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GIS-based determination of potential snow avalanche areas: A case study of Rize Province of Türkiye

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Abstract

Natural hazards are a part of critical issues affecting people and the environment. One of these natural hazards is snow avalanches. With the increase in the world population, it has emerged that decision-makers should take precautions against such natural hazards for population movements, construction, transportation, and tourism. Essential solution parts of this problem lay behind surveying, GIS, and spatial analysis-planning. This situation will be primarily due to the snow conditions, but certain terrain areas are susceptible. Snow avalanches' release mechanism depends on many factors, such as terrain, meteorological reports, snowpack, and other triggering parameters. Areas with certain topographical features that allow the deposition of snow masses are called avalanche-release areas. GIS helps to make decisions concerning spatial planning within avalanche release areas and finding risky zones. This study aimed to determine the potential avalanche release areas in the GIS environment in Rize, Türkiye, which was chosen as the pilot region. In the study, the detection of these avalanche areas was estimated using a mathematical equation model proposed by Hreško (1998) and determined with the help of GIS. Factors such as elevation, curvature, aspect, slope, and land cover type were used to estimate avalanche risk areas. A Model Builder workflow has also been created to automate the process stages. As a result of the study, avalanche risk areas were determined and mapped for the Rize mountainous region.

1. Introduction

Natural disasters are among the critical problems that the world faces and affect people and the environment. One of the most important of these is snow avalanches, one of the natural disasters of meteorological character. Avalanches begin when weak layers of snow release the weight of the more stable snowpack above them, and then the snowpack continues to move downhill, accelerating and collecting more snow [1]. These appear as rapid mass movements controlled by weather conditions, snow cover, and topography of the land [2-4]. Avalanches usually occur in mountainous areas, affecting transportation corridors, ski areas, and buildings, disrupting infrastructure, and causing loss of lives. Today, it is experiencing precarious environmental conditions condemning deterioration and causing great harm to people and human-made features, leading to different adverse effects [5]. As a result of these worsening effects, hazard and risk assessment studies have become necessary to take preventive measures against avalanche events.

Determination of the potential avalanche release area is the first step in avalanche hazard and risk assessment and mapping. The formation of snow avalanches depends on many different parameters. These parameters can be classified into three groups: terrain parameters such as slope, curvature, roughness, and vegetation; meteorological parameters like wind, temperature, amount of snow, and air humidity; snowpack parameters such as weak layers and gain forms [6-8]. In addition, there is the triggering of the avalanche, which can be initiated by additional loading caused by humans naturally by fresh snow or by abrupt warming [6, 7].

GIS has been widely adopted in many fields with the advance of computers, geoinformatics, and their applications [9,10] within natural hazards zoning [11-14]. One of them is the studies in which snow avalanches are detected. GIS helps to make decisions concerning spatial planning within avalanche release areas and finding risky zones. Terrain models [15] and GIS have been used to estimate the probable avalanche release zones [16-17], model avalanche run-outs [18-19], or assess the protective function of the forest against avalanches [20-22].

Information about snow avalanches, predictions, and mapping of the danger they pose is very important from a scientific point of view [23-24]. Currently, avalanche, snowmelt, and landslide studies are addressed in many studies around the world; Many methods and techniques have been proposed and tried to be put into practice, especially for landslide hazard and risk mapping. Apart from these, there are also studies in which snow avalanche risk zones are detected and integrated with GIS, which is one of the favorites of information systems. In addition, there are analyses in which snow avalanche risk areas are determined using GIS and Multi-criteria decision analysis together. There are also analyses in which snow avalanche risk areas are detected using remote sensing. Potential snow avalanches are determined using machine learning methods that have become popular recently. The literature summary is shown in Table 1.

Modeling is one of the main tools for assessing natural hazards [55]. Modeling techniques are divided into two groups: deterministic and stochastic models. Physical or mathematical models are deterministic models, while models that include an analytic hierarchy process, such as fuzzy logic, are stochastic. In this study, a mathematical model was used to assess snow avalanches. In the literature, different mathematical algorithms are used to model potential snow avalanches and generate risk maps with GIS. Some of these methods were developed by Hreško [16], Barbolini [47], Bühler [7], and Marana [5] at different times. Hreško's [16] model approach was based on terrain factors. This model is developed to identify potential snow avalanche areas. Marana [5] has developed and suggested an avalanche risk model for determining risky areas. His model included height, slope, aspect, and land use data, and his model (Equation 1):

Table 1. Literature summary.

Reference	Study Region	Analysis method
[25]	-	landslide hazard and risk mapping
[26]	Croatia	
[27]	Western United States	
[28]	Canada	
[29]	-	
[30]	Global	
[31]	Austria	
[32]	-	
[33]	Kazakhstan	
[7]	India	snow avalanche risk zone mapping with GIS
[14]	Western Himalaya	
[17]	Switzerland	
[34]	Italy	
[35]	-	
[36]	Iran	
[37]	Switzerland	
[38]	Switzerland	
[39]	Switzerland	
[40]	Slovakia	
[41]	Türkiye	
[42]	Switzerland	
[43]	USA	
[44]	USA	
[45]	Slovakia	
[46]	Türkiye	
[47]	Between Italy and Switzerland	
[48]	Italy	
[49]	Türkiye	risk analysis using GIS and Multi-criteria decision
[50]	Colorado	
[51]	Serbia	
[52]	India	potential snow avalanche risk analysis using remote sensing
[53]	India	
[54]	Türkiye	Risk analysis using machine learning methods

$$\text{Avalanche Risk} = \text{Risk Height} \times (\text{Risk Slope} + \text{Risk Aspect} + \text{Risk Land} - \text{Use}) \tag{1}$$

Based on digital elevation models, Bühler's [7] model was about the automated identification of potential snow avalanche release areas. This model is partly based on the work of Maggioni [56] but has been improved so it can be used on DEM datasets with higher resolutions. The terrain parameters must be defined to identify the potential snow avalanche release areas with this model. Barbolini's [47] model was about avalanche hazard mapping over large undocumented areas [8].

In this investigation, Hreško's equation model was implemented and used to automate avalanche release area mapping in GIS [16]. The reason for this is that it is the most appropriate method to detect snow avalanche areas in the region and also because no study based on this method has been carried out before in our country. The study focused on land parameters; because they can be obtained from digital elevation models (DEMs) and do not change as rapidly as meteorological and snow cover parameters [7]. Terrain can affect areas that are more or less susceptible to avalanches, while terrain parameters such as slope surface cover and profile curvature will affect the strength of the snowpack. In turn, factors such as aspect will determine the amount of sunlight an area receives and influence temperature direction [1].

Therefore, based on all this information, this study aims to develop a method to estimate potential avalanche release areas in a GIS environment. Rize province of Türkiye, which has high mountain zones named Kackar Mountains, was selected. The land cover layer and Digital Elevation Model (DEM) were this model's main data inputs. Factors such as aspect, slope, plan, and profile curvature were produced from DEM. Each factor and land cover were classified, and the final grid layer was calculated. A model builder was created in these process stages, and the calculation process was automated. As a result, avalanche release areas were estimated and mapped for Rize. This study is important because there is no similar study representing snow avalanches in our country and it will serve as an example for future studies on this subject. A regional study will provide a basis and guidance for the provinces suffering from snow avalanches.

2. Method

2.1. Methodology

The study consists of 9 stages.
- Selecting the study area
- Determining criteria and obtaining data
- Editing the data and associating it with the coordinates. Conversion of data to WGS 1984 Lambert Conformal Conic projection system.
- Adding the edited data to the geographic database in ArcGIS 10.8.
- Determination of the criteria scores to be used in the avalanche release area determination model
- Application of the avalanche release area determination model to the data
- Detection of potential snow avalanche risky areas as a result of the analysis performed with the model and identification of alternative points
- Presenting visual maps.

2.2. Study area

This study was performed in the Rize province of Türkiye. Rize is located in the northeastern parts of Türkiye and located between 40°21′ - 41°25' east longitude and 40°33′ - 41°20′ north latitude (Figure 1). Rize covers an area of 3,920 km2, and 78% of this area is mountains, 21% is plateaus, and 1% is plains. 25% of Türkiye's forest areas are located in the Black Sea region where Rize province is located. The population of Rize in 2018 was 346.608 [57]. Total rainfall values for Rize province are 238 mm for December, 234 mm for January, and 185 mm for February; these months are the coldest periods in Rize [58]. Weather is generally -10˚C or colder at high altitude areas.

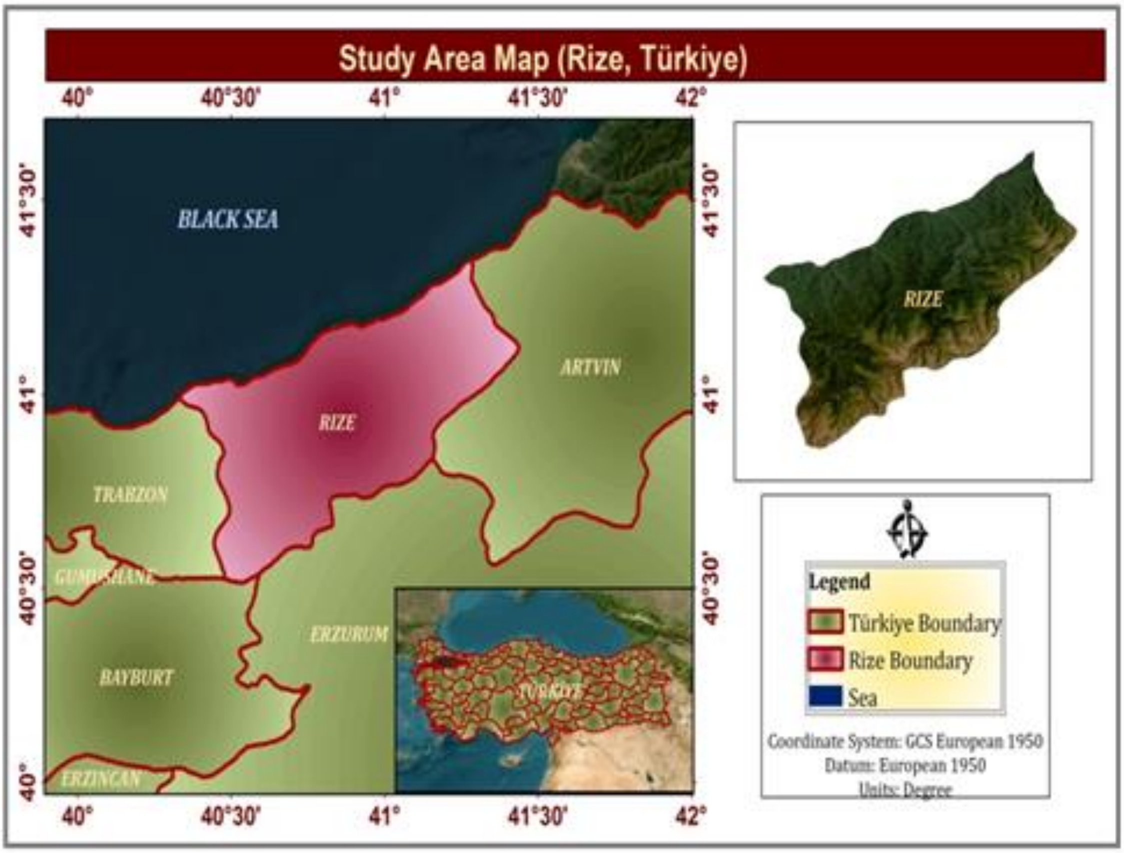

Figure 1. Study area.

The most important reason for choosing Rize is the fact that many avalanche disasters have occurred in this region in the past years has been deemed important in terms of examining the avalanche risk points of the region. The other reason is; that this province is surrounded by high and rugged mountains that extend parallel to the Black Sea. Kackar mountain range is within the boundaries of the province area, one of Türkiye's most important mountains. With a total height of 3,932 meters, the Kackar mountain range is also the highest mountain in the Black Sea Region. The highest peaks of the Kackar mountain range are Altinparmak (3,480 m), Kavrun (3,932 m), and Vercenik (3,710 m) mountain [59].

2.3. Determining criteria

At this stage, two leading data inputs are needed to identify potential avalanche release areas. These are the land cover and the DEM layer. Apart from these, slope, aspect, plan curvature, and profile curvature are other criteria that should be used in the analysis, but these data are produced from DEM data. The reason for choosing these data is that they were selected from the criteria considered in the detection studies of potential snow avalanches and that they are criteria that can be provided in the analysis to be carried out in the region. To briefly explain the data used in the analysis;

Land cover: The type of terrain and the land cover influence the strength of a snowpack. A dense enough forest inhibits large avalanche formation because it influences the amount of deposited snow and the stability of the snow cover itself [60-61]. The regions covered by forest are thus excluded from the potential release areas [47]. The falling snow slowly accumulates between the trees and forms an irregular snow cover. In addition, tree trunks can support fixing snow cover to the ground, preventing avalanches from occurring [62]. Open, extensive hollow forests cannot fix the snow mass and prevent avalanche formation [63]. Areas covered with trees, large shrubs, and rocks will provide attachment points where snow can hold. This will increase the strength of the snow mass and become an important trigger by requiring more weight. Barren areas with permanent ice and snow or grassland will increase the likelihood of an avalanche occurring as there will be less friction to stop the avalanche [8].

Elevation: In snow avalanche risk assessment, elevation is an essential parameter because factors such as snowfall, wind, and temperature change depend on the elevation. In higher areas, more snowfall occurs, and more cooling occurs at air temperatures. In addition, as the elevation increases, vegetation can be diluted, exposure to solar radiation is higher, and stronger winds are observed [64].

Slope angle: The priority in the slope parameter is to determine the steepness limit of the slopes. Avalanches are typically released on slopes with inclinations between 30° and 50°, but depending on snow conditions, the range can be; between 25° and 60° [2, 6, 8]. Below 28, the gravitational force is too weak to initiate an avalanche, whereas on slopes steeper than 50, releases are limited to persistent small avalanches [47]. Delparte [19] states that deep snow masses, which cause the formation of large avalanches, cannot accumulate on such slopes if the slope exceeds 60°.

Aspect: It is an essential topographic parameter, but that does not have a direct effect on avalanche formation. It is the direction of the slope. The aspect depends on local circumstances. In the Northern Hemisphere, northern slopes receive less sun than southern slopes. Therefore, a cold snowdrift forms in this area. Eastern slopes will develop a colder snowpack than western slopes due to the difference between morning and afternoon sunlight [1]. The situation in the Southern Hemisphere is the opposite of the Northern Hemisphere.

Curvature: Curvature is examined in two parts: profile and plan curvature. Profile curvature is the curvature in the direction of the maximum slope and is in the vertical direction. Plan curvature is perpendicular to the profile curvature and is in the horizontal orientation. Positive values donate concave slopes, negative values donate convex slopes, and 0 means almost no curvature. The frequency of formation of avalanches is higher in concave profile global lands [65]. Plan curvature is also defined as several fractures in the avalanche flow path, with a change in inclination of at least 5 ° [66]. The stress areas occurring in the snow cover and the fractures just below it is caused by convexity. Another important factor is land curvature. This factor is used effectively in determining the spatial limitation of avalanche release areas. Those paths that have a concave plan curvature, such as bowls or cirques, can trap blowing snow from several directions about the wind direction [67], while paths that have convex plan curvature have a thinner snowpack because the snow is often blown away [47]. The plan curvature separates open areas from flat and convex areas to define the snow avalanche potential release areas. Open areas differ from convex areas by the following rule [17]:

- Concave zones: plan curvature ≤ - 0.002 m-1
- Flat zones: - 0.002 m-1 < plan curvature < + 0.002 m-1
- Convex zones: plan curvature ≥ + 0.002 m-1

2.4. Obtaining data and data processing

At this stage, the data belonging to the determined criteria were obtained and arranged for use in the analyses. A 10 m interval contours were used for creating DEM, obtained by Karadeniz Technical University (KTU) GISLab. Land cover layer and topography (for DEM) obtained topographical geodatabase provided by the General Directorate of Mapping / Türkiye. The other terrain factors, such as slope, aspect, plan curvature, and profile curvature raster layers, were derived from DEM. The obtained data were converted to the WGS 1984 Lambert Conformal Conic projection system, and all data were made ready for analysis by integrating the geodatabase to be used in the ArcGIS 10.8 program. The provided data is shown in Figure 2.

2.5. Mathematical model of determination potential avalanche area

The mathematical model used to identify potential snow avalanche risk areas has been created in this part of the study. While establishing the mathematical model, the criteria mentioned in the previous paragraphs affecting the avalanche formation were considered.

Hreško (1998) [16] proposed a mathematical equation model to estimate potential avalanche areas [16, 68]. In this study, we used Hreško's model to estimate potential avalanche areas in Rize Province of Türkiye (Equation 2).

$$Av = (Al + Ex + Fx + Fy) * S * Rg \qquad (2)$$

Here, Av is the value estimating potential avalanche trigger zones; Al is the elevation factor; Ex is the aspect factor; Fx is the profile curvature factor; Fy is the plan curvature factor; S is the slope inclination factor, Rg is the land cover factor.

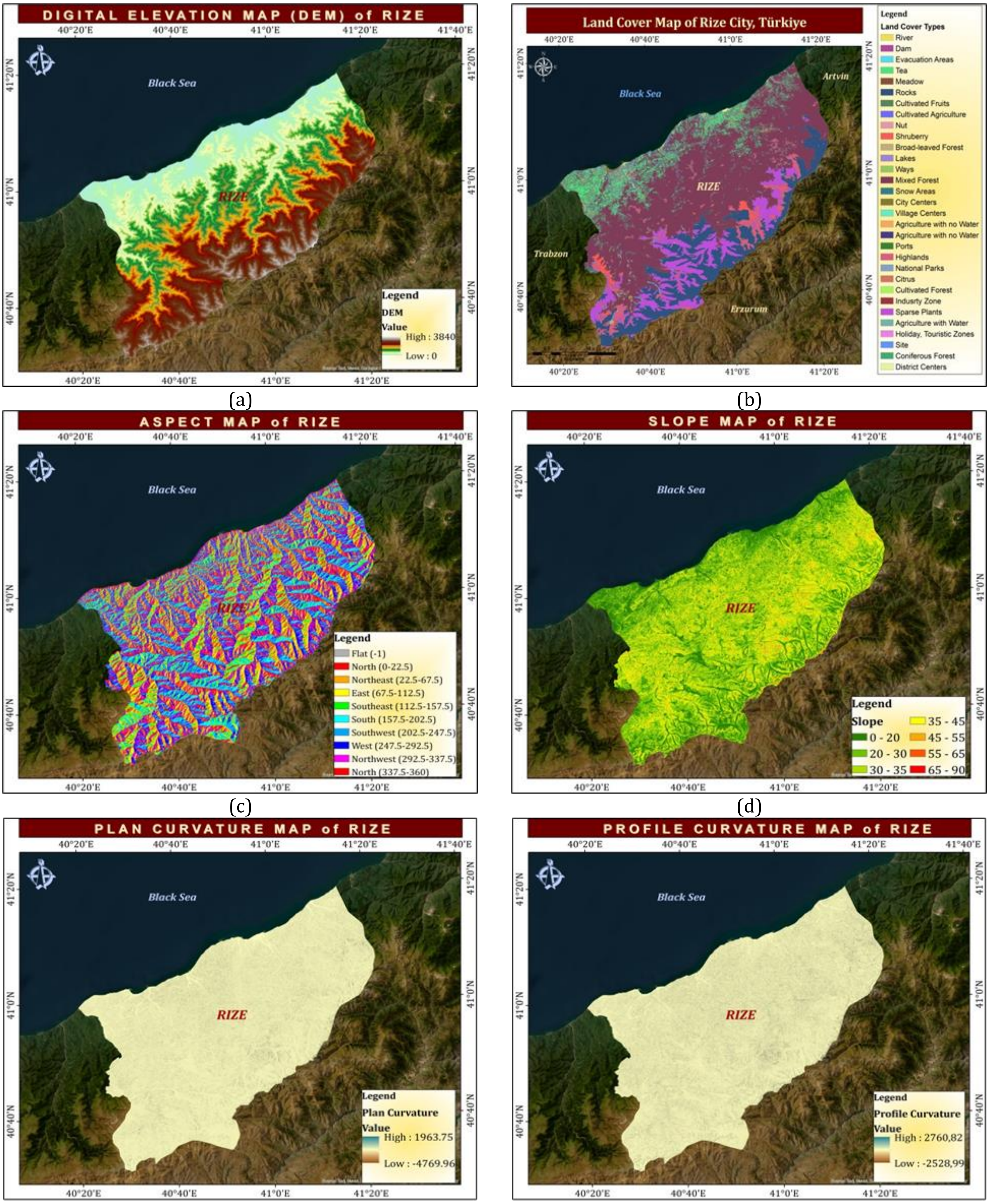

Figure 2. Input geographic data used in the study. Elevation map (a), Land cover map (b), Aspect map (c), Slope map (d), Plan curvature map (e), Profile curvature map (f).

2.6. Reclassifying criteria

The sub-criteria of the criteria required for detecting potential snow avalanche risky areas were determined, and the importance levels of the sub-criteria in determining snow avalanche areas were tried to be determined. At this point, the studies in the literature were used, and the sub-criteria were classified [5, 6, 7, 22, 40, 63, 69].

North or South Hemisphere directly changes aspect values. Marana [5] has aimed to detect avalanche-risky areas in a North Hemisphere Country, Italy. Türkiye is also located in the North Hemisphere. We have derived aspect classification and score from Marana's study.

Slope score is used widely in most avalanche studies, and the score is similar in different literature studies. In this study, the slope score was derived from McClung and Schaerer [6], Biskupič and Barka [40] and Maers [63]. Plan-profile curvature classification and score were derived from the study by Bühler et al. [7]. The elevation score was derived from Türkiye's National Avalanche Risk Activation Plan Report [64]. The land cover types score was derived from Marana [5], Biskupič and Barka [22] and Richnavský et al. [70]. Finally, classification and scoring of land cover type factors were done by commenting on related sub-factors of land cover types. With a small example, if a zone is filled with rocks, it means this is a risky area and gets a high score, but if a zone is filled with dense forest, it brings a barrier for avalanches catching snow and getting a low score.

The determined sub-criteria were scored on a scale of 0-10, and their values, which were important in detecting potential snow avalanches, were determined. In this range, 0 indicates the lowest value, while a value of 10 indicates the regions with the highest potential avalanche risk. Table 2 and 3 show the factors, sub-factors, and their scores (points) used in the study. The classification row matches with sub-factors. We have applied all the analysis due to the score calculations shown in the tables.

Table 2. Factor, sub-factors, and their score calculations used in the study.

	Classification	Elevation Score
Elevation	0-750	0
	750-1600	2
	1600-1900	6
	1900-2200	8
	2200-2700	10
	2700-3850	2
Slope	0-20°	2
	20° - 30	4
	30° - 35°	6
	35° - 45°	10
	45° - 55°	8
	55° - 65°	5
	65° - 90°	0
Aspect	Flat areas (-1)	0
	N (0° - 22.5°)	10
	NE (22.5° - 67.5°)	10
	E (67.5° - 112.5°)	8
	SE (112.5° - 157.5°)	5
	S (157.5° - 202.5°)	4
	SW (202.5°- 247.5°)	2
	W (247.5° - 292.5°)	5
	NW (292.5°- 360°)	7
Plan Curvature	-4769,96 - (-4)	0
	(-4) – (-0,2)	0
	(-0,2) – 0,2	5
	0,2 – 0,5	3
	0,5 - 4	1
	4 - 1963,75	0
Profile Curvature	2760,82 - 4	0
	4 – 0,2	2
	0,2 – (-0,2)	2
	(-0,2) – (-0,5)	2
	(-0,5) – (-4)	2

Table 2 is related to topology and its post-processed layers. Table 3 is related to the classification of the land cover layer. Table 4 shows the final classification of the calculated accumulated cost surface for determining risky areas.

The final classification of analysis results is directly related to our score points. The lowest score is 0, and the highest point is 2700. This scale was separated into five evaluation intervals, as seen in Table 4.

Table 3. The classified land cover factor and score.

Land Cover Type	Land Cover Score
Rocks	10
Sparse Plants	8
Snow Areas Agriculture with no Water Agriculture with no Water Highlands Citrus Agriculture with Water	7
Cultivated Agriculture Cultivated Fruits	6
Tea Meadow Nut Shrubbery Cultivated Forest Site	5
Mixed Forest National Parks	3
Coniferous Forest	2
River Dam Evacuation Areas Broad-leaved Forest Lakes District Centers Ways City Centers Village Centers Ports Industry Zone Holiday, Touristic Zones	0

Table 4. Final reclassification.

Equation result	Potential avalanche risky areas
0 - 225	Low
225 - 468	Moderate
468 - 850	Considerable
850 - 1440	High
1440 - 2700	Very High

3. Results and discussion

At this stage, the data belonging to the criteria for detecting potential snow avalanche risky areas were classified by considering the sub-criteria scores determined in the ArcGIS 10.8 program and converted to a raster format. Thus, the model developed for detecting potential snow avalanches is ready for analysis. Then the classified raster maps were used in the avalanche release area determination model. As a result of the analysis carried out with the model, the potential snow avalanche risk areas were determined and presented with maps. Alternative potential snow avalanche risk areas were determined with the outputs obtained and presented with maps.

3.1. Classification of criteria by points

The determined criteria are classified according to sub-criteria in this section. First of all, DEM data was classified according to its subclasses. The subclasses of the criteria were reclassified according to the scores and converted to raster format. Then, slope, aspect, land cover, plan curvature, and profile curvature data of all layers were classified and made ready for analysis in raster format, respectively. The resulting raster maps are shown Figure 3. In the study, 10 * 10 pixels were chosen as the raster pixel size, and this value was considered when converting all spatial data to raster formats.

3.2. Determining harmonized model for avalanche risky area detection

The model analysis developed for detecting potential snow avalanche risky areas was carried out at this stage. This model was implemented by harmonizing recent models and formulas. Each factor was classified according to the following tables, and then the equation was performed with ArcGIS. A Model Builder workflow has been created to automate the process steps. In this way, the analysis hierarchy has been re-applicable. GRID layer was provided with a 10 m* 10 m resolution. The final layer was reclassified into five classes. A model builder is developed to enable the re-applicable analysis process for different areas. The model builder brings time reduction. On the other hand, it is possible to convert the model to Python codes and use it in an add-in or interface development process. One other benefit of the model builder is enabling users to see all the process hierarchy and operations in one figure and replace and remove any operation if not necessary or wrong.

3.3. Detection of potential avalanche risk areas and identification of alternative areas

Specific determination of risky areas has been done after the general determination. Figure 4 shows areas that have high avalanche possibilities. Application steps of this stage have been done by reclassifying raster data getting the highest scores. Then these areas were converted to vector (shape) files. We can estimate avalanche risky areas by understanding the mathematical formula proposed by Hreško of nature and topography. The second essential factors are land cover and land use because they directly affect avalanche accidents. For example, intensive forest areas avoid avalanches because of becoming natural barriers. When visiting the land at some points, it has been determined that there are snow-melting lines to prevent avalanches. These are artificial settings to guide snow movements. There were also metal barriers at some points. However, the areas with the highest avalanche risk were determined from the identified areas, and most were open to accident risk.

According to the classification range in Table 3, the resulting product map was classified as low, moderate, considerable, high, and very high, respectively, and it was determined where the risky areas of snow avalanches were more intensified. This classification as low, moderate, considerable, high, and very high was made according to the European 5 danger levels reference scale [71]. According to the results obtained, it has been determined that the low suitable area was % 43.04 of the whole area, the moderate suitable area was % 32.20, the considerable suitable area was % 15.30, and the high suitable area was % 6.82, the exceptionally high suitable area was % 2.64 (Table 5), (Figure 5).

Looking at the map, it can be observed that the riskiest areas in the selected pilot region are generally in the regions where the slope is quite intense in Rize Province. In addition, the areas close to the sea have been identified as areas where the potential snow avalanche risk is quite low, with the effect of decreasing slope. It is seen that the potential snow avalanche risk is intense, especially in many parts of the mountainous regions of Rize province, and these areas coincide with 149,985 points. Among these risky areas, the most dangerous areas in terms of risk were determined as alternative areas (alternative 1, alternative 2, alternative 3) and shown on the map (Figure 6).

In Figure 6, the Alternative 1 area corresponds to the Yaylaköy village region of Rize province and covers an area of approximately 3,411.53 square meters. It is the first area that is highly risky in terms of snow avalanches. Since the determined area is very close to the Kaçkar Mountains National Park, it coincides with an important point of the province. In addition, the region is close to many tourist plateaus such as the Amlakit, Palovit, and Trovit plateaus.

Alternative 2 area corresponds to Yukarışimşirli village region and covers an area of approximately 3,169.27 square meters. The determined area is important because it has an important location in terms of its proximity to the Ayder plateau, which is one of the most important tourist points of the province.

Alternative 3 coincides with the Başköy village region of Rize province and covers an area of approximately 2,104.46 square meters. These three regions determined as alternatives and the regions determined as high risk as a result of the analysis appear as important points with potential snow avalanche risk. Therefore, great attention should be paid to the risk of snow avalanches in this region, which is presented as an alternative, measures should be taken against a possible snow avalanche that will occur at these identified points, and if necessary, prevention policies should be developed by planning.

When these most dangerous alternative areas in terms of risk were examined, it was observed that there was no forest in these areas and there were sparse plant settlements. In fact, it can be seen from the figure that the alternative 3 area consists of rocks. This makes these regions attractive for avalanches [60-63]. On the other hand, the elevation value in these areas is between 2000-3000. As the elevation increases, vegetation can be diluted and more cooling occurs at air temperatures [63].

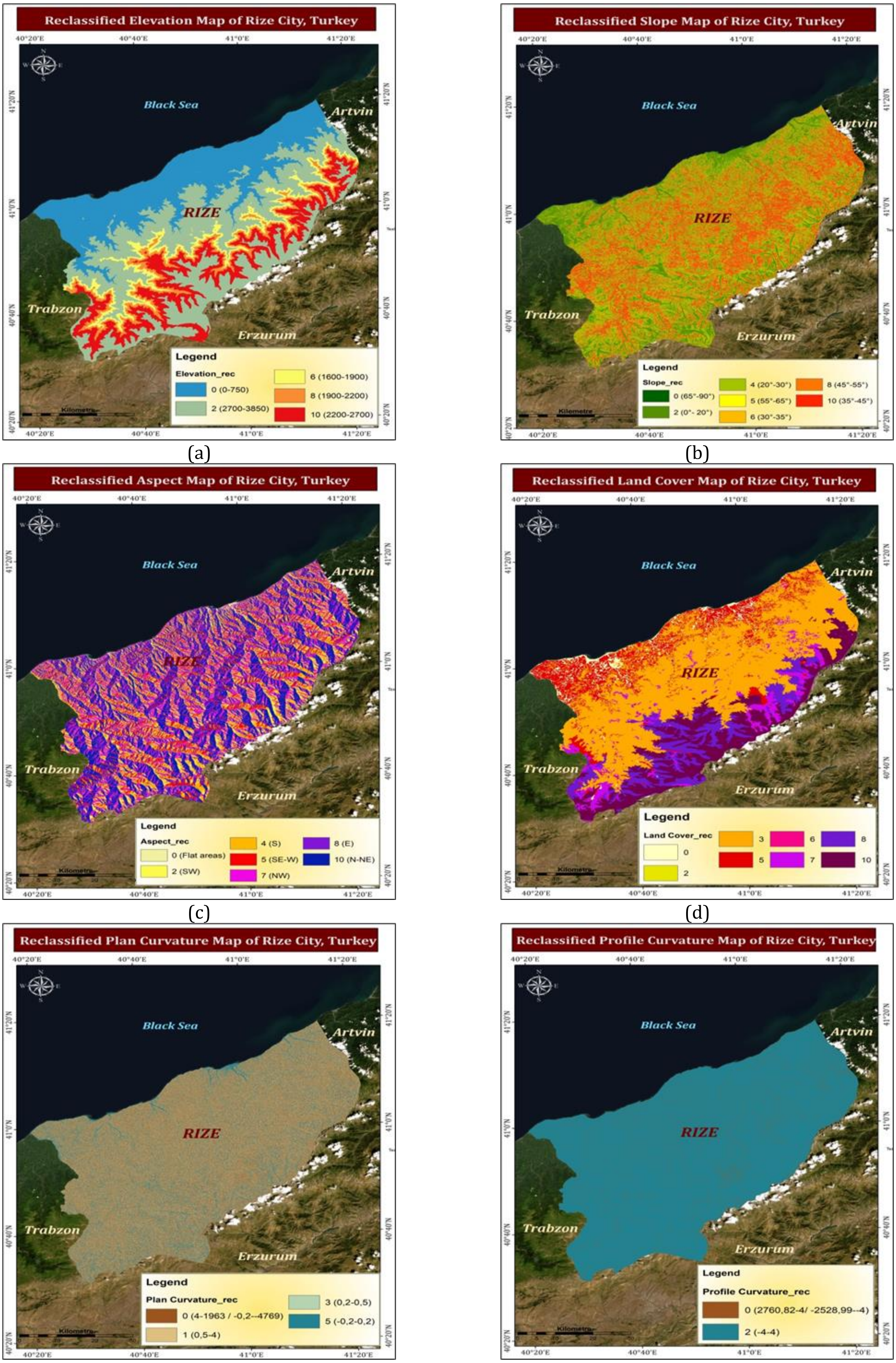

Figure 3. Raster classification map of criteria according to scores. Elevation (a), Slope (b), Aspect (c), Land cover (d), Plan curvature (e-f).

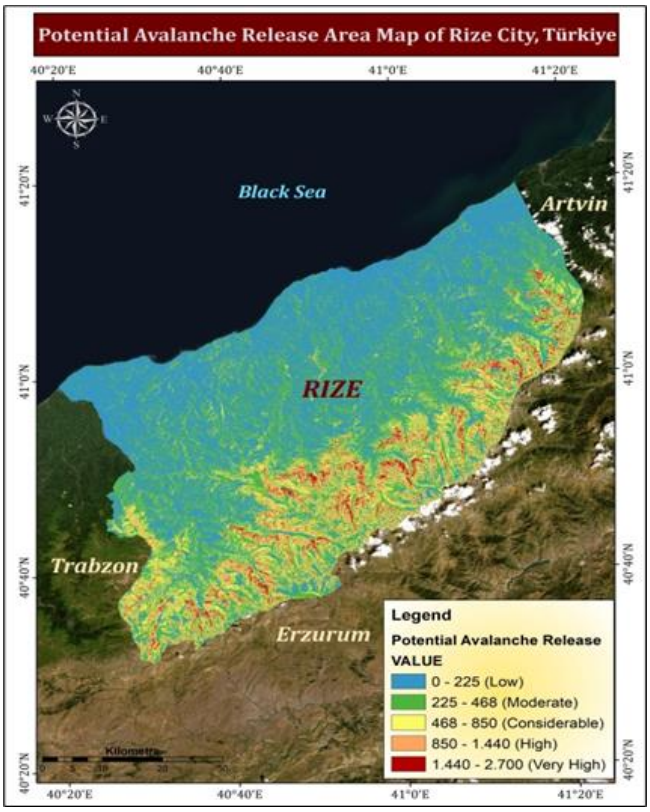

Figure 4. Determined avalanche risky areas.

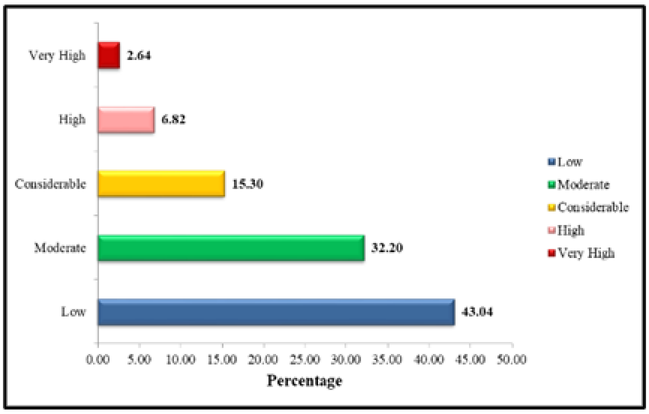

Figure 5. Percentage results of potential avalanche zones in the study area.

Table 5. Analysis results.

Equation Result	Total Area (m^2)	Total Area (km^2)	Percentage%
Low	1,651,607,516.10	1,651.61	43.04
Moderate	1,235,930,624.41	1,235.93	32.20
Considerable	587,186,885.00	587.19	15.30
High	261,821,601.36	261.82	6.82
Very High	101,151,372.36	101.15	2.64

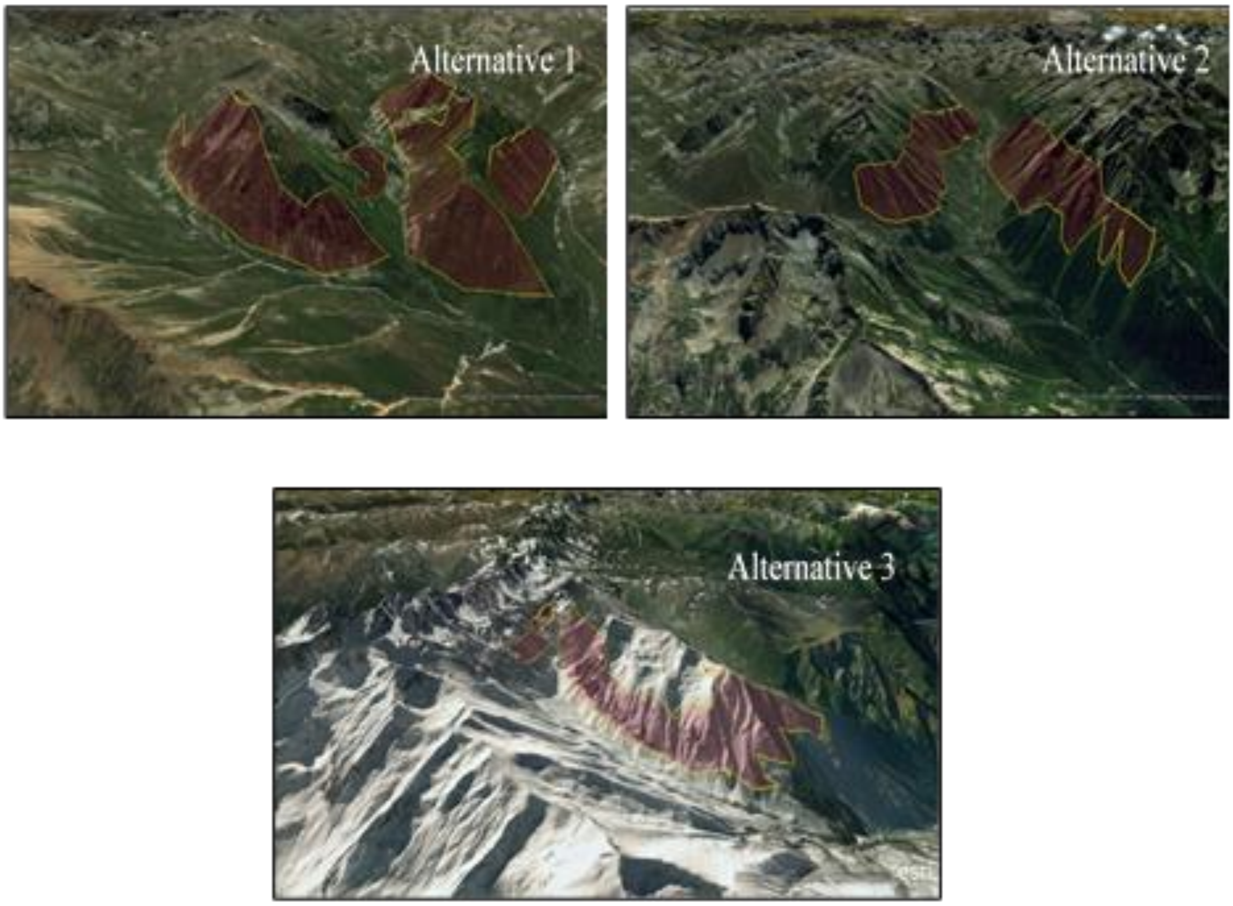

Figure 6. Determined avalanche risky alternative areas.

This situation may trigger an avalanche. In addition, when the slope value of these regions is examined, the region generally has slope values varying between 35°-50°. According to literature, these values are considered to be the most suitable values for avalanche formation [2, 6, 8]. The combination of all these different impacts has made these regions the most dangerous alternative regions for avalanches.

4. Conclusion

Potential risk areas should be identified before natural hazards occur. Risk analysis studies should be conducted in this context, and risk regions should be defined with maps. Risk maps are essential for the development of emergency action plans. For snow avalanches, one of the natural hazards of meteorological origin, it is necessary to determine the potential risk zones regarding hazard-related studies.

In this study, we have determined possible avalanche areas with the help of GIS methods. The first analysis group included all areas of Rize province, which was the general determination of risky areas. In the second stage, we examined risky areas in detail and detected exact avalanche risky areas. Results have shown that GIS technology is essential for determining risky areas. The relevant data and analysis model for this study is raster-based methods. In this way, all the areas can be analyzed in pixels.

In this study, the area with the highest total value was accepted as the riskiest in terms of potential snow avalanches. As a result of the analysis, the area of 10115.14 hectares was determined to be risky in terms of potential snow avalanches. Three different alternative areas were selected from this area, and these areas were determined as the points with the highest risk in terms of risk. Therefore, minimizing the snow avalanche risks that will occur in risky areas, including these selected alternative areas, or carrying out necessary precautions is essential. Thus, snow avalanche risks can be minimized.

This study shows that recent risky avalanche area determination studies are valuable in applicability and accuracy. However, every practical study for developing risky area determination algorithms supports and enriches GIS studies. Soon, we will focus on determining risky avalanche areas with the help of machine learning. Using technology and newly developed GIS systems will decrease labor loss and budgets for risk planning. Moreover, more human and animal life and nature will be protected.

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Author contributions

Ebru Colak: Conceptualization, Data Collection, Reviewing and Editing **Gamze Bediroğlu:** Conceptualization, Data Collection, Methodology, Software, Visualization, Investigation, Writing-Reviewing and Editing **Tugba Memişoğlu Baykal:** Conceptualization, Data Collection, Methodology, Software, Visualization, Investigation, Writing, Reviewing and Editing

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Renner K. (2015). Avalanche risk terrain susceptibility. http://hydrology.usu.edu/giswr/Archive15/Renner/Termproject.pdf
2. Schweizer, J., Bruce Jamieson, J., & Schneebeli, M. (2003). Snow avalanche formation. Reviews of Geophysics, 41(4). https://doi.org/10.1029/2002RG000123
3. Castebrunet, H., Eckert, N., & Giraud, G. (2012). Snow and weather climatic control on snow avalanche occurrence fluctuations over 50 yr in the French Alps. Climate of the Past, 8(2), 855-875. https://doi.org/10.5194/cp-8-855-2012
4. Korzeniowska, K., Bühler, Y., Marty, M., & Korup, O. (2017). Regional snow-avalanche detection using object-based image analysis of near-infrared aerial imagery. Natural Hazards and Earth System Sciences, 17(10), 1823-1836. https://doi.org/10.5194/nhess-17-1823-2017
5. Marana, B. (2017). An ArcGIS geo-morphological approach for snow avalanche zoning and risk estimation in the Province of Bergamo. Journal of Geographic Information System, 9(2), 83-97. https://doi.org/10.4236/jgis.2017.92006
6. McClung, D., & Schaerer, P. A. (2006). The avalanche handbook. The Mountaineers Books.
7. Bühler, Y., Kumar, S., Veitinger, J., Christen, M., Stoffel, A., & Snehmani. (2013). Automated identification of potential snow avalanche release areas based on digital elevation models. Natural Hazards and Earth System Sciences, 13(5), 1321-1335. https://doi.org/10.5194/nhess-13-1321-2013
8. Waldenström B. (2016). Identifying potential snow avalanche release areas in Sweden: An analysis of GIS methods and data resolutions. [Doctoral Dissertation, Stockholm University].
9. Çolak, E., & Memişoğlu, T. (2021). Thornthwaite iklim sınıflandırma yöntemine göre Karadeniz Bölgesi iklim sınır haritasının CBS ile üretilmesi. Geomatik, 6(1), 31-43. https://doi.org/10.29128/geomatik.651702
10. Doğan, A., Başeğmez, M., & Aydın, C. C. (2023). Geniş çalışma alanlarında jeofizik ve jeoteknik ölçümlerin yerine geçebilecek vekil özelliklerin CBS ile belirlenmesi. Geomatik, 8(3), 293-305. https://doi.org/10.29128/geomatik.1161434
11. Uyan, M. (2017). Güneş enerjisi santrali kurulabilecek alanların AHP yöntemi kullanılarak CBS destekli haritalanması. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 23(4), 343-351. https://doi.org/10.5505/pajes.2016.59489
12. Geymen, A. (2017). Coğrafi bilgi sistemlerinde kullanılan konumsal analizlerin animasyon tabanlı öğrenimi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 23(2), 165-170. https://doi.org/10.5505/pajes.2016.02703
13. Eşsiz, M., & Acar, Z. (2023). Synoptic analysis of the January 2004 snowstorm: Example of Çanakkale. International Journal of Engineering and Geosciences, 8(1), 11-18. https://doi.org/10.26833/ijeg.988115

14. Siddique, F., & Rahman, A. U. (2023). Genesis and spatio-temporal analysis of glacial lakes in the peri-glacial environment of Western Himalayas. International Journal of Engineering and Geosciences, Geosciences, 8(2), 154-164. https://doi.org/10.26833/ijeg.1097912
15. Toppe, R. (1987). Terrain models: a tool for natural hazard mapping. International Association of Hydrological Sciences (IAHS), 629–638.
16. Hreško, J. (1998). Avalanche hazard of the Tatra high mountain landscape. Folia Geographica, 2, 348-352.
17. Maggioni, M., & Gruber, U. (2003). The influence of topographic parameters on avalanche release dimension and frequency. Cold Regions Science and Technology, 37(3), 407-419. https://doi.org/10.1016/S0165-232X(03)00080-6
18. Barka, I. (2003). Identification of snow avalanche trigger areas and avalanche paths by the GIS. Geomorphologia Slovaca, 3(2), 60-63.
19. Delparte D. (2008). Avalanche Terrain Modeling in Glacier National Park, Canada. [Doctoral Dissertation, University of Calgary].
20. Sitko R. (2008). Identification, classification, and assessment of forest function with the use of geoinformatics. [Doctoral Dissertation, Technical University in Zvolen].
21. Bebi, P., Kienast, F., & Schönenberger, W. (2001). Assessing structures in mountain forests as a basis for investigating the forests' dynamics and protective function. Forest Ecology and Management, 145(1-2), 3-14. https://doi.org/10.1016/S0378-1127(00)00570-3
22. Biskupič, M., & Barka, I. (2009). Statistical avalanche run-out modelling using GIS on selected slopes of Western Tatras National park, Slovakia. International snow Science Workshop, Davos, 482-487.
23. McClung, D. M. (2002). The elements of applied avalanche forecasting, Part I: The human issues. Natural Hazards, 26, 111-129. https://doi.org/10.1023/A:1015665432221
24. AS Mohammed, A. A., Naqvi, H. R., & Firdouse, Z. (2015). An assessment and identification of avalanche hazard sites in Uri sector and its surroundings on Himalayan Mountain. Journal of Mountain Science, 12, 1499-1510. https://doi.org/10.1007/s11629-014-3274-z
25. Leroi, E. (1996). Landslide hazard-risk maps at different scales: objectives, tools and developments. In Landslides, 35-51.
26. Mihalić, S. (1998). Recommendations for landslide hazard and risk mapping in Croatia. Geologia Croatica, 51(2), 195-204.
27. Birkeland, K. W., & Mock, C. J. (2001). The major snow avalanche cycle of February 1986 in the western United States. Natural Hazards, 24, 75-95. https://doi.org/10.1023/A:1011192619039
28. Jamieson, B., & Stethem, C. (2002). Snow avalanche hazards and management in Canada: challenges and progress. Natural Hazards, 26, 35-53. https://doi.org/10.1023/A:1015212626232
29. Glade, T., Anderson, M. G., & Crozier, M. J. (2005). Landslide hazard and risk, 807. Chichester: Wiley.
30. Nadim, F., Kjekstad, O., Peduzzi, P., Herold, C., & Jaedicke, C. (2006). Global landslide and avalanche hotspots. Landslides, 3, 159-173. https://doi.org/10.1007/s10346-006-0036-1
31. Höller, P. (2007). Avalanche hazards and mitigation in Austria: a review. Natural Hazards, 43(1), 81-101. https://doi.org/10.1007/s11069-007-9109-2
32. Maggioni, M., Gruber, U., Purves, R. S., & Freppaz, M. (2006). Potential release areas and return period of avalanches: is there a relation?. International Snow Science Workshop, 566-571.
33. Omirzhanova, Z. T., Urazaliev, A. S., & Aimenov, A. T. (2015). GIS for predicting the avalanche zones in the mountain regions of Kazakhstan. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, 39-44. https://doi.org/10.5194/isprsarchives-XL-2-W4-39-2015
34. Cappabianca, F., Barbolini, M., & Natale, L. (2008). Snow avalanche risk assessment and mapping: A new method based on a combination of statistical analysis, avalanche dynamics simulation and empirically-based vulnerability relations integrated in a GIS platform. Cold Regions Science and Technology, 54(3), 193-205. https://doi.org/10.1016/j.coldregions.2008.06.005
35. Peitzsch, E. H., Hendrikx, J., & Fagre, D. B. (2015). Terrain parameters of glide snow avalanches and a simple spatial glide snow avalanche model. Cold Regions Science and Technology, 120, 237-250. https://doi.org/10.1016/j.coldregions.2015.08.002
36. Yariyan, P., Avand, M., Abbaspour, R. A., Karami, M., & Tiefenbacher, J. P. (2020). GIS-based spatial modeling of snow avalanches using four novel ensemble models. Science of The Total Environment, 745, 141008. https://doi.org/10.1016/j.scitotenv.2020.141008
37. Teich, M., & Bebi, P. (2009). Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—A case study in Switzerland. Forest Ecology and Management, 257(9), 1910-1919. https://doi.org/10.1016/j.foreco.2009.01.046
38. Gruber, U., & Bartelt, P. (2007). Snow avalanche hazard modelling of large areas using shallow water numerical methods and GIS. Environmental Modelling & Software, 22(10), 1472-1481. https://doi.org/10.1016/j.envsoft.2007.01.001
39. Maggioni, M., Gruber, U., & Stoffel, A. (2002). Definition and characterisation of potential avalanche release areas. Proceedings of the ESRI Conference, San Diego.
40. Marek, B., & Ivan, B. (2010). Spatial modelling of snow avalanche run-outs using GIS. Proceedings from Symposium GIS, Ostrava.
41. Aydin, A., Bühler, Y., Christen, M., & Gürer, I. (2014). Avalanche situation in Turkey and back calculation of selected events. Natural Hazards and Earth System Sciences, 14(5), 1145-1154. https://doi.org/10.5194/nhess-14-1145-2014

42. Harvey, S., Schmudlach, G., Bühler, Y., Dürr, L., Stoffel, A., & Christen, M. (2018). Avalanche terrain maps for backcountry skiing in Switzerland. International Snow Science Workshop, Innsbruck, Austria, 1625-1631.
43. Peitzsch, E. H., Hendrikx, J., & Fagre, D. B. (2014). Assessing the importance of terrain parameters on glide avalanche release. International Snow Science Workshop, 708-716.
44. Bolognesi, R., Denuelle, M., & Dexter, L. (1996). Avalanche forecasting with GIS. International Snow Science Workshop (ISSW), Banff, Canada, 11-13.
45. Košová, V., Molokáč, M., Čech, V., & Jesenský, M. (2022). Avalanche hazard modelling within the kráľova hoľa area in the low tatra mountains in Slovakia. Land, 11(6), 766. https://doi.org/10.3390/land11060766
46. Aydın, A., & Eker, R. (2017). GIS-Based snow avalanche hazard mapping: Bayburt-Aşağı Dere catchment case. Journal of Environmental Biology, 38, 937-943. https://doi.org/10.22438/jeb/38/5(si)/gm-10
47. Barbolini, M., Pagliardi, M., Ferro, F., & Corradeghini, P. (2011). Avalanche hazard mapping over large undocumented areas. Natural Hazards, 56(2), 451-464. https://doi.org/10.1007/s11069-009-9434-8
48. Pistocchi, A., & Notarnicola, C. (2013). Data-driven mapping of avalanche release areas: a case study in South Tyrol, Italy. Natural Hazards, 65, 1313-1330. https://doi.org/10.1007/s11069-012-0410-3
49. Selcuk, L. (2013). An avalanche hazard model for Bitlis Province, Turkey, using GIS based multicriteria decision analysis. Turkish Journal of Earth Sciences, 22(4), 523-535. https://doi.org/10.3906/yer-1201-10
50. Yılmaz B. (2016). CBS tabanlı bulanık mantık ve analitik hiyerarşi sürecinin (AHP) kar çığı duyarlılık haritalamasına uygulanması, Kuzey San Juan, Colorado. [Master's Thesis, Karadeniz Technical Üniversity].
51. Durlević, U., Valjarević, A., Novković, I., Ćurčić, N. B., Smiljić, M., Morar, C., ... & Lukić, T. (2022). GIS-based spatial modeling of snow avalanches using analytic Hierarchy process. a case study of the Šar Mountains, Serbia. Atmosphere, 13(8), 1229. https://doi.org/10.3390/atmos13081229
52. Bhardwaj, A. S., Pandit, A., & Ganju, A. (2014). Demarcation of potential avalanche sites using remote sensing and ground observations: a case study of Gangotri glacier. Geocarto International, 29(5), 520-535. https://doi.org/10.1080/10106049.2013.807304
53. Kumar, S., Srivastava, P. K., & Snehmani. (2018). Geospatial modelling and mapping of snow avalanche susceptibility. Journal of the Indian Society of Remote Sensing, 46, 109-119. https://doi.org/10.1007/s12524-017-0672-z
54. Akay, H. (2021). Spatial modeling of snow avalanche susceptibility using hybrid and ensemble machine learning techniques. Catena, 206, 105524. https://doi.org/10.1016/j.catena.2021.105524
55. Nefeslioglu, H. A., Sezer, E. A., Gokceoglu, C., & Ayas, Z. (2013). A modified analytical hierarchy process (M-AHP) approach for decision support systems in natural hazard assessments. Computers & Geosciences, 59, 1-8. https://doi.org/10.1016/j.cageo.2013.05.010
56. Maggioni, M. (2004). Avalanche release areas and their influence on uncertainty in avalanche hazard mapping. [Doctoral Dissertation, University of Zurich].
57. Turkish Statistical Institute. (2022). Address Based Population Registration System Database Online. https://biruni.tuik.gov.tr/medas/?kn=95&locale=tr
58. State Meteorological Service (2022). Rize sıcaklık istatistikleri. https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=RIZE
59. T.C. Culture and Tourism Ministry (2022). Rize-Kaçkar Dağları. https://yigm.ktb.gov.tr/TR-9905/rize-kackar-siradaglari.html
60. Gubler, H., & Rychetnik, J. (1991). Effects of forests near timberline on avalanche formation.
61. Weir, P. (2002). Snow avalanche management in forested terrain. British Columbia, Forest Science Program.
62. Aydın, A., & Eker, R. (2014). Topografik Parametreler Kullanılarak Potansiyel Çığ Başlama Bölgelerinin CBS Tabanlı Olarak Belirlenmesi. II. Ulusal Akdeniz Orman Ve Çevre Sempozyumu, 426-435.
63. Mears, A. I. (1992). Snow-avalanche hazard analysis for land-use planning and engineering. Colorado Geological Survey, Department of Natural Resources.
64. Fredston, J. A., & Fesler, D. (1994). Snow sense: A guide to evaluating snow avalanche hazard. Alaska Mountain Safety Center, Incorporated.
65. McClung, D. M. (2001). Characteristics of terrain, snow supply and forest cover for avalanche initiation caused by logging. Annals of Glaciology, 32, 223-229. https://doi.org/10.3189/172756401781819391
66. Schaerer, P. A. (1977). Analysis of snow avalanche terrain. Canadian Geotechnical Journal, 14(3), 281-287. https://doi.org/10.1139/t77-034
67. Armstrong, B., & Williams, K. (1986). The Avalanche book: Golden. Colorado, Fulcrum Inc, 240.
68. Boltižiar, M., Biskupič, M., & Barka, I. (2016). Spatial avalanche modelling by application of GIS on the selected slopes of Western Tatra Mts. and Belianske Tatra Mts., Slovakia. Geographia Polonica, 89(1), 79-90.
69. T. C. Ministry of Forestry and Water Management (2016). National Avalanche Risk Activation Plan Report. Ankara, Turkey.
70. Richnavský, J., Biskupič, M., Mudroň, I., Devečka, B., Unucka, J., Chrustek, P., ... & Matějíček, L. (2011). Using modern GIS tools to reconstruct the avalanche: A case study of Magurka 1970. Proceedings of the 8th International Symposium GIS Ostrava, 175-185.
71. http://mintsnowboarding.com/blog/avalanche-facts-and-tips/