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DEVELOPMENT OF AN EROSION MAP USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND BASED ON THE HIERARCHICAL ANALYTIC PROCESS (AHP) CASE STUDY OF BOUMERDES-ZEMMOURI, EASTERN OF ALGIERS

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Abstract: The objective of the study is to provide a comprehensive assessment of the vulnerability to future erosion in the region of Boumerdes-Zemmouri located in Eastern Algiers. A multi-criteria analytical Hierarchy Process (AHP) combined with (GIS) analysis was used to evaluate the effects of various geomorphologic factors that influence the land, these include slope, geology, land use, and rainfall. The results showed that the most vulnerable surfaces occupy more than 63% of the study area.

The vulnerability of this region is significantly high due to the multiple factors that affect its preservation and sustainability.

Keywords: AHP, Boumerdes, Erosion dynamics, Geographic Information System, Geomorphology, Vulnerability

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INTRODUCTION

The primary cause of soil erosion is the transport and detachment of soil particles through the combined effects of rainfall and runoff (Dumas, et al., 2010). This phenomenon is common in the Mediterranean basin countries (Sánchez-Lozano, et al., 2013) and the study area represents one of the basins that belong to the Mediterranean regions. The factors that influence the development and maintenance of this process are identified as four domains: topography (relief), lithology (soil), climate, and land use.

The Wilaya of Boumerdes is located along the coast of Algeria and Africa, and it serves as a prominent illustration of the vulnerability that can be found in this region (Haythem, et al., 2023). The multiple geological, climatic, and geographical features that make up this area make it incredibly susceptible to different influences (Meghraoui, 2004; Tout & Rebouh, 2024). The various factors that contribute to the development of the Wilaya's vulnerability profile are not limited to its composition. Besides its geographical features, other factors such as the land use practices and the climatic dynamics also affect the area's vulnerability. This is why it is important that the Boumerdes is focused on its efforts in becoming resilient and sustainable (Christine , 2017; Batouche, et al., 2024). The study conducted in this project aims to explore the various factors that influence the vulnerability of the Boumerdes. Through the use of the AHP, an analytical tool, it will be able to gain a deeper understanding of the multiple factors that affect this region (Oudni, Dinar & Zedam, 2016). The objective of the study is to reveal the cumulative effects of these factors on the vulnerability fabric of the landscape. Moreover, through an efficient analytical method, the research can evaluate the intricate nature of the interaction between these elements. The study's core objective is to provide a comprehensive analysis of the vulnerability of the Boumerdes. Through the use of the AHP, it will be able to disentangle the various factors that influence this region's vulnerability (Haythem, et al., 2023). This study places a spotlight on the multiple facets of the vulnerability of the Wilaya of Boumerdes, providing a more precise comprehension of the issue and allowing for quick resolution. As Algeria struggles with its evolving problems, this research contributes to the discourse by providing a comprehensive picture of vulnerability, facilitating the creation of sustainable development plans and strategic decisions.

The analytical hierarchy process, which is commonly referred to as an AHP (Saaty, 2008), is a multi-criteria method that can be used to solve problems related to the selection and implementation of solutions (Le Cozannet, 2013). It combines multiple criteria to produce a cartographic result that shows the areas that are most likely to be able to solve the issue. One of the most important steps in the process of implementing an AHP is the selection of the appropriate criteria to perform a successful spatial multi-criteria analysis (Malczewski, 1996). This method has been widely used in different domains to identify the factors that can affect a decision-making process (Sabrina, et al., 2025).

AREA OF STUDY

The Wilaya of Boumerdes is located in the center of the country and has a coastal profile of 100 kilometers. It is an integral part of the East of Algiers metropolitan area (Figure 1). The area of the Wilaya of Boumerdes is approximately 1,456,16 km² long between 36° 46' 3.346" North and 3° 42' 10.441" East. The wilaya of Boumerdes is limited by: the Mediterranean Sea to the North; the wilaya of Algiers to the West; the wilaya of Tizi Ouzou to the East and the wilaya of Blida (Mitidja plain) to the South West.

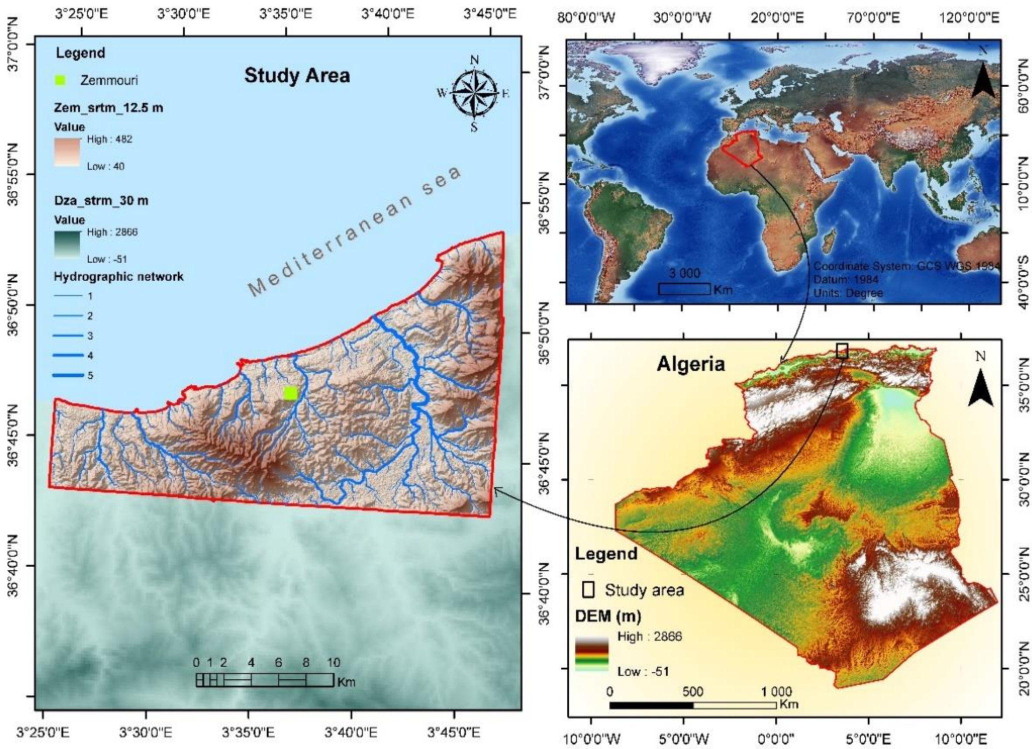

Figure 1. Location of the Study area
(Source: Google Earth Pro, ArcGIS)

The Wilaya of Boumerdes has a unique combination of physical settings, with varying terrains and plains. Due to its Mediterranean climate, the city of Zemmouri experiences hot and humid summers and cold winters. The rainfall in the area varies between 500 and 1,300 millimeters annually.

The region of zemmouri in the Wilaya of Boumerdes receives an average rainfall of 900 millimeters annually. This is higher than the other areas of the region. The low thermal amplitudes are usually found in the Wilaya of Boumerdes due to its location near the sea. The average temperature in the area is around 18° near the coast and 25° inland.

MATERIALS AND METHODS

The AHP is commonly used as a tool for developing a strategy or a method for analyzing and ranking various entities. It can be used as a technical estimation or a multi-criteria decision-making method (MCDM) (Rebouh, et al., 2025). It requires a hierarchy of properties to perform its operations. This includes a pairwise comparison of the various entities in the hierarchy (Saaty, 1990).

The AHP process is usually performed in phases. It first involves identifying the possible factors that could affect the decision-making process (Omidipoor, Jelokhani-Niaraki & Alizadeh, 2019). Then, it arranges the factors for each alternative and develops a list of alternatives. In addition, the AHP process also takes into account the importance of the other factors that are related to the vulnerability assessment. Finely it analyzes the weight of each factor (King, 2015).

The list below (Table 1) shows the various factors that are involved in the spatialization of the vulnerability to local erosion.

Table 1. Parameters involved in the assessment
(Source: Dinar Haythem)

Parameters	Weights
Slope	C 1
Lithological formations	C 2
Rainfall	C 3
Land use	C 4

The Slope

The slope of a topographic area (Table 2) can highly affect the severity and amount of runoff (Sánchez-Lozano, Teruel-Solano, Soto-Elvira & García-Cascales, 2013). When the slope is too steep, the water is allowed to flow profusely, and the rock formations become more susceptible to water erosion (Kheir, et al., 2001). This is because its gravitational action can greatly influence the flow of water and its erosive energy (Dumas, et al., 2010).

Table 2. Ranking of slope Influencing
(Data source: ArcGis)

Values	Class of Parameters	Ranking
0 - 10	Gentle	1
10-30	medium	2
30 - 60	Steep	3
60 - 90	Very Steep	4

The slope factor is a critical parameter that can be used in the analysis of the spatial distribution of the study area. It shows the potential risk of erosion in areas with steep and very steep slopes (Figure 2).

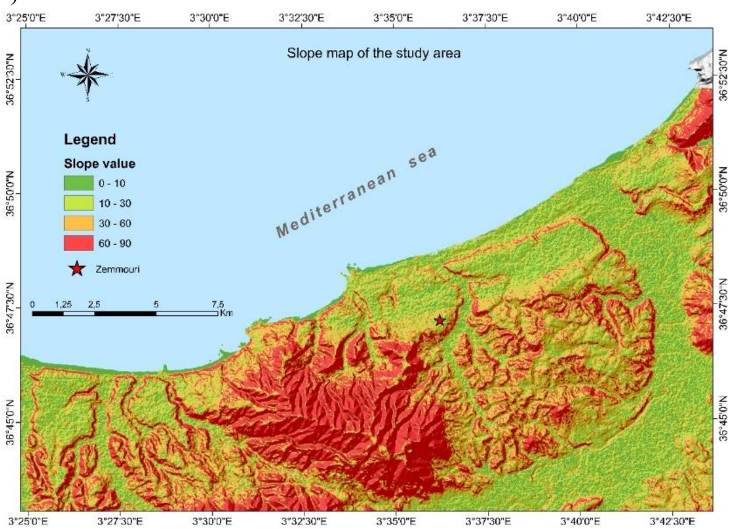

Figure 2. Slope map with relief of the Zemmouri region and surroundings
(Data source: United States Geological Survey, SRTM-12.5m, DEM)

The lithological formations

The quality of the lithological properties of the formations and the spatial distribution of the structures influence the erodibility of the various reliefs (Mueller & Pitlick, 2013). Based on the 1/500.000 Soil map of Algeria (Figure 3), the soils were classified into four classes according to their resistance (Table 3).

Table 3. Ranking of the friability materials according to lithological formations
(Data source: Dinar Haythem)

Lithological formations	Materials friability	Ranking
Association of calcareous soils and solonetz	Resistant materials	1
Alluvial soils	Relatively resistant	2
Unsaturated soils	Susceptible materials	3
Dune soils	Highly Susceptible materials	4

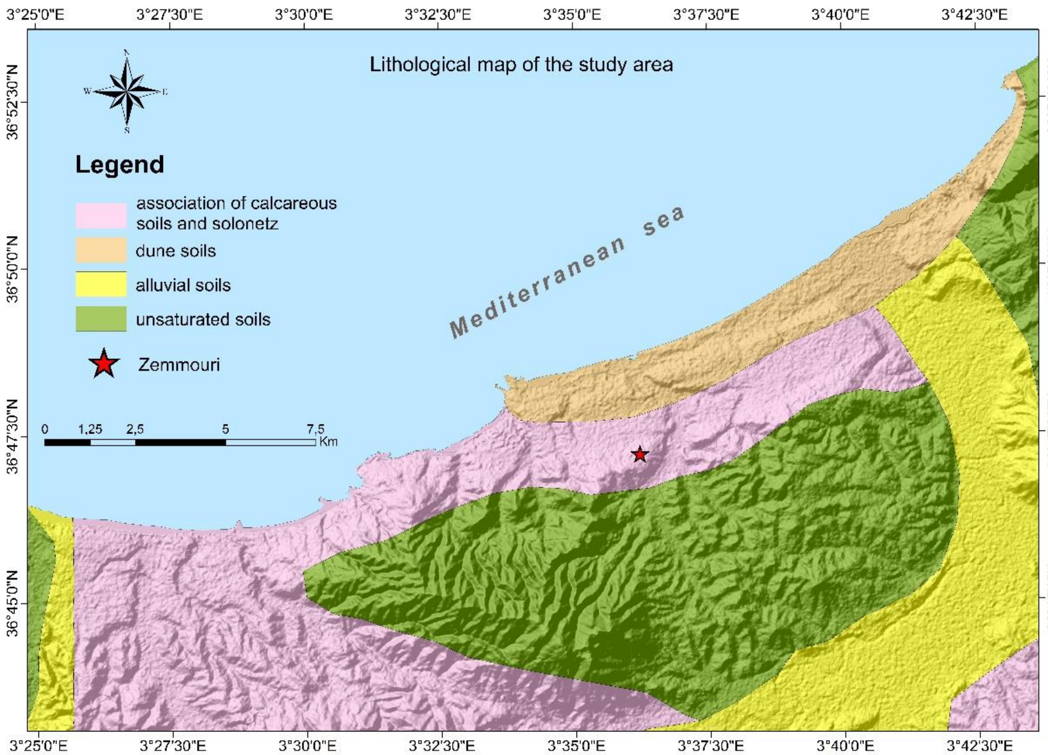

Figure 3. lithological map of the study area
(Data source: 1/500 000 Soil map of Algeria)

Average annual rainfall

The spatial distribution and intensity of rainfalls are the factors that contribute to the development of the erosion phenomenon (Chakhar & Mousseau, 2006).

The friction forces on the soil surface decrease as the runoff collects in nets. It then becomes more abrasive and moves deeper into the soil surface (Roose & Sterrer, 1984; Nouali, et al., 2025). To further contextualize the impact of rainfall, (Table 4) presents a ranking of different rainfall intensity ranges and their corresponding influence. These rankings provide insight into the varying degrees of erosive potential associated with different levels of rainfall (Figure 4).

Table 4. Ranking of rainfall Influencing
(Data source: High-resolution gridded datasets)

Rainfall (mm)	Ranking
510 - 519	1
520 - 527	2
528 - 536	3
537 - 545	4

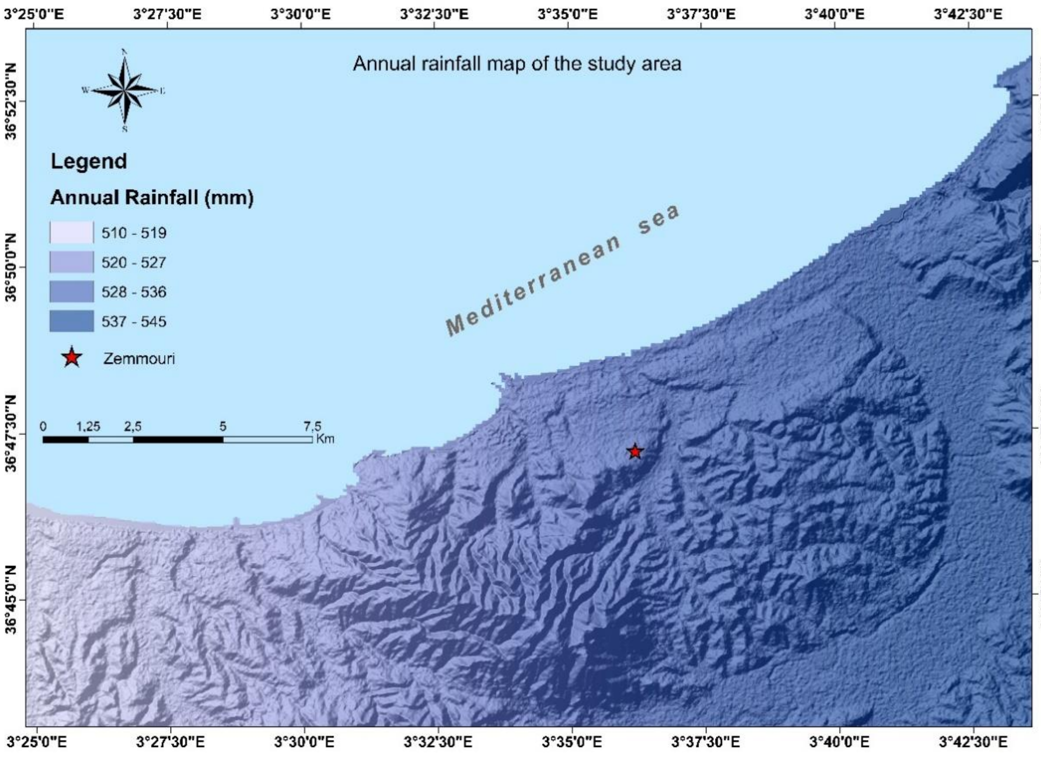

Figure 4. Annual rainfall 2022
(Data source: from High-resolution gridded datasets)

Land use

The land cover is responsible for controlling the various morphogenic processes that occur in the area. It is also related to the land use pattern and contributes to the protection of the soil (Dumas, et al., 2010) . A map of the land cover was created using a 30 m resolution image of the satellite ETM+ Land SAT 8 (Figure 5). The classification of the various land-use elements allowed us to gain a deeper understanding of their spatial distribution (Table 5).

Table 5. Ranking of land use impact on the study area
(Data source: Dinar Haythem)

Row Labels	Sum of Area (Km²)	Percentage (%)
Water Body	3,0165	1%
Barren Land	44,2469	13%
Built Area	56,2379	17%
Vegetation	228,1534	69%
Total	331,6547	100%

Table 6. Surfaces and percentages of land cover lithology
(Data source: ArcGis)

Land use	Ranking
Water Body	1
Barren Land	2
Built-Up Area	3
Vegetation	4

Although, it should be noted that the zero-vulnerability criterion excludes aquatic environments and urban areas, such as lakes and dams. The weight for each class of criterion is computed the same way as for the other criteria (Table 6). The goal of pairwise comparisons is to determine which item has the most influence over another in terms of a given attribute's importance.

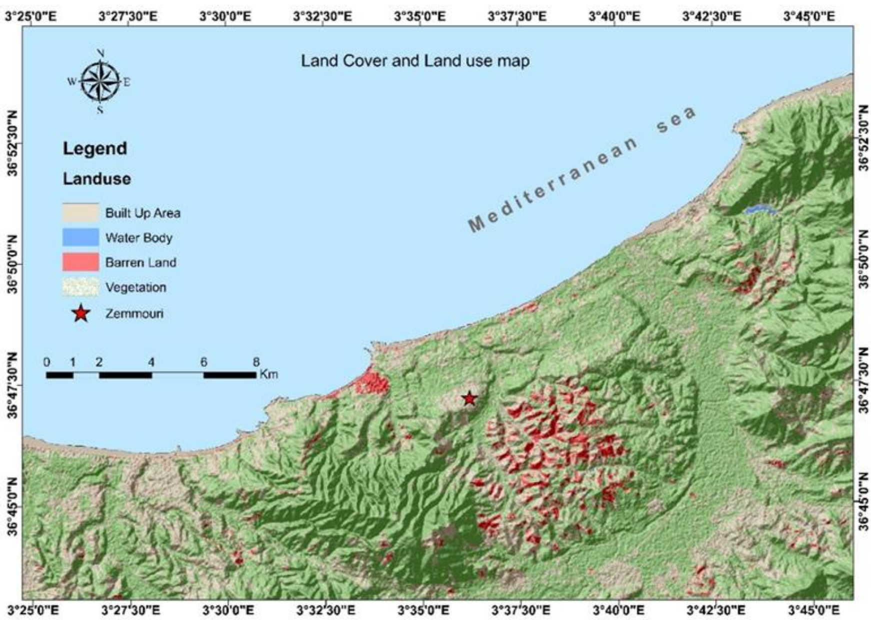

Figure 5. Land Cover and Land use Map (LcLu)
(Data source: USGS, Land SAT Oli 8 satellite image classification)

This process is carried out using a scale known as Saaty's scale (Le Cozannet, (013). It takes into account the various qualitative assessments and transforms them into numerical values from 1 to 9 (Table 7). The priority scales are then calculated by taking into account the eigenvector associated with each comparison matrix (Saaty, 1990).

Table 7. The basic scale for comparison between absolute numbers (Saaty, 2003)
(Data source: Dinar Haythem)

Scale (importance)	Degree of preference (definition)	Explanation
1	Equal importance	Two actions contribute equally to the objective
2	Weak or slight	-
3	Moderate importance of one factor over another	Experience and decision slightly favor one parameter over another
4	Moderate plus	-
5	Essential importance	Experience and decision strongly favor one parameter over another
6	Strong plus	-
7	Very strong importance	One parameter is favored very strongly and is considered superior to another in practice. This demonstrates the dominance of this parameter.
8	Very very strong	-
9	Extreme importance	Proof of the superiority of one parameter over another is of the highest possible order of affirmation
2,4,6,8	The number for inverse comparison	Can be used to specify mid-range values

The AHP procedure begins by making pairwise comparisons between the various criterion. The results of these comparisons are described in terms of integer values from 1 (equal value) to 9 (extremely different). For instance, if the chosen factor has a higher number, it will be considered more important than the other factor being compared with.

RESULTS AND DISCUSSIONS

Analysis of Erosion Vulnerability Using AHP and GIS

The AHP can play an important role in deciphering complicated project components and identifying associated risks (Yang, et al., 2020). The AHP's widespread adoption can be attributed to its ease of execution (Table 8). This approach helps users quickly identify the relative weight of various criteria in complex projects (Malczewski, 1996).

The AHP's intuitive approach to decision-making makes it an ideal choice for projects that require quick and precise evaluations (Fernandes, Quintela & Alves, 2018).

The pursuit of spatial accuracy requires the use of geographic information systems. With its broad capabilities, such as storage, analysis, and visualization, GIS can play a vital role in making informed decisions (Arda, Bayrak & Uzar, 2025).

The AHP's ability to accommodate different spatial analysis techniques makes it an ideal choice for projects that require quick and precise evaluations (Kiberet, Nebere, Workineh & Jothimani, 2025).

By utilizing the capabilities of geographic information systems, we can unravel intricate coastal patterns, empowering them to make more sound choices and improve their efficiency in planning and executing projects (Hasan, et al., 2023).

Table 8. Comparison matrix
(Source: Dinar Haythem)

Factor	Slope	Lithology	Rainfall	Landuse	Eigenvalue (Eg)	weight	
Slope	1,000	2,000	3,000	4,000	2,213	0,470	
Lithology	0,500	1,000	2,000	3,000	1,316	0,280	
Rainfall	0,333	0,500	1,000	1,000	0,639	0,136	
Landuse	0,250	0,333	1,000	1,000	0,537	0,114	
Total					4,706	1	
				Number of Criteria =		4	
				C. I. =		0,010	
				R. I. =		0,890	
				C. R. % =		1,160	Consistency OK

Ensuring Consistency in Decision-Making

One of the most critical factors that decision-makers need to consider when it comes to making decisions is the logical and coherent interconnection of their data structures (Rebouh, et al., 2025).The Consistency Ratio is a metric that can help them determine if their decisions are being made properly (Zheng, et al., 2013).

A decision matrix with a consistent CR value of less than 0.10 can be considered robust (Tout, et al., 2024).This can help prevent statistically irregularities and ensure that the outcomes are being made correctly (Bekhouch, et al., 2023).

The study's meticulous calculations resulted in a consistent CR value of 0.0116 (Table 8). This finding substantiates the construction of the matrix and helps strengthen the reliability of the conclusions and analyses that follow.

Quantifying Vulnerability through a Composite Equation

The study's objective is to quantify coastal erosion's vulnerability. This intricate phenomenon is affected by different contributing elements.

The vulnerability equation can be calculated as follows:

Vulnerability = 0.470 * Slope + 0.280 * Lithology + 0.136 * Rainfall + 0.114 * Land use.

The vulnerability equation condenses the interrelationships of lithology, rainfall, land use, and slope into a quantifiable form, making vulnerability more relatable (Rocha, Antunes & Catita, 2020).

Mapping Complex Phenomena and Classifying Vulnerability

The study's spatial analysis method allowed to thoroughly study coastal dynamics and reveal the intricate processes that drive vulnerability (Figure 6). Through this approach, we can also map the multiple factors that affect coastal erosion. In addition, the flexibility of the study's design allows to utilize different techniques to fit our specific needs.

The study's final report, which includes the vulnerability classes and their corresponding percentages, is presented in (Table 9). The resulting data categorized coastal erosion's vulnerability into four subclasses: High, Medium, Very High, and Low.

The findings show that 63.68% of the studied area falls under the High category, which highlights the scale of the threats that coastal erosion poses.

Table 9. Surfaces and percentages of vulnerability classes
(Data source: ArcGis)

Vulnerability	Areas in km2	Percentage	
Low	42.98	12.96 %	
Medium	77.47	23.36 %	
High	159.79	48.18 %	**63.68 %**
Very high	51.41	15.50 %	
Total	**331.65**	**100 %**	

Validation and Future Prospects

The study's findings have helped improve our knowledge about coastal erosion's vulnerability in the region of Nemourid (Figure 6). But, further research is needed to expand our understanding of this phenomenon.

A field-based validation is needed to strengthen the credibility of the methodology and its practical applicability. This process can help stakeholders feel more confident about its reliability.

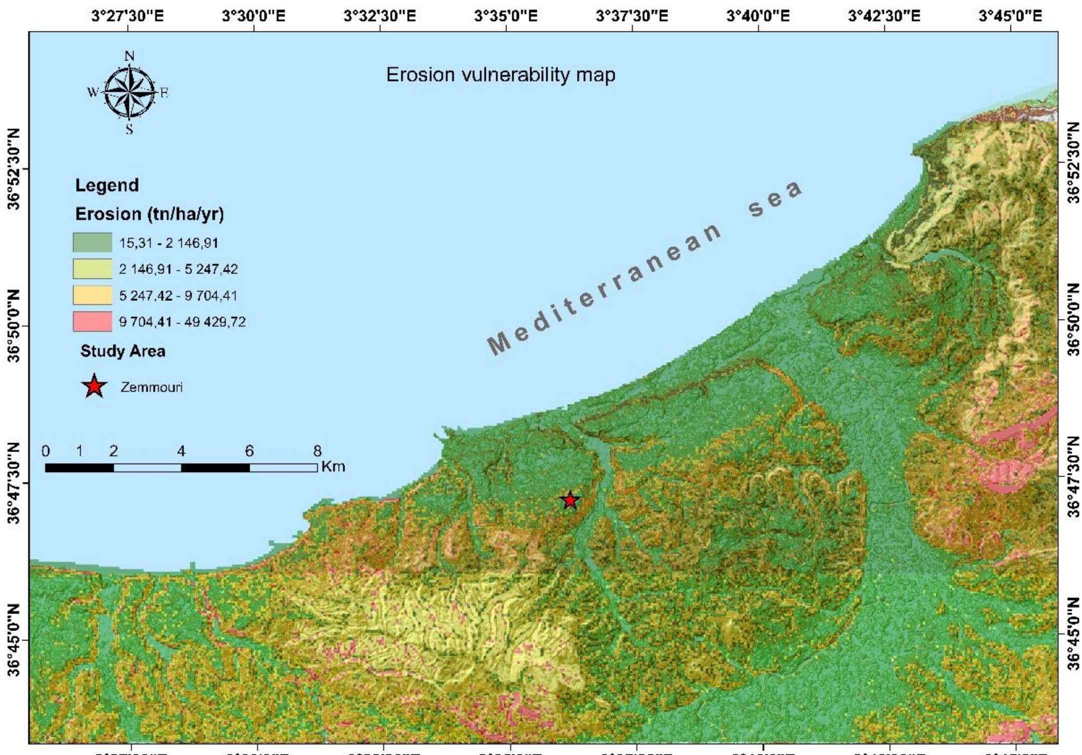

Figure 6. Erosion vulnerability map
(Data source: USGS, Land SAT Oli 8 satellite image classification)

The study's comprehensive assessment of coastal erosion's vulnerability shows the link between the various elements of GIS, AHP, and analysis (Taib, et al., 2022).

The study's combination of methodologies allowed planners, researchers, and decision-makers to thoroughly study coastal erosion's dynamics and develop targeted interventions (Singh, Jha & Chowdary, 2018).

CONCLUSION

The study revealed the outcomes of the AHP's application in identifying and mapping the erosion vulnerability in the Wilaya of Boumerdes in Zemmouri. The study also utilized the GIS's synergistic capabilities. Through the use of the AHP, the study was able to navigate through the vast amount of data sources and ultimately gain a deeper understanding of the vulnerability of the area.

The study revealed that a significant portion of the area's erosion vulnerability is higher than 63.68%. This vulnerability can be attributed to the multiple factors that affect the region's development trajectory. The study also highlighted the multiple factors that influence the development of the region's erosion vulnerability. These factors are interrelated with the region's sustainability.

The study's successful use of the AHP method in mapping the erosion vulnerability of the Nemourid region has highlighted the advantages of this technique. By combining various criteria and weights, this method can help identify and categorize the vulnerability patterns.

The AHP method's ability to provide decision support in the formulation of strategies related to the management of erosion is clear. However, it is also important to note that its effectiveness can be affected by various factors such as the accuracy and quality of the input data and the assumptions supporting the hierarchy. The study's importance in providing a comprehensive understanding of the multiple factors that affect the development of the region's erosion vulnerability is also acknowledged by the wider community.

The study's findings have also highlighted the importance of continuing to explore the various aspects of the erosion vulnerability of the area. It is clear that conducting comprehensive assessments of this type requires ongoing validation and refinement.

By utilizing the AHP technique alongside the GIS, we can create a resilient strategy to manage and mitigate the effects of erosion on our communities and landscapes.

AUTHOR CONTRIBUTIONS

Author Contributions: H.D conceptualized the study, conducted the experiments, and wrote the initial draft. N.R contributed to data analysis and interpretation. F.T provided expertise in statistical analysis. T.B and Z.M reviewed and edited the manuscript. All authors approved the final version of the manuscript.

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The research presented in this study was conducted without external financial support. The study's design, execution, and interpretation were carried out solely by the authors.

DATA AVAILABILITY STATEMENT

The data sets generated and analyzed during the current study are available in the https://earthexplorer.usgs.gov/; https://crudata.uea.ac.uk/cru/data/hrg/. Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest that could affect the integrity or impartiality of the research presented in this paper.

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