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Impact of land instability on road infrastructure in the Southern Central Rif (Case of PK 144 on regional road 408 - Taounate, Morocco)

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KEYWORDS

Southern central Rif
Structural unit
Instability
Landslide

INTRODUCTION

This study is situated within the **context of natural hazards** that affect, to varying degrees, all regions of the world. These hazards have detrimental impacts on ecological balances, ecosystem quality, socio-economic development, and result in significant material and human losses. Morocco is particularly vulnerable to these threats, facing an increasing frequency of phenomena such as droughts, climate change, floods, desertification, earthquakes, landslides, collapses, rockfalls, solifluction, and mudflows.

In Morocco, the Rif region stands out for its heightened vulnerability to these hazards due to its unique geological and geomorphological characteristics. A combination of factors, including the fragility of rock formations, steep slopes, dense hydrographic networks, instability of geological units, seismic activity, and extreme climatic conditions, promotes the occurrence of hazards. Furthermore, anthropogenic pressures related to deforestation, urbanization, and infrastructure development exacerbate these risks.

This study focuses on the southern central Rif (the central Rif nappe zone). This region is characterized by a wide variety of instability phenomena affecting both slopes (landslides, mudflows, rockfalls) and valley bottoms (lateral bank erosion). These phenomena cause recurrent problems, leading to high maintenance costs for public authorities and hindering local development.

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METHODOLOGY

Regional road 408, located in the Mesorif zone, is particularly affected by these instabilities related to mass movements and fluvial dynamics. At kilometer 144, the road is subject to a combination of complex processes: surface phenomena such as gully erosion and material removal, as well as deeper-seated mass movements manifested by subsidence and landslides.

This study aims to enhance our understanding of natural hazards associated with instability phenomena, within a fragile structural and geological context that favors the development of morphodynamic and morphostructural processes. More specifically, it seeks to characterize these phenomena, identify their controlling factors, quantify their temporal evolution, and assess their spatial and socio-economic impacts.

To achieve these objectives, a geographical and geomorphological methodology was adopted. This methodology includes several steps that can be divided into three main parts:

- **Fieldwork** involved the precise monitoring of mass movements using 18 metal markers installed along the scarp. Photogrammetric surveys were conducted at regular intervals to document morphological and spatial changes on the slope. Additionally, supplementary data was collected from public administrations (climatic data, geotechnical reports, etc.) to enhance the analysis of the factors controlling these movements;
- Our study was based on a comprehensive review of scientific literature pertaining to the Rif region, with a particular focus on the southern central Rif. In parallel, we utilized available geotechnical data for the study site, including the results of boreholes conducted by the Taounate Department of Equipment and Transport in collaboration with the Public Laboratory for Studies and Tests (LPEE). These boreholes included pressuremeter tests (PMT) and dynamic penetration tests (DPT), which allowed for the determination of soil bearing capacity and dynamic resistance, respectively. Additionally, robotic drilling was carried out, followed by laboratory analyses. The results of these investigations enabled the characterization of soil behavior through the measurement of creep pressure (CP), limit pressure (LP), and modulus of elasticity (EM), according to Ménard's method;
- **Laboratory Work:** The laboratory work involved a grain size analysis and Atterberg limits tests:
    - ***Grain Size Analysis*:** A soil sample was subjected to sieve analysis, where it was passed through a stack of sieves with progressively smaller openings. Particles larger than the sieve opening were retained, while smaller particles passed through and were collected in the sieve below. The equipment used included a set of standardized sieves (NF P 18-552), a mechanical shaker, a precision balance, a bottom collector, and a brush. The procedure involved: preparing the sample (drying and determining the total mass M), assembling the sieves in descending order of aperture size, pouring the dry sample onto the top sieve, shaking for 10 minutes, weighing the retained material on each sieve, and finally calculating the percentage of each grain size fraction relative to the total mass of the sample. The percentage passing through sieve i was calculated using the equation (M-Σmj (j=1 to i)/M* 100), and the percentage retained on sieve i was calculated using (mi / M) * 100.
    - ***Atterberg Limits Tests*:** To identify and evaluate the soil's behavior, Atterberg limits tests were conducted according to the NF P94-051 standard. These tests determined the following:
        - Liquid limit (LL): the water content at which the soil behaves as a viscous liquid;
        - Plastic limit (PL): the water content below which the soil loses its plasticity;
        - Plasticity index (PI): the difference between the liquid limit and the plastic limit, characterizing the plasticity of the soil;
        - Consistency index (CI): used to characterize the water content of the soil and evaluate its consistency. The formula used is: CI = (LL - w) / IP (where LL is the liquid limit, w is the water content, and PI is the plasticity index).

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RESULTS

The methodological approach adopted in this study of slope instability at kilometer 144 of regional road 408 has led to several findings, namely:

- ***Results concerning the triggering and/or reactivating factors of the phenomena***, which can be classified into two groups:
    - Factors related to the increase in slope (forces) and the removal of underlying support by erosion, the surcharge exerted either by natural agents (water) or by anthropogenic activities (road cutting);
    - factors related to the decrease in material resistance, whether intrinsic factors related to the nature of the original materials, so the minerals and rocks constituting the soil, or active factors indirectly affecting the affected materials, such as weathering due to atmospheric agents, increased interstitial pressures, and modification of the intergranular structure.

- ***Findings regarding the characteristics of instabilities***: Field investigations revealed two primary types of mass movements within the study area:
    - Localized subsidence**:** A rapid subsidence occurred at the center of the slope in April 2018, induced by water saturation of the materials;
    - Large-scale landslide**:** A tongue-shaped landslide, approximately 286 meters long and 160 meters wide, was identified. Borehole investigations revealed an average failure depth of about 3.5 meters. The average annual movement rate of this landslide, measured between 2016 and 2021, was approximately 30.7 cm. It is important to note that these mass movements exhibited significant spatial and temporal variability. Movement velocities were greatest between measurement points P4 and P7, with a marked decrease towards the edges. The most substantial movements occurred during the rainy seasons (autumn and winter).

- ***Impact assessment results***: This study assessed the impacts of the dynamic processes at two levels: morphological changes, including surface subsidence, material erosion, and the development of deep gullies that fragmented the slope; and socio-economic impacts, such as road and infrastructure degradation, leading to traffic disruptions. This situation is particularly prevalent in the southern central Rif region.

CONCLUSION

In conclusion, this study highlights the complexity of geomorphic processes in the southern central Rif, resulting from the interaction of multiple physical and anthropogenic factors. To better understand these processes, it is essential to identify critical thresholds (precipitation, hydrogeological conditions, slopes, material properties) beyond which the system transitions from a stable to an unstable state.

To achieve this goal, a detailed geotechnical study of the soils is indispensable, with a particular focus on clays. This study will allow for the identification of degradation mechanisms, quantification of triggering factors for instabilities, and determination of critical failure thresholds.

The data obtained will provide a solid foundation for developing accurate risk maps and implementing appropriate mitigation measures, particularly for road infrastructure located on similar slopes.

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