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The risks of geomorphological processes - rockfalls, in the area between Negoiu and Moldoveanu Peaks, at over 1800 meters for tourism

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Abstract: The present study investigates the geomorphological processes and associated risks of rockfalls in the high-altitude sector between Negoiu and Moldoveanu peaks (above 1800 m) in the Făgăraș Massif, Romania. Using field surveys, remote sensing data, and geomorphological analysis techniques, the research aims to identify the predisposing factors, triggers, and potential impacts of rockfalls in this area. Findings underscore the significance of geological structures, slope characteristics, climatic conditions and human activities in influencing landslide occurrence and magnitude. The study contributes valuable insights for land management strategies, hazard mitigation, and sustainable development efforts in mountainous regions prone to geomorphological hazards.
Key words: *rockfalls*, *risks, geomorphological processes, Făgăraș Massif, Romania*

1.Introduction

Even before the appearance of human species on earth, numerous geophysical events took place, such as earthquakes, floods, and volcanic eruptions. With the appearance of the human species and as a result of the interaction with the natural environment, these events were transformed into natural disasters. The evolution of phenomena that have serious consequences on civilization and its development has led to the analysis in the global issue of scientific research of the notions of hazard, risk, and disaster.

Natural disasters can occur anywhere in the world, but their effects can be influenced by various factors, such as the link between geographical location and its geological and geomorphological characteristics, but also depending on the stage of development of the affected country. Fritz (1961) stated in the early 1960's, that disasters were considered as uncontrollable events in which human society was endangered by all or some of its functions.

Risks and then disasters appear in the interaction between nature and man (White, 1974, UNDRO, 1982). The relief risks remain subjects of concern for people, as a result of the manifestation and direct interaction of certain phenomena related to the relief or its components. The processes which affect and shape the relief, considered normal as a result of its evolution, wear some risks for people and human settlements, being perceived as hazards or disasters depending on the intensity and damage caused.

The particularities of risk perception differ from region to region, country to country, or population to population. Under these conditions, what may be a catastrophe for one country may be just a disaster for another. These terms are not very well defined and clarified in the minds of citizens, leading to confusions which may arise during of such events. They are prone to pay attention mostly to the disasters instead of knowing the hazards as a mean to alleviate the losses

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(ElKady, et al., 2022). It can be the natural vulnerability when the environment gives way and hazards are formed and when the human being is affected, it is about human vulnerability.

The importance of research of the relief's risks, disasters and vulnerability grew steadily as it represents the support for human activities, and mountains areas are often a ssociated to tourism, especially due to the potential given by geomorphologic complexity. Therefore, the scientific approaches of these relations were developed in the last decades on diverse palettes. Thus, Eagles (1995) clearly underlined that the most important element in defining the quality of a tourist product is the natural setting, while Comănescu and Nedelea, (2010) drew attention that the variety and complexity of landforms and their use in tourism became a priority for researchers. In Romania there is a series of works that address the tourist role of relief, such as those of Grigore (1979), Cocean (1996, 1997, 2010), Muntele and Iaţu (2006). Their works analyze mainly the contribution of relief to the origin of tourist resources. On the other side, due to the increasing intensity and frequency of natural disasters caused by climate change rock fall processes pose a growing risk on slopes (Ovreiu et al., 2024). Special attention is paid on hazards and risks on geomorphosites, visited by a large number of tourists (Voiculescu, 2009, Andra-Topârceanu, 2019, Voiculescu et al., 2023).

The present paper aims to analyze the vulnerability of the territory to the risks of geomorphological processes such as rockfalls, in the central sector of the Făgăraş Massif. This approach is essential for mountainous areas, where geomorphological processes are influenced by multiple factors and significant spatial variations.

This study aims to contribute to understanding terrain vulnerability to geomorphological processes, considering both natural aspects and implication for tourist activities. To achieve this goal, the following main objectives were established: assessing terrain vulnerability (identifying and mapping areas prone to geomorphological processes such as rockfall), correlating geomorphological risks with tourist activity (analyzing the overlap between tourist trails and vulnerable areas to evaluate potential injury risks for visitors), identifying critical sectors (highlighting high-risk areas within the area that could impact the safety of tourists or the stability of mountain trails).

2.Study area

The area of research interest is situated in the central part of the Fagaras Massif, along the main ridge, being limited in the western part by the Negoiu Peak (2535 m) and in the eastern part by the Moldoveanu Peak (maximum altitude 2544 m) and Viştea Mare Peak (2527 m); in the northern and southern parts, the boundary of the area drops to an altitude of 1800 m, registering a difference level of 744 m. Geologically, the Făgăraş Massif is composed almost entirely of metamorphic rocks (crystalline shales) (Voiculescu et al., 2011).

The analyzed sector has the highest altitudes in the country, which allowed the installation of glaciers in the Pleistocene, with action up to altitudes of 1100 m-1200 m, at maximum extent. (Urdea, 1992). It has the most complex and impressive forms of glacial and periglacial relief (Voiculescu et al., 2023). The predominant relief is ruinous with saddles, high ridges, needles, and towers. It belongs to the glacial relief, characterized by valleys, cirques, in which lakes were formed, and mutated rocks have developed. Therefore, this area represents one of the most popular mountain areas in Romania. It attracts the largest number of tourists in summer, when the numerous tourist routes, but also in winter due to the design of the Bâlea Lake ice hotel. Also, in Făgăraş Massif, tourists benefits by a very high accessibility due to the Transfăgărăşan Road,

which gets to the Bâlea Lake, a sit that plays the role of the junction point for the most of the trails, being served, in the winter, by the cable car on the northern slope.

3. Materials and methods

The methodology of this study is harmonized with Romanian legislation for natural hazards following normative acts: Government Decision 645/2005 - Criteria for classifying territorial administrative units, public institutions, and economic operators in terms of civil protection according to specific types of hazards (reference to all types of natural hazards and including safety measures aimed at reducing risks) and the Law no 107/1996 - Water Law, with subsequent additions (treatment of floods and extreme weather events and prohibition of storage of chemicals in areas at risk of flooding).

The methodology used is based on methods adapted to the geomorphological specifics of the studied area. The morphographic method involves the analysis of the relief. In order to identify the vulnerability of the researched area, the documentation phase using the specialized literature was performed in the initial phase, in the second phase the cartographic basis necessary to determine the vulnerability of the area was designed, using the geographical mapping method, which is based on measurements, observations, and comparisons. This GIS based method and advanced cartographic techniques were chosen because they allow the integration and simultaneous analysis of complex parameters. In the ArcMap program data vectors were introduced: and using the level curves, the hypsometric map is performed, showing the altimetry of elevation (Figure 1).

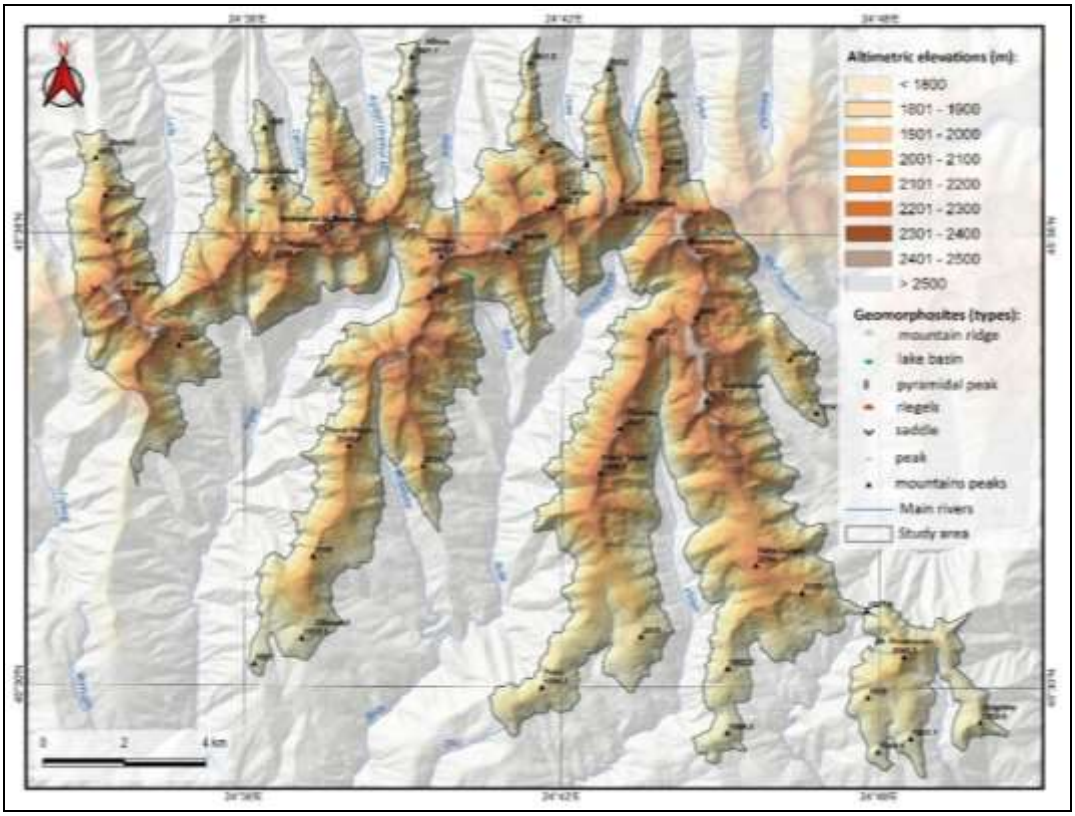

Figure 1 – The hypsometric map. Processed by author in GIS

The functions of the program are used for the following maps: slope orientation (Figure 2), geology, geodeclivity (Figure 3). For each map, the results obtained must be reclassified.

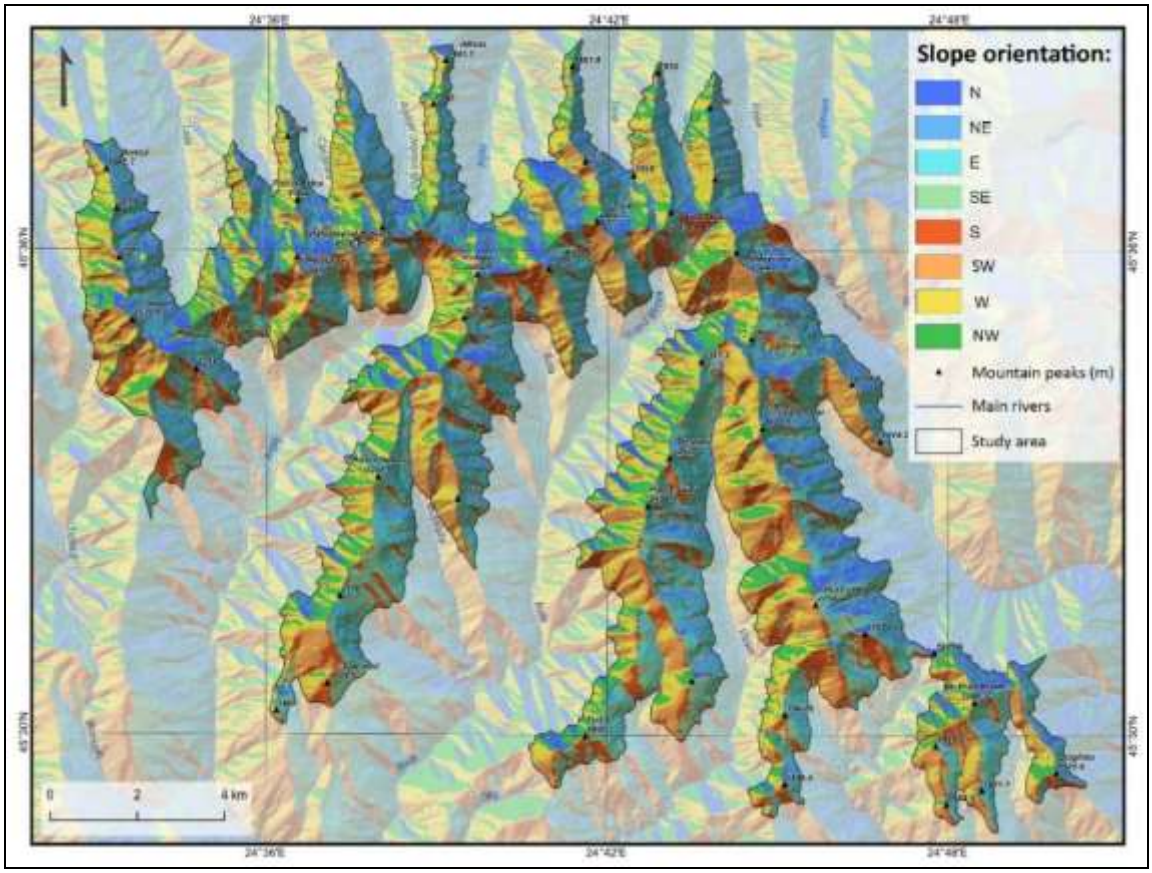

Figure 2 – The slope exposure map. Processed by author in GIS

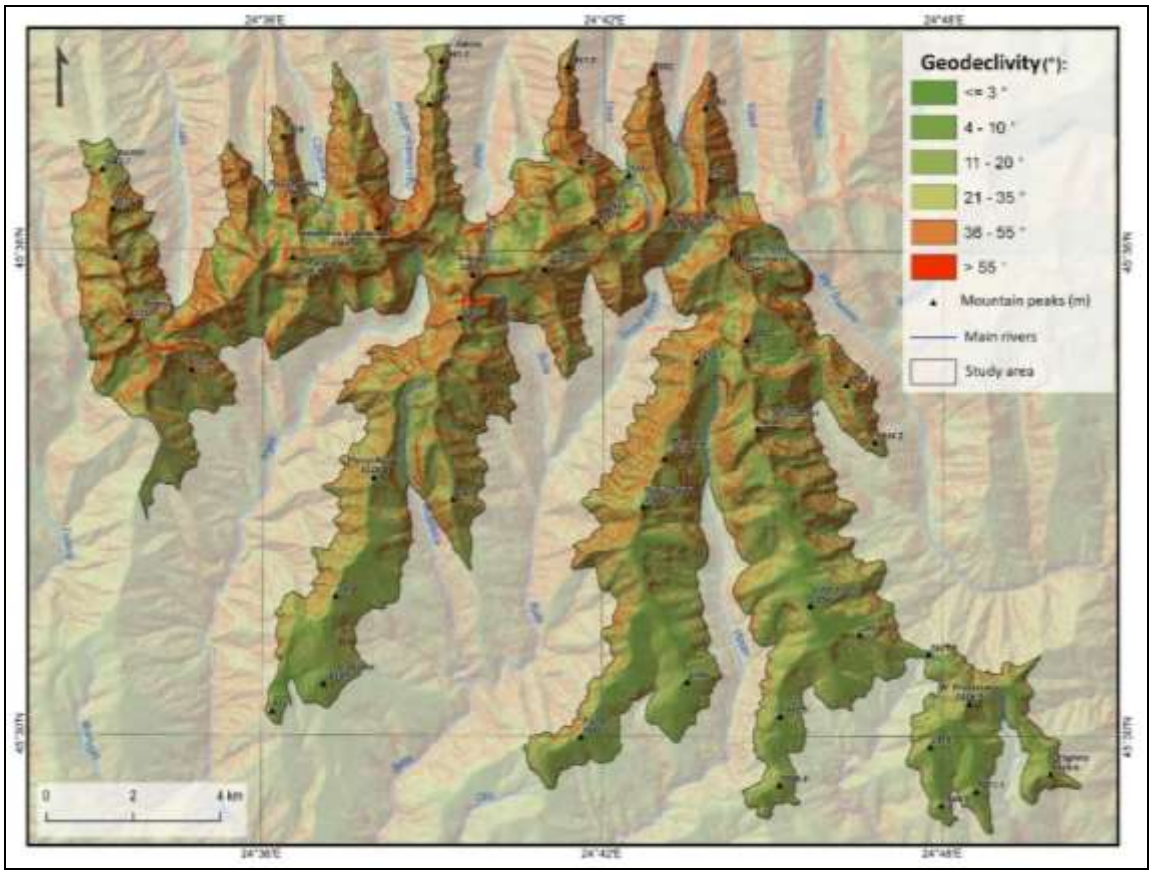

Figure 3 – The geodeclivity map. Processed by author in GIS

Thus, the reclassification of petrography is done as follows: soft rocks (gravels, sands), medium rocks (paragnais), hard rocks (shales, limestones). Land use is also classified according to the dominant characteristic, thus resulting in three categories of land use: the first, which includes forests; the second, which includes juniper and shrubs; and the third, which includes meadows and rocks. After reclassification, the geological maps are multiplied by the land use. The analysis of land use in a morphometric analysis is an important step because the land use in correlation with geology is closely related to favouring or preventing the occurrence or manifestation of the evolution of current geomorphological processes and slope dynamics. Further, the interpolation of the slope exposure map with the geodeclivity map is performed. The resulting map is important for the analysis of the distribution of geomorphological processes. The two ridges are open: reclassified slopes and orientation. This multiplication is done in order to see where there are inclinations of 00 to 100 and what exposure they have. At the end, in order to obtain the map of the vulnerability of the area, the reclassified maps of geology, slope, and exposure will be multiplied. The result obtained is also reclassified, resulting in the final map of vulnerability for geomorphological processes such as rockfalls.

4. Results and discussions

Natural phenomena occur depending on certain conditions, so in the analyzed area, being located at an altitude of over 1800 m, it can be analyzed only certain processes that take place in this perimeter. In the studied area, individual rockfalls, characteristic of the rocky slopes of the mountains in the alpine floor, are individualized (Figures 4, 5).

Figure 4 – Scree accumulation. The author's photo

Figure 5 - Rockfalls, The author's photo

Disaggregation is the main process, after the rocks are dislodged, they fall in the form of single blocks, in the form of cones or scree and are arranged at the base of the slope. They can cause human accidents as well as temporary blockage of circulation arteries.

The areas where rockfalls occur are predominantly located in the space of the main ridge. The section of the route that connected the Negoiu Peak and Călţun Lake, known as Strunga Dracului (more precisely, a chimney of approximately 180 m, with a slope of 70º-80º), was closed firstly for a while, and later permanently due to falling rocks, aiming to avoid injury to tourists. This measure was based on the rescuers request of a geotechnical study carried out by the specialists from the Western University of Timişoara (2017), and upon its completion, following the evaluation, it was found that at any moment in that sector of the route, rockfalls can occur, which cannot be provided.

In figure 6, shows areas with a high susceptibility to rockfalls identified on the basis of the morphological analysis of the level curves on the topographic map. Thus, it was evaluated the potential for instability of the land, and, also, the places where rockfall phenomena have occurred or are possible in the near future, have been identified.

According to figure 7, in the analyzed area there are low risks at altitudes of 1800, medium risks up to altitudes of about 2000, and on the ridge areas and certain strips the risks are expected to increase, reaching the small areas to be high. The tourist routes cross various sections with medium risks, but overall, the analyzed area does not present a high risk for tourists in terms of geomorphological processes. The marked geomorphosites can be visited mostly easily; only the western ones seem to be more difficult to access, being fairly long trails with steep ascent and descent sectors, where the use of cables is necessary.

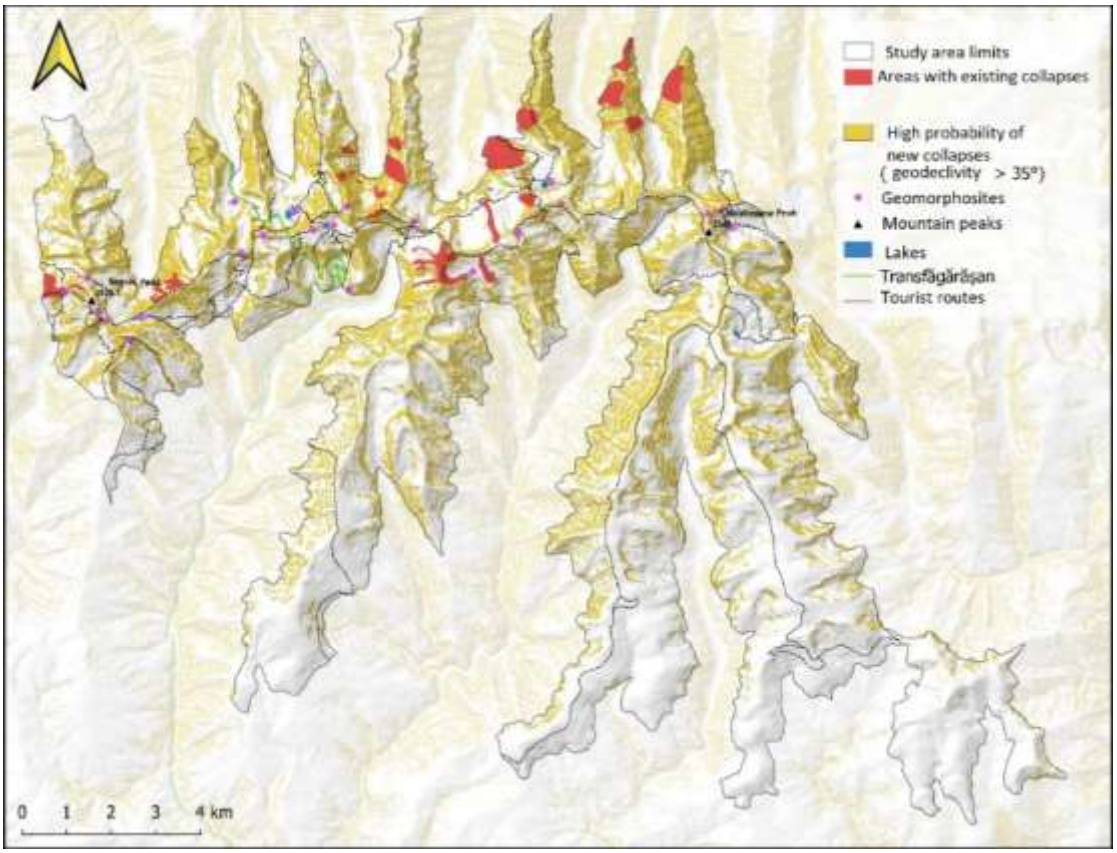

Figure 6 – Map of rockfalls. Processed by author in GIS

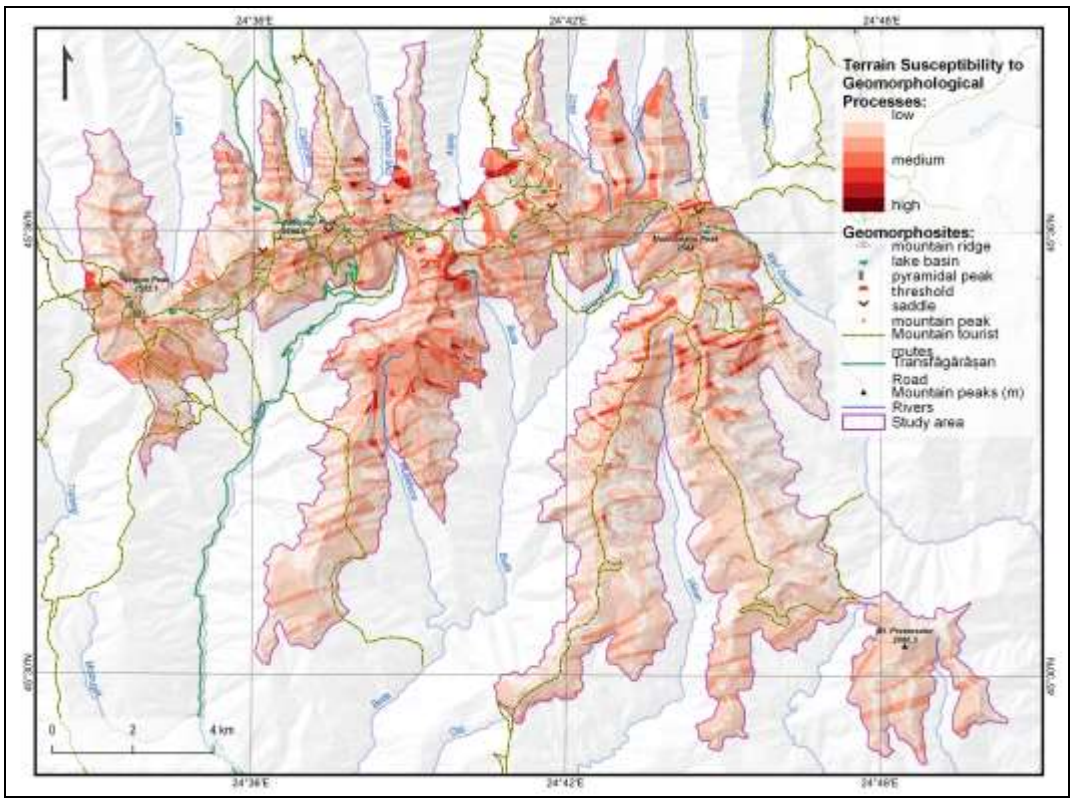

Figure 7– The map of the vulnerability of the area to the risks of rockfalls processes. Produced by author, in GIS

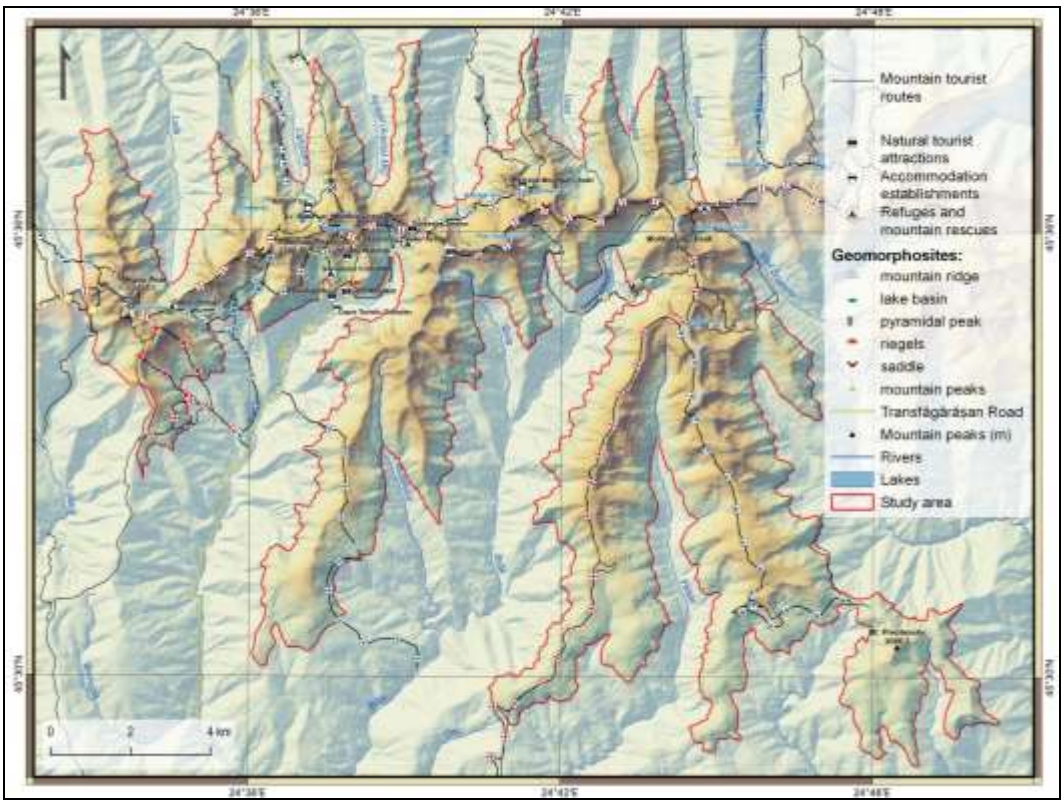

Figure 8 – The tourist map. Processed by author in GIS.

It can be seen from figure 8 that geomorphosites and tourist routes are distributed on the ridge area, at over 1800 meters.The main routes branch off below the limit of 1800 meters. Comparing the data from figure 6 with figure 8, it is obviously that the areas identified with existing collapses (in red), on figure 6–overlap in few sites with tourist routes mainly on the northern slopes than on the southern, and less in few geomorphosites marked on figure 8. There is a complex network of hiking trails stretches over approximately 60 km. Among these, the main ridge trail, connects Negoiu (2535 m) and Moldoveanu (2544 m) peaks and has a distance of 20-25 km, complemented by secondary trails providing access from various points and valleys. A detailed analysis reveals that areas exposed to rockfalls account for an estimated 5% of the total trail length. The most affected are sections of Strunga Dracului, Custura Sărății, Strunga Doamnei and rocky areas characterized by rugged terrain. Based on the results which indicate that the research area is safe to visit, following all provide safety recommendations, and proper equipment for mountain.

Conclusions

This study helps identify vulnerable sectors that may pose a danger to tourists and provide valuable insights for planning accessibility and ensuring safety in this area. By employing GIS-based analysis and advanced cartographic techniques in ArcMap, the study provides a detailed vulnerability map, integrating parameters such as hypsometry, slope, aspect, rockfall inventory. This approach offers a comprehensive understanding of spatial distribution patterns and risk factors to support a better-informed decision-making for land management and hazard mitigation in high-altitude environments.

Following the analysis performed on the area, most geomorphosites and routes can be accessed by tourists. Regarding the vulnerability of the territory, concering the geomorphological processes is reduced. The risks to which tourists are exposed by visiting the analyzed area are minimal, depending on other factors than the relief.The morphology enhances the attractiveness of the Făgăraş Massif due to certain features, such as the diversity, complexity, and originality of its shapes. From a legislative protection standpoint, there are no specific measures in place for this area, as it is not part of a protected natural area and lacks a specific legal basis for the conservation of geomorphosites. Effective management belonges to the local authorities or national. One of the most vulnerable geomorphosites, such as Strunga Dracului, needs specific interventions to prevent and/or slow down the natural degradation process.

The study has several limitations, firstly the vulnerability analysis relies on data available and updated at the time of research, while geomorphological processes may vary over time due to climatic or anthropogenic factors. Secondly, the vulnerability map was created using medium-resolution datasets, which may limit the accuracy of details at a local scale. The study did not include a detailed analysis of the seasonal dynamics of the processes or the potential impact of global warming on slope instability.

The limitations encountered during the study can, however, serve as starting points for future research. Based on the conducted study, several directions for future research can be proposed: detailed impact analysis on tourism (how geomorphological risks influence the safety and accessibility of tourist trails in the area), real-time monitoring of geomorphological processes (using advanced methods such as drones, motion sensors or satellite imagery, future studies could evaluate the real-time dynamics), modeling geomorphological processes under future climate scenarios (this study provides a basis for simulating the effects of climate change on slope instability, considering variables such as precipitation, temperature).

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