THE USE OF DIGITAL ELEVATION MODELS (DEMs) IN MORPHOMETRIC ANALYSIS OF TERRAIN AND LAND CLASSIFICATION IN THE COASTAL BASIN OF ROMANIA

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Abstract. *This study aims to enhance the morphometric analysis of terrain and land classification in Romania's coastal basins through the advanced application of Digital Elevation Models (DEMs). While DEMs are increasingly utilized worldwide for environmental mapping and analysis, their application in the Romanian context, especially for detailed geomorphological studies including flow accumulation, sink routes, and landform classification, remains underexplored. Utilizing DEMs, this research integrates Geographic Information System (GIS) technologies with statistical analyses to investigate geomorphological features such as watershed basins, specific catchment areas, the topographic position index, LS factor, plan curvature, and the topographic wetness index. Results demonstrate the effectiveness of DEMs in identifying complex terrain features and in classifying land with high accuracy, highlighting the utility of incorporating advanced morphometric parameters like geomorphons and flow directions. However, the study acknowledges limitations related to the resolution of DEMs and the necessity for ground verification. The findings have significant implications for environmental management, urban planning, and conservation, offering new insights for land use planning and disaster risk reduction in coastal regions. The relevance of this research lies in its targeted application of DEMs to the complex terrain of Romania's coastal basin, contributing significantly to the field of geomorphology by offering nuanced insights and practical methodologies for terrain analysis and land classification.*

Keywords*: digital elevation models (DEMs), morphometric analysis, terrain classification, coastal basin, Geographic Information System (GIS)*

INTRODUCTION

A digital elevation model (DEM) is an essential dataset for many land feature analyses, such as geomorphological feature analyses, which are very important for many types of studies (Ibrahim et al., 2020).

Digital Elevation Models (DEMs) have revolutionized the way researchers analyze terrain morphology and classify land types, offering unparalleled insights into landscape dynamics and environmental processes. In the coastal basin of Romania, characterized by its diverse topography and ecological significance, the utilization of DEMs has become instrumental in understanding the intricate interplay between landforms, hydrology, and land cover. This paper presents a comprehensive exploration of the applications of DEMs in morphometric analysis and land classification within the Romanian coastal basin.

By harnessing high-resolution elevation data, DEM-based analyses provide detailed representations of terrain features, including slope, aspect, and curvature, facilitating the quantification of landform parameters critical for geomorphological studies. Moreover, DEM-derived attributes serve as valuable inputs for land classification algorithms, enabling the delineation of distinct land cover categories such as forests, wetlands, and urban areas.

Through a synthesis of morphometric analysis and land classification methodologies, this study aims to elucidate the spatial patterns and processes shaping the coastal landscape of Romania. Furthermore, the integration of DEMs with Geographic Information Systems (GIS) enhances the spatial modeling capabilities, enabling researchers to simulate terrain dynamics, predict flood susceptibility, and assess landscape changes over time. Such analytical frameworks not only contribute to a deeper understanding of natural processes but also support informed decision-making for sustainable land management and environmental conservation in the coastal basin of Romania.

The coastal basin of Romania spans two counties, Constanța and Tulcea, and comprises 83 administrative territorial units and 90 sub-basins.

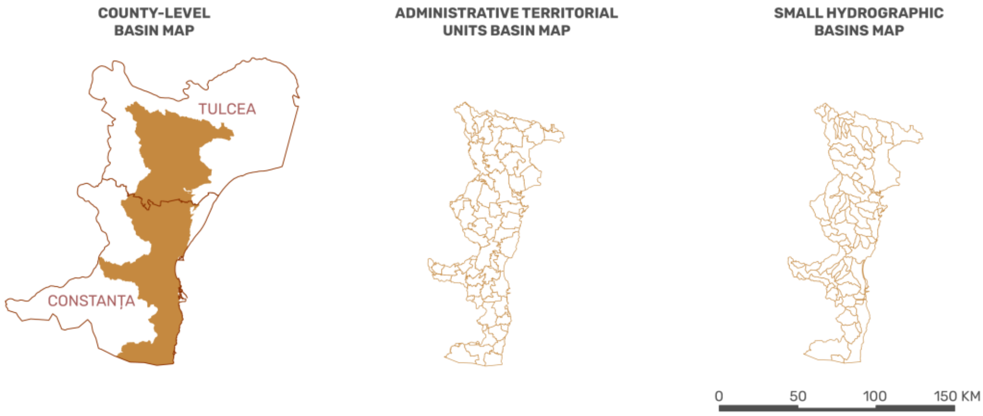


Figure 1. Map depicting the Coastal Basin's alignment with the counties of Dobrogea's region (Constanța and Tulcea). Figure 2. Map depicting the Coastal Basin's alignment with the administrative territorial units. Figure 3. Map depicting the Coastal Basin's alignment with the sub-basins

Table 1

Dobrogea's region counties, their surfaces within the Coastal Basin and number of administrative territorial units

County name	Surface (km²)	Percentage (%)	Number of units
Constanța	2474.62 km²	45.56	51
Tulcea	2957.39 km²	54.44	32

MATERIAL AND METHODS

Spatial structural and morphometric analysis of Digital Elevation Model (DEM) is defined as a methodology of information inventory of landscapes and their geoecological status. The effectiveness of this methodology is determined by the reliability of the DEM (Bilous et al., 2020).

This study focuses on the application of DEMs to analyze and classify terrain within the coastal basin of Romania. This methodology involves data collection and processing them through multiple software in order to extract various land types attributes. The primary tools employed for data processing included QGIS, Global Mapper, SAGA GIS, which facilitated the manipulation, analysis, and visualization of spatial data.

The integration of high-resolution DEMs with GIS tools and advanced analytical techniques offers significant potential for enhancing our understanding of terrain dynamics and supporting sustainable management practices. The approach demonstrates the utility of DEMs in providing nuanced insights into the geomorphological and hydrological features of complex landscapes. Moreover, this study highlights the importance of utilizing advanced geomatic techniques for comprehensive environmental assessments and informed land use planning.

Table 2

Types and sources of data used

Type of data extracted	**Data sources**
Vector data: administrative territorial units, county limits, sub-basins limits	https://geoportal.ancpi.ro/portal/home/ https://geo-spatial.org/
DEM (Digital Elevation Model)	https://land.copernicus.eu/ https://www.opendem.info/
Data processing software	QGIS, Global Mapper, SAGA GIS
Map styling software	Adobe Illustrator
Software for creating graphics and histograms	Microsoft Excel

RESULTS AND DISCUSSIONS

Digital elevation models are used to automatically map the stream channel and divide networks of a watershed. These topographic skeletons are used to partition the watershed into a set of fundamental, runoff producing subregions, each of which drains into one stream link (Band, 1986).

The following maps are designed to show the spatial distribution and extent of watershed basins. The northern region shows large watershed basins with significant hydrological activity, while the central and southern parts show varied but generally smaller basins.

The first map uses a color gradient to represent different basin sizes, with warmer colors indicating larger basins and cooler color indicating smaller ones. The second map provides a more detailed view of the terrain, highlighting the elevation and slope variations within the watershed basins. The intricate patterns help identify areas prone to erosion or flooding.

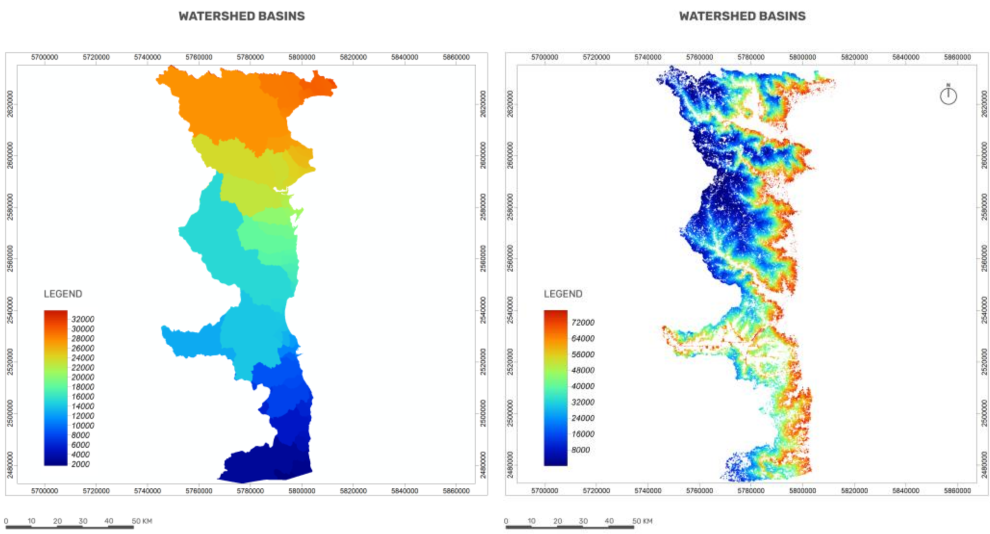
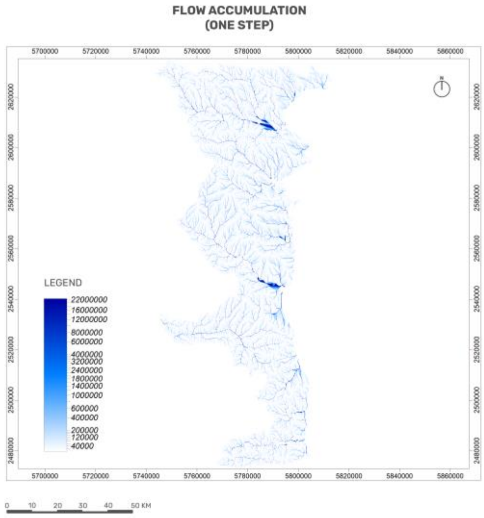


Figure 4 & 5. Watershed basins



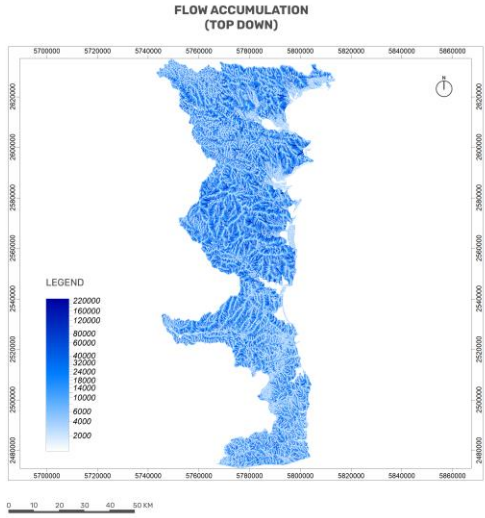
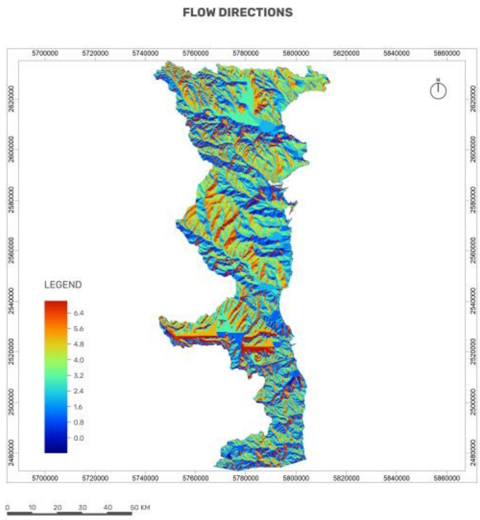


Figure 6. Flow accumulation (one step). Figure 7. Flow accumulation (top down)



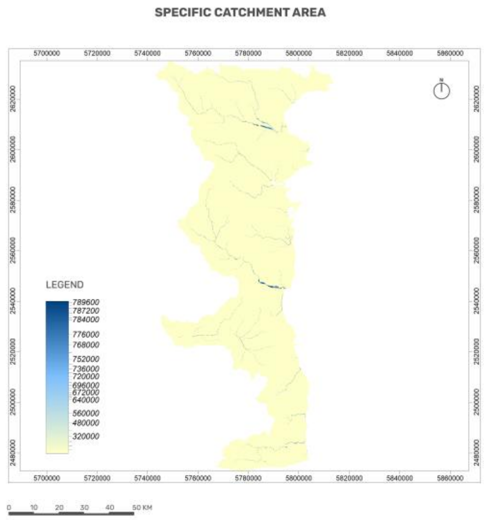


Figure 8. Flow directions. Figure 9. Specific catchment area

Flow direction and flow accumulation are important watershed characteristics that need to be determined before an analysis can be made. Other important characteristics which can be gleaned from analysing the digital elevation model (DEM) of a watershed include channel networks, stream lengths and watershed boundaries (Zhang et al, 2017).

Flow accumulation can be broadly described as the total amount of water that flows into each terrain cell (Moore et al., 1991). It can be defined as a measure of how many upstream cells contribute flow to a particular cell, and it helps identify potential watercourses and stream networks.

Figure 6 shows flow accumulation in a single step, highlighting the primary channels where water collects, while Figure 7 illustrates top-down flow accumulation, providing a comprehensive view of how water accumulates and moves through the entire watershed. This last map is also offering insights into the overall drainage pattern and identifying areas with significant water movement, which are crucial for flood risk assessment and management.

Flow direction is determined by the steepest descent from each cell, guiding how water will move across the landscape. These are displayed in Figure 8, using a color gradient to indicate the direction of water flow across the terrain. This map is essential for understanding the pathways water will take during rainfall events and is fundamental for modeling hydrological processes.

The specific catchment areas are shown in Figure 9, representing regions contributing runoff to specific points in the watershed. A catchment area, also known as a drainage basin, is defined as the area from which all precipitation flows to a single stream or set of streams. This map highlights the spatial extent of each catchment, which is important for water resource management, planning, and conservation efforts.

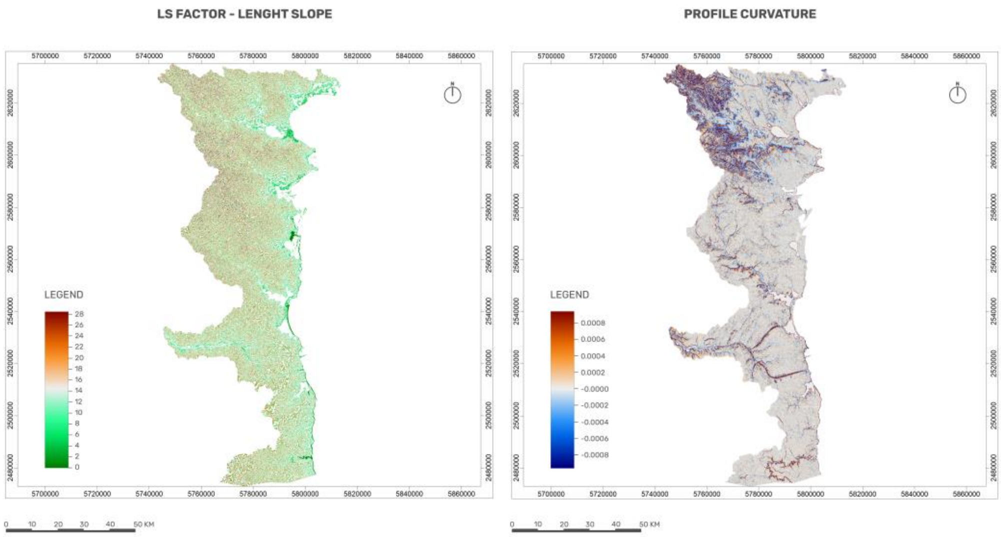
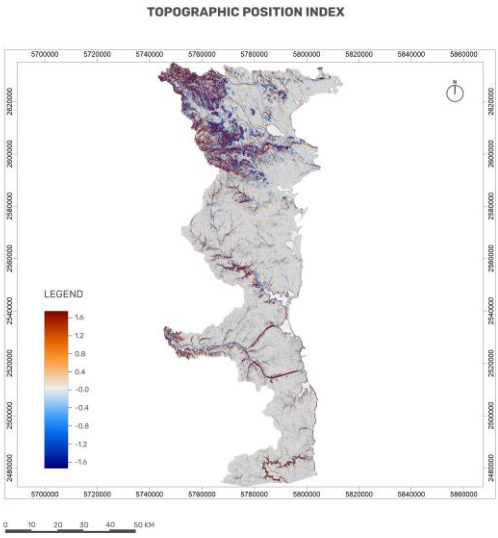


Figure 10. LS Factor. Figure 11. Profile Curvature

Figure 10 illustrates the LS factor, which stand for the Length-Slope factor. The LS factor is a component of the Universal Soil Loss Equation (USLE) and reflects the effect of topography on erosion. Areas with higher values, shown in orange, indicate regions with longer and steeper slopes, which are more susceptible to soil erosion. Lower values, shown in green, indicate flatter areas with less potential for erosion.

Terrain curvature is one of the most important parameters of land surface topography. Well-established methods used in its measurement compute an index of plan or profile curvature for every single cell of a digital elevation model (Krebs et al., 2014).

For our site, we established the profile curvature (Figure 11) of the watershed. Profile curvature refers to the curvature of the land surface in the vertical plane, affecting water flow acceleration and deceleration. The map uses a color gradient from blue to brown, with blue indicating concave areas (where water is likely to accumulate) and brown indicating convex areas (where water is likely to disperse). Understanding this parameter is crucial for predicting soil moisture patterns and potential erosion areas, thereby aiding in effective land management and conservation practices.



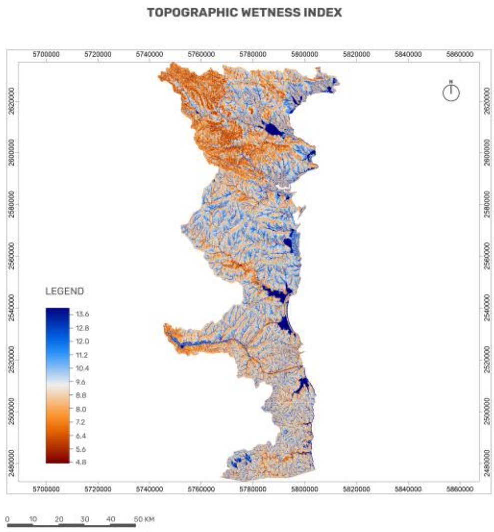


Figure 12. Topographic Position Index. Figure 13. Topographic Wetness Index

TPI is a method of terrain classification where the altitude of each data point is evaluated against its neighbourhood. If a point is higher than its surroundings, the index will be positive, as for example on ridges and hilltops, while the figure will be negative for sunken features such as valleys (Čučković, 2019).

Figure 12 illustrates the Topographic Position Index (TPI), which measures the relative elevation of each point on the landscape compared to the mean elevation of its surrounding points. The map uses a color gradient from blue to brown, where blue indicates lower values (valleys or depressions) and brown indicates higher values (ridges or elevated areas).

The values for the coastal basin range between 1.6 and -1.6. High positive values characterize peaks, isolated mounds or terraces, those negative values characterize low surfaces, while values close to zero indicate surfaces quasi-horizontal or with a constant slope. For the studied basin, the most common values are between -0.0 and 0.4, located at the level of the entire area, with the exception of the northern area which registers the most high altitudes (Măcin Mountains), as well as hydrographic courses (Danube - Sea Canal Black).

Topographic Wetness Index (TWI) integrates the water supply from upslope catchment area and downslope water drainage for each cell in a DEM. Figure 13 shows the Topographic Wetness Index, which quantifies the effect of topography on the location and size of saturated areas. The map uses a color gradient from blue to brown, where blue indicates higher values (wetter areas) and brown indicates lower values (drier areas).

In the TWI, the slope gradient approximates downslope water drainage, and the specific catchment area, calculated as the total catchment area divided by the flow width, approximates the water supply from upslope area (Beven, Kirkby, 1979). For the coastal basin, the recorded values are between 13.6 and 4.8, graphically indicating the sectors prone to water accumulation. These sectors are represented by the low, reduced altitudes. In this map, lakes are also highlighted, having the most high values.

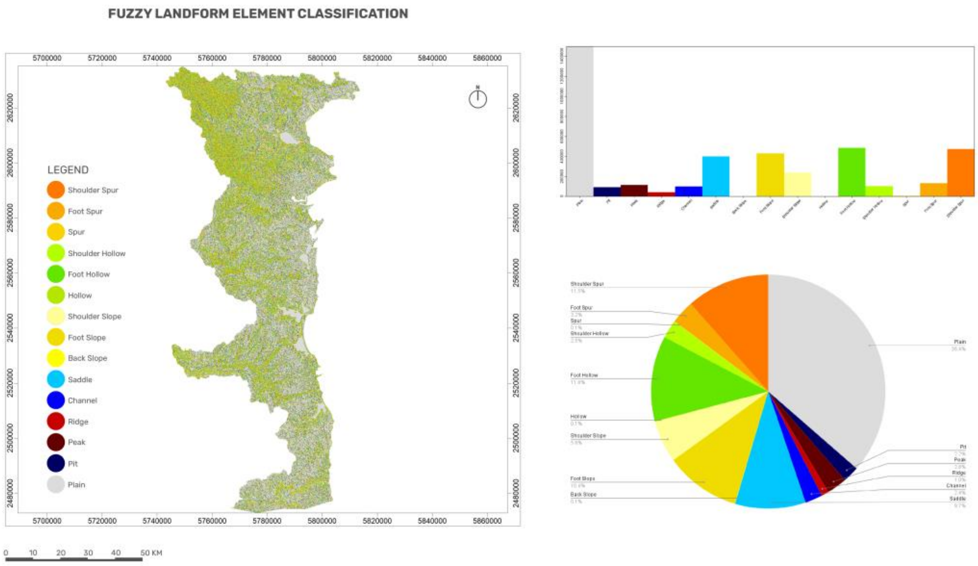


Figure 14. Landform

The Landform map (Figure 14) illustrates the classification of various landforms within the watershed using a color-coded system. This map categorizes the terrain into different landform types such as peaks, ridges, plains, valleys, and slopes based on elevation and slope criteria.

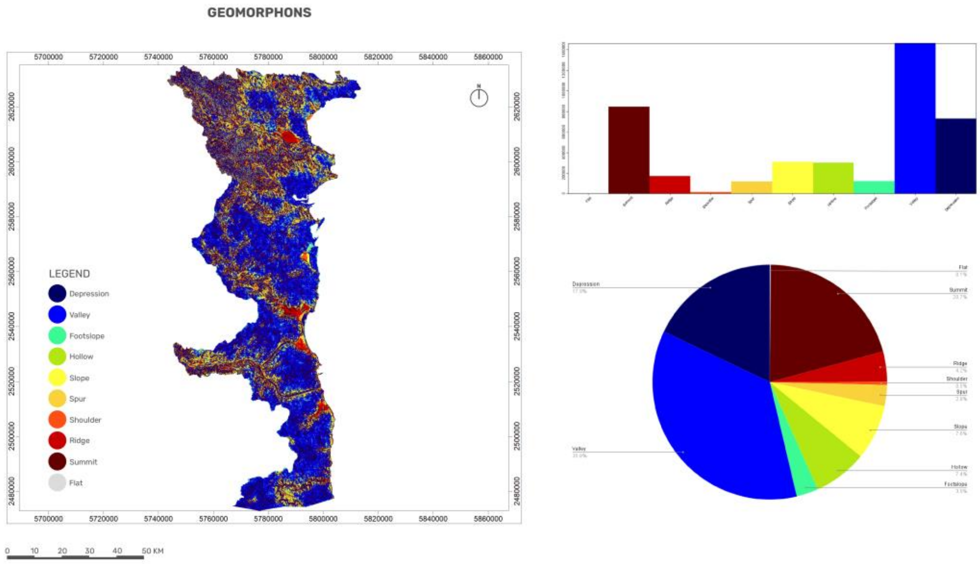


Figure 15. Geomorphons

The Geomorphons map (Figure 15) uses a technique to identify and classify various geomorphic forms in the landscape. This map simplifies the terrain into distinct geomorphic patterns, providing a generalized view of the landscape's structural features.

This map helps in recognizing patterns such as ridges, valleys, and plains, aiding in landscape analysis and geomorphological studies.

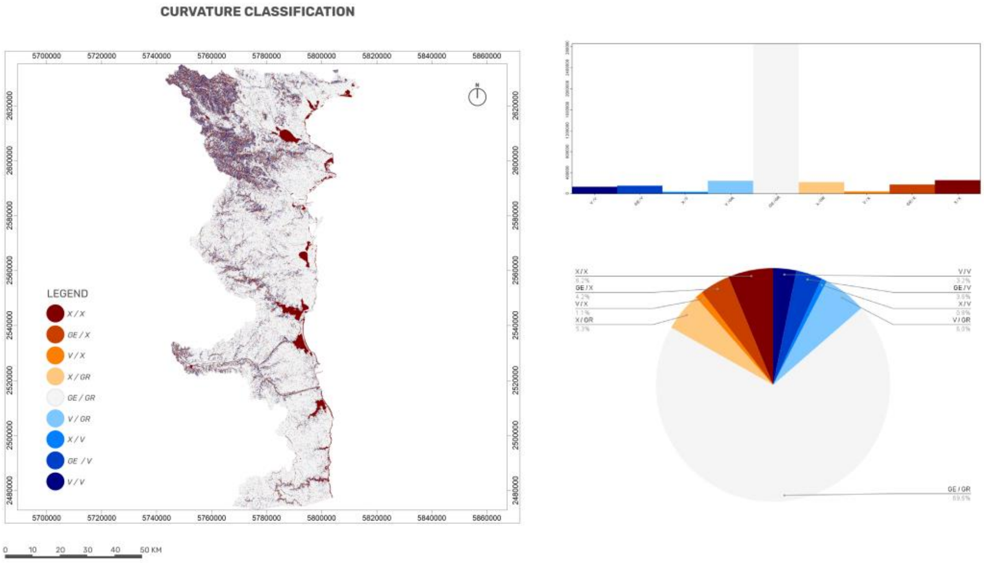


Figure 16. Curvature Classification

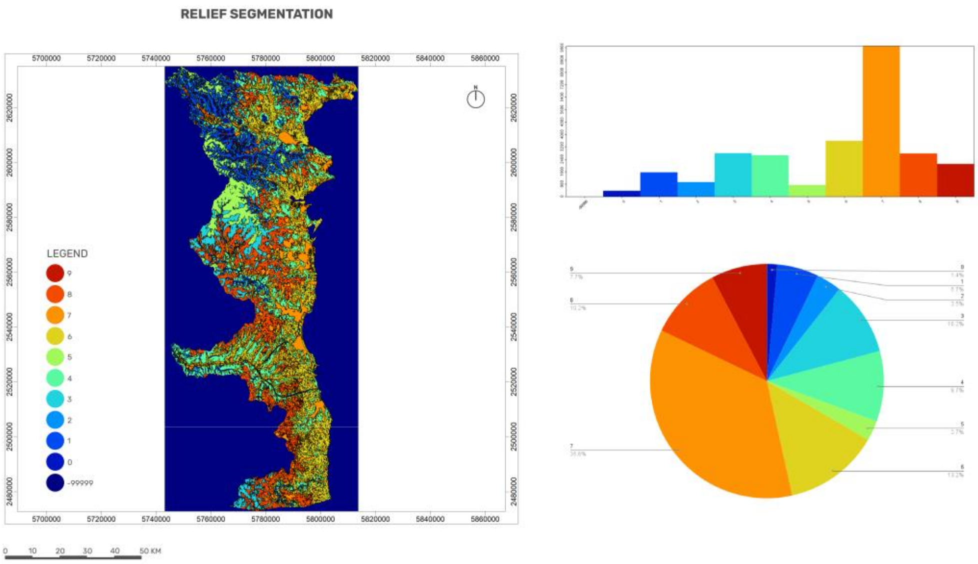


Figure 17. Relief Segmentation

The Curvature Classification map (Figure 16) categorizes the terrain based on its curvature, distinguishing between convex, concave, and flat areas. This map helps in understanding the flow of water and potential erosion areas by highlighting the curvature of the land surface. Convex areas are likely to shed water, shown in brown. Concave areas indicate where water is likely to accumulate, shown in blue, while flat areas are shown in neutral colors, indicating stable regions with minimal water movement.

The Relief Segmentation map (Figure 17) divides the landscape into segments based on elevation and slope, providing a segmented view of the terrain. This map helps in understanding the distribution of different elevation zones and their connectivity.

CONCLUSIONS

The integration of DEMs with GIS technologies in this study provides a robust framework for analyzing and managing the coastal basin's complex terrain and hydrology.

This approach contributes to more effective terrain analysis, by enabling precise identification of terrain features and their implications for water flow, erosion, and landform classification. Moreover, understanding watershed characteristics such as flow accumulation, flow direction, and specific catchment areas helps in managing water resources effectively, predicting flood risks, and planning for sustainable water use.

Detailed maps of topographic features, landforms, and curvature aid in informed decision-making for land use, ensuring that development activities are aligned with the natural landscape to minimize environmental impact.

Last, but not least, the insights gained from DEM-based analyses are crucial for conservation planning, helping to protect vulnerable areas, manage soil erosion, and maintain ecological balance.

Overall, the integration of DEMs with GIS technologies in this study provides a robust framework for analyzing and managing the coastal basin's complex terrain and hydrology, contributing to more effective environmental and urban planning efforts.

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