

Mass Movements Analysis along a Road Segment (Batushë-Rrasa e Kosharës) in an Alpine Region in Kosovo

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ABSTRACT

The article represents a contribution to the assessment of slope processes, with special emphasis on landslides, rockfalls, and creeps along the road sector Batushë-Rrasa e Kosharës (municipality of Gjakova) in Kosova. The analysis of natural factors, as well as their role in triggering and evolving slope processes, was conducted by observing the processes in the field and, with a multidisciplinary approach, analyzing the natural factors (geology, tectonics, climate, vegetation) as well as the role of humans. By using GIS/RS techniques, the causes and features of processes were identified and presented with various illustrations and maps, assessing the potential risk in the future with the aim of proper management, considering the movement of citizens, and preserving the road infrastructure in a segment with historical and touristic values. The slopes with a 35–40° gradient are more prone to landslides, while the presence of unconsolidated rocks and fractured limestone has accelerated slope destabilization and rock mass movements. Slope stability techniques should be implemented in order to keep the road open for future visitors to historical sites.

Keywords: mass movements, natural factors, GIS/RS technique, risk assessment, Batushë-Rrasa e Kosharës road segment, Kosova.

INTRODUCTION

Earth surface processes are present everywhere and are very frequent on different types of slopes. Gravity force and progressive weakening of rocks and geological structures, influenced by weather and climate conditions, could initiate rock mass movements with fatal consequences. Mass movements are defined as downward or outward movements of slope-forming material under the influence of gravity.

Mass movements have different causes for triggering them, including earthquakes, volcanic activity, heavy rainfall, etc. (Geertsema & Chiarle, 2013). They should be observed by their distribution, types, and patterns in relation to morphological, geological, and climatic characteristics. Mass movements as geological

disasters in mountainous areas are a serious threat to human lives and the natural environment. They consist of rapid down-slope motion of rocks and are responsible for major accidents (Cinosi et al., 2023). The phenomenon of slope instability is classified as one of the most hazardous natural events affecting the society (Mineo & Pappalardo, 2023). Landslides pose a major threat in particular areas across Europe and on the Balkan Peninsula too (Tavoularis, 2023). Contemporary assessment of mass movements could prevent hazardous situations (Bruchev et al., 2007). Every mass movement poses its own hazards and risks (Glade et al., 2006) and could have immense consequences (Crozier, 1990).

Alpine environments are more prone to mass movements than flat ones, while climate change projected with more rainfall could trigger further

mass movements in alpine regions (Chiarle et al., 2021; Mersha and Meten, 2020). Mass movements mostly occur within clayey and complex structural formations, and their interaction with human-made structures could cause damage. Humans have played a considerable role in triggering mass movements, mostly with construction works, road and traffic expansion, deforestation, etc., where landscapes have changed and hillslopes processes have accelerated (Norris et al., 2008). Alpine environments are gathering more attraction, and the number of tourists is increasing every year. Thus, analyzing landslide susceptibility could prevent human loss and infrastructure damage (Abad et al., 2022). Mountain ecosystems are very delicate. They are susceptible to soil erosion and slope processes (Meçaj, 2004).

Environmental protection is the focus of the international community, while natural factors and features have been the cause of mass movements in different forms (Ivanik et al., 2019). Mass movement events should be followed by inventory programs, where their identification is the first step toward monitoring and hazard mitigation (Falcão Barella et al., 2019). Inventory contains spatial information, complementing other information, such as terrain characteristics, volume, occurrence, triggering factors, and damages caused (Guzzetti et al., 2012; Zhao et al., 2021). Monitoring mass movements has high importance and could lead to minimizing damages and life losses (Loew et al., 2016). Geographic Information System (GIS) and Remote Sensing (RS) are important techniques in studying and inventorying mass movements, with a high possibility of investigating their future evolution and interpretation (Scaioni, 2013).

In the newest history of Kosovo, the locality of Koshare represents a moment in the Kosovo liberation war during 1999, when the border between Albanians (Kosova and Albania) was eliminated. After the independence declaration (2008), a zone with special interest was declared with an area of 25 km², which consisted of a war memorial that attracted the attention of locals as well as other national and international visitors.

The conducted study was focused on the analysis of factors that have triggered the mass movements along the Batushë-Rrasa e Koshares road segment, where in the newest history of the country, the settlements of Koshare have gained touristic attraction and the road segment is becoming more frequently used. Analyzing triggering factors with future monitoring would mitigate

infrastructure damages or possible live losses. Field surveys with morphometric landslide measurements combined with the GIS/RS technique have made identification and assessment of the potential risk of the area possible. The data presented are of practical importance, in particular to understand the mass movements and hillslope processes in general, while the recommendations given enable a proper evaluation and continuous monitoring of these phenomena, which in certain cases can be devastating for people and cause great damage to the infrastructure.

MATERIALS AND METHODS

The road segment Batushë-Rrasa e Kosharës (Kosova) was chosen as a study site because of its historic and touristic values in the newest era of the country. Different methods are used to analyze mass movements and their characteristics. Empirical-statistical and analytical methods are the most common approaches to studying mass movements (McDougall, 2017). Descriptive methods were combined with field measurements and surveys as direct surveying methods, combined with GIS/RS techniques, where field observation data with geospatial technologies were synthesized. A digital elevation model (DEM) with 10 m spatial resolution was used to analyze terrain morphometric features such as altitude, slope, aspect, curvature, etc. and was useful to find potential risk areas. Aerial images of different years (2016, 2019 and 2022) provided in Google Earth Pro and a topographic map of scale 1:25000 were used to analyze the findings of the relationships between geological settings, climatic conditions, and topographic features along road segments. Subsequently, three study sites were selected to be analyzed and interpreted using a multidisciplinary approach. By analyzing aerial images throughout the years, it was possible to track changes in terms of dimension, season, and movement direction. Each potential factor was analyzed individually in the ArcMap 10.8 software environment and is presented with graphics and illustrations.

RESULTS AND DISCUSSION

Kosovo, as a country, has diverse physical-geographical features and complex geological settings where rocks of different ages from

pre-Cambrian to Quaternary and different compositions are found (Pruthi, 2013), which in structural-tectonic terms is very complex and belongs to six geological-tectonic zones. Diverse morphology is impacted by a high percentage of territory with altitudes above 700 m (51.8% of the total area), which in Kosovo are considered hilly-mountainous areas of medium to high-altitude terrains (Pllana, 2013). The average altitude of the country is 807 m. Throughout hilly-mountainous terrains, most of the river sources are created, while their flow toward plains has created river valleys of different sizes with canyon features. Different types of valleys in alpine terrains have indicated high slope gradients and slope instability, with a high degree of landslide and other mass movement hazards.

The western part of Kosovo is known for its diverse morphology, with Accursed Mountains (Albanian: Bjeshkët e Nemuna), a high mountain range of the Dinaric arc, above 2,500 m, very complex in geological, geomorphological, hydrological, and biogeographical features (Pruthi, 2013; Pllana, 2013; Elezaj & Kodra, 2008; Mustafa et al., 2018), where mountains crests divide deep river valley sourcing in high-altitude mountains. Bjeshkët e Nemuna are bordered with Dukagjini Plain in the east, a large graben depression, where the contact line has created a large escarpment. During the Neogene period, Dukagjini Plain was a lacustrine environment (Krstić et al., 2012),

serving as an absolute erosion base for the rivers flowing from Bjeshkët e Nemuna. During the tectonic uplifting of the Balkan Peninsula, rivers and streams deepen their valleys, creating gorges like Rugova, Deçani, Ereniku, and, among others, the Gusha River valley.

The study areas lie in the western part of Kosova, on the southern slopes of the Accursed Mountains. Hillslopes belong to the catchment of the Gusha River, a right tributary of the the Erenik River, where surface waters are flowing toward the Adriatic Sea. On the left side of the Gusha River lies the area of Koshare, where a settlement in hilly-mountainous areas was established (42°27'14"N and 20°12'09"E) at an altitude of 747 m above sea level. Fluvial erosion has created a narrow mountain valley where, due to the slope gradient and aspect, preconditions for mass movements are favorable. Landslides of different sizes are present almost throughout the road sector. Most landslides that appeared were soil-mantled hillslopes, with a small presence of bedrock hillslopes. Soil-mantled hillslopes with a soil layer in the upper part combined with fractured limestone are prone to hillslope processes. The geomorphology of the area consists of the Gusha River valley, which stretches in a west-east direction toward Dukagjini Plain. The incised valley was created in sandstone, phyllite, chlorite schist, conglomerate, chert, and limestone (fig. 1), mostly hard rocks, where its evolution was accelerated

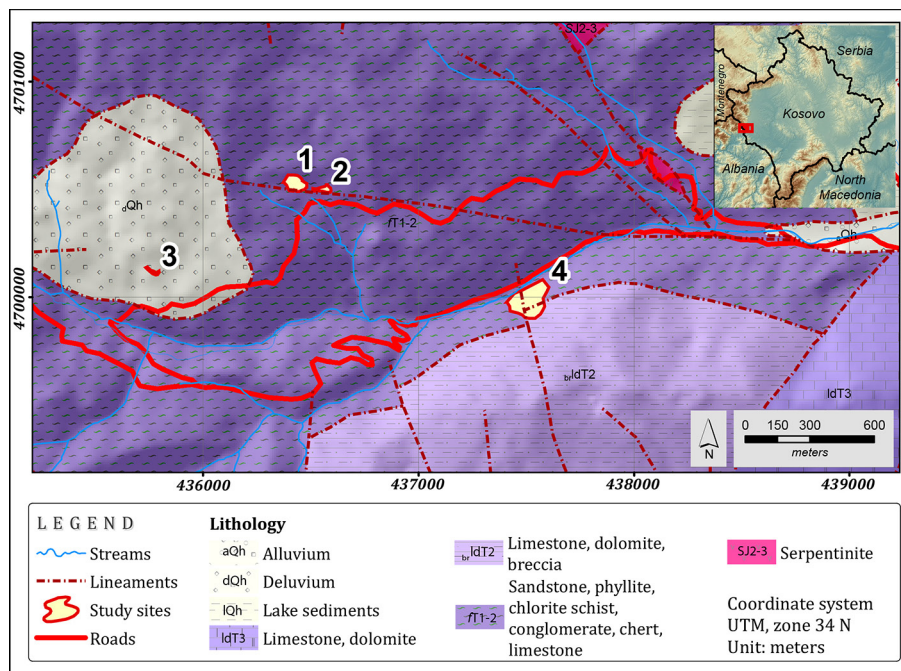


Figure 1. Location and geological map of the study sites

with changes in erosion at the base level and later with surface as well as fluvial erosion. The selected study site lies between 580 m and 900 m with different slope orientations (Figs. 2, 3). The climatic condition belongs to a mountainous climate in the upper part of the valley, while the lower part is mostly moderate continental. The annual average amount of rainfall is between 1,500 and 1,600 mm, with the rainfall regime mostly linked to the Mediterranean climate, with a high amount of rainfall during the winter season and lower rainfall during the summer months. The vegetation cover of the area consists mostly of deciduous forest and small areas of shrubs and grasslands, which in the last decades have been under human pressure with the forest's degradation.

Along the road sector Batushë-Rrasa e Kosharës, many hillslope processes can be seen; however, three prominent ones, which are the largest and have caused most of the damage, have

been analyzed; the authors think that human intervention is needed in this road segment. Two of them are on a south-oriented slope, while the third is on a north-oriented slope.

Interpretation by illustration (Fig. 4) shows that on the top (head) of a landslide, where the depletion zone is, slump blocks appear in the form of terraces. The sliding plane of the slope is 30 degrees, with a width of 102 m and a total length of 78 m. After its appearance, it affected infrastructure, causing damage as well as endangering visitors.

During the timespan, the second case followed the first case and caused great damage, which resulted in the road closing for a certain time. The object of the movement was the soil-mantled layer (eluvium), whereas during its slide, it included the uppermost layer until the bedrock. The sliding plane was 30°, with the length from head to road being 55.5 m, while overpassing the

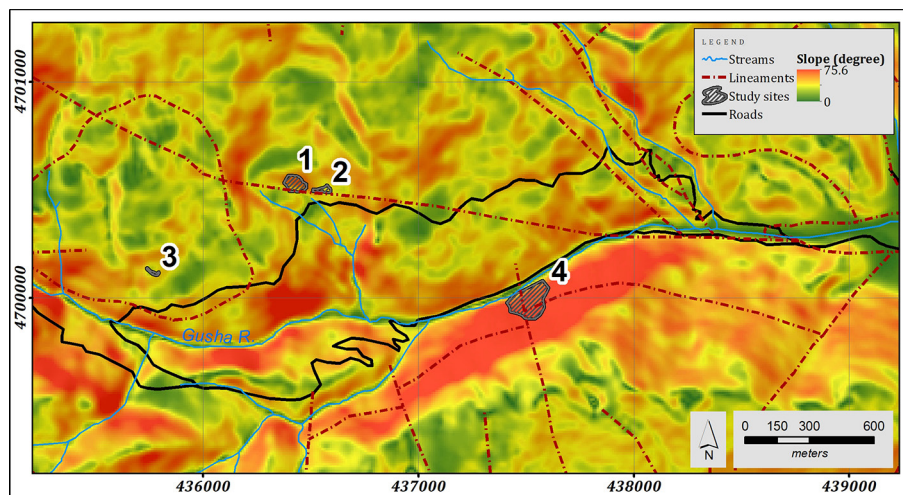


Figure 2. Slope map of the study area

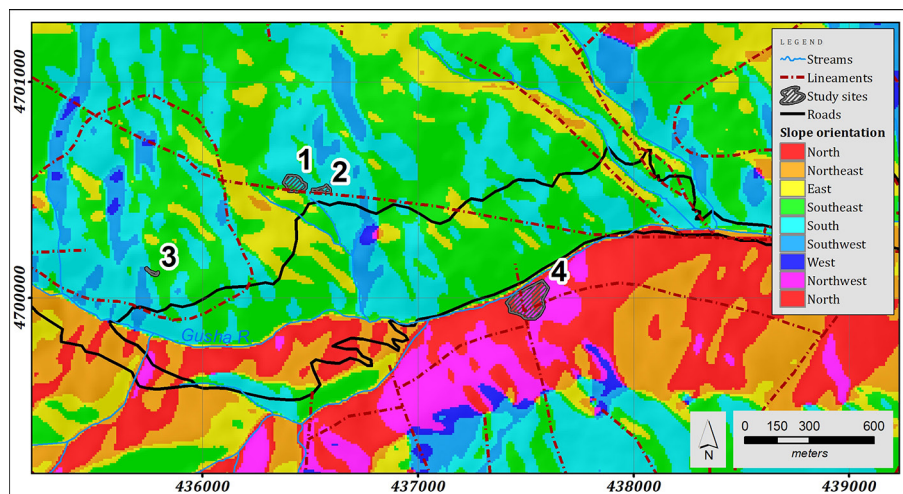


Figure 3. Aspect map of the study area

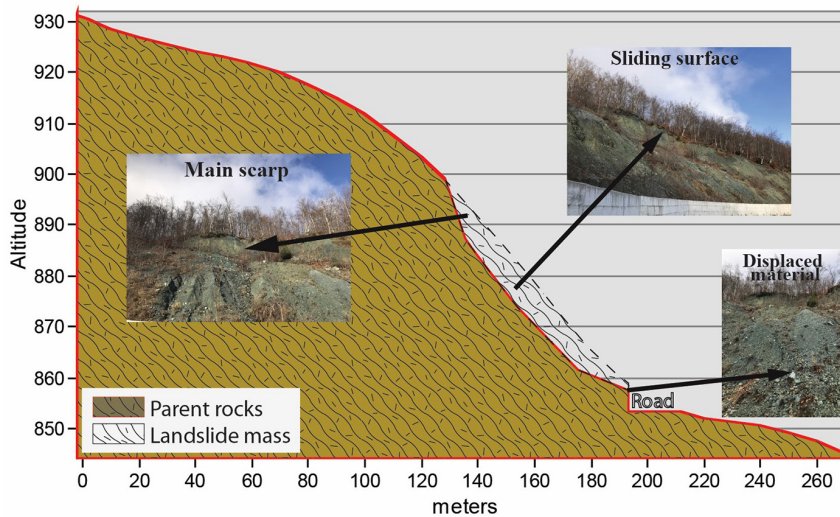


Figure 4. Schematic profile of slope processes

road was 34.1 m. The main contributing factors are the dynamic ones with water pressure on pores or the inactive ones like rock structure (Crozier, 2013). These types of landslides appear periodically, with a slow rate from the last few years until today. Their dimensions continue to grow under the influence of various factors; among them are climatic conditions and geological settings.

The territory of Gjakova municipality has gone through several stages of geological-tectonic evolution, with rocks from the newest ages having lacustrine and fluvial origins (Kastrati et al., 2018). The area of Koshare tectonics has played an important role in the initiation of landslides. In the case of study number 4 (Fig. 1), at the intersection of tectonic lines, a landslide occurred. Tectonic lines in new age rocks and terrains, like Bjeshkët e Nemuna, are very common

and serve as weakness points of rocks. The first two landslide cases, as well as Case 4, mainly occur in terrains composed of sandstone, phyllite, and conglomerate rocks of the lower and middle Triassic ages, while the third one appears in deluvium, which, in comparison with other rocks, is an unconsolidated rock of slope debris. Study cases in field observation show that unconsolidated rocks and materials are subject to higher rates of erosion. Sandstones are uncemented and fractured, while their porosity allows water to percolate and reduces cohesion. The highest rate of landslides appears on hillslopes between 15–25° and 35–45°, whereas gravity initiation slides are common causes of landslides. Slope destabilization in Study Case 4 is initiated by human activity through the extraction and breaking of rocks, followed by the intersection of tectonic lines,



Figure 5. Landslide along the road segment (no. 1 at Fig. 1)



Figure 6. Landslide along road segment (no. 2 at Fig. 1)

fractured rocks, and rainfalls. South-oriented slopes are prone to rock breakdown by heating and cooling, causing the disintegration of rocks and lowering slope stability. Study case number 4 has north- and north-west-oriented slopes; it contains more moisture and increases the weight of the soil. An important factor in the occurrence of landslides is the amount of precipitation and the process of snow melting. The highest amount of precipitation is in the winter season with 33%, the autumn season with 30%, the spring season with 22%, and the summer with 15%. The rainfall regime is of the Mediterranean type, with a greater amount of precipitation during the winter and a smaller amount during the summer. Water percolates through rock layers, increases the pore pressure, and loses strength, causing landslides (cases 1 and 2).

The area of Koshare has underground aquifers with numerous water sources and streams (74), whereas the total amount of water from all sources within the area (measurements performed within 24 hours), is 14.983 m³ or 0.174 m/s⁻¹. During field surveys in January 2023, numerous surface flows were observed, which are as a result of heavy rainfall in this area. While in the observations made in September 2022 there were no such surface water flows. These surface water flows have appeared along the slopes, causing surface erosion and higher intensity of landslides. Such natural activities are concentrated mainly during winter and spring seasons, as well as during the mentioned seasons surface activity with different types of mass movements are densely appearing.

On the basis of the field study and the analysis of all landslide triggering factors, the risk profile of landslides, where the most severe impact is on road infrastructure, environmental degradation, and river bed degradation, was created. The possibility of a direct attack to cause damage to people who use this road sector for certain purposes, especially during the rainy season, is not excluded.



Figure 7. Stream through the area of Koshare

Table 1. Mass movements hazard’s profile for the study sites

| Profile | Possible consequences | Severity scale |
|----------------------|--|----------------|
| Inhabitants/tourists | Injured | Small |
| Natural resources | Degradation of the Gusha River bed | Severe |
| Environment | Environmental and vegetation degradation | Severe |
| Economic damages | Major destruction or damages to vital infrastructure | Severe |
| Services | Damages to services towards inhabitants | Moderate |

The area of Koshare has been continuously exposed to slope processes throughout the years. From the images provided by Google Earth Pro, it was noted that in 2016, landslides were present but on a very small scale, and the surface erosion process was dominant. Over time, the rate of landslides has increased as a result of weathering and geological settings causing slope instability. From the measurements carried out, it can be seen that the surface of the slides has doubled and caused material damage. The increase in the intensity of

landslides is related to the weather that prevails in the Koshare area, mainly rain and snow, creating temporary water flows. These processes are increasing and becoming more destructive from year to year; therefore, intervention with engineering protection measures along the road sector is necessary, which will minimize their impact on the environment and people’s lives.

CONCLUSIONS

On the basis of field observations and measurements, complementing the GIS/RS technique in analyzing the hillslope processes throughout the road sector Batushë-Rrasa e Kosharës in the municipality of Gjakova, most of the natural factors contributing to slope processes were identified, whereas human impact is evident. Terrains with a slope gradient of 35–40° are more prone to landslides. The geological settings of the terrain, consisting mainly of uncemented and fractured sandstones, and the tectonic lineaments along the terrain have contributed to slope instability. These phenomena are more visible during snow melting and rainfall in the spring season, where temporary water flows along the slopes are created, helping in the acceleration of large landslides. Southern-oriented slopes with more alienation are triggered easily. Human activity, including rock excavation and deforestation, has impacted landslide initiation and slope instability. Its degree of impact is severe in terms of economic damage, infrastructure, and environmental degradation, while the degree of impact on people is smaller, but the possibility of a direct attack is not excluded. Since these processes have been present for many years and landslides are increasing as a process, it is recommended that continuous monitoring, land use planning, protective walls and nets, and forestations be implemented in order to prevent rockfall, landslides, debris, or other slope processes that could endanger human lives and infrastructure. Since the area of Koshare is an



Figure 8. Changes in the hillslopes throughout the years (source: Google Earth Pro)

important site of the newest history of Kosovo, in the last few years it has become a tourist attraction, so safety for residents and visitors should be a higher priority. On the basis of the complex geological settings and diverse morphography of Kosovo, mass movement susceptibility mapping with new methodology and technique should be implemented not only in the study area but also at the national level.

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