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SOIL EROSION RISK ASSESSMENT IN ARID MEDITERRANEAN REGIONS USING GIS AND THE MEDALUS MODEL: THE SOUBELLA SUB-CATCHMENT, ALGERIA

This study investigates soil erosion and land degradation in the Soubella sub-watershed of the Hodna region, Algeria, an area shaped by dryland climatic conditions ranging from semi-arid to arid. To evaluate erosion risk, the MEDALUS (Mediterranean Desertification and Land Use) model was combined with GIS-based spatial analysis. Soil erosion represents a critical environmental challenge in water-limited regions, where harsh climate and human pressures intensify land degradation. The methodological approach relied on four indices: Soil Quality (SQI), Climate Quality (CQI), Vegetation Quality (VQI), and Anthropogenic Quality (AQI). These indicators were derived from remote sensing data, GIS tools, and field surveys, offering an integrated framework for assessing ecosystem vulnerability. The sub-watershed spans 1,837.33 km², with elevations ranging from 376 to 1,871 m and an average slope of 19.02 m/km, indicating moderately rugged terrain. The semi-arid climate is characterized by high temperatures, scarce and irregular rainfall, and significant variability. At the Soubella dam site, the mean annual rainfall is only 289 mm, highlighting the climatic stress on soil and vegetation. The erosion sensitivity map revealed three categories: non-affected areas (27.5 %), sensitive areas (16.1 %), and highly sensitive areas (56.4 %). This pattern illustrates the combined influence of climate, relief, vegetation cover, and land use in driving erosion dynamics. The findings highlight the predominance of highly sensitive zones, underlining the fragility of dryland ecosystems and the need for preventive measures. By identifying erosion-prone sectors, the research provides essential guidance for decision-makers to implement sustainable land management strategies that mitigate erosion risks and enhance resilience in the Hodna region.

Keywords: erosion sensitivity, soubella sub-catchment, dryland environment, MEDALUS, GIS.

Introduction

Soil erosion and land degradation are complex processes resulting from the interaction between natural dynamics and human activities that are inappropriate [Akbari et al., 2020]. From an environmental perspective, soil erosion constitutes one of the most widespread forms of degradation, transforming once-productive lands into infertile and barren areas. It is considered a central driver of land degradation in arid, semi-arid, and dry sub-humid regions, where it is acelerated by human pressures and climate change [De la Rosa et al., 2004]. Deforestation, overgrazing, droughts, pollution, and unsustainable farming greatly accelerate soil erosion and desertification. Globally, soil erosion is recognized as one of the most pressing environmental challenges, with nearly 65 % of the world's soils affected by degradation processes, including erosion and desertification [Fadl et al., 2022]. The situation is exacerbated by climate change, which increases rainfall variability and the frequency of extreme weather events, as well as by poor agricultural management practices [Achim and Ouillon, 2015; Seghiri et al., 2022; Bensefia et al., 2024]. The impacts of erosion are multifaceted, ranging from vegetation decline and soil depletion to reduced crop yields, expansion of deserts, and the disappearance of tree cover vital for agriculture [Madani et al., 2023]. Although industrialized nations are not immune, developing countries are more severely affected due to their higher dependency on land resources. In Africa, nearly 12.5 million hectares are estimated to be vulnerable to wind and water erosion [Pushpam et al., 2015].

In Algeria, soil erosion is a particularly severe issue, especially in mountainous regions where steep slopes and fragile ecosystems amplify degradation processes.

Studies have shown that erosion is responsible for an annual loss of nearly 20 million cubic meters of dam storage capacity due to sedimentation [Remini, 2000]. This loss not only reduces water availability for irrigation and domestic use but also exacerbates flooding risks downstream [Roose et al., 2010]. In addition, erosion contributes to the gradual depletion of soil fertility and biodiversity, thereby diminishing agricultural productivity essential for sustaining rural livelyhoods [Khali et al., 2016]. These impacts extend beyond agriculture, affecting water management, infrastructure safety, and community resilience.

Over the past decades, several models and methodologies have been developed to evaluate soil erosion intensity and to guide conservation strategies. Among the most widely used approaches are the Universal Soil Loss Equation (USLE) [Cherif, 2008], its revised versions [Foster et al., 1987], the Water Erosion Prediction Project [Tra Bi, 2013], and the MEDALUS model [Plaiklang et al., 2020]. Each method incurporates various environmental parameters to simulate and predict erosion risks, but the MEDALUS framework has been particularly effective in dryland regions. By integrating physical, climatic, ecological, and anthropogenic variables, it provides a comprehensive understanding of vulnerability patterns at both local and regional scales. The Algerian steppe, particularly the southern Hodna basin, is undergoing a rapid ecological transformation due to the combined effects of climatic and anthropogenic pressures. The area is marked by advancing sand encroachment, recurrent droughts, and severe soil erosion, which together intensify desertification processes [Liazid, 2013; Abdesselam & Halitim, 2014]. These disruptions are degrading ecosystems that play a critical role in regulating microclimates and sustaining the livelihoods of local populations [Seghiri et al., 2022; Ouzir, 2023]. Given the urgency of the situation, assessing erosion risks in the Hodna basin has become a scientific and strategic priority.

The present study addresses these challenges by focusing on the Soubella sub-catchment, part of the endorheic Hodna basin. The research utilizes the MEDALUS model in conjunction with Geographic Information Systems (GIS) to identify, classify, and map areas prone to erosion. This integrative approach relies on spatial data, remote sensing, and field observations to evaluate the combined effects of natural and human-induced drivers of land degradation.

The main objectives of this study are fourfold:

· To assess the susceptibility of the Soubella sub-catchment to soil erosion under arid Mediterranean conditions.

· To identify the main physical and anthropogenic drivers of erosion and analyze the spatial distribution of erosion-prone areas through MEDALUS indices and GIS-based analysis.

· To evaluate the relative influence of environmental (climate, topography, soil quality, vegetation cover) and anthropogenic (deforestation, overgrazing, fires) factors on erosion intensity.

· To provide a scientific basis for designing sustainable land management strategies and effective desertification control policies in the Hodna basin.

· Map spatial distribution of erosion susceptibility in the Soubella sub-basin using GIS and MEDALUS.

By integrating methodological rigor with applied environmental analysis, this study seeks to produce an erosion sensitivity map that can serve as a valuable decision-making tool for land managers, policymakers, and local stakeholders. Ultimately, the findings will contribute to the implementation of targeted conservation measures aimed at reducing soil erosion, safeguarding natural resources, and ensuring the long-term resilience of the Hodna region.

Methodological approach

Study area

The Soubella sub-catchment (code 05-11), part of the Hodna Basin (code 05, NAHR), spans 1837.33 km². Located north of the Magra commune, approximately 340 km southeast of Algiers and about 60 km east of the capital of M'Sila Province, between 35°51'32"–35°23'52" N and 4°48'9"–5°31'18" E (Fig. 1), it stretches from the southern slopes of the Hodna Mountains in the north to the northern edge of Chott El Hodna in the south, and borders the Bou Taleb Massif to the center-west. The Soubella sub-catchment features elevations ranging from 376 to 1,871 meters, with an average slope of 19.02 m/km, indicating moderately varied terrain (Table 1). Its climate is semi-arid, with mean annual temperatures between 14.2 and 17.6 °C [Hasbaia et al., 2017] and an average rainfall of around 289 mm [NAHR, 2020]. Precipitation is unevenly distributed, exhibiting a bimodal regime characterized by hot, dry summers and rainfall peaks during the autumn and winter months [Seddiki & Khemissa, 2021].

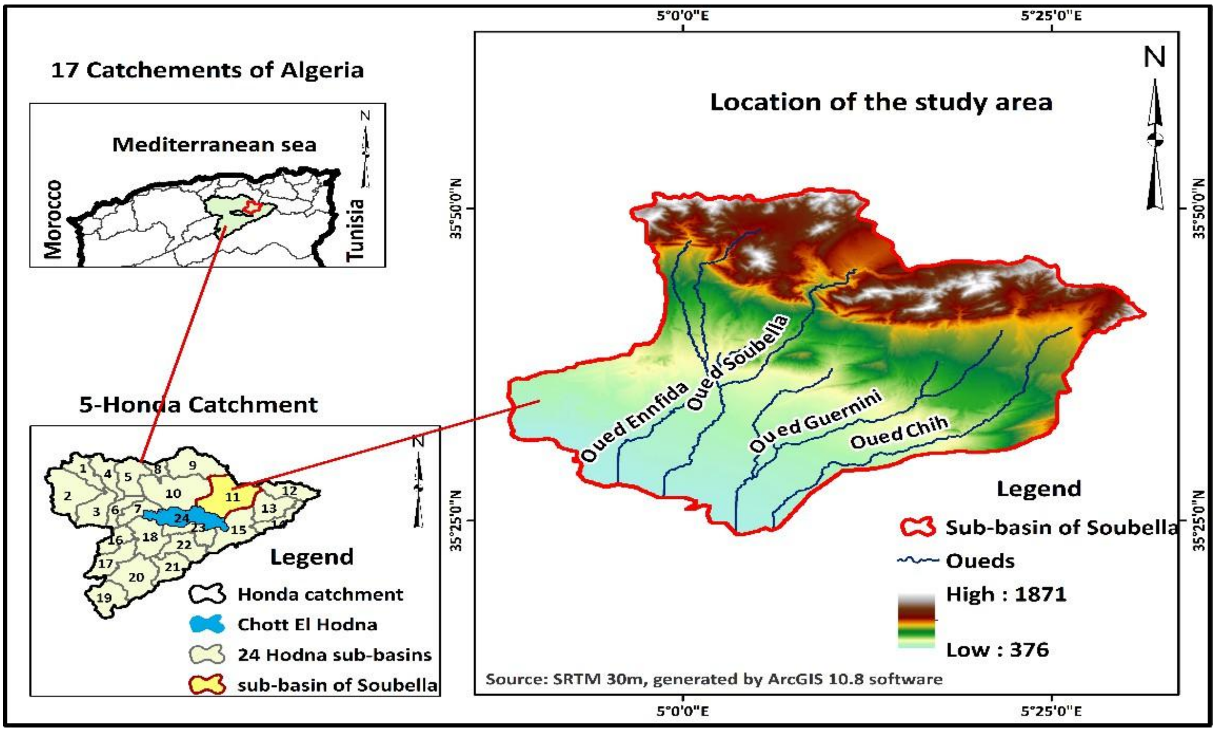

Fig. 1. Geographical Location and Elevation Profile of the Soubella Sub-Catchment.

Table 1

Morphological and hydrographic characteristics of the Soubella sub-basin

Features	Symbol	Unit	Value
Sub-basin area	*A*	km²	1,837.33
Perimeter	*P*	km	231.275
Sub-basin length	*L*	km	96.62
Sub-basin width	*I*	km	19.02
Form factor	*K*	/	1.51
Maximum altitude	*H*max	m	1871
Minimum altitude	*H*min	m	376
Medium slope	*Im*	m/km	19.02
Length of the main river	*Lp*	km	53.61
Drainage density	*Dd*	km/km²	0.15

Data and materials used

To build the database and generate the thematic layers needed for applying the MEDALUS model, several erosion-related variables were collected from existing sources and processed in a GIS environment. These datasets enabled the calculation of four quality indices: Soil (SQI), Climate (CQI), Vegetation (VQI), and Anthropogenic (AQI), along with the integrated Erosion Sensitivity Index (ESI), which served as the foundation for spatial assessment (Table 2, Fig. 2).

Table 2

Materials used

Documents						Programs
Image satellite	Satellite	Sensor	UTM Zone	Acquisition Date	Cloud Coverage	Envi 5.4
	LANDSAT_9	OLI_TIRS	31	10-05-2024	0.02	
DEM	Digital Model Elevation (DEM) of the Soubella sub-basin (SRTM).					
Cartographic data	Title			Scale	Support	ArcGIS 10.8
	Ø Maphydro-climatological and water quality monitoring network [ANRH., 2005]			1/500000	Scan	
	Ø Surface geological map of Africa (geo7_2ag), published on June 21, 2021 [Publication Date 2021-06-21]			/	Download	Global Mapper 15.1
Other data	Ø Monography of the M'Sila and Setif provinces [DPSB. 2020]. Ø Statistical data from the M'Sila and Setif provinces [DSA. 2020]. Ø Climatic data for the province of M'sila [ANRH. 2020].					

Image satellite : ID :LC09_L1TP_195035_20240510_20240510_02_ T1.Satellite data extracted from the USGS (United States Geological Survey) website.
DPSB–Directorate of Programming and Budget Monitoring-Msila.: 2020.
DSA: Department of Agricultural Services.: 2020.
ANRH: National Agency of Hydraulic Resources(NAHR. 2020).

Using the MEDALUS Model to Analyze Erosion Risk

This study applies the MEDALUS model, which assesses erosion sensitivity by calculating the geometric mean of key quality indices related to soil, climate, vegetation, and land use [Plaiklang and al., 2020]. These factors, identified by Fadl et al. [2022], are known to significantly influence soil degradation.

The indices used in this model were derived from a multi-source dataset (Fig. 2).

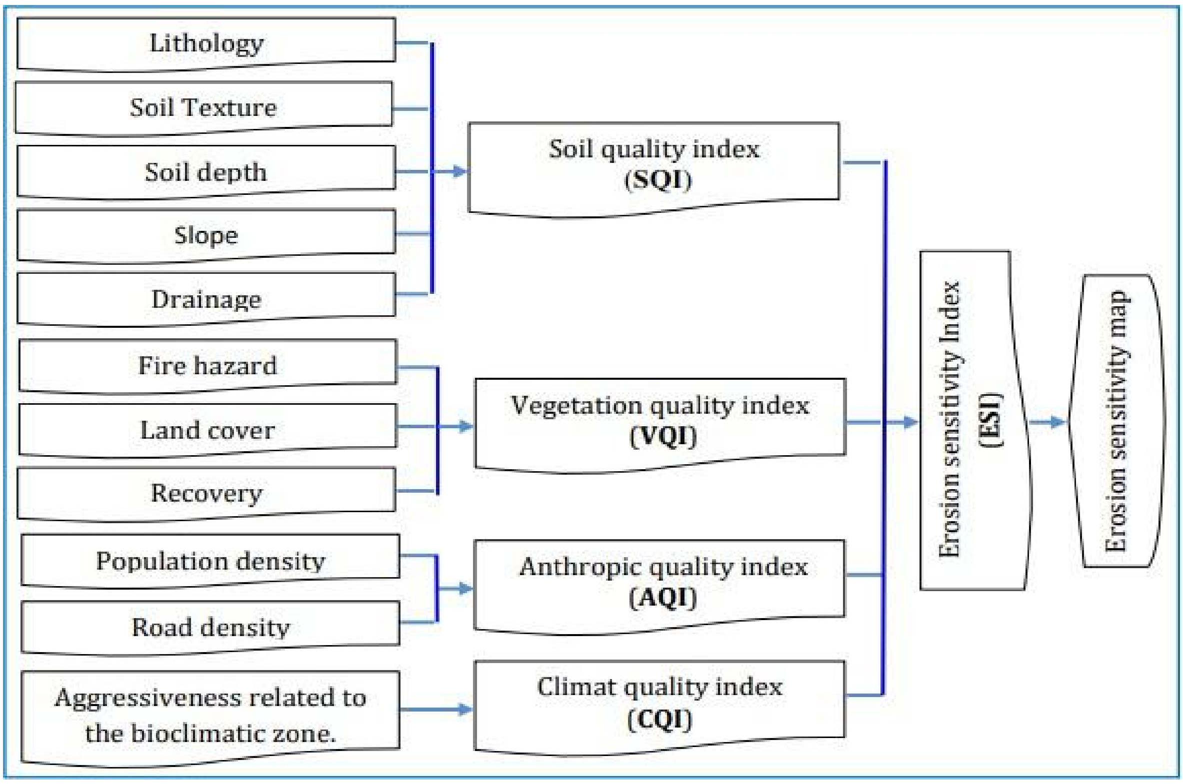

Fig. 2. Schematic Illustration of the ESI Index Computation Process.

The evaluation considered four factors, each represented by a specific quality index. Scores were assigned on a scale ranging from 1, reflecting low sensitivity, to 2, reflecting high sensitivity. Based on these scores, desertification sensitivity was classified into five categories: very low, low, moderate, high, and very high. This classification provides a structured framework for analyzing the degree of land vulnerability. The results of this assessment are summarized and presented in Table 3.

Table 3

Classification of Parameters and Index Values for SQI, CQI, AQI, and VQI

Index	Erosion Factor	Class	Features	Description	Score
SQI	Lithology	1	Blue marls, sandstone	Good	1
		2	arls, sandstones, limestones, diatomites, gypsum marls, carbonates marl-limestone Sandy clays, carbonates, and sandstones. Sandy marls, alluvium marls, limestones, and clays	Moderate	1.7
		3	Clayey-carbonate, clayey-sandstone	Poor	2
	Texture	1	L, CL	Good	1
		2	C	Moderate	1.6
	Slope	1	< 6	Verygentle	1
		2	6–12	Soft	1.2
		3	12–25	Steep	1.5
		4	>25	Verysteep	2
	Drainage	1	Well drained	Good	1
		2	Medium-drained	Moderate	1.4
		3	Imperfectly drained	Poor	2
	Depth	1	<75	Deep	1
		2	30–75	Moderate	2
		3	15–30	Shallow	3
		4	>75	Veryshallow	4
CQI	Bioclimatic Zones	1	Q >40	Upper Arid	1
		2	Q<40	Lower Arid	2
AQI	Population density	1	<15 people/km²	Good	1
		2	15–20 people/km²	Moderate	1.33
		3	20–50 people/km²	Poor	1.66
		4	>50 people/km²	Verypoor	2
	Road density	1	<3 km/km²	Good	1
		2	3–7 km/km²	Moderate	1.66
		3	>7 km/km²	Poor	2
VQI	Fire hazard	1	Baresoil, steppe	Low	1
		2	Crop, shrubsteppe	Medium	1.3
		3	Scrub-forest	High	2
	Erosion protection	1	Scrub-forest	High	1
		2	Shrubsteppe	Medium	1.3
		3	Steppe	Low	1.6
		4	Baresoil, cultivation	Very low	2
	Drought resistance	1	Bare soil	High	1
		2	Steppe	Medium	1.4
		3	Shrub steppe	Low	1.7
		4	Forest and scrub, cultivation	Very low	2
	Recovery	1	>40 %	High	1
		2	10–40 %	Medium	1.8
		3	<10 %	Low	2

Explanations: L=Loam, CL= ClayLoam, C = Clay.
Source: Personal work inspired by studies from KOSMAS et al. (1999) and BASSO et al. (2012).

In Algeria, soils are undergoing increasing degradation, both in quality and quantity, posing a threat to agroecological sustainability [Morsli et al., 2013]. Soil erosion sensitivity, defined by four key factors: lithology, texture, slope, and drainage, was assessed using digitized maps and Digital Elevation Models (DEMs). These variables were integrated into a Soil Quality Index (SQI) to identify the areas most vulnerable to degradation.

$$\boldsymbol{SQI} = (\boldsymbol{Lithology} \cdot \boldsymbol{Texture} \cdot \boldsymbol{Solpe} \cdot \boldsymbol{Drainage} \cdot \boldsymbol{Depth})^{1/5} \quad (1)$$

Erosion increasingly threatens Algeria’s arid and semi-arid ecosystems, where the gradual and often irreversible loss of vegetation cover calls for strengthened conservation strategies [Chermat et al., 2013]. Vegetation status was assessed using indicators such as fire risk, erosion control, drought tolerance, and recovery ability (Equation 2), derived from processed Landsat 9 satellite imagery. Image processing included area extraction and atmospheric correction to enhance data reliability. A land cover map was produced through visual classification of remote sensing indices, notably the NDVI, enhancing image quality and enabling key data extraction. This allowed for the calculation of the Vegetation Quality Index (VQI), which accurately reflects the vulnerability of vegetation to erosion. The integrated approach supports informed decision-making for the conservation and sustainable management of fragile ecosystems.

$$\boldsymbol{VQI} = (\boldsymbol{Firerisk} \cdot \boldsymbol{Erosion\ protection} \cdot \boldsymbol{Drought\ resistance} \cdot \boldsymbol{Recovery})^{1/4} \quad (2)$$

Algeria’s Mediterranean climate, shaped by maritime influence, topography, and altitude, is marked by intense and irregular rainfall [Achite and al., 2006]. Climatic vulnerability was evaluated using annual precipitation and the aridity index (Equation (3)), with data sourced from the NARH and platforms like Infoclimat. These indicators supported the calculation of the Climate Quality Index (CQI), reflecting the region’s sensitivity to erosion.

$$\boldsymbol{CQI} = \boldsymbol{Bioclimatic\ zones} \quad (3)$$

Human activities significantly intensify erosion processes, underlining their growing role in accelerating soil degradation [Harkat et al., 2011]. This impact is assessed using indicators such as population density, livestock density, and land use (Equation (4)), with data sourced from institutions like DAS and DPBM. These parameters are used to calculate the Anthropogenic Quality Index (AQI), which quantifies human influence on land degradation.

$$\boldsymbol{AQI} = (\boldsymbol{Population\ density} \cdot \boldsymbol{Road\ density})^{1/2} \quad (4)$$

The Erosion Sensitivity Index (ESI) was calculated by combining the Soil, Vegetation, Climate, and Anthropogenic Quality Indices, as expressed in formula (5).

$$\boldsymbol{ESI} = (\boldsymbol{SQI} \cdot \boldsymbol{VQI} \cdot \boldsymbol{CQI} \cdot \boldsymbol{AQI})^{1/4} \quad (5)$$

The results were mapped using ArcGIS 10.8, allowing for the spatial visualization of vulnerable areas and the identification of high-risk zones within the Soubella sub-basin.

Results and discussion

Erosion is driven by the interaction of slope, soil erodibility, and vegetation cover. Human activities, such as grazing and cultivation on marginal lands, further intensify this natural vulnerability.

Soil Quality Index (SQI)

The distribution of soils according to their quality in the Soubella sub-basin is illustrated in Table 04, highlighting clear spatial variability. A large portion of the territory (62.6 %) consists of high-quality soils, indicating a good state of conservation and satisfactory fertility. Conversely, 28.9 % of the area is affected by significant degradation, characterized by low organic matter content, severe erosion, and physico-chemical alterations. The intermediate class, representing 8.5 % of the area, corresponds to soils in a transitional phase, requiring restoration measures to prevent further degradation. Fig. 3 shows the distribution of soil according to its quality in this catchment.

Table 4

Distribution of the three Soil Quality Classes

Class	Description	Rank	Area, %
1	High quality	≤1.13	62.6
2	Moderate quality	1.13- 1.45	8.5
3	Low quality	≥1.46	28.9

Source: personal analysis in ArcGIS software.

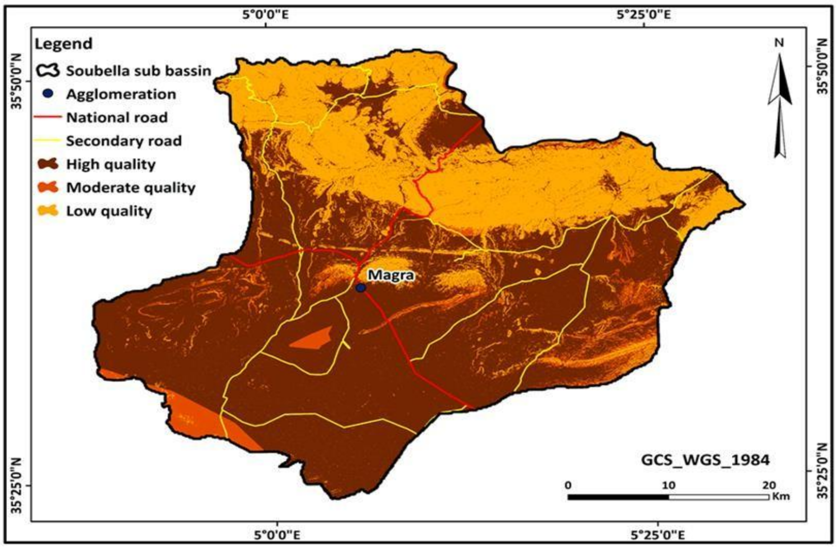

Fig. 3. Distribution of soil Quality.

Climatic Quality Index (CQI)

The distribution of climatic quality in the Soubella sub-basin is shown in Table 5, based on an index that integrates aridity and rainfall variability. Most of the area (78.13 %), mainly in low-altitude zones, experiences unfavorable conditions that increase erosion risk. Only 4.67 % of high-altitude land benefits from favorable climates, while 17.20 % in mid-altitudes show moderate vulnerability. These results reveal a strong correlation between elevation and climate deterioration, as illustrated in Fig. 4.

Table 5

Distribution of the three Climate Quality Classes

Class	Description	Rank	Area, %
1	High quality	≤1.22	27.9
2	Moderate quality	1.23- 1.44	13.2
3	Low quality	≥1.44	58.9

Source: personal analysis in ArcGIS software.

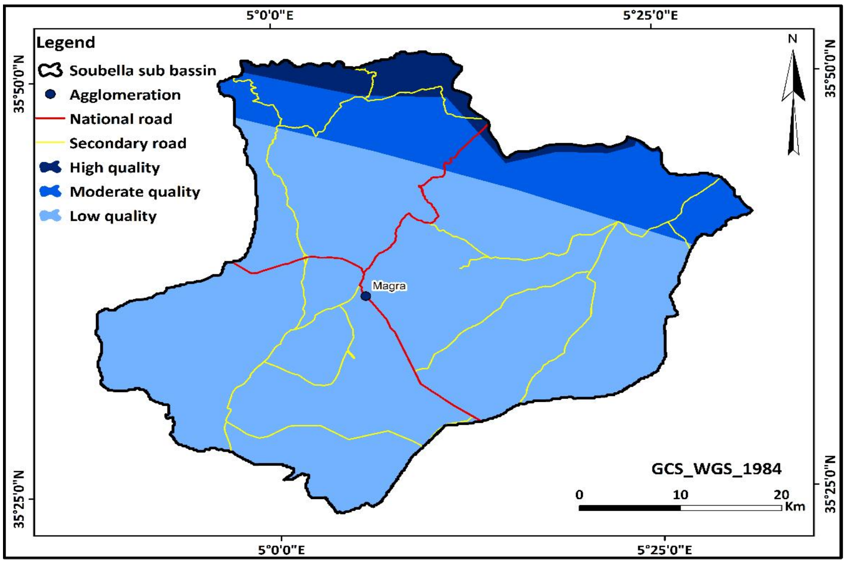

Fig. 4. Distribution of climate Quality.

Anthropogenic Quality Index (AQI)

The distribution of anthropogenic quality classes is illustrated in Table 6, evaluating the impact of human activities on land degradation. Most of the area (58.9 %) experiences strong human pressure, while 27.9 % benefits from more sustainable practices.

The remaining 13.2 % shows a moderate impact. These results emphasize the need for integrated land management to mitigate degradation (Fig. 5).

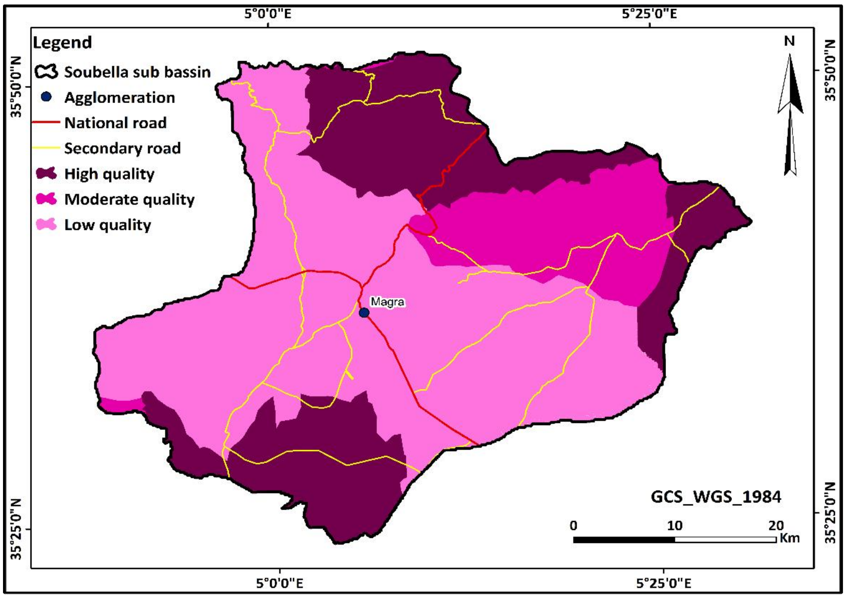

Fig. 5. Distribution of Anthropogenic Quality.

Table 6

Distribution of the three Anthropogenic Quality Classes

Class	Description	Rank	Area, %
1	High quality	≤1.22	27.9
2	Moderate quality	1.23- 1.44	13.2
3	Low quality	≥1.44	58.9

Source: personal analysis in ArcGIS software.

Vegetation Quality Index (VQI)

Table 7 presents the classification of vegetation quality based on factors such as vegetation cover density, fire risk, erosion protection, and drought resistance. The analysis shows that 48.5 % of the land has low vegetation quality, primarily in low-altitude areas affected by aridity, low rainfall, and degradation due to factors such as desertification, overexploitation, and drought. In contrast, 26.2 % of the territory has high vegetation quality, mostly at higher altitudes with more favorable climatic conditions.

The remaining 25.3 % is of mode-rate quality, indicating partial degradation. These fin-dings underscore the urgent need for vegetation restoration in vulnerable lowland zones to enhance resilience to erosion and climate change (Fig. 6).

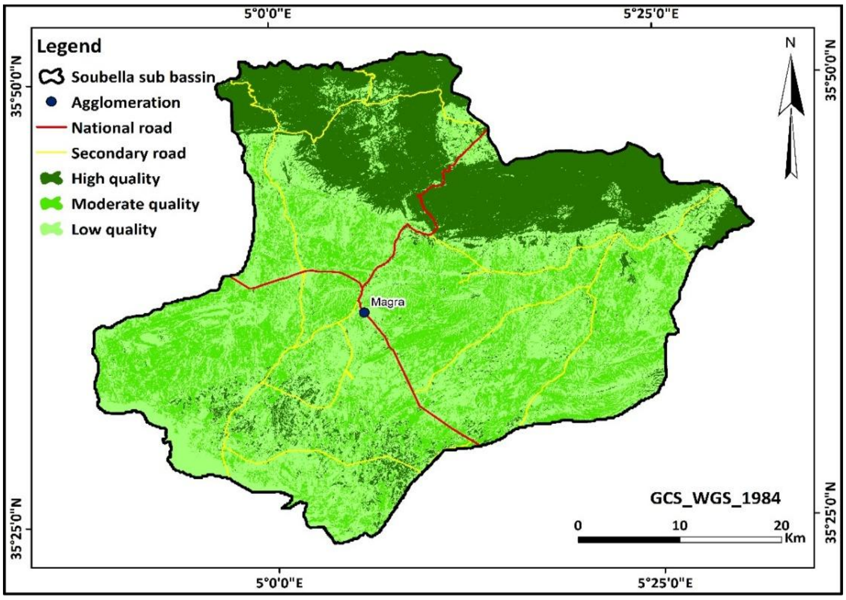

Fig. 6. Distribution of Vegetation Quality.

Table 7

Distribution of the three Vegetation Quality Classes

Class	Description	Rank	Area, %
1	High quality	≤1.23	26.2
2	Moderate quality	1.23- 1.44	25.3
3	Low quality	≥1.44	48.5

Source: Personal analysis in ArcGIS software.

Map of Erosion Sensitivity Index (ESI)

The ESI cartographic analysis revealed three distinct erosion sensitivity zones: non-affected, sensitive, and highly sensitive, closely linked to environmental conditions and human activity (Table 8 & Fig. 7). These findings, consistent with M'hamdia et al. [2016], underscore the decline in vegetation due to climatic and anthropogenic pressures.

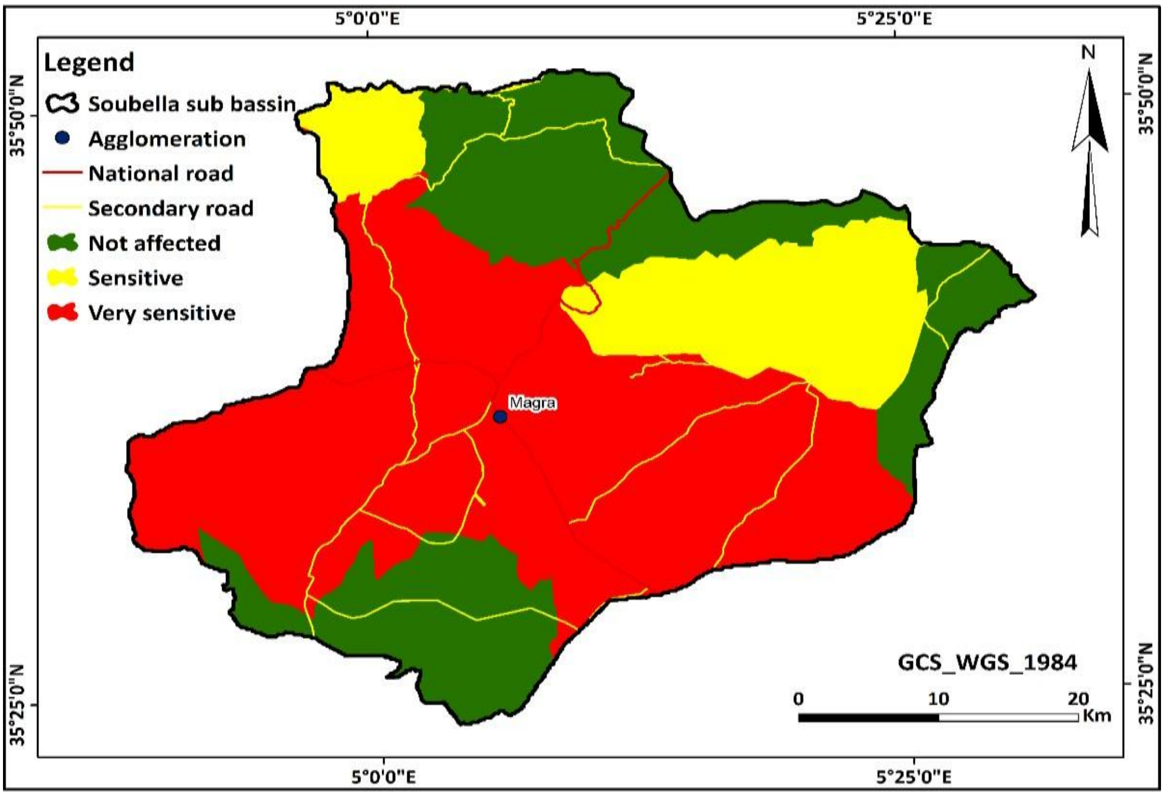

Fig. 7. Erosion Sensitivity map of the Soubella Sub-catchment, Hodna.

Table 8

Erosion sensitivity classification according to the ESI

Class	Description	Rank	Area, %
1	Non-affected	≤1.37	27.5
2	Sensitive	1.38- 1.53	16.1
3	Very sensitive	≥1.53	56.4

Source: personal analysis in ArcGIS software.

Highly sensitive zones, covering 56.4 % of the area, are characterized by harsh climatic conditions, including aridity, low and erratic rainfall, and high variability that weaken ecosystem resilience. Additionally, 48.5 % of the land has poor vegetation quality, which reduces natural protection against erosion and limits soil regeneration. This finding is consistent with that of Fredj et al. [2024]), who reported severe erosion in several areas, necessitating urgent soil conservation measures. Human pressure is also a key factor, affecting 58.9 % of the land through overgrazing, deforestation, and urbanization. While 62.6 % of the territory consists of high-quality soils, 28.9 % of the degraded soils are in poor condition (Fig. 7 & Fig. 8).

Sensitive zones represent 16.1 % of the total area and are characterized by moderate levels of degradation. These areas, mostly at intermediate altitudes, experience less severe climatic conditions (17.2 %) and moderate human pressure (13.2 %) compared to highly sensitive zones. Vegetation is slightly degraded but still provides some erosion control. Consistent with Djoukbala et al. [2024], these zones show noticeable erosion and regional disparities, emphasizing the need for targeted mitigation and sustainable management strategies to reduce desertification risk (Fig. 8).

Approximately 27.5 % of the land is classified as non-affected or insensitive to desertification. These areas, mainly located at higher altitudes, benefit from favorable climatic conditions and dense, resilient vegetation, providing strong resistance to erosion. This finding aligns with Boudjemline et Semar [2018], who noted that land degradation in the Hodna region varies by zone, with mountainous areas generally showing lower sensitivity. In contrast, lowlands and high steppe plateaus are more affected due to factors such as rainfall variability, altitude, and human or livestock pressure. Similarly, Djamila et al. [2023] emphasized that erosion poses a serious threat in vulnerable areas, leading to vegetation loss, soil degradation, reduced agricultural productivity, and deforestation. These impacts are particularly evident in the highly sensitive zones identified in this study.

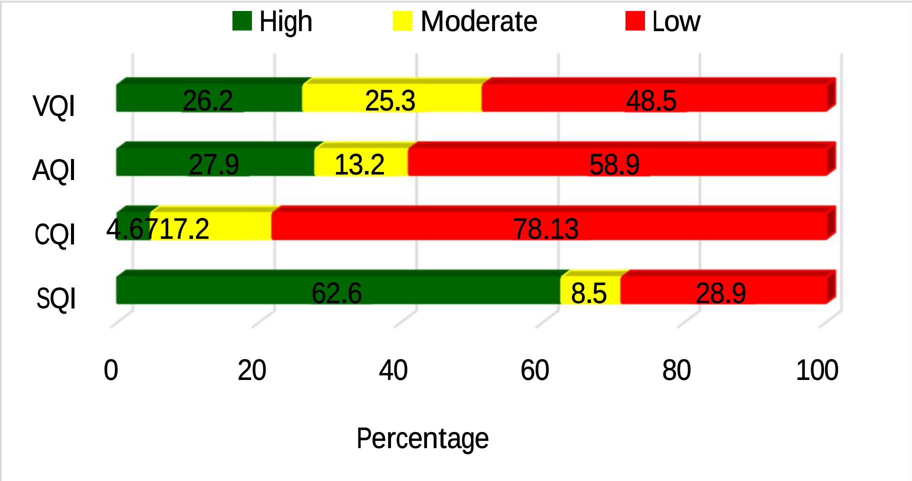

Fig. 8. Demonstrates the influence of individual quality indicators on erosion vulnerability (Personal analysis in ArcGIS software).

In conclusion, the distribution of various indices played a crucial role in determining erosion sensitivity levels. Highly sensitive zones, marked by adverse conditions, are the most at risk, whereas non-sensitive areas, with more favorable environments, show greater resilience to erosion.

The MEDALUS model offers a valuable tool for spatial diagnostics; however, its predictions may be over- or underestimated at the local scale unless complemented with field data and stakeholder knowledge. Ultimately, the effectiveness of erosion management depends on adapting interventions to both the physical environment and socio-economic context, for instance, by implementing check dams in gullies or introducing incentive programs to encourage grazing rest.

Conclusion

This study evaluated erosion sensitivity in the Soubella sub-basin (Algeria) through an integrated approach that combined the MEDALUS model with geomatics tools. The approach allowed for a detailed spatial analysis of erosion-prone areas, revealing a complex pattern of vulnerability shaped by the combined influence of climate, ecological characteristics, and human activities. The findings indicate that most of the basin is exposed to a high erosion risk, particularly in zones characterized by harsh climatic conditions, degraded vegetation, fragile soils, and unsustainable land-use practices. Conversely, areas located at higher altitudes exhibit lower vulnerability due to denser vegetation cover, more consistent rainfall, and relatively lower anthropogenic pressure.

From an explanatory perspective, these results confirm that erosion is not solely the result of natural processes but rather the outcome of interactions between environmental fragility and socio-economic drivers. Climatic aridity and irregular rainfall events reduce soil stability, while human activities such as overgrazing, deforestation, and cultivation on marginal lands accelerate degradation processes. This interplay reinforces the idea that soil erosion must be addressed as both an environmental and a developmental challenge, requiring integrated management responses.

In terms of discussion, the MEDALUS–GIS integration proved effective in capturing the spatial variability of erosion sensitivity and in producing a decision-support map that can guide local and regionnal planning. However, the model's predictive value depends on continuous updating with field data and stakeholder input to capture dynamic changes in land use and ecological conditions. Furthermore, the results emphasize that management strategies must be tailored to local realities, as a single intervention can-not adequately address the diverse conditions within the basin.

Based on these findings, several management recommendations can be proposed. Highly sensitive zones should be prioritized for urgent interventions, including reforestation with native species, the construction of check dams and terraces to control runoff, and the introduction of agroforestry systems that combine soil protection with livelihood support. Moderately sensitive areas require preventive strategies to avoid further degradation, such as sustainable agricultural practices (e. g., conservation tillage, crop rotation, and organic amendments), controlled grazing, and the rehabilitation of degraded rangelands. In contrast, less sensitive areas, while relatively resilient, still require protection through careful monitoring, zoning, and land-use planning to prevent future pressures. Additionally, raising community awareness and promoting participatory land management are essential to ensuring the success of conservation efforts, as local populations play a critical role in maintaining and restoring ecological balance.

Overall, this research demonstrates that combining the MEDALUS framework with GIS provides not only a robust diagnostic of erosion sensitivity but also a practical foundation for designing sustainable land management strategies. By integrating ecological restoration with improved agricultural practices and socio-economic measures, decision-makers and stakeholders can mitigate erosion risks, safeguard natural resources, and strengthen the resilience of both ecosystems and local communities. The insights gained from this study are particularly relevant for arid and semi-arid regions, where land degradation poses a significant threat to food security, livelihoods, and long-term sustainability.

While the present study demonstrates the value of integrating the MEDALUS framework with GIS to assess erosion sensitivity, several avenues remain open for future exploration.

First, the use of high-resolution remote sensing data such as Sentinel-2, UAV imagery, or LiDAR could improve the spatial accuracy of erosion sensitivity maps by capturing fine-scale variations in vegetation cover, soil characteristics, and topography [Koirala et al., 2019; Phinzi&Ngetar, 2019]. Second, expanding the set of biophysical and socio-economic variables considered in the MEDALUS model – such as soil moisture, land tenure, grazing intensity, or population pressure – would provide a more comprehensive understanding of erosion dynamics [Borrelli et al., 2017; Fenta et al., 2020].

Another promising direction involves integrating erosion models with hydrological and sediment transport simulations, which would enhance predictive capacity and allow for the testing of different land management scenarios under varying climatic and land use conditions [Panagos et al., 2015; Nearing et al., 2017]. In addition, long-term monitoring through time-series analysis is crucial for capturing seasonal and interannual variability in erosion sensitivity, particularly in arid and semi-arid regions where rainfall variability has a significant impact on land degradation [García-Ruiz et al., 2017].

Finally, future research should adopt participatory and transdisciplinary approaches, combining scientific modeling with local knowledge and stakeholder engagement to design context-specific solutions. Incorporating socio-economic assessments and community priorities would ensure that proposed interventions are not only technically sound but also socially acceptable and economically viable [Stringer et al., 2009; Reed et al., 2018]. Such approaches would strengthen the link between scientific diagnostics and sustainable land management policies, particularly in regions like northern Algeria, where rural livelihoods are closely tied to fragile ecosystems.

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ОЦІНЮВАННЯ РИЗИКУ ЕРОЗІЇ ҐРУНТУ В ПОСУШЛИВИХ СЕРЕДЗЕМНОМОРСЬКИХ РЕГІОНАХ З ВИКОРИСТАННЯМ ГІС ТА МОДЕЛІ MEDALUS: ПІДВОДОЗБІР СУБЕЛЛА, АЛЖИР

Мета цієї роботи – дослідження ерозії ґрунту та деградації земель у підводозбірному басейні Субелла регіону Ходна, Алжир, районі, що формується посушливими кліматичними умовами від напівпосушливих до посушливих. Для оцінювання ризику ерозії модель MEDALUS (Середземноморське опустелювання та землекористування) була поєднана з просторовим аналізом на основі ГІС. Ерозія ґрунту є критичною екологічною проблемою у регіонах з обмеженим водним балансом, де суворий клімат та антропогенний тиск посилюють деградацію земель. У методологічному підході використано чотири індекси: якість ґрунту (SQI), якість клімату (CQI), якість рослинності (VQI) та антропогенна якість (AQI). Ці показники отримано на підставі даних дистанційного зондування, інструментів ГІС та польових досліджень. Запропоновано інтегровану основу для оцінювання вразливості екосистеми. Підводозбірний басейн охоплює площу 1837,33 км² з висотами від 376 до 1871 м та середнім ухилом 19,02 м/км, що вказує на помірно пересічений рельєф. Напівпосушливий клімат характеризується високими температурами, рідкісними та нерегулярними опадами, а також значною мінливістю. На ділянці греблі Субелла середньорічна кількість опадів – лише 289 мм, що свідчить про кліматичний стрес для ґрунту та рослинності. Карта чутливості до ерозії виявила три категорії: неуражені території (27,5 %), чутливі території (16,1 %) та високочутливі території (56,4 %). Ця закономірність ілюструє комбінований вплив клімату, рельєфу, рослинного покриву та землекористування на динаміку ерозії. Результати дослідження демонструють переважання високочутливих зон, підкреслюючи крихкість посушливих екосистем та необхідність превентивних заходів. Визначаючи схильні до ерозії сектори, дослідження надає важливі рекомендації для осіб, що приймають рішення щодо впровадження стратегій сталого управління земельними ресурсами, які пом'якшують ризики ерозії та підвищують стійкість у регіоні Ходна.

Ключові слова: чутливість до ерозії, підводозбір Субелли, посушливе середовище, MEDALUS, ГІС.

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