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GEOMORPHOLOGICAL ANALYSIS OF EROSION DYNAMICS AT FĂGETU IERII: INTEGRATING UAV TECHNIQUES AND GIS FOR ENHANCED PRECISION

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Abstract. Advanced Geomorphological Analysis of Erosion Dynamics at Făgetu Ierii: Integrating UAV Techniques and GIS for Enhanced Precision. This article delves into the realm of high-resolution geomorphological analysis, with a particular focus on soil erosion assessment. To achieve a more precise analysis of surface erosion, our study selected the former quartz sand exploitation site at Făgetu Ierii, in the Iara commune. This location serves as a focal point for studying various geomorphological processes, including landslides and gully formation, characterized by their significant intensity. Traditional methods for monitoring erosion dynamics involve substantial investments in both human effort and technical resources. This entails on-field tasks such as identification and detailed measurements, as well as office-based activities involving mapping and spatial analysis. Recognizing the challenges associated with these conventional approaches, our research explores more efficient methods that harness rapidly evolving modern technology. In this pursuit, the adoption of Unmanned Aerial Vehicle (UAV) techniques and methodologies appears as particularly promising. UAVs facilitate the creation of comprehensive databases capturing the three-dimensional (3D) structure of the terrain within the study area. The advantages are multifaceted: UAVs significantly reduce the time and costs associated with fieldwork while simultaneously enhancing the precision and accuracy of digital databases. These databases play a pivotal role in conducting spatial analysis within Geographic Information Systems (GIS), allowing for a more accurate identification of the impact and risk factors present in the territory. This study underscores the transformative potential of UAV technology in advancing geomorphological analysis, enhancing our understanding of erosion processes, and supporting sustainable land management practices in areas vulnerable to erosion due to both natural and human-induced factors.

Keywords: UAV, erosion, GIS, USLE

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INTRODUCTION

To analyse surface erosion with greater precision, we selected the former quartz sand exploitation site at Făgetu Ierii (Iara commune) (Fig. 1.). This area is a focal point for studying current geomorphological processes, such as landslides and gully formation, due to their significant intensity. Our observations indicate that these processes primarily result from human intervention (Rus et. al. 2021). Historically, this was seen through quartz sand extraction activities until 1996. Currently, it manifests in various form of overgrazing practices.

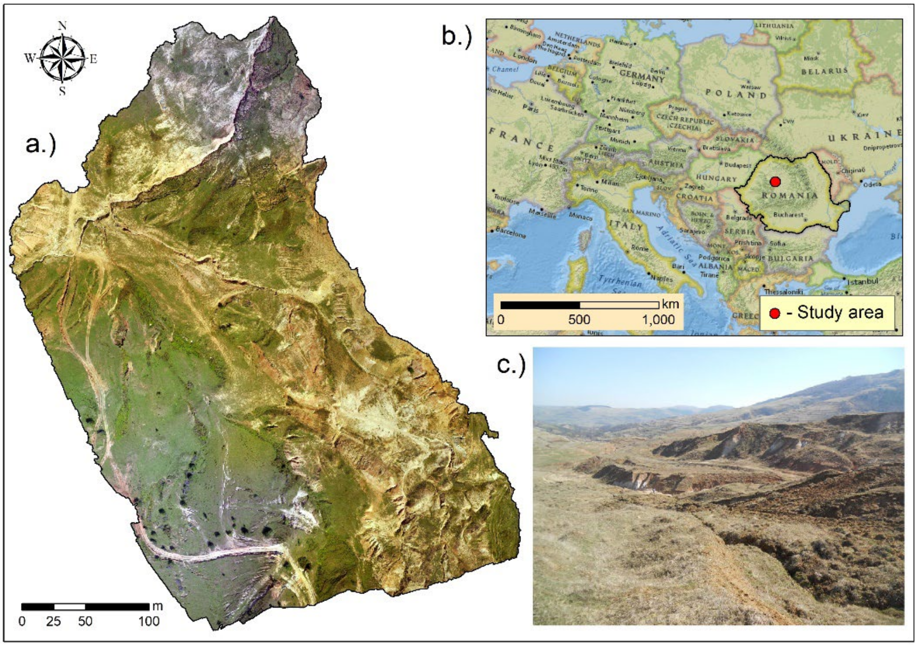

Fig. 1 Study area (a - high resolution orthophoto, b – study area location, c – study area snapshot)

Classical methods for monitoring the spatial dynamics of erosion involve a significant investment of human and technical resources. In the field, this includes tasks like identification and detailed measurements. In the office, it involves mapping and spatially identifying dynamics. Recognizing these challenges, we are exploring new, more efficient methods that leverage modern, rapidly evolving technology.

In this pursuit, the adoption of UAV (Unmanned Aerial Vehicle) techniques and methods is particularly promising. These methods enable the creation of databases capturing the three-dimensional (3D) structure of the terrain in the area under study. The advantages are clear: not only do UAVs substantially reduce the time and costs associated with fieldwork (Uysal et. al. 2015, Park et. al., 2020), but they also enhance the precision and accuracy of the digital databases. These databases are crucial for conducting spatial analysis in GIS (Geographic Information System), allowing us to identify the impact and risk more accurately in the territory.

METHODOLOGY

The integration of photogrammetric sensors and high-precision GPS systems into UAV devices marks a significant advancement in applied geomorphology. This powerful combination greatly improves the quality of the digital database derived from aerial images, capturing intricate details with high precision and accuracy.

When it comes to analyzing and pinpointing regions with heightened denudation dynamics, particularly in areas like spoil heaps, we rely on three main categories of high-precision data sources. These are based on their method of acquisition (Fig. 2.):

1. Direct Measurements: These include coordinates obtained through differential GPS. Such data serve dual purposes: they are used as ground control points (GCP) and also assist in validating and identifying georeferencing errors.
2. UAV-Sourced Data: This category encompasses databases built from UAV flights, primarily consisting of high-resolution photographs that offer a detailed view of the terrain.
3. Processed Aerial Images: The third category includes databases derived from the meticulous processing of aerial images. Notable examples are the Digital Surface Model (DSM) and the Digital Elevation Model (DEM), which provide comprehensive topographical representations.

This structured approach not only ensures precision in our analysis but also allows for a nuanced understanding of the geomorphological changes occurring in these dynamic areas

The primary goal of this analysis was to underscore the pivotal role that UAV technology plays in the surveillance and understanding of geomorphological changes and, broadly, in the assessment of deteriorating landscapes. The study unfolded through a tripartite methodology, as delineated in Figure 1: initially, meticulous planning and execution of the drone flightplan to capture high-resolution aerial imagery; subsequent to this, the methodical processing of the data amassed during the flight; and finally, a detailed spatial analysis and elucidation of the findings. An orderly, chronological exposition of these phases will be provided next, shedding light on how each segment seamlessly dovetails into the next, thereby offering an integral view of the research methodology.

To map the micro-relief details of the study area, a flight was conducted with the Phantom 3 Advanced drone (DJI company), aiming for extensive coverage of the analysis area.

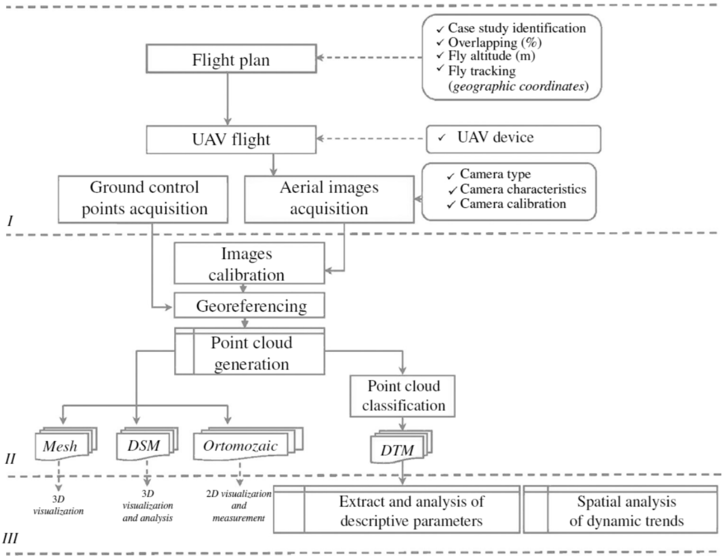

Fig. 2 UAV Methodological diagram (Bilasco et al. 2019)

Aerial photography stands as the cornerstone for creating three-dimensional representations of various erosional forms and evaluating their evolving patterns. The utilization of UAV methodologies streamlines this data collection process, offering a cost-effective solution through the use of affordable equipment, like drones and cameras. Moreover, the quality of the insights gleaned from this approach significantly eclipses that of traditional analysis techniques, which often rely on lower-resolution satellite imagery or the rudimentary tracking of landslides with ground markers.

Acquiring aerial photographs involves a two-stage process. The initial stage, conducted within a laboratory setting, includes the identification of the study area, the formulation of a flight plan, and the calibration of the camera's coefficients. The flight plan is customized based on the quality standards required for the database. In instances where high-grade aerial photographs are needed, a dual flight plan is deployed via the Pix4Dcapture application (Car, Juric Kacunic, & Kovacevic, 2016). Selected flight parameters comprise an altitude of 90 meters, which aids in creating an accurate digital elevation model, a moderate pace of flight to ensure both the conservation of battery and the stability of the camera, a camera angle of 90 degrees to guarantee images are perfectly perpendicular to the surface being examined, and an 80% overlap in adjacent images to optimize data collection efficiency during the flight mission (as shown in Fig 3).

The fieldwork primarily consisted of Ground Control Points (GCPs) identification, crucial for calibrating and georeferencing UAV imagery. Measurement of these points was executed via the Real-Time Kinematic (RTK) method, employing a differential GPS (GeoMax Zenith 35 Pro). This setup guaranteed positional accuracy to within 0.04 m (X, Y) and 0.05 m (Z) in the 1970 stereographic coordinate system, anchored to the Cluj-Napoca station.

Aerial imagery was secured using the Phantom 3 Advanced drone, fitted with a 12-megapixel Full HD FC300S_3.6_400033000 (RGB) camera.

speed:

angle: 90°

overlap: 80%

Alt: 50 m

211x 201... 17min:00s

Fig. 3 Flight plan

AERIAL IMAGE PROCESSING

The processing of aerial images represents the second vital phase in the comprehensive heap monitoring process, utilizing UAV technologies within applied geomorphology. Specialized software, including Agisoft PhotoScan and Pix4D, processes the previously captured 285 images, creating essential databases like the point cloud, digital surface model (DSM), and digital elevation model (DEM). These datasets are then incorporated into GIS spatial analysis to discern critical terrain morphometric and morphographic parameters, including slope angle, aspect, and elevation.

The point cloud quality, crucial for DEM accuracy, hinges on the UAV-obtained image quality, focusing on contrast, texture, and clarity. This study's images are high-resolution (12 megapixels) and were captured at a low flight altitude of 90m, ensuring detailed image representation (scale 1:0.013).

For DEM creation, AgiSoft PhotoScan was selected for its automated image calibration and high-quality database generation. Camera calibration was meticulously conducted using the Agisoft Lens, applying the Brown model (1966) to set initial parameters across the analyzed area. This phase emphasized calibration precision by examining five images taken from the same height but at varying angles.

For data precision from UAVs, images were georeferenced using four Ground Control Points (GCPs) and strategically placed points in the study area. Georeferencing errors were thoroughly assessed, showing values within the RTK measurement tolerance of the four GCPs.

Aerial image processing initially involves creating a point cloud for 3D reconstruction of the ground's visible surface. This point cloud, derived from processed and georeferenced aerial images, contains 61,301,552 entries at a density of 344 points/m² over 0.26 km². From this point cloud, several databases (DSM, Mesh, Orthophoto Plan with 3.87 cm resolution) were created to facilitate visual interpretation and analysis of the terrain.

The database used in the spatial analysis models for detailed observation of the study area is the DEM generated through point cloud processing. To achieve a high-precision 3D representation in the DEM, it's essential to classify the point cloud using the main territorial components. In this case, the point cloud was classified into two main components: tall vegetation (trees, plants taller than 0.05 m) and territorial infrastructure elements in the immediate vicinity of the study area.

The DEM, instrumental in the spatial analysis for erosion dynamics, was crafted from a point cloud by omitting vegetation and infrastructure, boasting a spatial resolution of 0.077 m in the 1970 stereographic coordinate system. The high-resolution highlights both the precision of the representation and the accuracy of the results in the spatial analysis phase, considering that the resolution is nearly equal to the tolerance value established in the control point coordinate acquisition stage.

SURFACE EROSION ANALYSIS

Surface erosion, a multifaceted issue affecting land management, significantly impacts soil fertility and ecosystems (Horvath et. al. 2008). Our goal is to assess the surface erosion risk in the study area through an integrated methodology, combining GIS modeling and the ROMSEM model (Moțoc & Sevastel, 2002, Bilasco et. al 2009).

The ROMSEM model, an empirical method recognized in the specialized literature, was chosen for the erosion risk assessment. Its calibration was carried out based on field data recorded in several research stations in Romania. This involved analyzing erosion rates on various surfaces concerning slope and land use.

The equation of the ROMSEM model,

$$E=K\times S\times LS\times C\times Cs, \qquad [1]$$

the model was employed to assess how climatic elements, soil characteristics, topography, vegetation, and soil conservation practices influence erosion risk (Fig. 4).

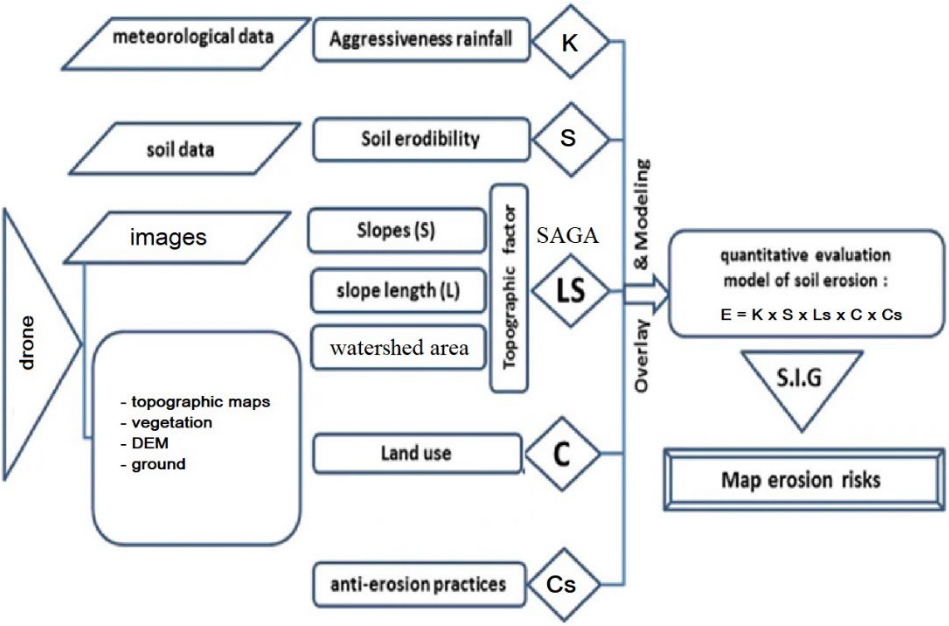

Fig. 4. ROMSEM methodology diagram

The discourse surrounding the climatic factor (K) in erosion risk evaluation delves into a multifaceted issue intricately tied to the specificities of the geographic area under study. The literature indicates that establishing a stable value for this factor has been the subject of numerous attempts and debates, highlighting the importance of local rainfall characteristics in defining this critical parameter.

Throughout previous research, it has been observed that rainfall aggressiveness generally serves as a metric for determining the value of the climatic factor. However, this approach is not without challenges, especially in the context of trying to identify the extreme component of soil erodibility. In some cases, the values of this rainfall aggressiveness might actually underestimate the real impact of erosion, particularly in areas where the erosion process is already active, such as in gullies or torrents.

In light of these considerations, selecting an appropriate value for the climatic factor (K) becomes crucial for the accuracy of the erosion assessment model. In this instance, a rational and well-documented approach was adopted, choosing a specific value for zone 6 from the map of average multi-year erosivity, according to the study by Moțoc and Sevastel from 2002. This value, 0.130, was carefully selected to adequately reflect the local climatic characteristics and to ensure as accurate an assessment as possible of the erosion potential in the study area.

This balanced approach, integrating data from specialized literature with local specificities, underscores the need for high adaptability in assessing factors influencing erosion. Ultimately, this decision represents an effort to enhance the model's accuracy and relevance, thereby strengthening the foundation for making informed decisions regarding soil conservation and land management in this specific region.

Calibrating the soil factor (S) involves combining soil type, erosion status, and soil texture to provide a comprehensive view of soil influences on erosion processes in the study area. This method ensures that the assessment model faithfully reflects specific local characteristics, thus yielding more precise and relevant results for managing erosion risk.

Through this integrated and adaptable methodology, our research aims to provide a comprehensive perspective on the soil factor and contribute to the development of effective soil conservation and land management strategies, tailored to the specific context of the study area. The Soil Map of Romania at a scale of 1:200,000 has been an essential reference resource for this detailed assessment, ensuring that the evaluations are grounded in accurate and region-specific data. This approach not only enhances the understanding of soil-related dynamics but also supports the implementation of targeted and effective land management practices.

Following a detailed study conducted on a relatively small territory of 11 hectares, it was observed that there was an exclusive presence of a single type of soil, namely, brown argiluvial soil with a medium loamy texture. This soil exhibited varying degrees of degradation, being severely affected by erosion in certain areas, while only showing moderate to minor damage in others. In light of these conditions, it was decided to assign a value of unity in the severely affected areas, while a coefficient with a value of 0.9 was applied in the other areas. This differentiation reflects the varying intensity of erosion and degradation across the study area, allowing for a more nuanced and accurate assessment of the soil's condition and the necessary conservation measures.

The choice of methodology for the relief factor (LS) (Fig. 5) is a critical aspect in assessing erosion risk, as this factor plays a pivotal role in modeling topographic processes that directly influence surface erosion. In the context of our research, an advanced and well-grounded approach was adopted, utilizing the methodology embedded in the Saga GIS application, developed by Moore and his colleagues in 1991. The Saga methodology incorporates two main components: slope and the area of the corresponding watershed. The land slope is a significant indicator in assessing erosion risk. Areas with steeper slopes are more susceptible to erosion processes because rainfall water tends to flow rapidly in inclined areas. Employing data on land slope within the Saga GIS methodology allows for a detailed characterization of the relief and the identification of areas at increased risk of erosion.

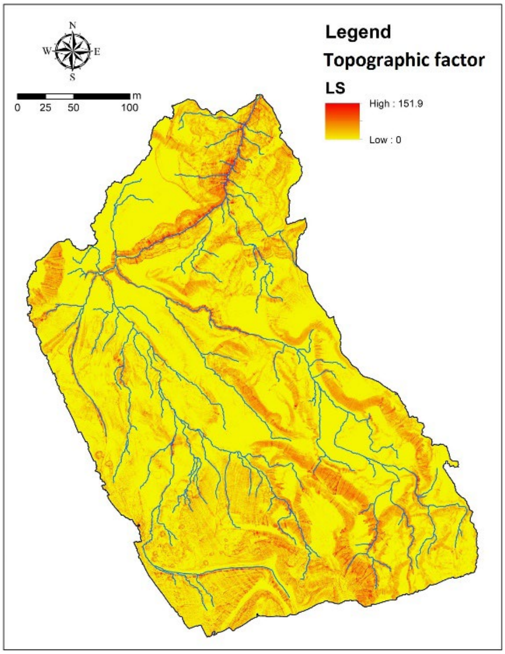

Fig. 5 The topographic factor (LS)

The watershed area measures the water collection zone from the slopes and provides insights into how rainfall accumulates and flows in a specific area. This component of the Saga GIS methodology adds an additional dimension to the evaluation of hydrological processes and in pinpointing areas with an increased potential for erosion. The relief factor (LS) not only quantifies the topographic characteristics of the area but also provides essential data to understand the interaction between water and soil. A thorough understanding of the relief is crucial in anticipating how rainfall will flow and impact the soil, thereby influencing erosion.

The C factor, representing vegetation cover, is pivotal in controlling erosion. Even under less favorable hydrothermal conditions, plant species adapt to protect the soil. These plants intercept raindrops, reducing kinetic energy and preventing direct impact. Stems increase the land's roughness, limiting runoff speed and the formation of streams. Plant residues, such as forest litter or agricultural remnants, retain precipitation, reducing runoff and fostering conditions favorable for plant growth. Roots stabilize the soil, enhancing water stability and organic matter accumulation. The replacement of natural ecosystems with agro-ecosystems impacts the soil's protective capacity. The database used combines field data with C factor values derived from specialized literature.

Largely, the area is devoid of vegetation, with only some regions in the southwest presenting pastures in various stages of degradation.

The Cs factor represents the contribution of measures and arrangements for soil protection. In the case of natural vegetation, no additional control measures are necessary as long as the integrity of the vegetation is maintained. For agricultural areas, particularly in rural zones and along lake banks, assessing this factor is quite challenging. Moreover, its value changes in accordance with the type of crop. Therefore, in this context, it has been considered equivalent to unity, meaning it won't significantly influence the final result. This approach underscores the importance of maintaining natural vegetation where possible and recognizes the complexity of accurately assessing conservation practices in varied agricultural settings.

DISCUSSIONS

In the specified study area, it has been observed that surface erosion, primarily driven by hydrological mechanisms, reaches significant magnitudes, with annual erosion rates approaching 40 tons per hectare, as illustrated in Figure 6. This distressing rate of soil loss is largely ascribable to the insufficient arboreal cover coupled with the distinctive soil composition of the region. The inherent properties of the soil facilitate a swift and widespread erosion process, further accelerating land degradation.

The depth and breadth of the analysis conducted are particularly noteworthy, characterized by its extensive scope and the employment of high-resolution imagery, achieving a pixel resolution as fine as 7 centimeters. These factors accentuate the crucial influence of morphometric variables in comprehending and confronting this environmental issue. Specifically, the slope and intrinsic characteristics of the hillside terrain are identified as key determinants in localizing areas most susceptible to erosive forces. This granular understanding highlights the significance of topographical and geomorphological

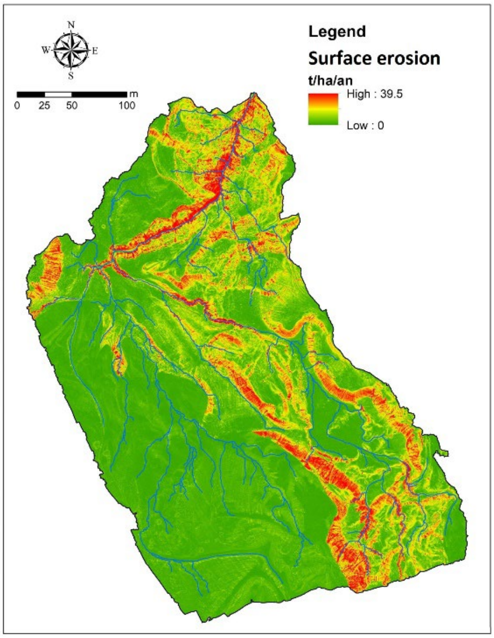

Fig. 6 Study area detailed surface erosion map

features in influencing the magnitude and spatial distribution of erosion within the landscape.

The findings from this rigorous analysis underscore the immediate necessity for the implementation of robust soil conservation practices and erosion mitigation strategies. This is particularly imperative in areas identified as highly vulnerable to erosion, where the adverse effects of this phenomenon are markedly severe. Interventions, informed by the detailed, morphometrically-oriented analysis, are pivotal in curtailing ongoing soil deterioration and in safeguarding the ecological integrity and productivity of the land. In summation, the outcomes of this research represent an emphatic call to action for stakeholders and policymakers to recognize and confront soil erosion with informed, efficient, and area-specific interventions.

CONCLUSIONS

In conclusion, the integration of high-resolution digital models in applied geomorphology research offers transformative advantages, enabling meticulous and precise analyses of geomorphic processes and forms such as vertical erosion, gully formation, and valley depth. These sophisticated technologies not only deepen our comprehension of terrain dynamics but also underpin the development of robust strategies for managing natural resources effectively. The precision and resolution provided by these models are decisive, facilitating nuanced assessments and targeted interventions that are essential for sustainable land use and conservation practices. Looking ahead, the plan to conduct subsequent measurements and evaluate the dynamics of these geomorphic processes promises an even more dynamic and interactive understanding of the terrain's evolution. This prospective approach will allow researchers to track changes over time, offering insights into the effectiveness of interventions and the natural progression of geomorphic phenomena. Such temporal analyses will undoubtedly enrich our understanding, enabling the anticipation of future landscape changes and fostering a proactive stance in land management and environmental preservation efforts.

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