Agr. Acad. J., v. 8, n. 1, Jan/Feb (2025)

Contents available at Scilit

Agrarian Academic Journal

agrariacad.com

doi: 10.32406/v8n1/2025/100-115/agrariacad

Contribution of GIS to mapping sensitivity to sand encroachment in the Boussaada sub-basin (South-west of Hodna, Algeria) using the MEDALUS approach. Contribuição do SIG para o mapeamento da sensibilidade à invasão de areia na sub-bacia de Boussaada (sudoeste de Hodna, Argélia) usando a abordagem MEDALUS.

Zohra Bidi[1,2], Djamel Khoudour[1,2], Djamel Sarri[1,2*], Sofiane Bensefia[3], Somia Bouafia[1]

[1-] Department of Nature and Life Sciences, Faculty of Sciences, University of M'Sila, University Pole, Road Bordj Bou Arreiridj, 28000 M'Sila, Algeria.
[2-] Laboratory of Biodiversity and Biotechnological Techniques for the Valuation of Plant Resources, University of M'Sila, University Pole, Road Bordj Bou Arreiridj, 28000 M'Sila, Algeria.
[3-] Health and Environment Laboratory, Department of Agricultural Sciences, Faculty of Nature and Life Sciences, Earth and Universe Sciences, University Mohamed El Bachir El Ibrahimi of Bordj Bou Arreiridj, 34000, Algeria.
[*] Corresponding author. E-mail: djamal.sarri@univ-msila.dz

Abstract

Desertification is a critical issue of our time, posing an immediate challenge to Algeria. The Hodna region is undergoing rapid landscape transformation due to sand encroachment. 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 (such as vegetation quality map, soil quality map, etc.), and create a database (DB) 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 mapped by combining four major indicators: Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), and Anthropogenic Quality Index (AQI). Analysis of the desertification sensitivity map of the Boussaada sub-basin identified five zones: very sensitive, sensitive, moderately sensitive, less sensitive, and non-sensitive. The map shows that three-quarters of the Boussaada sub-basin, totaling 76%, are classified as sensitive to very sensitive to desertification. The area is characterized as pre-desert due to its arid climate with low and irregular precipitation, as well as poor land management practices.
Keywords: Desertification. Database. Climate aride. MEDALUS GIS.

Resumo

A desertificação é uma questão crítica do nosso tempo, representando um desafio imediato para a Argélia. A região de Hodna está passando por uma rápida transformação da paisagem devido à invasão de areia. Proteger contra a desertificação e melhorar as condições de vida das populações dependentes se tornaram prioridades nacionais na Argélia. O objetivo deste estudo é avaliar a sensibilidade à desertificação, desenvolver um conjunto de mapas temáticos (como mapa de qualidade da vegetação, mapa de qualidade do solo, etc.) e criar um banco de dados (BD) da área de estudo usando o Sistema de Informação Geográfica (GIS) com base na abordagem MEDALUS (Desertificação Mediterrânea e Uso da Terra). O Índice de Sensibilidade à Desertificação (DSI) é mapeado pela combinação de quatro indicadores principais: Índice de Qualidade do Solo (SQI), Índice de Qualidade Climática (CQI), Índice de Qualidade da Vegetação (VQI) e Índice de Qualidade Antropogênica (AQI). A análise do mapa de sensibilidade à desertificação da sub-bacia de Boussaada identificou cinco zonas: muito sensível, sensível, moderadamente sensível, menos sensível e não sensível. O mapa mostra que três quartos da sub-bacia de Boussaada, totalizando 76%, são classificados como sensíveis a muito sensíveis à desertificação. A área é caracterizada como pré-desértica devido ao seu clima árido com precipitação baixa e irregular, bem como práticas precárias de manejo da terra.
Palavras-chave: Desertificação. Banco de dados. Clima árido. MEDALUS GIS.

2. Introduction

The UNCED (United Nations Conference on Environment and Development) in Rio de Janeiro in June 1992 defines desertification as "the degradation of land in arid, semi-arid, and dry sub-humid areas resulting from various factors including climate change and human activities" (LEE et al., 2019). Desertification and land degradation are characterized by several phenomena (MAINGUET; DUMAY, 2006), including vegetation degradation, expansion of sandy areas, soil impoverishment, reduction in agricultural productivity, and deforestation (MADANI et al., 2023).

Desertification poses a significant environmental challenge for Algeria and neighboring countries in the Maghreb and the Middle East (MOSTEPHAOUI et al., 2013). Arid and steppe regions cover more than 600,000 km² north of the Sahara, with approximately 34% located in Algeria (LE HOUÉROU, 1995). In recent years, the Algerian steppe has experienced ecological and climatic imbalance, resulting in pronounced degradation of its fragile environment (LIAZID, 2013). Climate variability exerts continuous pressure on ecosystems, intensifying further south (BENMESSAOUD, 2009). The southern Hodna region has undergone rapid landscape transformation due to sand encroachment, a consequence of desertification. This situation presents a significant challenge for the region's inhabitants (ABDESSELAM; HALITIM, 2014).

This degradation is not isolated; consequently, the natural spaces of the region suffer from deterioration and poor conditions, despite their vital importance in human life (SEGHIRI et al., 2022) and their ability to create a microclimate (OUZIR, 2023). Preserving steppe, combating desertification, and improving the living conditions of dependent populations are now national priorities in Algeria (DAOUDI et al., 2010).

The objective of this work is to assess the degree of land degradation in the Boussaada sub-basin, located in the southwest area of Hodna, and to develop a set of thematic maps (such as Land use map, soil quality map, etc.), along with creating a DataBase (DB) of the study area. The method employed categorizes areas based on their degree of desertification sensitivity, evaluates the extent and severity of land degradation in these regions, and identifies areas most exposed to high risks of degradation.

Remote sensing and GIS were utilized to assess the state of degradation and evaluate the extent of desertification using a desertification sensitivity map. This map is essential for developing effective management and conservation strategies.

After describing the physical characteristics of the study region and defining the methods used for this work, we analyzed the results obtained regarding the desertification of the Boussaada sub-basin. A desertification sensitivity map was developed, greatly facilitating the assessment of degradation status in the southwest Hodna region.

2. Materials and methodological approach

2.1. Study area

The Boussaada sub-basin is one of the eight sub-basins of the fifth major basin in Algeria. The Hodna watershed, covering an area of nearly 26,000 km², transitions between the Tellian domain to the north and the Sahara to the south (KEBICHE, 1994). The study area is located in the southwest part of the Hodna watershed, within M'Sila province. The Boussaada sub-basin itself spans an area of 2938.36 km² with a length of 96.8 km, comprising three distinct sub-basins: Maiter downstream, Boussaada, and Maiter upstream, covering 1263.05 km², 1018.81 km², and 656.5 km², respectively

(Figure 1). The study area is situated at 35°27'2.4013" North and 34°47'21.0125" South, as well as 3°35'56.3117" West and 4°31'7.7631" East. The elevation of the Boussaada sub-basin ranges from 393 to 1644 meters from north to south (Table 1), featuring predominantly low to moderate slopes (6 to 25%).

Table 1 – Morphological and hydrographic characteristics 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	119.88
Length of main river	L_p	Km	102,8
Drainage density	D_d	Km/Km²	0,16

Source: personal analysis in ArcGIS software.

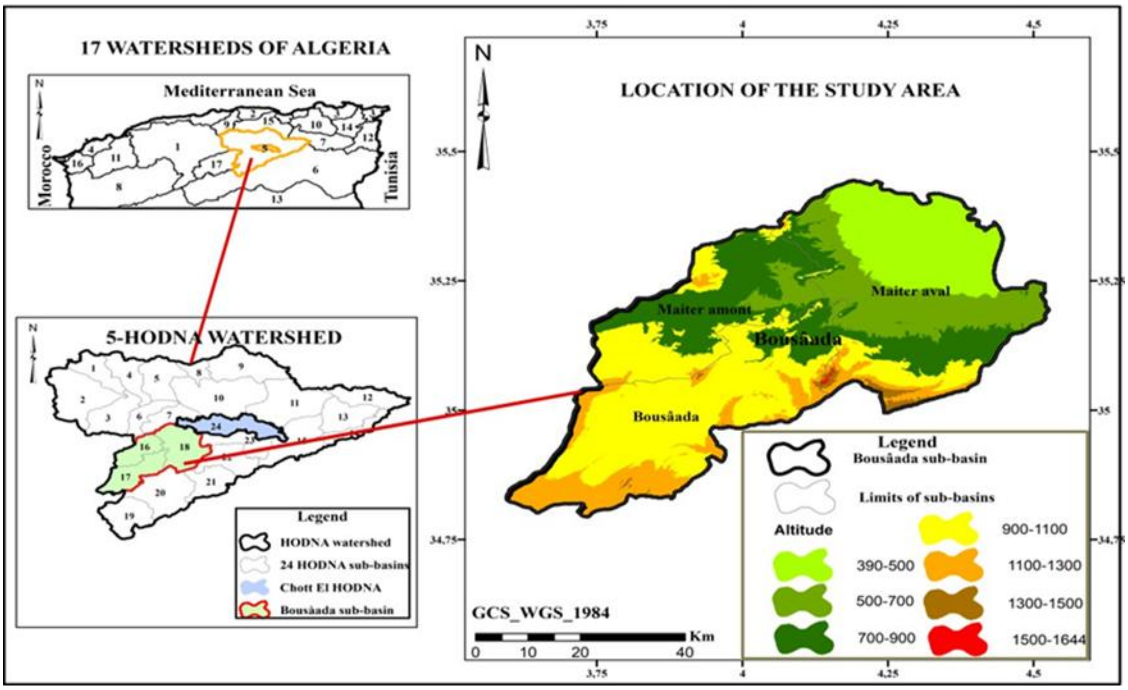

Figure 1 – Morphological and hydrographic characteristics of the Boussaada sub-basin.

2.2. Materials used

Various parameters relevant to the desertification phenomenon were compiled from available data of the study area and integrated into a Geographic Information System (GIS). These parameters were utilized to compute indices including CQI, SQI, VQI, AQI, and DSI. The equipment and data necessary for this study are outlined in Table 2.

Table 2 – Materials used.

Documents				Programs
Image satellite	A satellite image of a shuttle with a resolution of 30 m (Landsat 8 TM); March 2024.			ArcGIS 10.8
MNT	Digital Terrain Model (DTM) of the Boussaada sub-basin (Landsat 8 TM).			
Cartographicdata	**Title**	**scale**	**support**	
	Soil map of M'Sila as of [DURAND, 1954].	1/750 000	Scan	
	Hodna soil map [FAO, 1961].	1/500 000	Scan	
	Map of hydro-climatological networks and water quality monitoring [ANRH, 2005]	1/500 000	Scan	
Other data	Monographie de la wilaya de M'Sila [DPSB, 2020]. Static data for the wilaya of M'Sila [DSA, 2020]. Climatic data for the wilaya of M'Sila [ANRH, 2020].			

2.3. Applied methodology

Desertification can be studied by examining various environmental factors, including topography, soil composition, geological features, vegetation, climatic conditions, and the impact of human activities. This study adopts the MEDALUS concept (D'ETTORRE et al., 2024), a methodology that utilizes easily identifiable indicators from soil, vegetation cover, climatic data, and human activities. The MEDALUS model relies on four primary indices: The Soil Quality Index (SQI), the Climatic Quality Index (CQI), the Vegetation Quality Index (VQI), and the Anthropogenic Quality Index (AQI). Each of these parameters is classified into homogeneous categories reflecting their influence on the desertification process (KOSMAS et al., 1999). The Desertification Sensitivity Index (DSI) is calculated using the following Eq. (1):

$$\boldsymbol{DCI = (SQI * VQI * CQI * AQI)^{1/4}} \qquad (\mathbf{1})$$

These indices are evaluated based on classes ranging from 1 (very good quality) to 2 (very poor quality), as illustrated in Figure 2. The parameters (CQI, SQI, VQI, AQI, and DSI) are computed using datasets specific to the study area, allowing for the assessment of desertification sensitivity.

2.3.1. Climatic quality index (CQI)

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). CQI was assessed using two parameters: average annual precipitation and the Bagnouls-Gaussen aridity index (Table 3). Climatic data were collected from the National Agency for Hydraulic Resources (ANRH) of M'Sila, as well as from various departments within the province (DSA, 2020, CFD, 2020 and DRE, 2020). This index is calculated using Eq. (2):

$$\boldsymbol{CQI = (Annual\ Precipitation * Aridity\ Index)^{1/2}} \qquad (\mathbf{2})$$

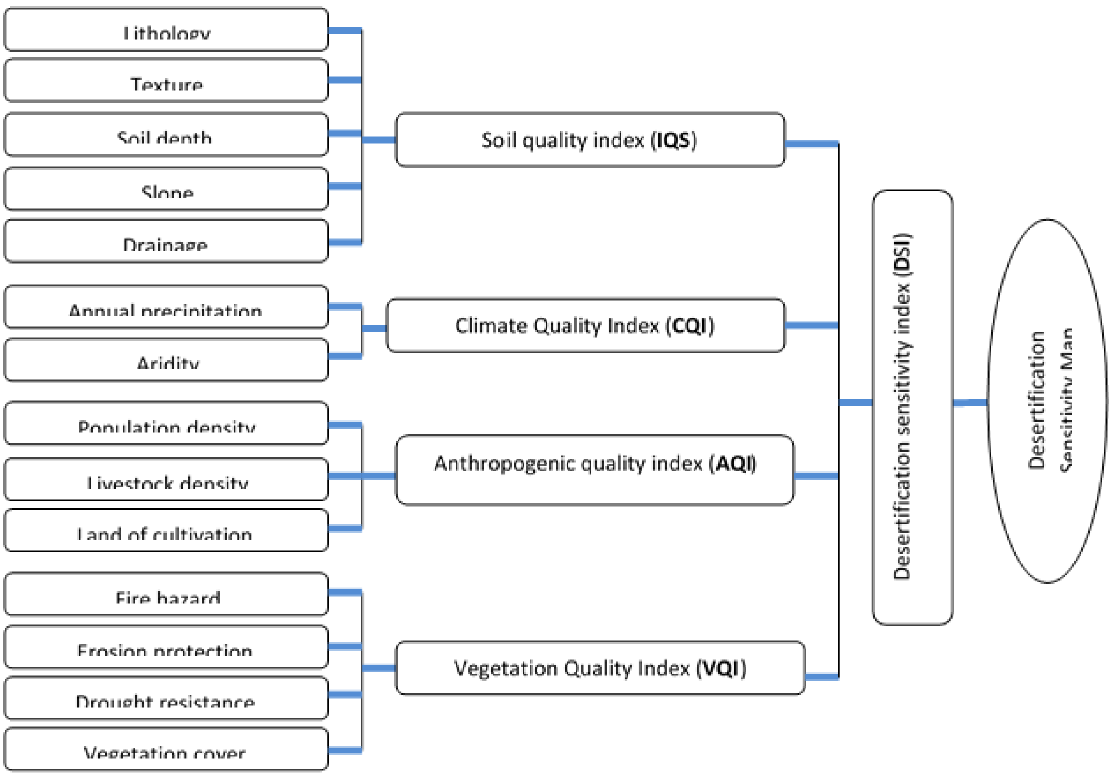

Figure 2 - Methodological diagram of the steps followed for the calculation of the ISD index.

Table 3 - IQC parameter classes and indices.

Factor	Class	Features	Index
Annual precipitation	1	>250 mm	1
	2	<250 mm	2
Aridity index	1	<5 (Hyper-arid)	2
	2	5-7.5 (Aride inferior)	1,8
	3	7.5-10 (Upper arid)	1

Source: ANRH - National Agency of Hydraulic Resources.: 2020, Climatic data of M'Sila province.
CFD - Forest Conservation M'Sila.: 2020, Climatic data of M'Sila province.

2.3.2. Soil quality index (SQI)

Soil quality plays a pivotal role in the desertification process (LAHLAOI et al., 2017), influenced by various indicators (AIT LAMQADEM et al., 2018). Five key indicators "lithology, depth, slope, drainage, and texture" are utilized to assess the Soil Quality Index (SQI) and its impact on desertification (Table 4). Given the prevalent sandy texture in the region, the soil exhibits low water retention capacity, leading to reduced soil moisture levels (WIJITKOSUM et al., 2013). The SQI is calculated using the following Eq. (3):

$$SQI = (Texture * Lithology * Depth * Slope * Slope)^{1/5} \qquad (3)$$

2.3.3. Anthropogenic quality index (AQI)

The anthropogenic quality index was calculated based on the degree of human-induced impact. Three parameters were considered to evaluate this index: Population density in 2020, livestock density in 2020, and land use (Table 5). Data were collected from the Department of Statistics and Planning (DPSB) and the Department of Agriculture (DSA). AQI is calculated according to Eq. (4):

$$\boldsymbol{AQI = (Population\ Density * Livestock\ Density * Cultivated\ Land)^{1/3}} \quad (4)$$

Table 4 - IQS parameter classes and indices.

Factor	Class	Features	Description	Index
Lithology	1	Hard limestone and Dolomite, Friable limestone	Good	1
	2	Conglomerats	Moderate	1,7
	3	Alluvium, sand and limestone crusts, Sebkha	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

Explanations: L = loam, SCL = sandy clay loam, SL = sandy loam, LS = loamy sand, SC = sandy clay, SiCL = silty clay loam, C = clay, SiC = silty clay, S = sand.

Source: Soil map of M'Sila as of [DURAND,1954]. Hodna soil map [FAO, 1961]. Digital Elevation Model of the Boussaada sub-basin.

Table 5 - AQI parameter classes and indices.

Factor	Class	Features	Index
Population density	1	<15 people / km²	1
	2	15-20 people / km²	1,33
	3	20-50 people / km²	1,66
	4	>50 people / km²	2
Livestock density	1	<60 heads/km²	1
	2	60-100 head/km².	1,66
	3	>100 head/km²	2
Land use	1	Cultivated	1
	2	Uncultivated	2

Source: DSA statistical data/DPSB - Directorate of Programming and Budget Monitoring - M'Sila.: 2020, Monograph of M'Sila province, 2020.

2.3.4. Vegetation quality index (VQI)

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) was evaluated using remote sensing techniques, utilizing interpretation of Landsat 8 satellite imagery with a spatial resolution of 30 meters from the year 2024. The image was processed to classify different land cover types by ArcGIS 10.8, using supervised classification. Four parameters were considered: fire risk, erosion protection, drought resistance, and coverage (Table 6). The VQI is calculated using Eq. (5):

$$VQI = (Fire\ Risk * Erosion\ Protection * Drought\ Resistance * Coverage)^{1/4} \quad (5)$$

Table 6 - VQI parameter classes and indices.

Factor	Class	Features	Description	Index
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	4
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

Source: from A satellite image (Landsat 8 TM); March 2024. (https://earthexplorer.usgs.gov).

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

The results obtained from the calculation of the Soil Quality Index (Figure 3) reveal three distinct classes of soil quality (Table 7). 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, generally exhibiting moderate to deep depths (The predominant soil class is characterized by a depth exceeding 30 meters). 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.

3.2. Climatic quality index

The results of the Climatic quality map (Figure 4) primarily highlight three classes of climatic quality distributed (Table 8) 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.

Table 7 - Distribution of the three soil quality classes.

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

Source: personal analysis in ArcGIS software.

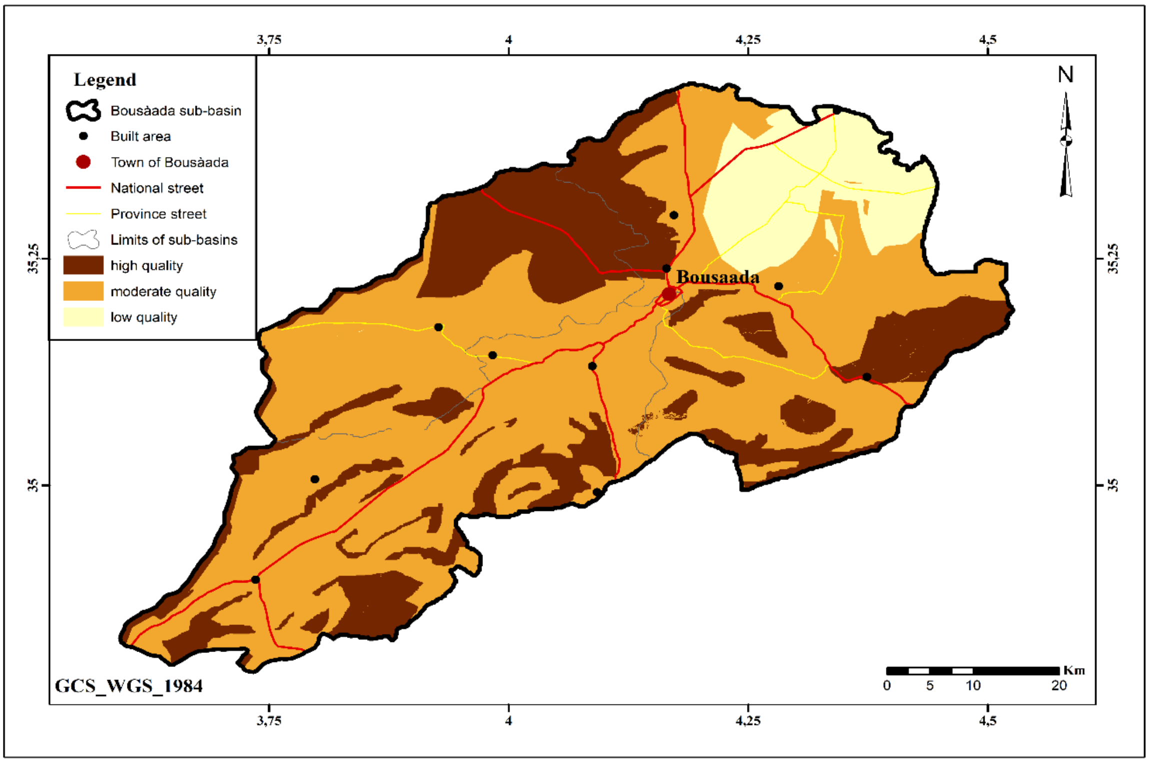

Figure 3 - Soil quality.

Table 8 - Distribution of the three climate quality classes.

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

Source: personal analysis in ArcGIS software.

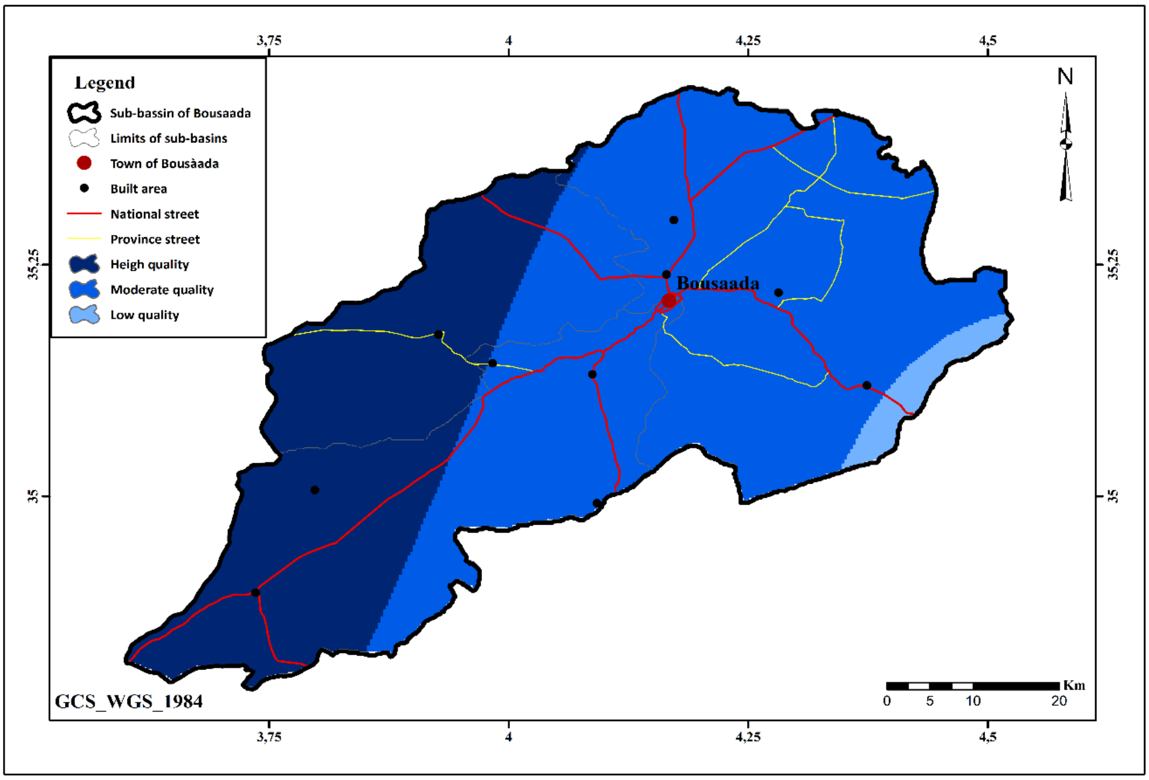

Figure 4 - Climate quality.

3.3. Anthropogenic quality index

The map of the anthropogenic quality index (Figure 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 has 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 (Table 9).

Table 9 - Distribution of the three anthropogenic quality classes.

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

Source: personal analysis in ArcGIS software.

3.4. Vegetation quality index

The map of the vegetation quality index (Figure 6) reveals three classes (Table 10) 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.

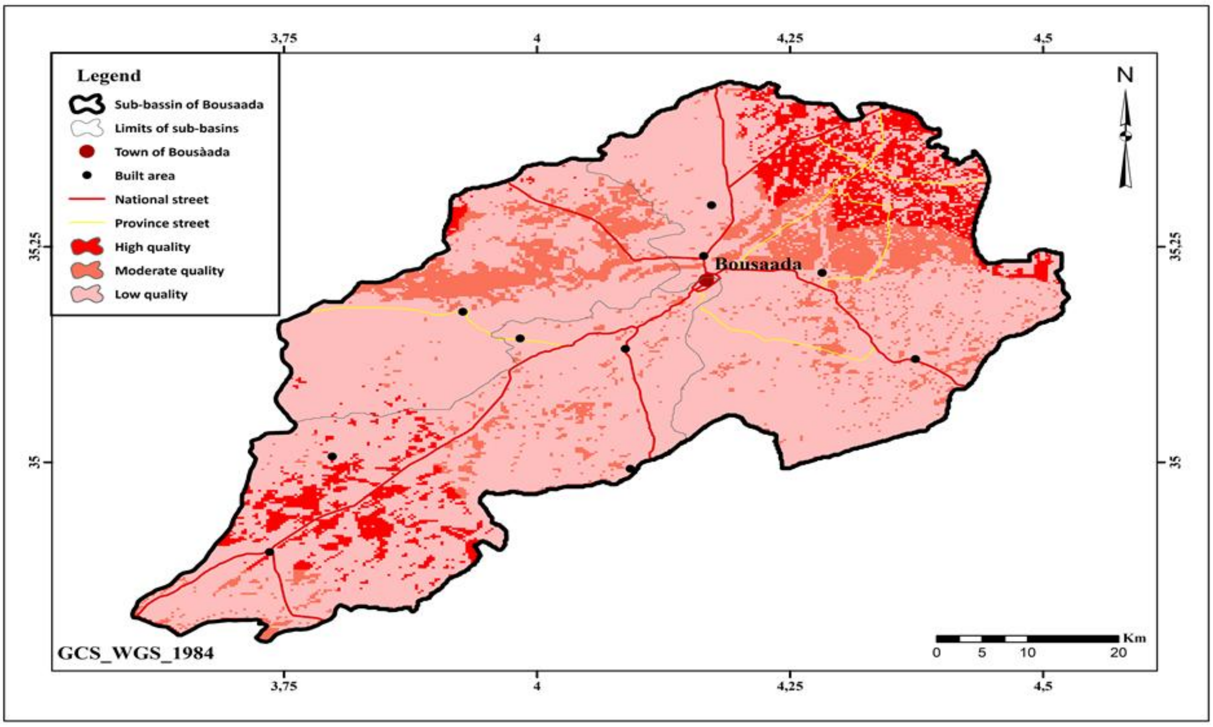

Figure 5 - Anthropogenic quality.

Table 10 - Distribution of the three vegetation quality classes.

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

Source: personal analysis in ArcGIS software.

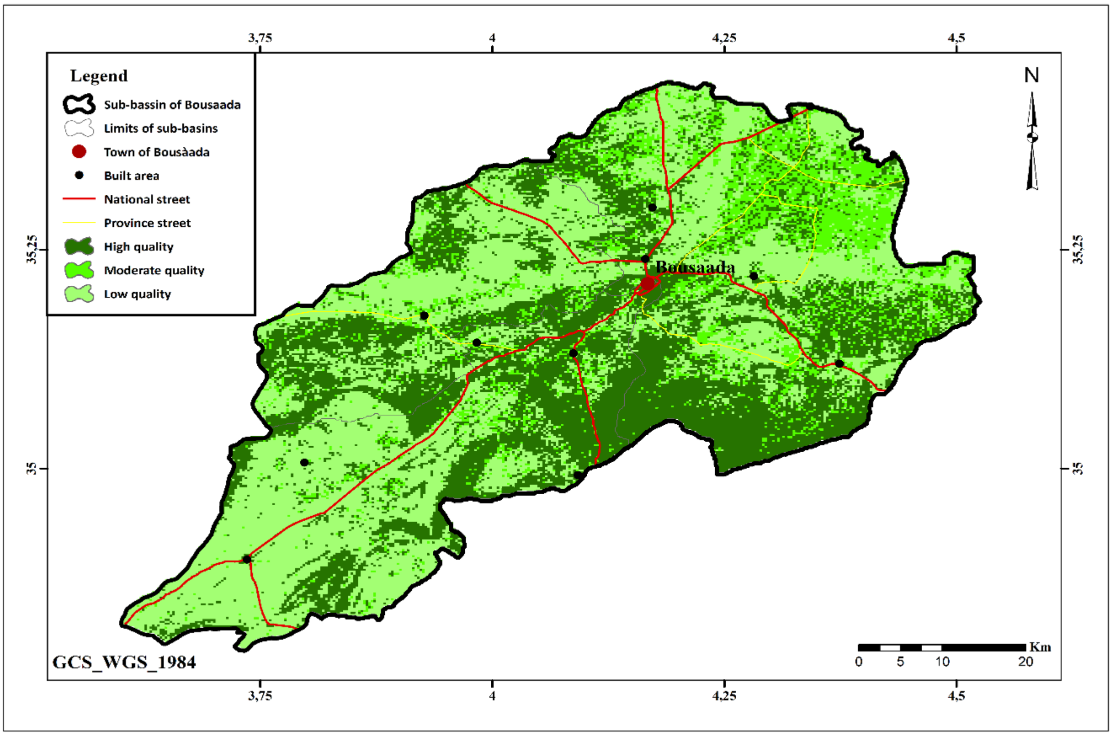

Figure 6 - Vegetation quality.

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 (Figure 7) categorizes the sub-basin into five zones: very sensitive, sensitive, moderately sensitive, less sensitive, and non-sensitive (Table 11). The results reveal that nearly 76% of the area is classified as highly to very sensitive to desertification. This is primarily due to the arid climatic conditions in the region, 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. Similar conclusions have been drawn 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).

Table 11 - Class and desertification sensitivity index (DSI).

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

Source: personal analysis in ArcGIS software.

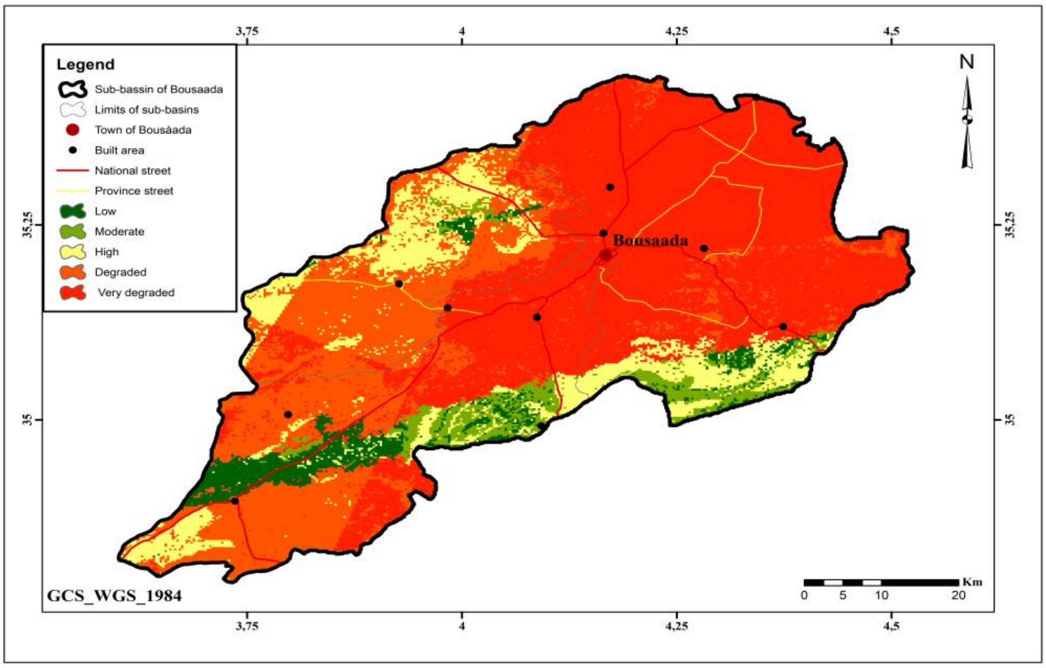

Figure 7 - Desertification sensitivity map of the Boussaada sub-basin.

The MEDALUS method also highlights areas that are moderately sensitive to desertification, which represent 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 to desertification, 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 refugees 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 (KHOUDOUR et al., 2024). 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. (2011), 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.

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 characterized 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 (Figure 8). 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).

Figure 8 - pre-desert area (Tamssa commune - Boussaâda) (year 2024).

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; BIDI et al., 2025).

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).

Interest conflicts

There was no conflict of interest between the authors.

Authors' contributions

Zohra Bidi, Sofiane Bensefia, Somia Bouafia - writing and translation into English; Djamel Khoudour - writing and correction of text and language; Djamel Sarri - reading and correction of text and language.

References

ABDESSELAM, S.; HALITIM, A. Land use change and soils degradation in arid area. A case study of south Hodna, Algeria. **International Journal of Innovation and Scientific Research**, v. 2, n. 1, p. 152-163, 2014. https://ijisr.issr-journals.org/abstract.php?article=IJISR-14-109-03

AIT LAMQADEM, A.; PRADHAN, B.; SABER, H.; RAHIMI, A. Desertification Sensitivity Analysis Using MEDALUS Model and GIS: A Case Study of the Oases of Middle Draa Valley, Morocco. **Sensors**, v. 18, n. 7, p. 1-19, 2018. https://doi.org/10.3390/s18072230

ANRH. National Agency of Hydraulic Resources. **Climatic data of M'Sila province**. 2020.

ANRH. National Agency of Hydraulic Resources. National Agency of Water Resource. **Map of hydroclimatological networks and water quality monitoring**. Scale 1: 500,000. 2005.

BENMESSAOUD, H. **Study of vulnerability to desertification using quantitative numerical methods in the Aurès Massif (Algeria)**. 54p. Thesis (Doctoral) - El Hadj Lakhdar University, Batna, 2009. http://eprints.univ-batna2.dz/568/

BENSEFIA, S.; KHOUDOUR, D.; BELAYADI, A.; LOUNIS, S. The status of artificial wetland areas in light of climate change using Geospatial systems: Case study Ain Zada Lake (Algeria). **Geografie**, v. 129, n. 3, p. 233-263, 2024. https://doi.org/10.37040/geografie.2024.013

BIDI, Z; KHOUDOUR, D.; SARRI, D.; BENSEFIA, S.; BOUAFIA, S.; REBBAS, K. Desertification Vulnerability in Arid Mediterranean Ecosystems: A Case Study of the Boussaada Sub-basin, (Southwest Hodna, Algeria). **Studies in Science of Science**, v. 43, n. 3, p. 143-156, 2025. https://doi.org/10.5281/zenodo.15032417

BOUDJEMLINE, F.; SEMAR, A. Assessment and mapping of desertification sensitivity with MEDALUS model and GIS - Case study: Basin of Hodna, Algeria. **Journal of Water and Land Development**, v. 36, n. 1-3, p. 17-26, 2018. https://doi.org/10.2478/jwld-2018-0002

BOUSSAADA, D.; YEROU, H.; BENABDELLI, K.; DJELAILIA, S. Evaluation of the pastoral potential of steppe rangelands. Algerian cases of M'Sila (Algeria). **Livestock Research for Rural Development**, v. 34, n. 1, 2022. http://www.lrrd.org/lrrd34/1/3404bouss.html

CFD. Forest Conservation M'Sila. **Climatic data of M'Sila province**. 2020.

D'ETTORRE, U. S.; LISO, I. S.; PARISI, V.; PARISE, M. Desertification Assessment Using the Modified Mediterranean Desertification and Land Use Model in a Karst Plateau. **Geosciences**, v. 14, n. 12, p. 1-21, 2024. https://doi.org/10.3390/geosciences14120320

DAOUDI, A.; BENTERKI, N.; TERRANTI, S. **Combatting desertification in steppe rangelands: The integrated agro-pastoral development approach**. Montpellier, France: ISDA, 2010, 11p. https://hal.science/hal-00520209

DPSB. Directorate of Programming and Budget Monitoring. **Monograph of M'Sila province**, Algeria, 2020.

DRE. Water Resources Directorate. **Climatic data of M'Sila province**, Algeria, 2020.

DSA. Department of Agricultural Services. **Agricultural statistics of M'Sila province**, Algeria, 2020.

DURAND, J. H. **Map of soils of M'Sila**. Scale 1: 750,000. 1954.

FERRARA, A.; KOSMAS, C.; SALVATI, L.; PADULA, A.; MANCINO, G.; NOLÈ, A. Updating the MEDALUS-ESA Framework for Worldwide Land Degradation and Desertification Assessment. **Land Degradation & Development**, v. 31, n. 12, p. 1593-1607, 2020. https://doi.org/10.1002/ldr.3559

HAFSI, L. H. KHALFALLAH, B. ALKAMA, D. and DEHIMI, S. Green spaces between water shortage and greed for urban sprawl, supported by fierce speculation: case study, the city of M'Sila. **Gazette of the Serbian Geographical Society**, v. 102, n. 2, p. 251-266, 2022. https://doi.org/10.2298/GSGD2202251H

KEBICHE., M. Le bassin versant du Hodna (Algérie): Ressources en eau et possibilités d'aménagement. *In*: **Travaux de l'Institut Géographique de Reims**, n. 85-86, p. 25-34, 1994. https://www.researchgate.net/publication/294608739_The_Hodna_River_watershed_water_resources_and_development_possibilities

KHOUDIR, S. **Study of desertification in the Hodna region (M'Sila province)**. 108p. Thesis (Master) - Houari Boumediene University of Science and Technology, Algeria, 2012.

KHOUDOUR, D.; BENSEFIA, S.; BOUNAR, R.; BIDI, Z.; ZEDAM, A.; BELDJAZIA, A.; MISSAOUI, K. Use of GIS for mapping sensitivity to erosion using the MEDALUS approach: Application in the Boussaada sub-watershed, Algeria. **Agricultural Mechanization in Asia, Africa and Latin America**, v. 55, n. 10, p. 19177-19189, 2024. https://www.shin-norinco.com/article/use-of-gis-for-mapping-sensitivity-to-erosion-using-the-medalus-approach-application-in-the-boussaada-sub-watershed-algeria

KOSMAS, C.; FERRARA, A.; BRIASOULI, H.; IMESON, A. Methodology for mapping Environmentally Sensitive Areas (ESAs) to desertification. *In*: KOSMAS, C.; KIRKBY, M..; GEESON, N. (Eds.). **The MEDALUS project: mediterranean desertification and land use. Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification**. European Union 18882, p. 31-47, 1999.

LADISA, G.; TODOROVIC, M.; LIUZZI, G. T. A GIS-Based Approach for Desertification Risk Assessment in Apulia Region, SE Italy. **Physics and Chemistry of the Earth, Parts A/B/C**, v. 49, p. 103-113, 2012. https://doi.org/10.1016/j.pce.2011.05.007

LAHLAOI, H.; RHINANE, H.; HILALI, A.; LAHSSINI, S.; MOUKRIM, S. Desertification Assessment Using MEDALUS Model in Watershed Oued El Maleh, Morocco. **Geosciences**, v. 7, n. 3, p. 1-16, 2017. https://doi.org/10.3390/geosciences7030050

LEE, E. J.; PIAO, D.; SONG, C.; KIM, J.; LIM, C.-H.; KIM, E.; MOON, J.; KAFATOSH, M.; LAMCHIN, M.; JEON, S. W.; LEE, W.-K. Assessment of ecologically sensitive lands for desertification using the MEDALUS method in Mongolia. **Forest Science and Technology**, v. 15, n. 4, p. 210-220, 2019. https://doi.org/10.1080/21580103.2019.1667880

LIAZID, M. **Evaluation of desertification phenomenon in Saida province**. 48p. Thesis (Master) - University of Science and Technology of Oran Mohamed Boudiaf, 2013.

MADANI, D.; TARAI, N.; TIR, C.; BENCHIKH, A. The state of awareness about the phenomenon of desertification by the inhabitants of the region of Khoubana, M'Sila, Algeria. **Natural Resources and Sustainable Development**, v. 13, n. 1, p. 167-178, 2023. https://doi.org/10.31924/nrsd.v13i1.126

MAINGUET, M.; DUMAY, F. **Fighting wind erosion: one aspect of the combat against desertification**. French Scientific Committee on Desertification – CSFD: Agropolis, n. 3, 2006, 48p.

MERDAS, S.; KOUBA, Y.; MOSTEPHAOUI, T. FARHI, Y.; CHENCHOUNI, H. Livestock grazing-induced large-scale biotic homogenization in arid Mediterranean steppe rangelands. **Land Degradation & Development**, v. 32, n. 17, p. 5099-5107, 2021. https://doi.org/10.1002/ldr.4095

MOSTEPHAOUI, T. ; MERDAS, S. ; SAKAA, B. ; HANAFI, M. T.; BENAZZOUZ, M. T. Cartographie Des Risques D'erosion Hydrique Par L'application De L'equation Universelle De Pertes En Sol A L'aide D'un Systeme D'information Geographique Dans Le Bassin Versant D'el Hamel (boussaada) Algerie. **Journal Algérien des Régions Arides**, v. 12, n. 1, p. 131-147, 2013. https://asjp.cerist.dz/en/article/76912

OUZIR, M. Green infrastructure, a thermal regulator for the arid city. Case study of the city of Bou-saada. **Gazette of the Serbian Geographical Society**, v. 103, n. 1, p. 419-432, 2023. https://doi.org/10.2298/GSGD2301419O

PLAIKLANG, S.; SUTTHIVANICH, I.; SRITARAPIPAT, T.; PANURAK, K.; OGAWA, S.; CHARUNGTHANAKIJ, S.; MANEEWAN, U.; THONGRUEANG, N. Desertification assessment using MEDALUS model in Upper LamchiengkraI watershed, Thailand. **The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences**, volume XLIII-B3-2020, p. 1257-1262, 2020. https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-1257-2020

PRĂVĂLIE, R.; PATRICHE, C.; SĂVULESCU, I.; SÎRODOEV, I.; BANDOC, G.; SFÎCĂ, L. Spatial assessment of land sensitivity to degradation across Romania. A quantitative approach based on the modified MEDALUS methodology. **Catena**, v. 187, 2020. https://doi.org/10.1016/j.catena.2019.104407

SALVATI, L.; BAJOCCO, S.; CECCARELLI, T.; ZITTI, M.; PERINI, L. Towards a process-based evaluation of land vulnerability to soil degradation in Italy. **Ecological Indicators**, v. 11, n. 5, p. 1216-1227, 2011.

SEGHIRI, D.; KHALFALLEH, B.; LAYEB, H. Green spaces between theory and reality. Case study of the city of M'Sila - Algeria. **Technium Social Sciences Journal**, v. 36, p. 619-628, 2022. https://doi.org/10.47577/tssj.v36i1.7337

WIJITKOSUM, S.; KROUTNOI, L.; YOLPRAMOTE, K. Factors affecting the desertification in Huay Sai Royal Development Study Center, Thailand. **Journal of Environmental Research and Development**, v. 7, n. 4, p. 1439-1443, 2013. https://www.researchgate.net/publication/296671823

Received on September 29, 2024
Returned for adjustments on November 29, 2024
Received with adjustments on December 26, 2024
Accepted on February 28, 2025