ASSESSMENT OF AVALANCHE RISK USING GIS IN MOUNTAIN AREAS - CASE STUDY ARIEȘENI, ALBA COUNTY

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Abstract: *Avalanches represent a significant threat in mountainous regions (Arieseni, Alba County), especially in areas without vegetation that contributes to the stability of the snowpack. This study proposes a GIS-based methodology for identifying and assessing avalanche risk, utilizing Corine Land Cover (CLC) vector data, digital elevation models (DEM), and proximity analysis to built infrastructure. Through raster reclassification and multicriteria integration, a detailed risk map was created, providing a useful tool for managing exposed areas and disaster prevention.*

Keywords: *avalanche; GIS; Corine Land Cover; terrain; slope; reclassification; natural risk*

1. Introduction

Avalanches are among the most severe natural hazards in mountainous areas, causing significant material damage and loss of life. The conditions that favor avalanche occurrence are well known: steep slopes, lack of stabilizing vegetation, and snowpack loading. Identifying vulnerable areas is essential for preventing these phenomena.

By using GIS technologies, it is possible to integrate multiple critical factors, such as terrain slope, land use and cover, or proximity to infrastructure, into a single model that reflects the spatial distribution of risk. The aim of this paper is to detail a methodology that highlights areas with a high risk of avalanches through the reclassification of thematic layers and their combination into an integrated risk model.

2. Data acquisitions

In our study, data acquisition was a crucial step in performing an accurate assessment of avalanche risk. This involved collecting relevant geospatial datasets for the factors that influence this natural phenomenon. The most important data sources used in this research were the following:

Corine Land Cover data represents an essential source of information about land use and land cover, provided by specialized European agencies. These data are available at the European level and are crucial for understanding how different land types can influence avalanche risk. CLC classifies land into several categories, including forests, grasslands, water bodies, and built-up areas. In this study, areas of land without vegetation or with sparse vegetation were considered the most vulnerable to avalanche occurrence, given that vegetation plays a crucial role in stabilizing the snowpack.

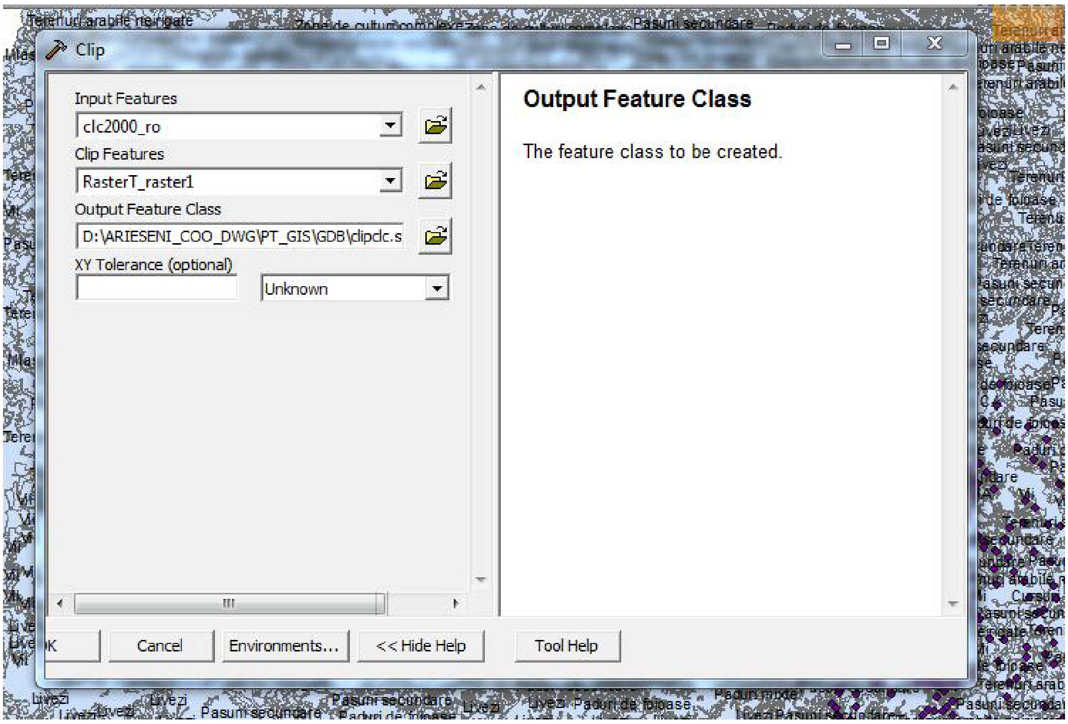

Fig. 1 The integration of the CLC layer and the clipping of L 34 058

The Digital Elevation Model (DEM) is another crucial dataset that provides precise information about terrain slope, an essential factor in avalanche risk analysis. The DEM was used to calculate the terrain slope and to identify areas with steep slopes, which are more likely to experience avalanches. These data are available through various sources, including SRTM (Shuttle Radar Topography Mission) data, which offer high-resolution terrain details.

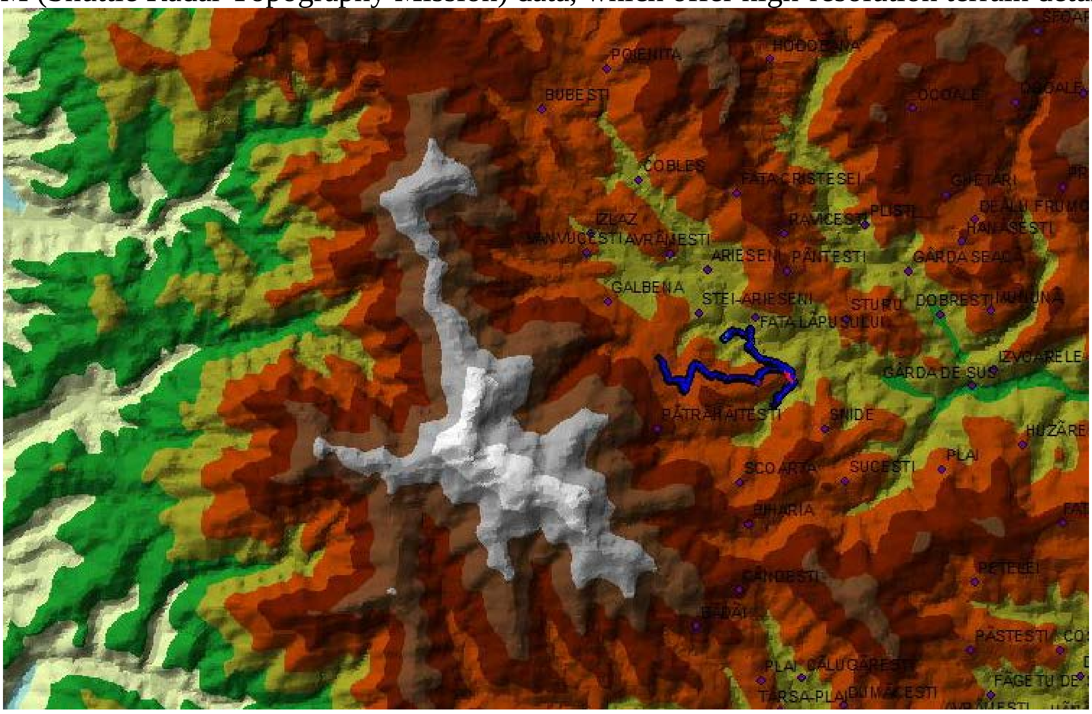

Fig. 2 Creation of the elevation model based on contour lines

Infrastructure data, such as the locations of roads, were obtained from various sources, including official topographic maps or public GIS databases. Proximity to roads and buildings is an important factor, as these structures can influence snow accumulation and may amplify risks in the event of an avalanche. Additionally, infrastructure plays a significant role in defining vulnerable areas, given that avalanches can cause significant damage to them.

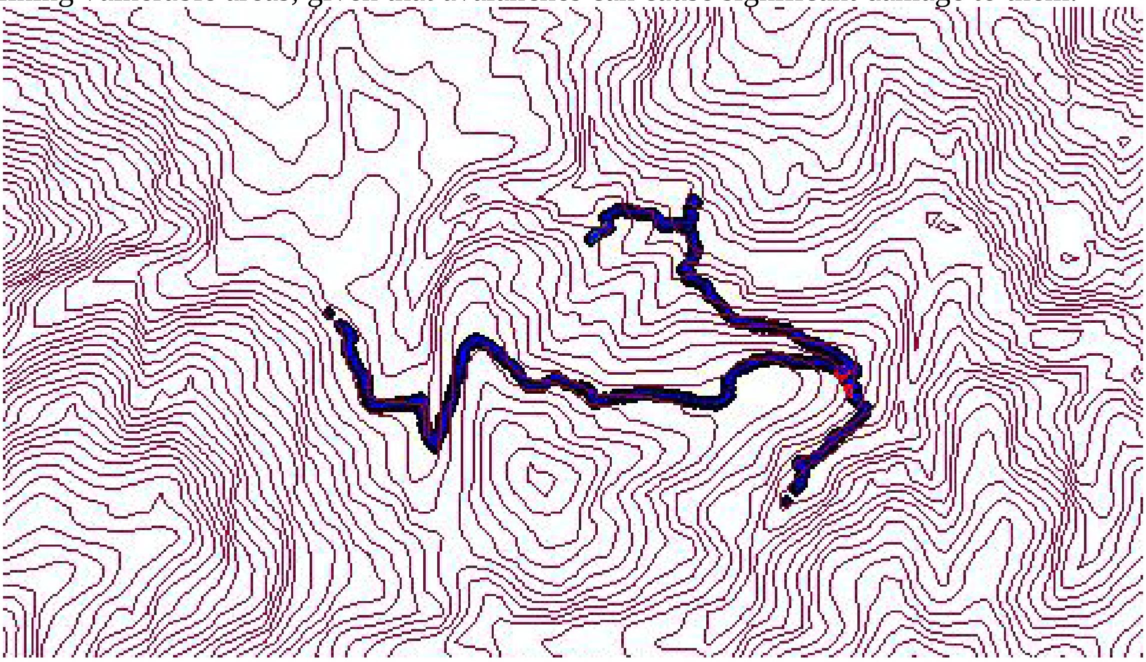

Fig. 3 Displaying roads in the area of interest

3. Multicriteria analysis methodology for avalanche risk assessment

Multicriteria analysis is the core of the methodology used for avalanche risk assessment, serving to integrate various factors with diverse influences into a coherent model. In this study, the process involved transforming the initial data into reclassified raster layers, followed by the application of the Weighted Overlay method. This section outlines the steps involved, as well as how each factor was quantified and weighted.

Multicriteria analysis is based on the combination of several thematic layers representing the main factors contributing to avalanche risk: terrain slope, land use, and proximity to infrastructure. The goal of this process is to transform spatial variables, with different characteristics and units, into a homogeneous format, so that they can be compared and integrated.

The main stages of the methodology include:

Reclassification is the process by which the initial values of a raster layer are reinterpreted to better reflect their contribution to the analyzed risk. For this study, the reclassification was performed so that the values were expressed on a uniform scale, ranging from minimum risk to maximum risk.

Slope is the most important factor in avalanche risk assessment. Based on derivatives obtained from the DEM, the terrain slope was reclassified into the following risk intervals:

- < 30°: minimal risk – the slope is not steep enough to allow snow to slide;
- 30°–35°: high risk – ideal conditions for avalanche triggering;
- 35°–45°: very high risk – maximum instability risk;
- 45°: moderate risk – snow slides quickly, reducing the risk of accumulation and avalanche triggering.

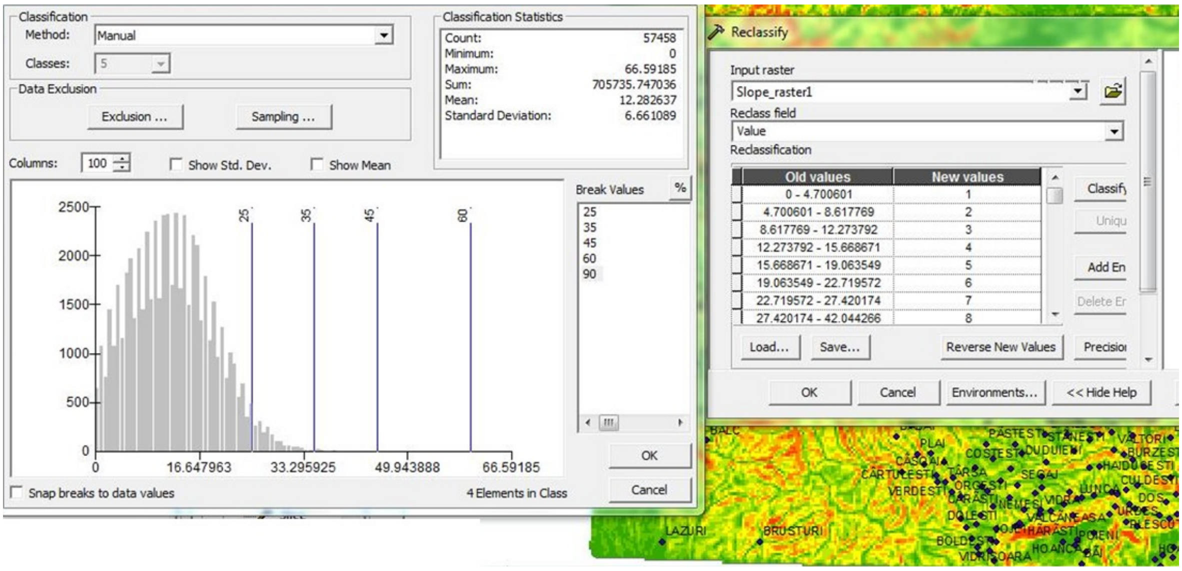

Fig. 4 Reclassification of the slope model

Corine Land Cover data were reclassified based on the stability provided by different types of land cover:

- Areas without vegetation (rocks, alpine meadows): very high risk;
- Areas with sparse vegetation: high risk;
- Forested areas: minimal risk– vegetation provides stability to the snowpack;
- Built-up areas: low risk – significant snow accumulation is usually rare.

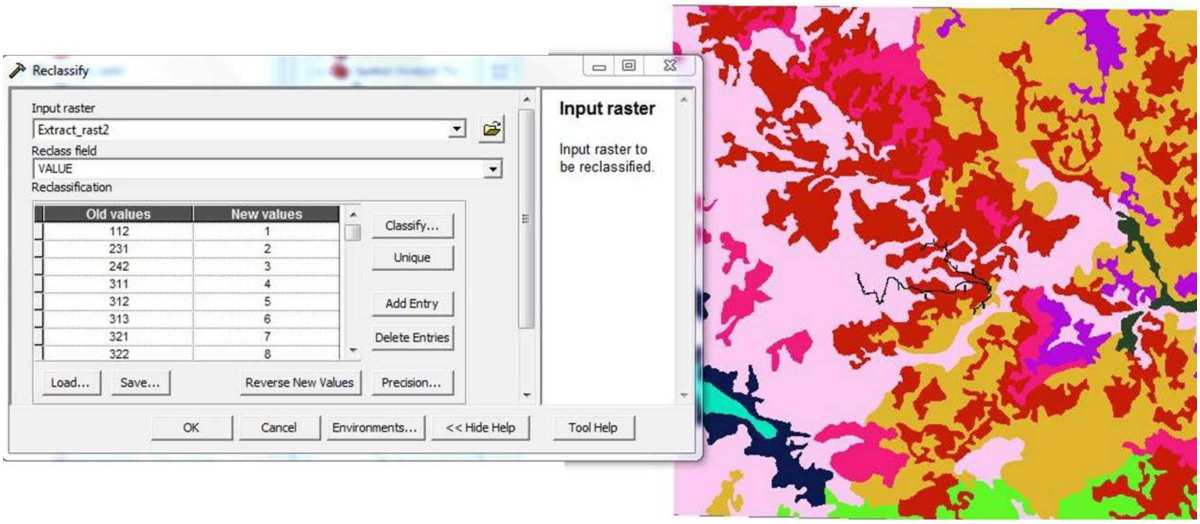

Fig. 5 Reclassification of the CLC raster

Proximity to roads and buildings is an anthropogenic factor that influences the potential impact of avalanches. The proximity layer was reclassified as follows:

- < 500 m: very high risk – the direct impact on infrastructure is maximum;
- 500–1000 m: moderate risk – low danger to built structures;
- 1000 m: low risk (1) – the impact is insignificant.

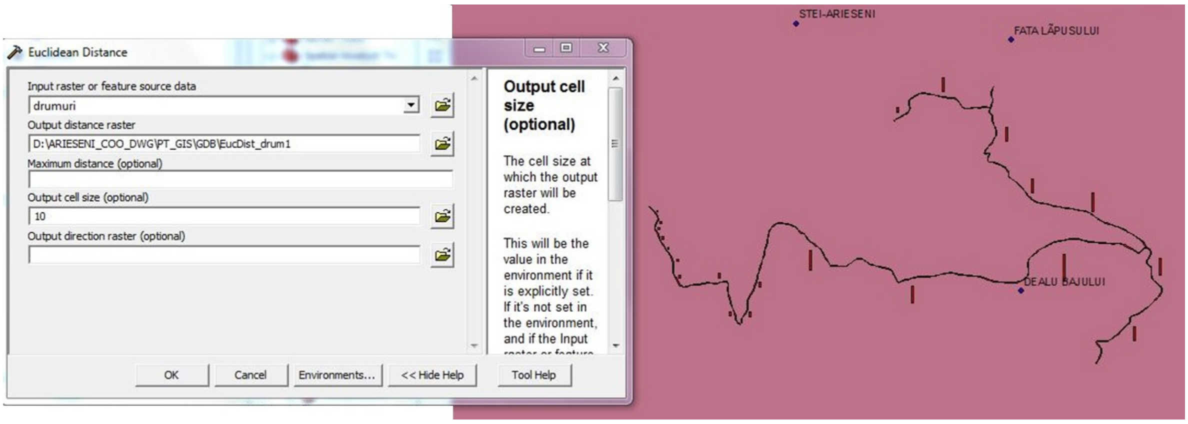

Fig. 6 Determination of areas with minimum distance to roads

4. Results and discussions

After reclassification, each layer was weighted based on its relative importance in determining avalanche risk. The weights were established based on specialized literature and local expertise. In this model, the weights were distributed as follows:

- Terrain slope: 50% – the main determinant of risk, due to its direct influence on snow stability.
- Land cover: 30% – contributes to terrain stability through the presence or absence of vegetation.
- Distance to infrastructure: 20% – a secondary factor, influencing mainly the impact of avalanches on population and property.

The formula used in the Weighted Overlay method is:

$$R_{\text{total}} = (R_{\text{slope}} \times 0.5) + (R_{\text{land cover}} \times 0.3) + (R_{\text{infrastructure}} \times 0.2)$$

The reclassified raster layers were overlayed using the Weighted Overlay method available in the GIS environment. This involves applying the previously defined weights and calculating a cumulative value for each raster cell, based on the contribution of each factor. The result is a final layer where each cell has a risk value ranging from 1 (minimal risk) to 3 (maximum risk).

The final risk map reflects the spatial distribution of medium-risk areas (2), providing a detailed view of the vulnerabilities in the terrain. The multicriteria analysis methodology offers flexibility and the ability to integrate diverse factors, but it also has some limitations.

Advantages:

- The ability to adjust weights according to the local specifics of the studied region;
- Reclassification of factors allows for their adaptation to different types of risks.
- Limitations:
- Excludes dynamic factors, such as snowpack thickness or weather conditions;
- Assigning weights can introduce subjectivity, especially if there is no solid local data.

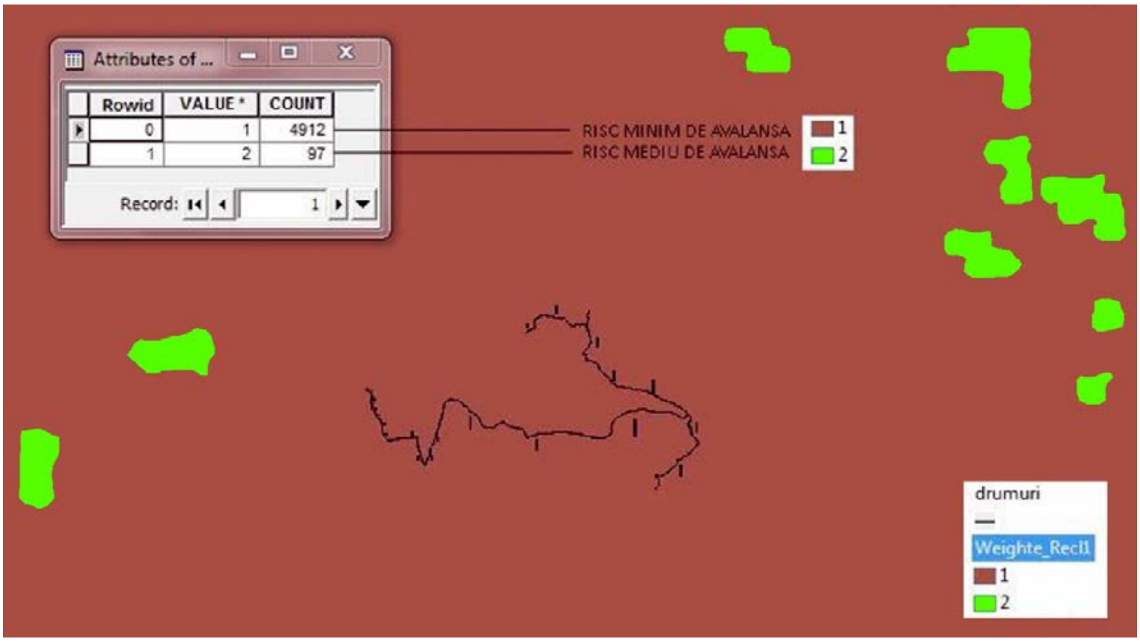

Fig. 7 Presentation of avalanche risk areas

5. Conclusions

This study, dedicated to avalanche risk assessment in the Arieseni area, demonstrates the importance of a methodological framework based on multicriteria analysis integrated with GIS, aimed at protecting the mountain area and the tourist infrastructure specific to this resort. Arieseni is a renowned tourist destination, particularly for winter sports such as skiing and snowboarding, and evaluating the avalanche risk in this area becomes essential not only for protecting human lives but also for ensuring the continuity of economic and tourism activities.

The use of GIS in avalanche risk analysis in Arieseni provided a valuable tool for integrating essential geospatial data, such as terrain slope, land use (CLC), and distances to infrastructure (roads and buildings). The results obtained by overlaying and reclassifying these data allowed for the identification of high-risk areas where steep slopes and lack of vegetation are significant contributing factors to avalanche triggers. This approach provided a clear picture of the vulnerabilities in the terrain, focusing on areas where tourist activities are concentrated, such as ski slopes, access roads, and accommodation zones.

Arieseni, as a notable tourist resort, benefits from a considerable number of visitors during the winter season due to its ski slopes and stunning mountain landscapes. However, avalanche risk poses a direct threat to both the safety of tourists and the tourist infrastructure. Ski slopes and the roads that provide access to the resort are exposed to natural risks, and assessing them based on the avalanche risk model is crucial for ensuring sustainable and safe tourism.

Risk maps obtained from multicriteria analysis can contribute to more efficient management of ski infrastructure and accommodation zones, thus offering better protection against avalanches. For example, identified high-risk areas can be protected by building snow barriers or by regulating access during certain times of the year when risks are highest.

The results of avalanche risk analysis provide local authorities and tourism operators in Arieseni with the necessary information to implement effective prevention and intervention measures. For example, identifying high-risk avalanche zones, such as ski slopes or roads leading to these slopes, allows for the creation of protection strategies, such as:

- Installing avalanche barriers on steep and exposed slopes;

- Regulating access to high-risk areas during periods when weather conditions favor avalanche triggering;
- Training resort staff and visitors about the risks and specific safety measures.

These measures not only protect the lives and property of tourists but also help maintain a positive image of the resort as a safe tourist destination, capable of supporting its winter economic activities in the long term.

An essential aspect of the study is the close link between environmental protection and the development of sustainable tourism. Natural risks, such as avalanches, can have a significant impact on tourism, but a rigorous evaluation of these risks can contribute to better risk management, minimizing damage and the negative impact on tourist businesses.

By using a GIS model for avalanche risk assessment, both infrastructure protection and visitor safety can be considered, contributing to the development of responsible and sustainable tourism. Additionally, risk analysis can support long-term planning, ensuring that resort development takes place harmoniously, without exposing vulnerable areas to additional risks.

The study conducted in Arieseni can serve as a model for avalanche risk assessment in other mountain resorts in Romania or in other regions with similar characteristics. Future research could address some of the limitations of the study, such as integrating real-time weather data and considering other dynamic factors that may influence avalanche triggering.

Moreover, GIS technologies can be extended to include constant monitoring of the terrain and updating risk maps based on seasonal developments or climate changes, thus contributing to more effective risk management.

The study conducted in Arieseni highlights the importance of using advanced technologies, such as GIS and multicriteria analysis, to assess and manage avalanche risks in a mountain tourist resort. By integrating both natural and anthropogenic factors, this risk assessment model helps protect not only infrastructure and population but also the economic activities essential to the region, such as skiing and other winter sports.

Implementing effective protection measures, such as avalanche barriers and access regulations in high-risk areas, will contribute to ensuring sustainable and safe tourism in Arieseni, consolidating the resort's status as a top tourist destination in Romania.

6. References

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