified into five categories (<25, 25-30, 30-50, 50-60, and > 60%), aspect data in nine categories (347.5-22.5, 22.5-67.5, 67.5-112.5, 112.5-157.5, 157.5-202.5, 202.5-247.5, 247.5-292.5, 292.5-337.5°, and "plan" areas with slope 0%), hypsometry in four categories (<900, 900-1400, 1400-2200, and >2200 m), then plan curvature (<–0.2, –0.2-0.2, and

>0.2), profile curvature (<–0.2, –0.2-0.2, and >0.2), topographic wetness (<5, 5-10, and >10) and topographic roughness (>15, 15-25, and >25) per three categories, solar radiation data in four categories (<30, 30-60, 60-90, and >90), while land cover layer in fourteen categories (settlement, industrial commercial area, arable land, pastures, heterogonous agricultural land, deciduous forests, coniferous forest, mixed forest, natural/herbal pastures, herbaceous soil/shrubs, rare shrubs and forests, area with rare vegetation, burned area, and aquatic land). Such reclassified data layers are source data for performing analyses with MDA/AHP and Fuzzy Logic methods, as it is shown in figure 3.

Fuzzy Logic method applies determining the avalanche frequency ratio and fuzzification/fuzzy membership process, while MDA/AHP method applies comparative pair matrix of the classes of each factor, and hierarchical weighing. Two separate maps of areas with avalanche potential based on the developed datasets by using both methods are main outputs of this model on determination of areas with avalanche release potential.

Defined methodology in Fig. 3 ends with evaluation of results through the ROC method based on maps of areas with avalanche potential as main research outputs and historical avalanche inventory.

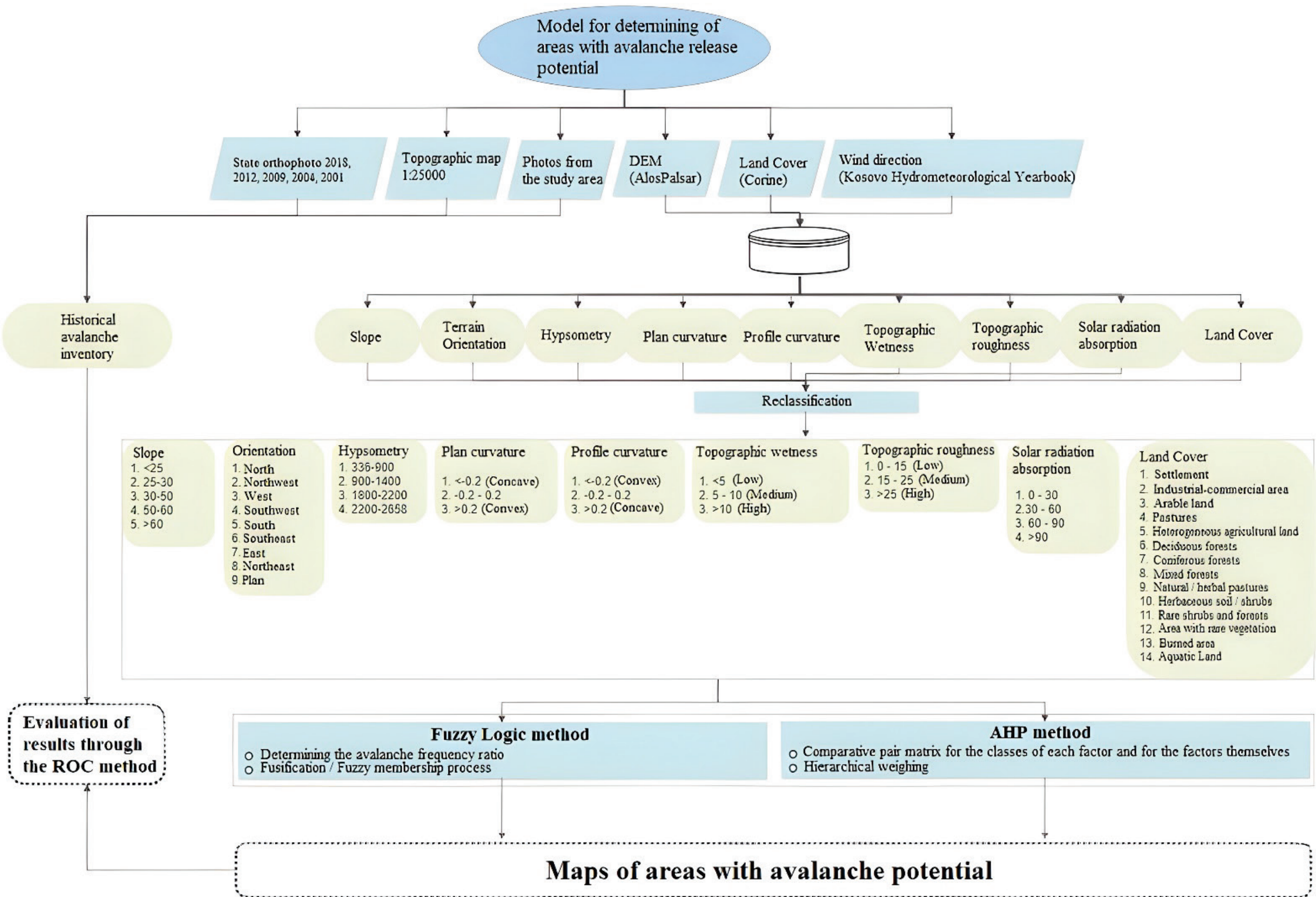

Figure 3 Model on determination of areas with avalanche release potential [4]

2.6 Source Data for Calculations of Potential Areas with Avalanche Release in Sharr Mountains

In this research, the biggest focus is on the topographic component but related to the meteorological, and not to the physical component, due to lack of data and lack of measurements on the structure of snow, density, thickness, distance from layer to layer and identification of icy layers between them.

Great importance was paid to the spatial resolution of the DEM, as its scale is directly related to its derivatives. In geographical areas in which the snow stability can't be longer than one year, we can say that high-resolution DEM can be used as any detail of the relief would contribute to the parameter of soil ruggedness and therefore the DEM resolution for the respective destination must also be selected. However, if the spatial analysis is done for a geographical area in which snow is continuously present and has permanent stability, then the snow-covered surface is smoother, and the ruggedness of the soil cannot be obtained as in a DEM with a resolution of up. In these cases, lower resolution DEMs are chosen so that the terrain is reflected more smoothly.

In next Tab. 2, a list of used topographic and meteorological data sources for performing spatial analyses for determination of snow avalanche release potential areas in Sharr Mountains is given [20-28].

Table 2 List of source data.

Data type	Data source	Technical details
Topographical data		
DEM	Alos Palsar Satellite	Spatial resolution: 12.5 m
Land cover	Corine	Spatial resolution: 100 m Categories: 47
Satellite image	Sentinel 2 MSI	Spatial resolution 10 m, 20 m and 60m Bands: 12
Satellite image	Landsat 8 OLI & TIRS sensors	Spatial resolution 30 m, 15 m, 60 m and 100 m Bands: 11
Satellite image	Landsat 5 TM	Spatial resolution 30 m and 120 m Bands: 7
Satellite image	Google earth	Spatial resolution 1 m
Meteorological data		
Winds	Global wind atlas	Spatial resolution 250 m
Temperature	Meteorological stations	List of data in excel file
Rain	Meteorological stations	List of data in excel file
Solar radiation	Global solar atlas	Spatial resolution 250 m

3 RESULTS DISCUSSIONS

3.1 GIS Database for Determination of Avalanches Release Potential areas of Sharr Mountains

Based on the model on determination of areas with avalanche release potential (Fig. 3), all source data have been preprocessed to adopt to the technical and content model requirements, as well as to be harmonized all layers between them. From source DEM with 12.5 m spatial resolution, new raster layers for terrain slope expressed in percentage (%), aspect (terrain orientation) of terrain expressed in degree based on the North direction as an initial value, profile terrain curvature, plan terrain curvature, terrain ruggedness index, and topographic wetness index have been created.

Since the CRS (Coordinate Reference System) and geometrical components (spatial resolution, point of origin and orientation) of all sources and developed raster data are different to each other, the data harmonization process [19] preceded as final step for establishing spatial database for determination of avalanches release potential areas in Sharr mountains. In next Fig. 4, the database structure is given.

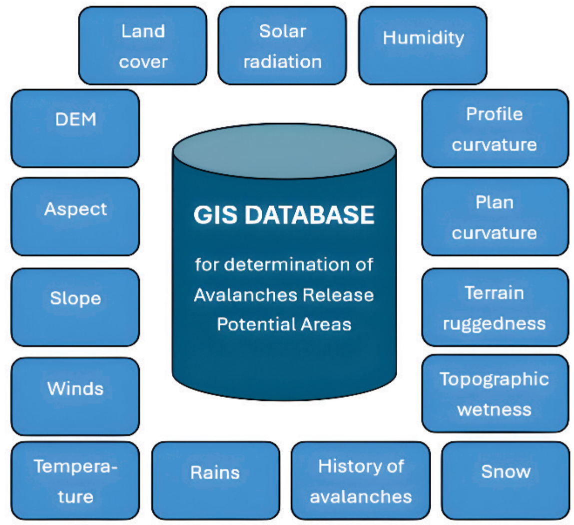

Figure 4 GIS database structure for determination of Avalanches Release Potential areas

3.2 Determination of Avalanches Release Potential Areas of Sharr Mountains with Fuzzy Logic Method

The Fuzzy Logic method first incorporates data from the avalanche history, and that the main locations of snow avalanches, although as very scarce data, but quite important. The avalanche frequency in each class of each contributing factor was then determined. During the fusion process, each class received the appropriate credits in relation to the frequency of avalanche occurrences from the snow avalanche inventory. Following the process of factor fusion, results of areas with the potential for avalanches are calculated. In next Tab. 3 the values of calculation of fuzzy membership for each category of input data, based on the criteria defined by [4] and shown in diagram in Fig. 3, are calculated.

Table 3 Fuzzy Logic determining the membership rate of each factor based on avalanche occurrences

Factor	Class	Nr. of class	% of avalanche areas	Fuzzy Membership	% of avalanche areas	Fuzzy Membership
			Kosova		North Macedonia	
Slope	<25	1	0.00	0.00	66.16	1.00
(%)	25-30	2	0.97	0.01	16.03	0.24
	30-50	3	99.02	1.00	17.45	0.26
	50-60	4	0.00	0.00	0.30	0.00
	>60	5	0.00	0.00	0.07	0.00
		∑	100		100	
			Kosova		North Macedonia	
Altitude	<900	1	0.00	0.00	12.38	0.47
(m)	900-1400	2	0.00	0.00	26.12	1.00
	1400-1800	3	0.00	0.00	19.25	0.74
	1800-2200	4	30.09	0.43	19.09	0.73
	2200-2747	5	69.90	1.00	23.16	0.89
		∑	100		100	
			Kosova		North Macedonia	
Profile	< -0.2 convex	1	32.03	0.79	34.96	1.00
curvature	(-0.2) – 0.2	2	27.66	0.68	30.00	0.86
	>0.2 concave	3	40.29	1.00	35.04	1.00
		∑	100		100	

			Kosova		North Macedonia	
Plan curvature	< -0.2 concave	1	60.19	1.00	33.91	0.97
	(-0.2) - 0.2	2	17.96	0.29	31.26	0.90
	>0.2 convex	3	21.84	0.36	34.83	1.00
		∑	100		100	
			Kosova		North Macedonia	
Terrain ruggedness	<15 low	1	100.00	1.00	99.86	1.00
	15-25 medium	2	0.00	0.00	0.12	0.00
	>25 high	3	0.00	0.00	0.02	0.00
		∑	100		100	
			Kosova		North Macedonia	
Topographic wetness	<5 low	1	65.53	1.00	0.01	0.00
	5-10 medium	2	34.46	0.52	75.40	1.00
	>10 high	3	0.00	0.00	24.59	0.33
		∑	100		100	
			Kosova		North Macedonia	
Solar radiation absorption	<30	1	70.38	1.00	0.41	0.01
	30-60	2	16.50	0.23	17.29	0.22
	60-90	3	13.10	0.18	78.55	1.00
	>90	4	0.00	0.00	3.74	0.05
		∑	100		100	
			Kosova		North Macedonia	
Land cover	Settlement	1	0.00	0.00	0.71	0.02
	Industrial-commercial area	2	0.00	0.00	0.00	0.00
	Arable land	3	0.00	0.00	0.00	0.00
	Pastures	4	0.00	0.00	0.83	0.02
	Heterogeneous agricultural land	5	0.00	0.00	1.18	0.03
	Heterogeneous agricultural land	6	0.00	0.00	6.81	0.16
	Deciduous forests	7	0.00	0.00	30.90	0.72
	Coniferous forests	8	0.00	0.00	0.71	0.02
	Mixed forests	9	0.00	0.00	2.79	0.06
	Natural / herbal pastures	10	33.01	0.89	43.04	1.00
	Herbaceous soil / shrubs	11	30.09	0.81	2.33	0.05
	Rare shrubs and forests	12	0.00	0.00	8.93	0.21
	Area with rare vegetation	13	36.89	1.00	1.22	0.03
	Burned area	14	0.00	0.00	0.00	0.00
	Aquatic Land	15	0.00	0.00	0.54	0.01
		∑	100		100	
			Kosova		North Macedonia	
DEM Aspect	(degree)					
Plan	slope 0%	1	0.97	0.02	0.00	0.00
North	337.5-22.5	2	35.92	1.00	8.15	0.38
Northeast	22.50-67.5	3	22.81	0.63	12.91	0.60
East	67.5-112.5	4	2.42	0.06	17.62	0.82
Southeast	112.5-157.5	5	0.00	0.00	21.45	1.00
South	157.5-202.5	6	0.00	0.00	16.91	0.79
Southwest	202.5-247.5	7	0.00	0.00	11.07	0.52
West	247.5-292.5	8	15.04	0.41	6.08	0.28
Northwest	292.5-337.5	9	22.81	0.63	5.80	0.27
		∑	100		100	

Table 4 Multicriteria Decision Analysis (MDA) - the analytic hierarchy process (AHP) determining the membership rate of each factor based on avalanche occurrences

	Slope	Altitude	Plan curvature	DEM Aspect	Profile curvature	Land cover	Solar radiation absorption	Topographic wetness	Terrain ruggedness
Slope	1	0.5	0.5	0.33	0.25	0.33	0.2	0.2	0.2
Altitude	2	1	2	0.33	0.33	1	0.25	0.25	0.25
Plan curvature	2	0.5	1	0.333	0.5	2	0.25	0.2	0.2
DEM Aspect	3	3	3	1	0.5	3	0.2	0.2	0.25
Profile curvature	4	3	2	2	1	3	0.333	0.25	0.333
Land cover	3	1	0.5	0.333	0.333	1	0.25	0.2	0.25
Solar radiation absorption	5	4	4	5	3	4	1	0.5	1
Topographic wetness	5	4	5	5	4	5	2	1	2
Terrain ruggedness	5	4	5	4	3	4	1	0.5	1
Weights	**0.255**	**0.148**	**0.162**	**0.097**	**0.071**	**0.171**	**0.035**	**0.026**	**0.035**

3.3 Determination of Avalanches Release Potential Areas of Sharr Mountains with Multicriteria Decision Analysis (MDA) - the Analytic Hierarchy Process (AHP) Method

In addition to the first method, the AHP method is used as the second method of determining potential areas. This method, as stated above, is based on expert judgments in setting weights for each factor and factor class, where subjective judgments based on rationality are also expressed. The Consistency Ratio (*CR*) of the matrix in pairs after setting the values shown in Tab. 4 was 0.052, indicating that the cumulative judgments derived from the matrix in the pair are satisfactory. In Tab. 4, the weighting was performed for the classes of each factor for the case of determining the potential areas with snow avalanche release, which then was executed based on calculated values in GIS by using Eq. (4) whereas Boolean data were used data on land coverage and terrain slope.

3.4 Four Level Classification of Avalanches Release Potential Areas of Sharr Mountains

The avalanche release potential zones are classified in four categories, as areas with low potential ($Z < 0.2$), moderate ($0.2 < Z < 0.5$), high ($0.5 < Z < 0.7$), and very high ($Z > 0.7$), using the Jenks optimization method [29, 30, 31, 32, 33]. In a case of analyses for the North Macedonian side of Sharr Mountains, additional category very low with value ($Z = 0$) is used. Next four maps, separately for Kosova and North Macedonia by using both analyzing methods of Fuzzy Logic and MDC-AHP, shown the study area classified based on the potential category calculated for each sell in spatial resolution of 12.5 m.

3.5 Verification the Accuracy of Determined the Avalanches Release Potential Areas of Sharr Mountains

After determining the locations with avalanche potential, simultaneously with the result, accuracy of the model was verified. A proper verification can be performed by making a comparison between the results obtained from performed analysis and the historical inventory of snow avalanches by using the ROC – Receiver Operating Characteristics method [35]. In next Tab. 5, the results of four results with the Area Under the Curve (AUC) value are given.

Table 5 AUC values obtained from the verification process.

	Fuzzy Logic	AHP
Kosova side	0.993	0.986
North Macedonia side	0.989	0.991

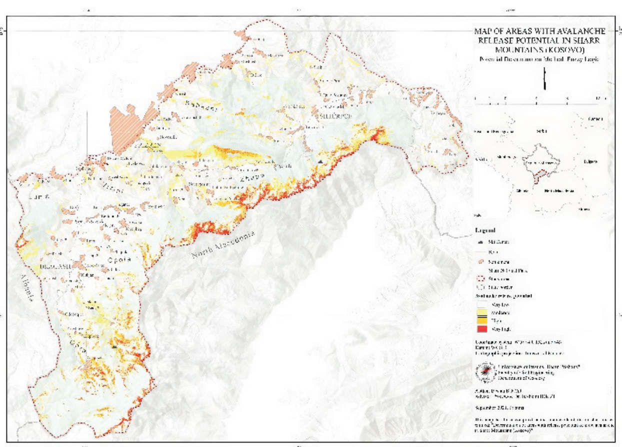

Figure 5 Map of potential snow avalanche release area determining the potential according to Fuzzy Logic method for Sharr Mountains in the side of Kosova [4]

The ROC analysis gave satisfactory results, close to each other and acceptable for such a spatial analysis.

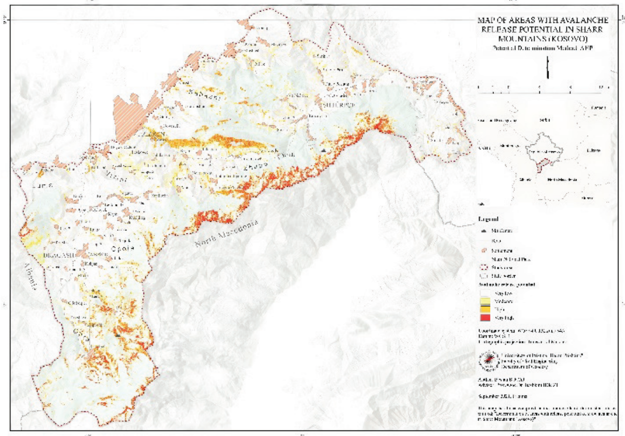

Figure 6 Map of potential snow avalanche release area determining the potential according to Fuzzy Logic method for Sharr Mountains in the side of North Macedonia

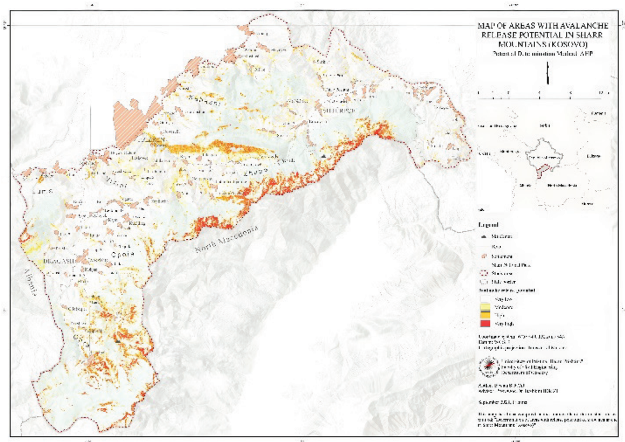

Figure 7 Map of potential snow avalanche release area determining the potential according to MDA-AHP method for Sharr Mountains in the side of Kosova [4]

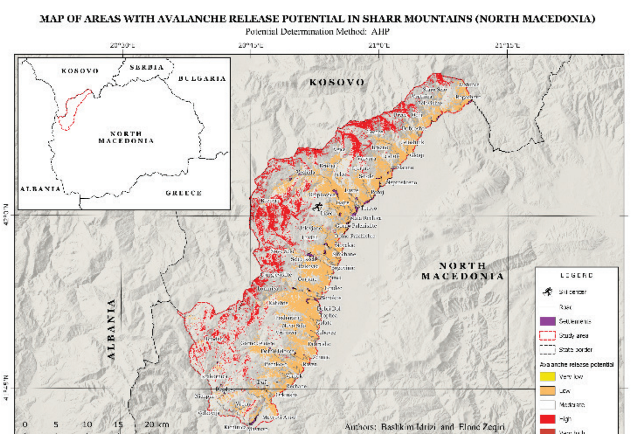

Figure 8 Map of potential snow avalanche release area determining the potential according to MDA-AHP method for Sharr Mountains in the side of North Macedonia

4 DISCUSSIONS

The methodology applied in this research consider relevant topographical, meteorological and physical components, by data classification, using processing algorithms of MDC/AHP and Fuzzy Logic methods, and automatic implementation in GIS platform. Our novel approach for assessing and zoning areas by risk level of snow avalanche is valid at large scales with a high level of accuracy, by adopting criteria in correlation with the microregional data for the study area. Establishing such a system as official at the national level will have positive impact in better spatial planning, and prevention from snow avalanches as natural hazards.

Developed methodology from a narrow and detailed point of view in the next period should be extended by using real-time data, GIS spatial analyses and machine learning technology, in relation to digital meteorological stations.

5 CONCLUSIONS

The results show that the area of Sharr Mountains is affected by avalanches, the danger of which should be accurately determined, by using more meteorological data on snowfall, temperature, and additional data about the speed and direction of the wind, given by the local meteorological stations instead the global databases [34]. Such data should include the longest possible time interval to obtain the extreme values of all factors, as well as to make the connection with the historical avalanches at a moment when they occurred. The avalanche hazard levels could be determined for each surface which has resulted as a potential surface separately.

Spatial analysis of natural disasters through GIS, helps all areas of interest in decision making as GIS in addition to the potential in the analysis allows the visualization of parameters or factors, so the assessment by experts will be easier and closer to reality. The obtained result within this research shows a satisfactory and quite good relationship between the map of areas with avalanche potential and avalanche location data from the history of events. Within the Fuzzy Logic model, the model can be easily revised and modeled, modifying the membership functions for different study areas, while in the AHP model care must be taken in the values of the evaluation weights, as this depends on the selected study area.

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