Revista de Estudios Andaluces (REA) | Núm. 50, julio (2025) | e-ISSN: 2340-2776
https://dx.doi.org/10.12795/rea.2025.i50 | © Editorial Universidad de Sevilla 2025
https://editorial.us.es/es/revistas/revista-de-estudios-andaluces
https://revistascientificas.us.es/index.php/REA

SUMMARY OF ARTICLE: HTTPS://DX.DOI.ORG/10.12795/REA.2025.I50.05

Rockfalls in the Zireg watershed: factors of genesis and mapping of risk zones (Middle Atlas - Morocco)

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KEYWORDS

Rockfall
Modeling
Zireg watershed
Middle Atlas
Morocco

INTRODUCTION

Rockfalls are characterized by the sudden separation of a rock mass from a sloping slope, descending rapidly downstream under the influence of gravity. These events represent one of the most common risks in mountainous areas, potentially causing damage to people and property, as well as generating significant financial costs, especially when they affect homes and essential infrastructure (roads, railways and power lines, etc.). Rockfalls represent a considerable challenge for farmers on fallow land and also on mountain roads. They expose users and personnel to dangers that continue to increase with the increase in traffic (Zireg tourist road connecting Oued Amlil and Bab Boudir) on the one hand, and on the other hand, by widening works.

The study of rockfalls in the Middle Atlas range remains essential due to their properties that contribute to the initiation of this phenomenon. The following article focuses on the development of a new approach to detect the risk of potentially unstable rocks and blocks falling on the slopes of the Zireg watershed, which represents a Middle Atlas landscape. This is achieved through a detailed knowledge of the lithological conditions that contribute to the formation of rocks and blocks, as well as the factors that affect their subsequent descent (inclination and land use) through the use of GIS.

Studying rockfall risk is crucial for improving their prevention and mitigating their impacts. It is also essential for assessing how this risk is triggered, depending on geographical conditions.

This research enhances the tourist appeal of the surrounding landscapes (Bab Boudir, Tazzeka National Park), protects users of the surrounding roads and also opens the way to a new method for describing rock falls in other mountain ranges.

STUDY AREA

The Zireg watershed is located on the left bank of the Inaouene watershed, representing a part of the Middle Atlas Mountains. It extends over an area of 73.2km² between the parallels 34°2′46″ and 34°10′19″ of

DOI: https://dx.doi.org/10.12795/rea.2025.i50.05
Formato de cita / Citation: Benaissa, M., & Gartet, J. (2025). Rockfalls in the Zireg watershed: factors of genesis and mapping of risk zones (Middle Atlas - Morocco). *Revista de Estudios Andaluces,*(50), 90-109. https://dx.doi.org/10.12795/rea.2025.i50.05
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North latitude, as well as the meridians 4°10’23” and 4°20’31” of East longitude. This watershed is located in the province of Taza, integrated into the Fez-Meknes region. It is found in the municipalities of Bouchfaa, Ghiyata Al-Gharbia and Bou-Hellou. It has a small extension towards the north.

The Zireg watershed presents a combination of diverse morphological landscapes manifested in mountains, hills and depressions. The highest altitudes of the basin are found in the south, crossing the limits of 1900 m, particularly at the summit of Tazekka (1980 m). On the other hand, the lowest places are located in the alluvial plain of Oued Inaouene, where it is observed that the altitude can drop below 300 m. This watershed is distinguished by the presence of sedimentary, metamorphic and volcanic rocks.

Geological and hydrostratigraphic research has revealed a lithological diversity within the buried and surface formations, composed respectively of Paleozoic shales and low-permeability Triassic clay formations. The latter are superimposed or juxtaposed by permeable Liassic carbonate formations. The Zireg watershed is characterized by significant plant diversity, particularly evident in the peaks of the northern Middle Atlas in the south (upper part of the watershed). In this area, the vegetation is dominated by holm oak and cork oak. In addition to these two types of formations, the landscape contains areas with mixed vegetation, including a variety of plants, artificial deciduous and coniferous forests, oak, Mount Tazekka cedar, thuja, and pine.

Rainfall patterns are an undeniable factor in the occurrence of ground movements. The speed of propagation of rock fragmentation processes is accelerated or slowed down by the water content of the rocks. Regarding precipitation, stations located near the Zireg watershed record the highest annual precipitation in the Inaouene watershed.

Landsat 8 satellite image analysis from June 15, 2019, revealed uneven variation in vegetation cover density in this basin. Nearly 52% of the area has a vegetation density ranging from 50 to 75%, encompassing an approximate area of 38 km^2, while 10% of the area has a density varying between 75% and 100%, encompassing an approximate area of 7.3 km^2. Forest cover is an element that affects the stability of rock masses on a slope through various key processes. One of its key elements is in situ rock fragmentation and block immobilization, where vegetation reduces the speed of propagation.

METHODOLOGY

Estimating rockfall hazard levels requires access to accurate information and a detailed analysis method combined with a solid geomorphological perspective depending on the intended purpose.

The approach adopted is based on a geomorphological diagnosis of the Zireg watershed, during which we identified the triggers of rock falls based on Flageolet’s definition (Flagiollet, 1989). The processes of thermoclasty, hydroclasty and cryoclasty are marked by climatic conditions that facilitate the degradation of rocks (limestone). In the absence of obstacles and on a steep slope, stones and blocks move downwards.

The method combines the three elements that control the production and movement of blocks (slope, lithology and land use), through a modeling that respects the importance of each factor, the data were reported on a graphic document: summary maps. The map was then presented according to the cartographic mode: map of the degrees of risk related to the class of block fall and collapse.

The risk map is a graphical synthesis that merges the levels of determining factors (slope, lithology and land use), created using ArcGIS software. To simplify the reading of the risk index summation map, we grouped the global index (GI) values into four large classes, thus reducing the probability results to four levels of increasing risk.

RESULTS

We coded the response of each rock category to weathering processes, the effect of tilt on rock movement, and then the surface condition in relation to plant cover, which promotes block stability or facilitates their descent in the event of insufficient cover.

According to the descriptive study, we have shown that 4% of the total area is marked by high and very high degrees of risk, mainly linked to the presence of carbonate rock slopes, high to very high slopes and low or medium density plant cover.

The movement of blocks is accelerated by the slope, in accordance with the principle of gravity. Due to local fragmentation of the rock, its fall is controlled according to the slope's inclination and the volume that has been displaced. The inclination also has an impact on the rhythm of streams on the slope. Indeed, a steeper slope results in a shorter duration of water concentration on the cracks, which makes the hydroclasty process more important.

The study of the land use map reveals that the forest (dense forest and low density forest) covers 66% of the total area, distributed between the upstream and middle zones of the watershed. The matorrals represent 13%, occupying areas within the forest and in the middle section.

The dense forest that covers almost the entire upper part protects the slopes from rock fragmentation processes, which explains the rarity of rockfall incidents, which is why we observe that the low and medium risk levels occupy a wide area. In the rest of the study area, there is a strong correlation between the factors examined, which justifies the presence of high and very high risk levels.

In the Zireg watershed, rockfall hazard modeling demonstrates a proportional correlation with the analyzed variables. This means that rockfall and boulder hazards are geomorphologically linked to high slopes and carbonate rocks in the absence of dense forest cover. The risk can occur on moderate slopes, in sparsely forested areas and in areas made of rocks prone to fragmentation (limestone).

CONCLUSION

Mapping rockfalls is a complex and meticulous task that requires a solid understanding of morphological features. Modeling this type of movement is particularly challenging because the source areas do not have comparable geological and geomorphological characteristics. As part of a study focused on rock triggering and propagation, the source area and its path were used to develop the rockfall sensitivity model.

The model is designed for its adaptation to the causal conditions of land movements of the block fall and collapse class in the Mediterranean climate in general and particularly in the Inaouene basin. Preliminary results have already made it possible to superimpose and analyze several factors, such as slope, material hardness (fragmentability and degradability of rocks) and land use type. A model that is based on the representation of factors such as slope, lithology and land use in a particular climate (high precipitation and significant annual thermal amplitude).

The analysis of rockfalls in the Zireg watershed, carried out using the approach used, demonstrates that the geomorphological features of the site constitute a geomorphological basis for the initiation of land movement processes of the rockfall and collapse class. The study demonstrated that 4% of the entire terrain is affected by high and extremely high risk levels. The factors studied facilitate the occurrence of more or less severe risks, hence the need to use the risk map as a reference point for considering the development of this landscape, a planning model that takes into account geomorphological perspectives.

It is clear that special attention must be paid to slopes identified as high and very high risk, by widening the route and starting tree planting from the base to the top of the slope. The objective is to reduce the slope gradient from flat surfaces with a high concentration of trees in order to reduce the energy of the blocks during a fall.