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Desertification Vulnerability in Arid Mediterranean Ecosystems: A Case Study of the Boussaada Sub-Basin, (Southwest Hodna, Algeria).

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Abstract

Desertification represents a pressing global concern, with Algeria facing significant challenges in this regard. The Hodna region is undergoing rapid landscape transformation due to Desertification. Protecting against desertification and improving the living conditions of dependent populations have become national priorities in Algeria. The aim of this study is to assess desertification sensitivity, develop a set of thematic maps (including vegetation quality, soil quality, etc.), and established GIS-based of the study area using Geographic Information System (GIS) based on the MEDALUS (Mediterranean Desertification and Land Use) approach. The Desertification Sensitivity Index (DSI) is derived by integrating four primary indicators: Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), and Anthropogenic Quality Index (AQI). The analysis of the desertification sensitivity map for the Boussaada sub-basin identified five distinct zones: highly sensitive, sensitive, moderately sensitive, less sensitive, and non-sensitive. The findings reveal that 76% of the Boussaada area is categorized as sensitive to highly sensitive to desertification. This region is defined as a pre-desert zone, characterized by an arid climate with scarce and erratic rainfall, alongside inadequate land management practices.

Keywords: Desertification; Sensitivity; Boussaada sub-basin; MEDALUS; GIS.

1. Introduction

The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992, defines desertification as "land degradation in arid, semi-arid, and dry sub-humid regions caused by a combination of factors, including climate change and human activities" (Eun Jung et al., 2019). Desertification and land degradation are marked by various phenomena (Mainguet, 2006), such as the deterioration of vegetation, the spread of sandy areas, soil depletion, declining agricultural productivity, and deforestation (Madani et al., 2023).

Desertification represents a major environmental issue for Algeria and other countries in the Maghreb and Middle East (Mostephaoui, 2013). Arid and steppe regions cover over 600,000 km² north of the Sahara, with around 34% of this area located in Algeria (Le Houérou, 1995). In recent years, the Algerian steppe has faced ecological and climatic instability, leading to significant degradation of its fragile environment (Liazid, 2013). Climate variability continues to exert pressure on ecosystems, particularly in the southern regions (Benmessaoud, 2009). The southern Hodna region has undergone rapid landscape changes due to desertification, posing a serious challenge for local communities (Abdesselam et al., 2014).

This degradation is not an isolated issue; the natural spaces in the region are suffering from poor conditions, including soil erosion, desertification, water scarcity, and biodiversity loss, despite their critical role in supporting human life (Seghiri et al., 2022) and their ability to create microclimates (Ouzir, 2023). Protecting the steppe, combating desertification, and improving the livelihoods of affected populations have become key national priorities in Algeria (Daoudi et al., 2010).

The aim of this study is to evaluate the level of land degradation in the Boussaada sub-basin, located in the southwestern part of Hodna, and to produce a series of thematic maps (e.g., land use map, soil quality map, etc.), as well as to establish a database (DB) for the study area. The methodology involves classifying areas based on their susceptibility to desertification, assessing the extent and severity of land degradation, and identifying regions most vulnerable to high degradation risks. Remote sensing and Geographic Information Systems (GIS) were employed to analyze the state of degradation and assess the extent of desertification using a desertification sensitivity map. This map is crucial for developing effective management and conservation strategies.

After outlining the physical characteristics of the study area and detailing the methods used, the results of the desertification analysis for the Boussaada sub-basin were examined. A desertification sensitivity map was created, significantly aiding in the evaluation of degradation levels in the southwestern Hodna region.

2. Materials and methodological approach

2.1. Study area

The Boussaada sub-basin, located in the southwest part of the Hodna watershed within M'sila province, is one of the eight sub-basins of Algeria's fifth major basin. The Hodna catchment, spanning an area of nearly 26,000 km², serves as a transitional zone between the Tellian domain to the north and the Sahara to the south (Kebiche, 1994).The Boussaada sub-basin covers an area of 2,938.36 km2 with a length of 96.8 km and is divided into three distinct sub-basins: Maiter downstream (1263.05 km2), Boussaada (1018.81 km2), and Maiter upstream (656.5 km2) (Fig. 1).Geographically, the study area is situated between 35°27'2.4013" North and 34°47'21.0125" South, and 3°35'56.3117" West and 4°31'7.7631" East. The elevation of the sub-basin ranges from 393 to 1644 meters from north to south (Tab. 1), with predominantly low to moderate slopes (6 to 25%).The sub bassin is characterized by limestone mountain ranges and sparse vegetation coverage. Climatic parameters, derived from meteorological data collected by the National Agency of Hydraulic Resources(ANRH) and other sources for the period 1990-2020, indicate a mean annual temperature of 19.67°C, with climatological means of annual minimum and maximum temperatures of 13.39°C and 25.95°C, respectively, and a climatological mean of annual precipitation of 180.97 mm. The sub-basin's position relative to the Saharan Atlas and its morphometric characteristics highlight its hydrological and geomorphological significance.

Table 1: Morphological and hydrographic attributes of the Boussaada sub-basin.

Features	**Symbol**	**Unit**	**Value**
Sub-basin area	A	Km²	2938,36
Perimeter	P	Km	317,87
Sub-basin length	L	Km	96,8
Sub-basin width	I	Km	30,35
Form factor	K	/	1,64
Maximum altitude	H_{max}	m	1644

Minimum altitude	H_{min}	m	393
Medium slope	I_m	m/Km	23,08
Length of main river	L_p	Km	102,8
Drainage density	D_d	Km/Km^2	0,16

Source: Own analysis using ArcGIS software.

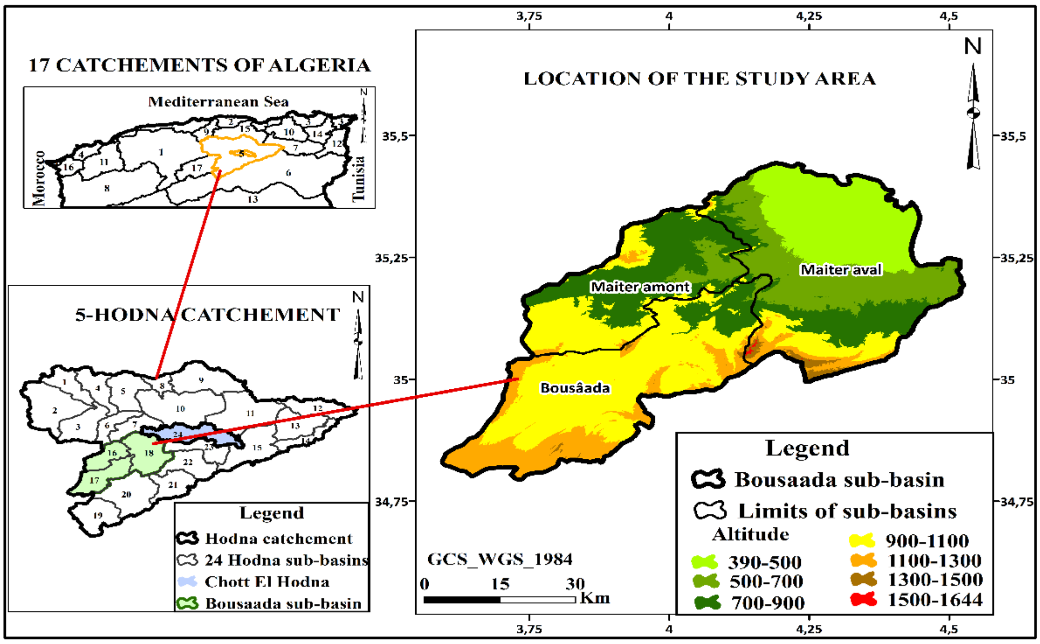

Fig. 1. Location and morphological features of the Boussaâda sub-basin. Source: SRTM 30 m, generated by ArcGIS 10.8.

2.2. Materials used

The study employed a variety of geospatial data, satellite imagery, and statistical records to extract indicators for evaluating desertification indices.

Table 2. Materials used

Documents							**Programs**
Image satellite	**Satellite**	**Sensor**	**UTM Zone**	**Acquisition Date**	**Cloud Coverage**		**ArcGIS 10.8**
	LANDSAT_8	OLI_TIRS	31	15-03-2024	0.04		
DEM	Digital Model Elevation (DEM) of the Boussada sub-basin (SRTM).						
Cartographic data	**Title**				**scale**	**support**	
	➢ Map of hydro-climatological networks and water quality monitoring [ANRH., 2005]				1/500 000	Scan	
	➢ Surficial geology of Africa (geo7_2ag) [Publication Date 2021-06-21]				/	download	
Other data	➢ Monographie for the province de M'sila[DPSB.,2020]. ➢ Static data for the province of M'sila [DSA., 2020]. ➢ Climatic data for the wilaya of M'sila [ANRH., 2020].						

Maps were digitized and processed, such as lithology maps, to assess soil characteristics, while drainage density and slope maps were derived from Digital Elevation Models (DEMs). Satellite imagery from Landsat 8 TM (LC08_L2SP_195036_20240315_20240401_02_T1) with a 30 m resolution was processed using ArcGIS 10.8. Key processing steps included image clipping to extract the region of interest, color composition for enhanced data visualization, and atmospheric correction to convert Top of Atmosphere (TOA) reflectance values to surface reflectance. Climatic indicators, such as average aridity, were calculated using the Bagnouls-Gaussen Index (BGI), and annual precipitation data were derived from statistical records provided by organizations such as ANRH and online platforms like Infoclimat. Socio-environmental indicators, including population density and livestock density, were obtained from statistical data provided by organizations such as DSA and DPSB. These datasets were integrated into a Geographic Information System (GIS) to compute indices such as CQI, SQI, VQI, AQI, and DSI. The materials and data sources used in this study are summarized in Table 2.

2.3. Applied methodology

Desertification was evaluated using the Mediterranean Desertification and Land Use (MEDALUS) approach, as outlined by D'Ettorre et al., (2024). The Desertification Sensitivity Index (DSI) for the study area was computed using the MEDALUS model, based on the methodology described by Kosmas et al.,(1999).This approach evaluates desertification risk through four primary indicators: The Soil Quality Index (SQI), the Climatic Quality Index (CQI), the Vegetation Quality Index (VQI), and the Anthropogenic Quality Index (AQI). Each of these indices is classified into categories ranging from 1 (very good quality) to 2 (very poor quality), reflecting their influence on the desertification process. The methodological workflow for calculating the Desertification Sensitivity Index (DSI) is illustrated in Figure 2 and Table 3, outlining the steps from data collection to index computation.

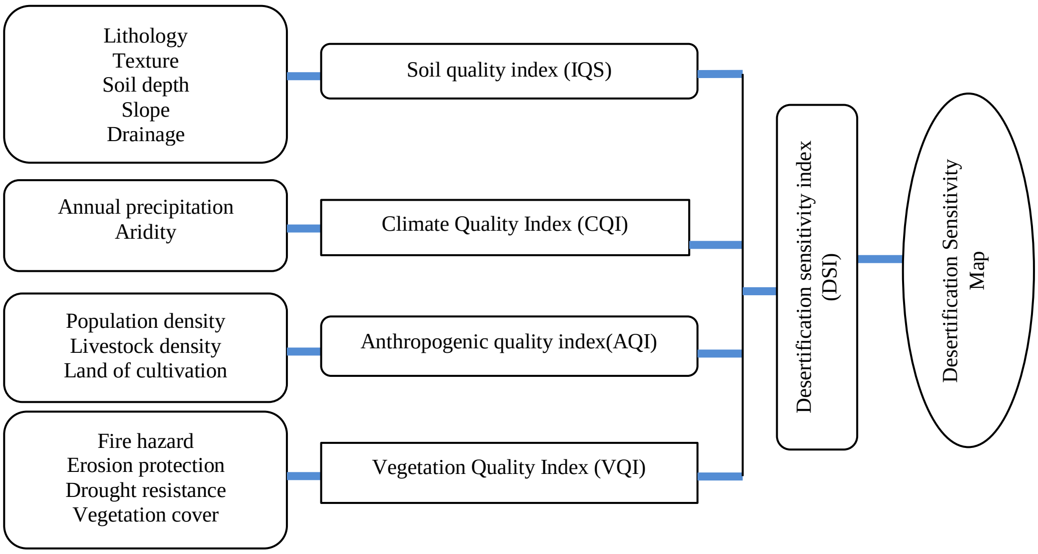

Fig. 2 Methodological diagram of the steps followed for the calculation of the ISD index.

Soil quality plays a pivotal role in the desertification process (Lahlaoi et al., 2017), influenced by various indicators (Ait Lamqadem et al., 2018).The Soil Quality Index (SQI) assesses soil characteristics, with key indicators including lithology, depth, texture, slope, and drainage (Tab.3). The region's sandy soil texture results in low water retention, exacerbating desertification. The SQI is calculated as:

$$SQI = (Lithology * Texture * Soil\ depth * Solpe * Drainage)^{1/5} \quad \dots \quad (1)$$

Climate is a limiting factor in the region. It helps to estimate the amount of water available for plant growth (Plaiklang et al., 2020; Bensefia et al., 2024).The Climatic Quality Index (CQI) evaluates climatic factors influencing desertification, focusing on average annual precipitation and aridity. Climatic data were collected from the National Agency for Hydraulic Resources (ANRH) (Tab.3). The CQI is calculated using the formula:

$$CQI = (Annual\ precipitation * Aridity\ index)^{1/2} \quad \dots \quad (2)$$

The Anthropogenic Quality Index (AQI) evaluates the impact of human activities on desertification, using three parameters: population density (2020), livestock density (2020), and land use. Data were sourced from the Department of Statistics and Planning (DPSB) and the Department of Agriculture (DSA) (Tab.3). The AQI is calculated as:

$$AQI = (Population\ density * Livestock\ Density * Cultivated\ land)^{1/3} \quad \ldots \quad (3)$$

Table 3. Parameter Classifications and Indices (SQI), (CQI), (AQI) and (VQI)

indicator	Factor	Class	Features	Description	Index
SQI	Lithology	1	Hard limestone and Dolomite, Friable	Good	1
		2	Conglomerats	Moderate	1,7
		3	Alluvium, sand and limestone crusts,	Poor	2
	Depth	1	>75	Deep	1
		2	30-75	Moderate	2
		3	15-30	Shallow	3
		4	<15	Very shallow	4
	Texture	1	L, SCL, SL, LS	Good	1
		2	SC, SiCL, C, SiC	Moderate	1.6
		3	S	Poor	2
	Slope	1	<6	Very gentle	1
		2	6-12	Soft	1,2
		3	12-25	Steep	1,5
		4	>25	Very steep	2
	Drainage	1	Well drained	Good	1
		2	Medium-drained	Moderate	1,2
		3	Imperfectly drained	Poor	1,5
		4	Poorly drained	Very poor	2
CQI	Annual precipitation	1	>250 mm	Moderate	1
		2	<250 mm	Poor	2
	Aridity index	1	<5 (Hyper-arid)	Very poor	2
		2	5-7.5 (Aride inferior)	Poor	1,8
		3	7.5-10 (Upper arid)	Moderate	1
AQI	Population density	1	<15people/ km²	Good	1
		2	15-20people/km²	Moderate	1,33
		3	20-50people/km²	Poor	1,66
		4	>50people/ km²	Very poor	2
	Livestock density	1	<60heads/km²	Good	1
		2	60-100head/km².	Moderate	1,66
		3	>100head/km²	Poor	2
	Land use	1	Cultivated	Good	1
		2	Uncultivated	Poor	2
VQI	Fire hazard	1	Bare soil and sand, steppe	Low	1
		2	Crop, shrub steppe	Medium	1.3
		3	Scrub-forest	High	2
	Erosion protection	1	Scrub-forest	High	1
		2	Shrub steppe	Medium	1.3
		3	Steppe	Low	1.6
		4	Bare soil and sand, cultivation	Very low	2
	Drought resistance	1	Bare soil and sand	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, SCL = sand*y clay loam, SL = sandy loam, LS = loamy sand, SC = sandy clay, SiCL = silty clay loam, C = clay, SiC = silty clay, S = sand.*

Source: Own elaboration acc. to KOSMAS et al., (1999) and BASSO et al., (2012)

Vegetation plays a crucial role in land degradation, with its impact varying based on resilience to climate change and its ability to protect soils against erosion (Prăvălie et al., 2020). The Vegetation Quality Index (VQI) assesses vegetation's role in mitigating land degradation, with its resilience to climate change and ability to protect against erosion being key determinants. The

VQI was evaluated using Landsat 8 satellite imagery, processed through supervised classification. Four parameters were considered: fire risk, erosion protection, drought resistance, and vegetation coverage (Tab.3). The VQI is calculated as:

$$\boldsymbol{VQI} = (\boldsymbol{Fire\ risk} * \boldsymbol{Erosion\ protection} * \boldsymbol{Drought\ resistance} * \boldsymbol{Recovery})^{1/4} \quad \dots \ (4)$$

Finally, the Desertification Sensitivity Index (DSI) is calculated using the following formula:

$$\boldsymbol{DSI} = (\boldsymbol{SQI} * \boldsymbol{CQI} * \boldsymbol{AQI} * \boldsymbol{VQI})^{1/4} \quad \dots \ (5)$$

3. Results and discussion

The desertification sensitivity index is primarily linked to climatic conditions, relief and topography of the environment, lithology and soil structure, vegetation cover, and land use. Each parameter was weighted based on its impact and contribution to the desertification process (Boudjemline et al., 2018).

3.1. Soil Quality Index (SQI)

The results obtained from the calculation of the Soil Quality Index (Fig. 3) reveal three distinct classes of soil quality (Tab.4): The class of good-quality soils is relatively rare in the region, covering approximately 21% of the total area. These soils are mainly associated with shrub formations and characterized by materials with balanced textures. The class of moderate-quality soils is the most widespread, covering about 64% of the study area. These soils are predominantly found under steppe formations. The class of poor-quality soils occupies approximately 13% of the total area and is less widespread. These soils are primarily located under shrub steppes and crops, especially prevalent in the northeastern part of the sub-basin. This classification provides critical insights into the distribution and quality of soils within the study area, which are essential for effective land management and planning.

Table4. Distribution of thethreesoil qualityclasses.

Class	Description	Rank	Area(%)
1	Highquality	≤1,13	21,94
2	Moderatequality	1,13-1,45	64,49
3	Low quality	≥1,46	13,57

Source: Author's analysis.

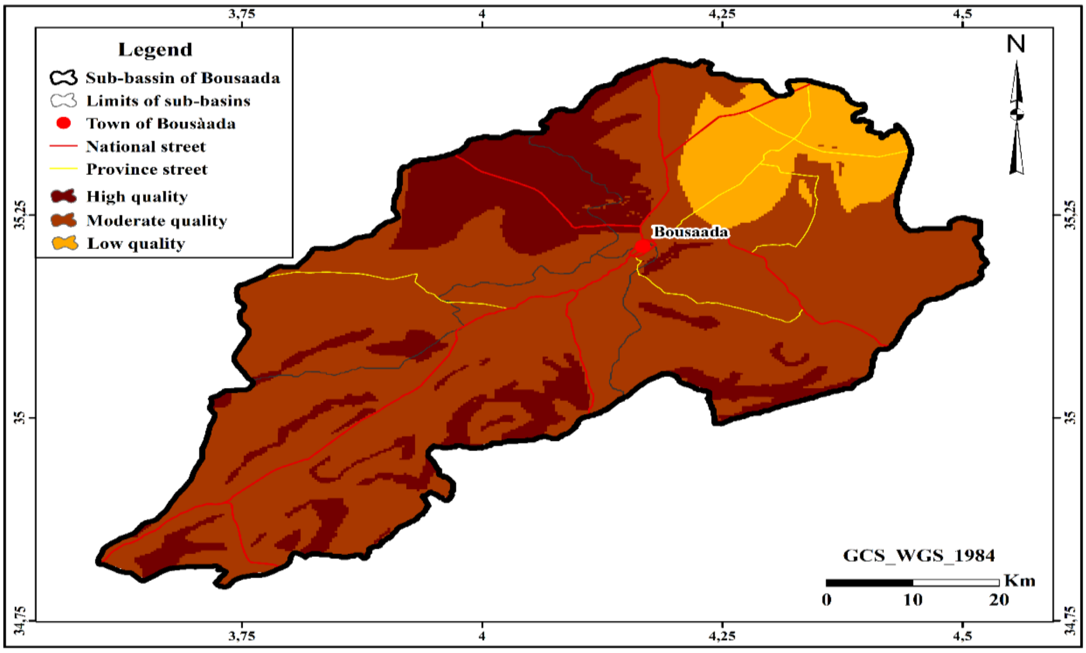

Fig.3 Soil quality.

3.2. Climatic Quality Index (CQI)

The results of the Climatic quality map (Fig. 4) primarily highlight three classes of climatic quality distributed (Tab. 5) as follows: The class of good climatic quality occupies nearly 35% of the sub-basin area, corresponding to the upper arid bioclimate. It is situated in the southwestern part of the study area. The class of moderate climatic quality covers approximately 63% of the sub-basin area, located in the northeastern part and corresponding to the lower arid bioclimate. The class of poor climatic quality represents a very small portion of the total surface area (2.45%) of the sub-basin, situated in the extreme south of the region.

Table5. Distributionof thethreeclimate qualityclasses.

Class	Description	Rank	Area(%)
1	Highquality	≤1,49	34,75
2	Moderatequality	1,49-1,90	62,80
3	Low quality	≥1,90	2,45

Source: Author's analysis.

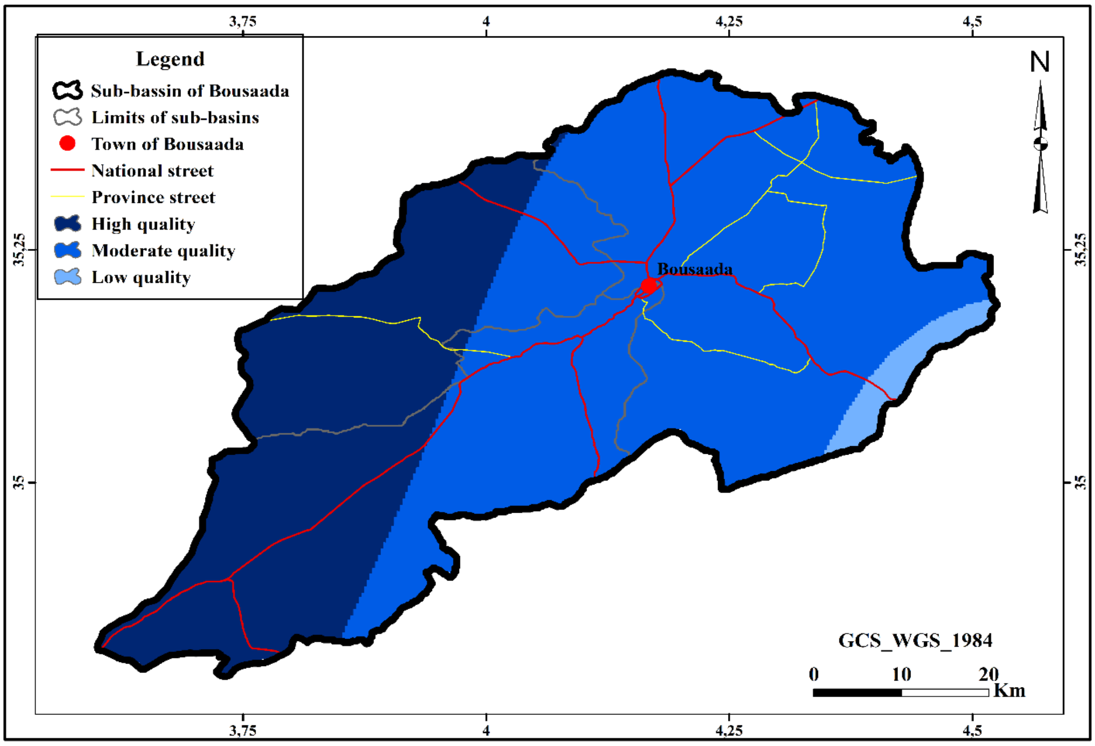

Fig.4 Climate quality.

3.3. Anthropogenic Quality Index (AQI)

The map of the anthropogenic quality index (Fig. 5) reveals that the majority of the Boussaada sub-basin (78%) exhibits poor quality. This situation is mainly attributed to overgrazing in pastoral lands and urban expansion, which have a negative impact on the quality of developments. Meanwhile, areas of good quality (9%) and moderate quality (12%) correspond to shrub formations and cultivated lands (Tab. 6).

Table6. Distributionof thethreeanthropogenicqualityclasses.

Class	Description	Rank	Area(%)
1	Highquality	≤1,22	9.57
2	Moderatequality	1,23-1,44	12.50
3	Low quality	≥1,44	77.93

Source: Author's analysis.

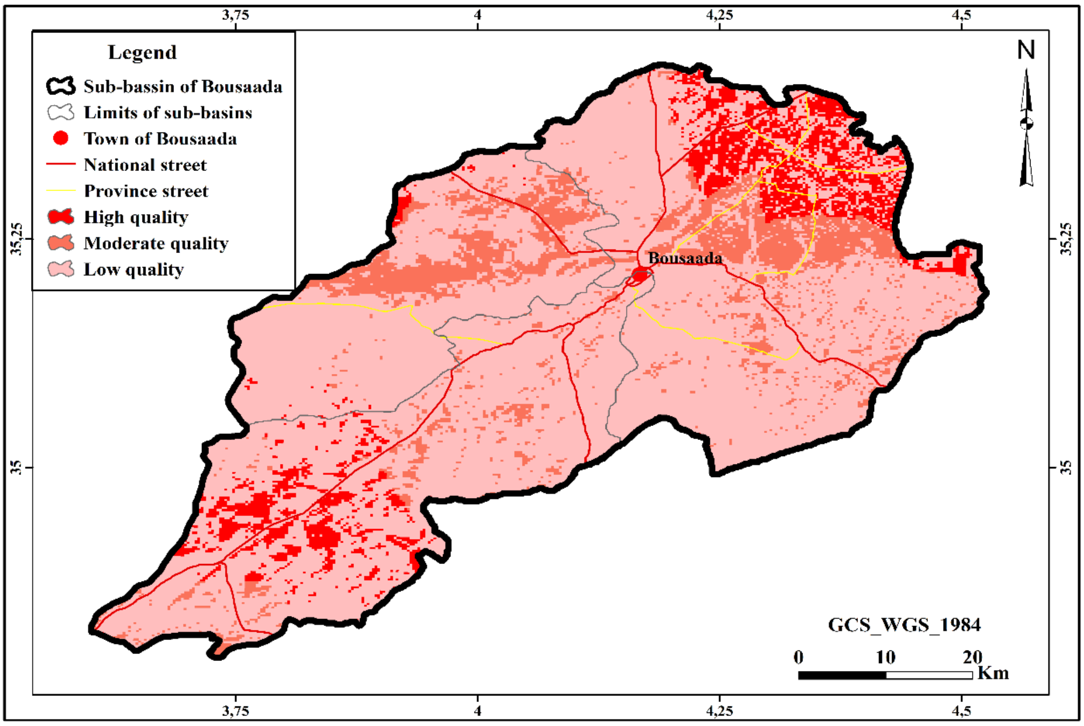

Fig. 5 Anthropogenic quality.

3.4. Vegetation Quality Index (VQI)

The map of the vegetation quality index (Fig. 6) reveals three classes (Tab. 7) distributed as follows: Areas with good vegetation quality are generally found in mountainous forest regions, occupying approximately 39% of the total area, this class is mainly characterized by shrub vegetation forming a significant barrier against erosion, the class of vegetation with moderate quality covers about 15% of the sub-basin area. It is less widespread and corresponds to shrub steppes and cultivated areas and the class of poor-quality vegetation represents nearly 48% of the total area. This is the most widespread class in the Boussaada sub-basin, corresponding to degraded steppes and desertified lands.

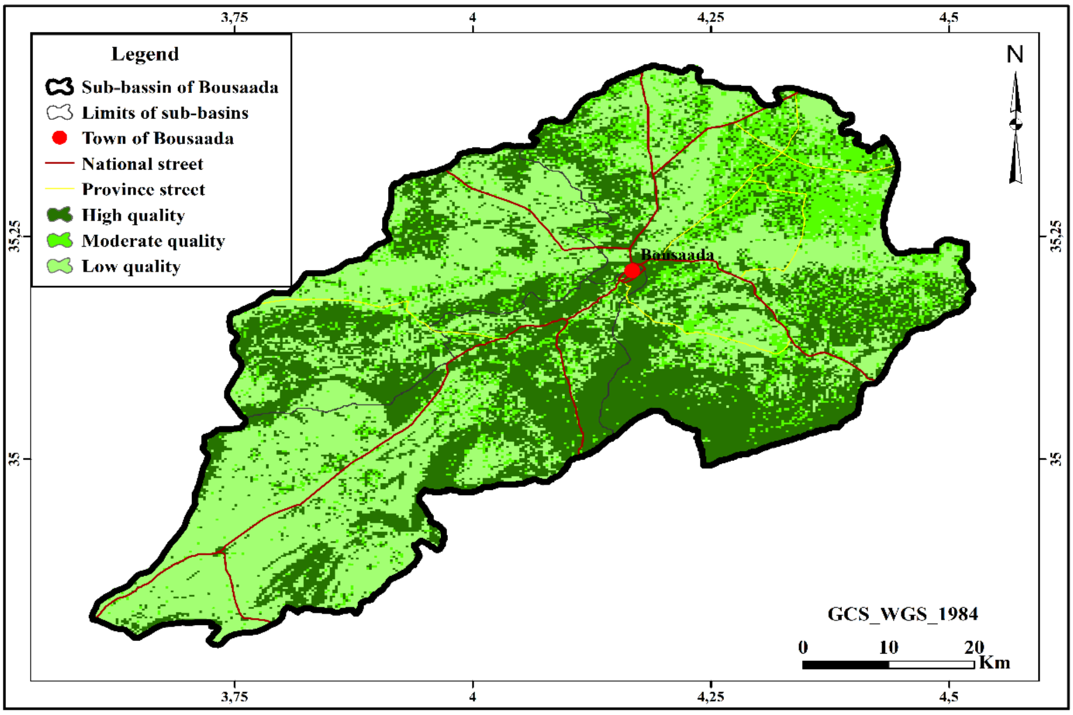

Fig.6 Vegetation quality.

Table7. Distributionof thethreevegetationqualityclasses.

Class	Description	Rank	Area(%)
1	Highquality	≤1,23	38,45
2	Moderatequality	1,23-1,44	14,09
3	Low quality	≥1,44	47,46

Source: Author's analysis.

3.5. Desertification Sensitivity Index (DSI)

The application of the MEDALUS method to evaluate desertification sensitivity in the Boussaada sub-basin highlights the region’s alarming vulnerability to desertification. The desertification sensitivity map (Fig. 8 & Tab. 8) categorizes the sub-basin into five zones: very sensitive, sensitive, moderately sensitive, less sensitive, and non-sensitive. The results reveal that nearly 76% of the area is classified as highly to very sensitive to desertification, primarily due to the region’s arid climatic conditions, characterized by low rainfall and high evaporation rates, which naturally predispose the landscape to desertification. In addition, human-induced factors such as inappropriate land management practices, including unsustainable agricultural activities and overgrazing, have compounded the region’s susceptibility, further deteriorating soil quality, reducing vegetation cover, and exacerbating soil erosion. These findings align with studies in other Mediterranean and arid regions, where climatic stress and improper land use have been identified as key contributors to desertification (Kosmas et al., 1999; Benmessaud et al., 2020).

The MEDALUS method also provides insights into the relative contributions of the four main factors of desertification. Vegetation Quality Index (VQI), Climate Quality Index (CQI), Soil Quality Index (SQI), and Anthropogenic Quality Index (AQI) as shown in Fig. 7. In high-quality areas, where desertification is less advanced, VQI and CQI are the most influential factors, contributing 38.45% and 34.75%, respectively. This underscores the critical role of vegetation cover and favorable climatic conditions in preventing land degradation. Conversely, in low-quality areas, AQI predominates with a contribution of 77.93%, indicating that poor land management practices are the primary driver of degradation. In moderate-quality areas, SQI and CQI are the most significant factors, contributing 64.94% and 62.8%, respectively, suggesting that soil degradation, interacting with variable climatic conditions, is a central factor in these intermediate zones. These results highlight the distinct contributions of each factor depending on the level of land degradation, emphasizing the need for an integrated and targeted approach to combat desertification, tailored to local specifics and dominant factors at each level of degradation.

The MEDALUS method also identifies areas that are moderately sensitive to desertification, representing around 12% of the study area. These zones, located at the northern and southern extremes of the sub-basin, generally exhibit better soil and vegetation quality compared to more sensitive regions. Such areas have relatively more fertile soils and healthier vegetation, making them less susceptible to desertification. These findings align with those of Ladisa et al. (2012), who observed that areas with good soil fertility and vegetation cover are less prone to desertification, even under arid conditions. These moderately sensitive zones could serve as focal points for conservation efforts, as they hold potential for recovery if appropriate management practices are implemented.

Moreover, the sub-basin’s mountainous regions, which cover only 12% of the area, are categorized as less sensitive to desertification. These areas are more resilient, benefiting from better soil structure, more vegetation cover, and favorable microclimatic conditions. Ladisa et al. (2012) have also pointed out that mountainous regions often act as refuges from desertification due to their ability to retain moisture and support more robust ecosystems.

To address the substantial desertification risks in the Boussaada sub-basin, it is essential to implement a comprehensive approach that tackles both the natural and human-induced causes of desertification. One of the first measures should be the adoption of sustainable land use practices, such as agroforestry, crop rotation, and conservation tillage. These methods can reduce soil erosion and degradation while enhancing the land's productivity. Integrating these practices into local agricultural systems has proven effective in other regions and can help restore degraded land and improve soil quality (Ferrara et al., 2020). Additionally, adopting drought-resistant crops and establishing sustainable grazing systems would ease the pressure from overgrazing and unsustainable farming practices, further mitigating desertification risks.

Water management is another critical area where improvements could be made. Efficient irrigation techniques, such as drip irrigation, can minimize water wastage and help prevent soil salinization a common challenge in arid regions. Exploring alternative water sources, like rainwater harvesting, could also alleviate pressure on conventional water supplies, especially in regions where water is scarce. In line with Kosmas et al. (1999), promoting water-efficient farming practices and raising awareness about the importance of water conservation can significantly reduce desertification pressures.

Additionally, afforestation and reforestation efforts using native, drought-resistant species would be vital in restoring vegetation cover, improving soil structure, and combating erosion. Such initiatives should focus on the most vulnerable areas, particularly those classified as highly sensitive to desertification. These efforts should also involve local communities, ensuring the sustainability of the projects and increasing their chances of success. This community-based approach is key to long-term desertification control, as highlighted by Salvati et al. (2008), who emphasized the importance of local involvement in land management strategies.

Finally, policy measures are crucial for regulating land use and incentivizing sustainable practices. Governments should implement policies that promote soil conservation and restoration efforts, such as providing financial support for sustainable farming and land rehabilitation. Strict regulations to prevent the overexploitation of natural resources and public education campaigns on the risks of desertification are also essential to foster a culture of environmental stewardship among local populations.

In conclusion, the Boussaada sub-basin faces significant desertification risks, with approximately 76% of the region classified as highly to very sensitive. The combination of an arid climate and improper land management practices has exacerbated this vulnerability. However, by adopting sustainable land use strategies, improving water management, and involving local communities in conservation efforts, the desertification potential can be reduced. Drawing on successful approaches from other regions (Ferrara et al., 2020; D'Ettorre et al., 2024), it is possible to reverse the negative trends and ensure the long-term ecological and socio-economic sustainability of the Boussaada sub-basin.

Table8. Classand desertificationsensitivityindex(DSI).

Class	Description	Rank	Area(%)
1	Non-sensitive	≤1,22	7.84
2	Lesssensitive	1,23-1,26	4,46
3	Moderatelysensitive	1,27-1,37	12,12
4	Sensitive	1,38-1,53	26,96
5	Verysensitive	≥1,53	48,62

Source: Author's analysis.

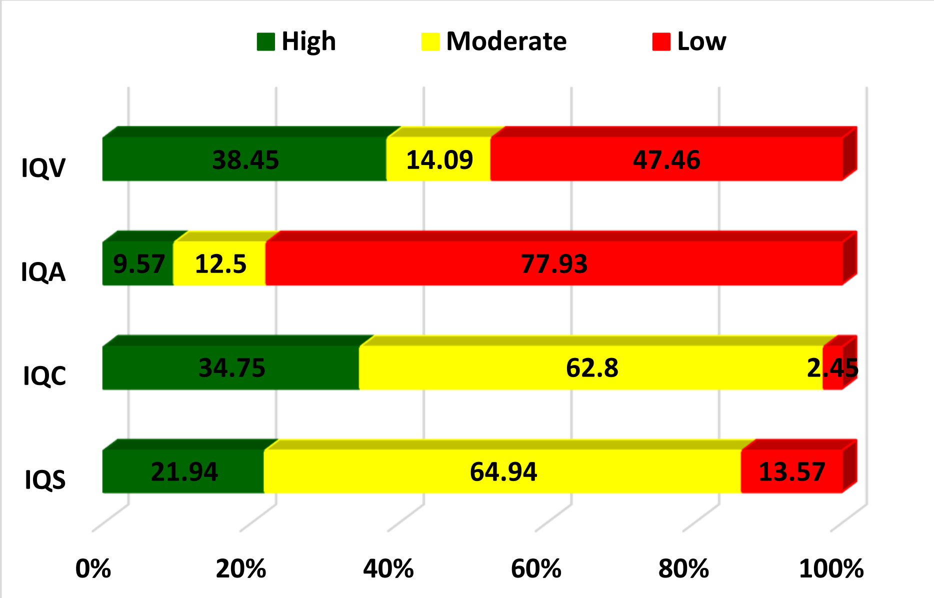

Fig. 7 The impact of each quality index on erosion sensitivity.

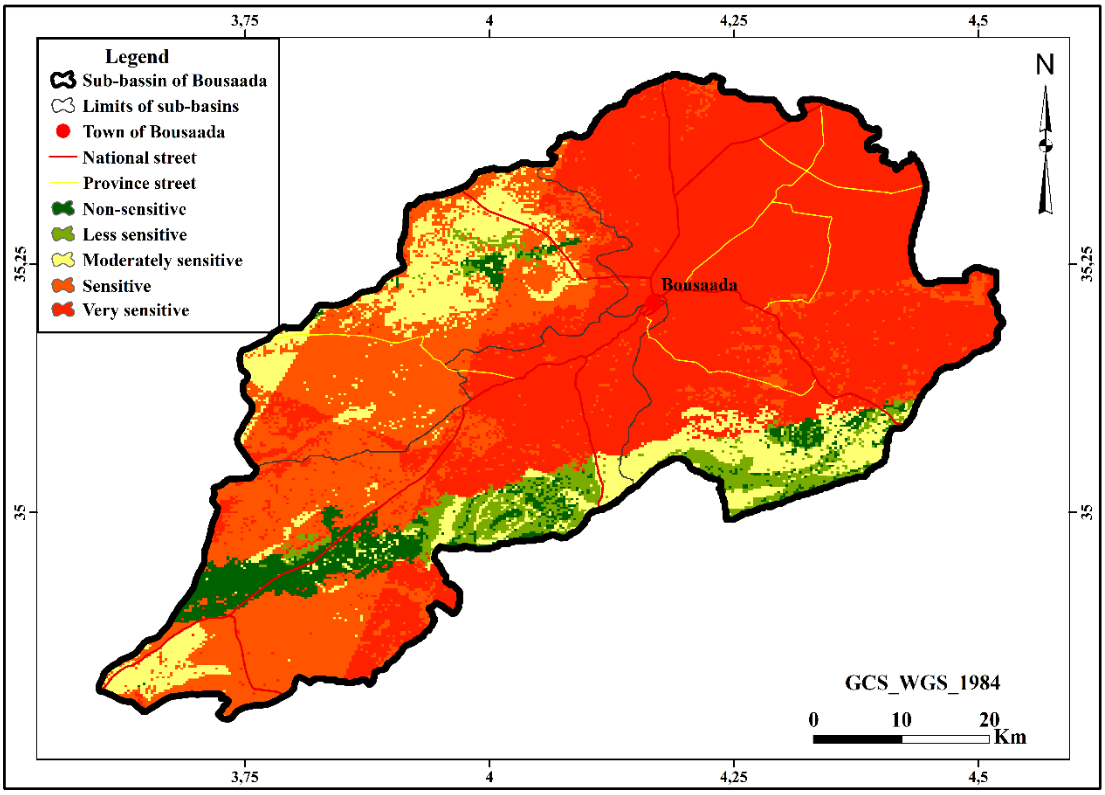

Fig.8 Desertification sensitivity map of the Boussaada sub-basin.

4. Conclusion

In this study, remote sensing data and GIS tools were employed to analyze, understand, and assess the level of degradation in the Boussaada sub-basin. After studying and analyzing various sensitivity indices in our study area, the following conclusions were drawn:

The moderate quality class of the soil index predominates, covering approximately 64% of the study area and mainly associated with steppe formations. The climate index of the sub-basin is characterised mainly by a moderate quality class, encompassing about 63% of its total area, corresponding to the lower arid bioclimate. Moreover, around 78% of the Boussaada sub-basin's territory exhibits poor anthropogenic quality, significantly impacting development quality.

Three-quarters of the sub-basin territory (76%) are classified as highly to very sensitive to desertification. This class can be considered pre-desert. This classification reflects its arid climate with scarce and irregular precipitation, coupled with poor land use practices. Only 12% of the area shows low sensitivity, located in regions with good land management and healthier vegetation. Intensive grazing is one of the main causes of decreased plant diversity, requiring better management to preserve lands and promote their ecological value (Merdas et al., 2021).

Among various strategies adopted, planting forage species stands out as crucial to enhancing pastoral productivity and combating desertification and sand encroachment (Boussaada et al., 2022).

In summary, the relationship between natural spaces and water, a limiting factor in the region, is essential but complex, influenced by numerous challenging factors (Hafsi et al., 2022). The desertification sensitivity map enables the classification of regions by degradation degree, crucial for developing action plans and combating desertification (Khoudir, 2012).

The map serves as a vital tool providing valuable information for decision-making and environmental management in the region. It is important to note that the study of desertification risk mapping using the adapted MEDALUS method and GIS tools faces several challenges, particularly related to the availability and collection of field data (Boudjemline et al., 2018).

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