



# Adaptation of MEDALUS method for the analysis depicting desertification in Oued Labiod valley (Eastern Algeria)

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## Abstract

The development of arid and semi-arid climatic mountain areas is strongly affected by land conservation and the fight against land degradation, which is the consequence of a set of several processes. In this study, we apply the Mediterranean Desertification and Land Use (MEDALUS) method integrated with the GIS tools, on a mountain area of Oued Labiod valley, located in the southern foothills of the Aures basin in the eastern part of Algeria. The mapping of the vulnerability to desertification of this region was developed by crossing four thematic layers obtained from geometric means of four other quality indices mainly from the environment and man actions; these indices are related to the climate quality (CQI), soil quality (SQI), the vegetation cover quality (VQI), and the Management System and Human Influence quality (MQI). The results show that areas of high vulnerability account for 45, 69% of the total area, and are generally located to the south where vegetation cover is almost absent and human activity and socialization are rapid. Relatively threatened areas come in second position and occupy 33.3% of the total area, but few years later, they could suffer the consequences of desertification in case of poor management influence. Finally, the low-risk areas only represent 21.1% of the total area; these later are less threatened by desertification due to their good geographical position and their land occupation by a rich forest vegetation cover. The results provide a document on the widespread of priority zones and allowed to make an integrated management of this mountainous area.

**Keywords** Desertification · MEDALUS · Oued Labiod · GIS

## Introduction

Desertification phenomenon is mainly resulted from the interaction of environmental factors, human activity, and climate variations (UNEP 1997). The desertification is manifested by processes that lead to changes in vegetation cover, elements of soil surface (litter, bare soil, frosting film, silting), to the impoverishment of the soil and its disappearance, and to the reduction or loss of biological or economic productivity and complexity in croplands, pastures, and woodlands (Ajaj et al. 2017). Today,

desertification is considered a major environmental problem for the twenty-first century (World Bank 2003). According to Adger et al. (2001) in Ajaj et al. (2017), over 250 million people are directly affected by desertification, and some one billion people in over 100 countries are at risk. More than 46% of Africa's surface is affected by desertification (AitLamqadem et al. 2018). Combating drought, land degradation and desertification is an international priority. In addition, desertification is one of the most serious problems in many countries (UNCCD 2008; Taddese 2001) in Masoudi et al. (2018).

In Algeria, the desertification is the result of a series of physical and climate processes in arid and semi-arid environments (Benmessaud et al. 2010; Bouhata and Kalla 2014; Ouladheddar et al. 2018; Boudjemline and Semar 2018). The process of desertification (MATE 2002) directly threatens more than 7 million hectares. It is one of the most affected countries by desertification. Nearly 20 million hectares of steppe rangelands and 12 million hectares of pre-Saharan rangelands, located in the semi-arid to arid bioclimatic stage, are threatened by this process of degradation, and which is increasingly accentuated by the irregularity of precipitation,

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the resurgence of periods of drought, and increased anthropogenic pressures in these already fragile environments. Therefore, Algeria loses a few thousand hectares each year (Bensaid 2006; Bensouiah 2003).

Different models have been proposed at different scales with different approaches and methodologies for the assessment of desertification (Boudjemline and Semar 2018; AitLamqadem et al. 2018). These approaches and methods have been developed to identify areas of land degradation. Some of them use biophysical indicators (Lamchin et al. 2016) and other integrative anthropogenic indicators (Sommer et al. 2011). But currently, it is accepted that desertification is best explained by the combination of both socio-economic and biophysical factors, rather than factors by a single variable (Lambin et al. 2009).

The MEDALUS model has been a widely recognized approach in different Mediterranean regions at local national and regional scales. The model served as the basis for work in several countries such as Italy, Turkey, Portugal, Spain, Greece, France, Morocco, Algeria, and Tunisia (Basso et al. 2002; Geeson et al. 2002; Salamani et al. 2012; Boudjemline and Semar 2018; AitLamqadem et al. 2018; Nouri et al. 2020; Ouachoua and Al Karkouri 2020).

The MEDALUS model identifies regions that are environmentally sensitive areas to desertification. In this model, different types of sensitive areas to desertification can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate, and human actions (Ouachoua and Al Karkouri 2020). Each of these parameters is grouped

into various uniform classes and a weighting factor is assigned to each class. Then, four layers are evaluated: soil quality, climate quality, vegetation quality, and management quality. After determining indices for each layer, the sensitive areas are defined by combining the four quality layers (Kosmas et al. 1999). All the data defining the four main layers are introduced in a regional geographical information system (GIS) which has the capacity to analyze digital data. One of the characteristics of the MEDALUS model is its ability to compare with other models. The model provides for a weighted layer procedure with GIS application. In addition, it ensures accuracy and speed of evaluation and mapping (Ouachoua and Al Karkouri 2020).

For the first time in the eastern part of Algeria, an effective contribution of mapping the desertification sensitive areas using the MEDALUS method was undertaken in Oued Labiod valley. This study came with a great help to address the problem of desertification and to specifically contribute in the determination of priority areas, for the development works, as well as the fight against desertification, especially in this very sensitive and vulnerable area in which desertification processes will be irreversible, if they are not truly studied and cared about sooner.

## Geographical settings

The watershed of Labiod valley is located in the Aures massif (Eastern part of the Saharan Atlas) (Fig. 1). It is a part of the great

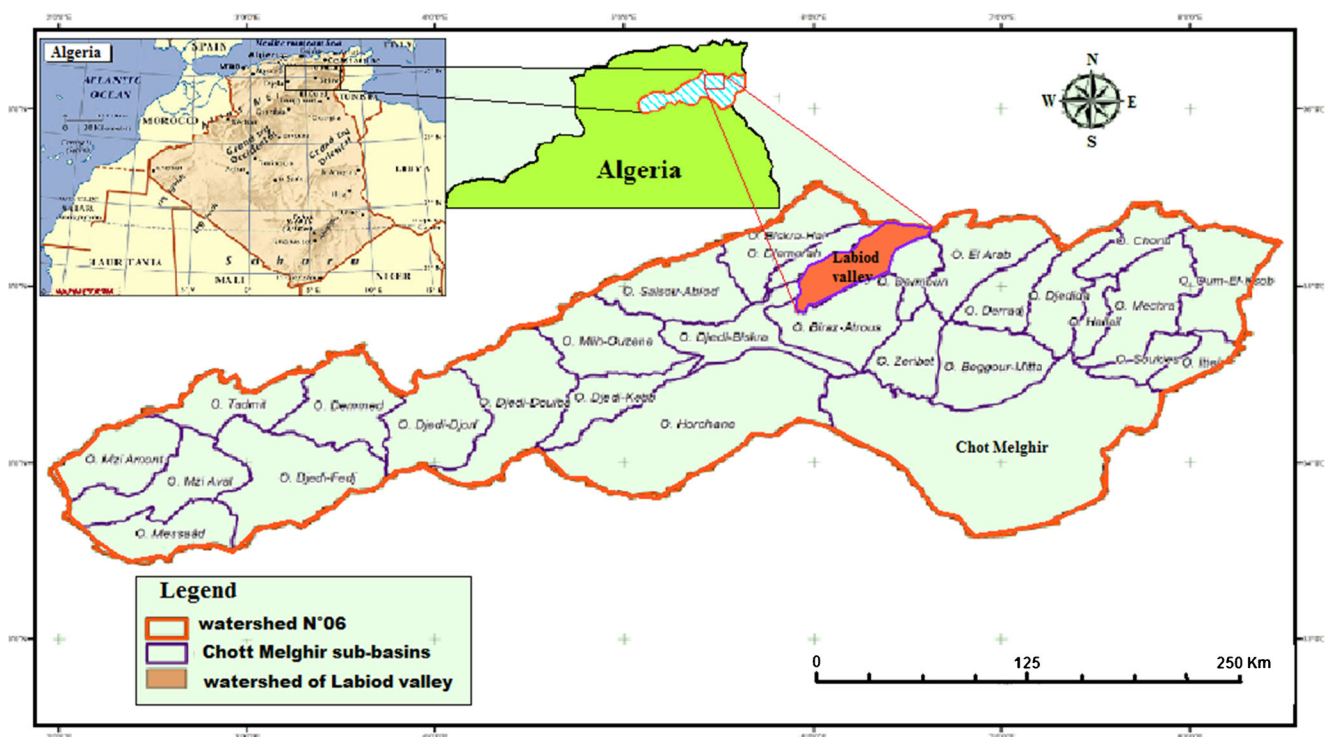


Fig. 1 Location map of the study area

Chott Melghir watershed and covers 1313 km<sup>2</sup>. It is formed by the meeting of descending torrents of the steep slopes of Chelia Mount which represents the highest peak (2326 m), to the Saharan plain then, towards the dam of Foum EL Gherza. The hydrographic network is constituted by the principal course: Labiod valley which crosses alternating formations between limestone and marls of the Cretaceous and Eocene ages. The watershed of Labiod valley is characterized by a semi-arid cold climate in winter, hot and dry in summer, with an average annual rainfall of 276 mm and an average annual temperature ranging between 16 °C and 23 °C. The vegetation consists of a permanent cover of cedar forests, holm oak and Aleppo pine. The rest is occupied by maquis, Alfa and poorly protected or bare land.

### Methodology

The MEDALUS model is one of the most widely used models in monitoring desertification sensitivity in Euro-Mediterranean countries. In the Southern side of the Mediterranean Sea, numerous studies were conducted to assess desertification (Benmessaud et al. 2010; Bouhata and Kalla 2014; Boudjemline and Semar 2018) in Algeria (Chakroun et al. 2006; Bedoui 2020; Nouri et al. 2020) in Tunisia (Bouabid et al. 2010; Mokhtari et al. 2013; Lahlaoui et al. 2017; AitLamqadem et al. 2018) in Morocco.

The methodology is inspired by the one developed in the MEDALUS project (Kosmas et al. 1999) identifying the vulnerability to desertification of Mediterranean ecosystems by a desertification sensitivity index (DSI). This DSI index is obtained from the geometric mean of four other quality indices taken from the environment and the man action. These indices are related to the following parameters: quality of the climate (CQI), quality of the soil (SQI), quality of the vegetation cover (VQI) and the quality of the Management System and Human Influence (MQI) (Benabderrahmane and Chenchouni 2010). Each of these indices is grouped into different uniform classes

with a weighting factor assigned to each class, then, the four layers cited above are evaluated. DSI is given by the following equation:

$$(DSI) = (CQI * SQI * VQI * MQI)^{\frac{1}{4}} \tag{1}$$

where:

- DSI desertification sensitivity index
- CQI climate quality index
- SQI soil quality index
- VQI vegetation cover index
- MQI Management System and Human Influence quality index

For each index, a score ranging between 0, as good condition, and 1 as deteriorated condition, was assigned based on factorial scaling technique. Additionally, a zero value was assigned when the measure was not appropriate for an area or where that area was not classified. In most cases, the score values generally ranges between 0 and 1: low values indicate a high quality or, conversely, a low connection with desertification. The final quality index QI is classified into three quality grades: high, moderate and low.

All data defining the four main layers are introduced into a geographic region under a (GIS) tool (Sepehr et al. 2007; Bouhata and Kalla 2014). These layers were created in (Arcgis 10.2) software using the spatial analysis tool (see Fig. 2).

### Results

#### Climate quality index

Climate quality index is determined by two factors: Average Annual Rainfall Index (PP) and Terrain Orientation Index (OR) (see Table 1). It is given by the following relation:

$$CQI = ((Weight * PP) + (Weight * OR)) \tag{2}$$

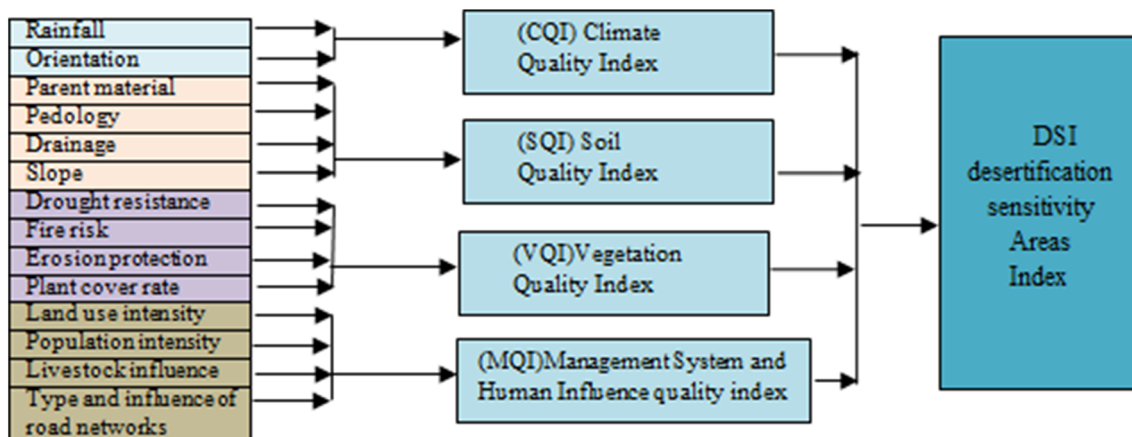


Fig. 2 Diagram mapping vulnerable areas to desertification

**Table 1** Classes and affected weights corresponding to the calculation of the climate quality index

Parameters	Classes	Description	Characteristics	Index
Rainfall	1	Strong	> 350 mm	0.2
	2	Average	300–350 mm	0.3
	3	Low	< 300 mm	0.5
Orientation	1	Very well exposed	North West	0.1
	2	Well exposed	Nord East	0.2
	3	Average exposed	South West	0.3
	4	Low exposed	South East	0.4

The determination of the PP factor is done according to the map of the isohyets established, while the Digital Terrain Model (DTM) allows generating the field exposures that will be used as a basis for calculating the OR.

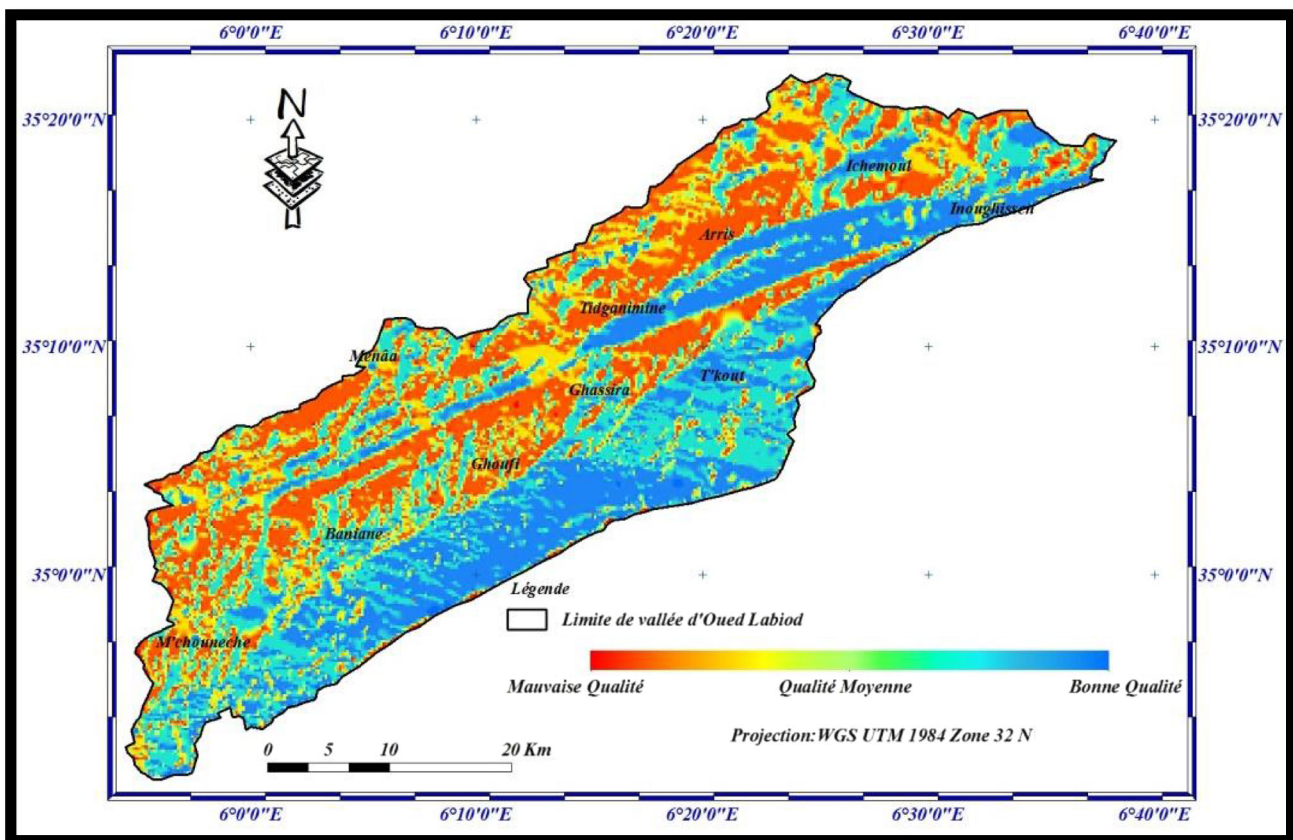
According to Fig. 3, the two classes of very good and good quality represent only 25, 83% of the total study area, emphasized in the map with dark and light blue color. These areas are generally located in South East and Eastern center of the watershed, and are low exposed and protected from the wind action.

The moderate quality class covers almost 25, 89% of the total surface, whereas the rest of the area which covers a considerable percentage of 48.28%, almost half of the total area, is

occupied by the poor quality class and the very poor class. These two classes are characterized by a very well exposition to the wind, a factor which increases the soil vulnerability year after year. These areas are located in both North and South West parts.

### Soil quality index

This index expresses the susceptibility to the removal of fine particles from soil, under the mechanical effect of winds, rain and runoff, while considering the homogeneity and importance of the relative soil distribution (Basso et al. 1998).



**Fig. 3** Map representing the climate quality index



Edaphic parameters (soil parameters) related to desertification sensitivity are numerous and varied. For this purpose, the methodology has been limited to certain simple, measurable,

and influential parameters such as parental material, drainage, pedology, and slope (Table 2).

The soil quality formula is as follows:

$$SQI = ((Weight * Slope) + (Weight * Parental material + (Weight * Pedology) + (Weight * drainage))) \tag{3}$$

The category of very good quality index covers almost 39.93% of the total area (Fig. 4). This class is mainly occupied mainly by forest vegetation and less subjected to entropic pressures than the other classes, which explains the great stability of the soil and less vulnerability to desertification. However, the moderate quality class almost covers most of the total area with a percentage of 41.76%. These areas are located in the North East, South and the East-West part (yellow color in the map of Fig. 4).

The last two classes (poor quality and very poor quality) occupy the rest of the total surface with a small percentage of 18, 28% (Fig. 4). These lands are located in the South and South West parts of the basin; they are characterized by a very poor vegetation cover with bare soils and rocky terrain. They

are highly subjected to entropic pressures due to their well exposition to wind which increase their vulnerability to desertification.

### Vegetation cover quality index

This index is determined by superimposing cartographic data on fire risk factors, protection against soil erosion, and drought resistance of the vegetation cover and recovery rate (Table 3). These four parameters influence the quality of vegetation to resist desertification. The LANDSAT 8 satellite image (2016) and the land cover map will serve as a basis for determining and indexing these factors.

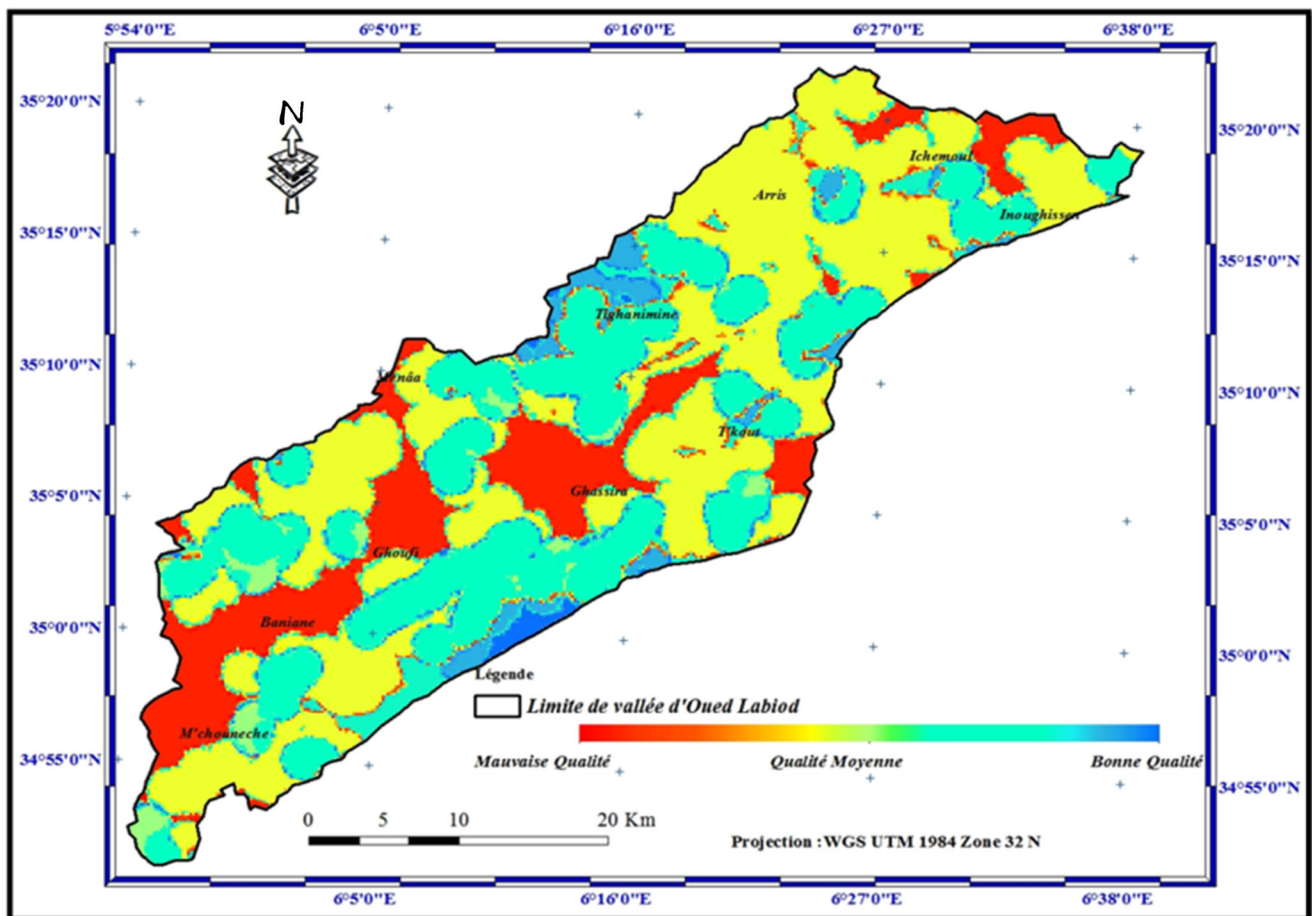


Fig. 4 Map of the soil quality index of Oued Labiod valley

**Table 2** Classes and affected weights corresponding to the calculation of the soil quality index

Parameters	Classes	Description	Characteristics	Index
Parental material	1	Coherent	- Dolomite limestone, conglomerates, massive limestone	0.2
	2	Moderately consistent	- Gypsum, limestone and marl, marl-limestone.	0.3
	3	Tender to friable	- Sand, alluvium, sandstone ...	0.5
Slope	1	Very soft to flat	< 3%	0.1
	2	fresh	3–12%	0.2
	3	Not fast	12–25%	0.3
	4	Very steep	> 25%	0.4
Drainage	1	Well drained		0.2
	2	Imperfect drainage		0.3
	3	Poorly drained		0.5
Pedology	1	Low	Humus calcareous soils, unsaturated humus soils	0.1
	2	Average	Calcium soils	0.2
	3	Strong	Wind ablation soils	0.3
	4	Very strong	Mother rocks	0.4

The vegetation cover quality index is given by the formula below:

$$VQI = ((\text{Weight} * \text{Fire risk}) + (\text{Weight} * \text{Erosion protection}) + (\text{Weight} * \text{Drought resistance}) + (\text{Weight} * \text{Recovery rate})) \quad (4)$$

The high quality class covers almost 10.66% of the total area, mainly located in the northeastern and the west center parts of the watershed. The vegetation of good quality occupies an area of 11.50%. However the

moderate quality class covers the smallest part with a percentage of 6.62% of the total area. For the class of poor quality and the class of very poor quality, they mostly occupy the largest area which represents more than

**Table 3** Classes and affected weights corresponding to the calculation of the vegetation cover quality index

Parameters	Classes	Description	Characteristics	Index
Fire risk	1	Low	Bare soils and rocky terrain	0.1
	2	Average	Cereals, irrigated crops	0.2
	3	High	Degraded maquis	0.3
	4	Very high	Dense forest	0.4
Erosion protection	1	Very high	Dense forest	0.1
	2	High	Degraded maquis	0.2
	3	Average	Cereals, irrigated crops	0.3
	4	Low	Bare soils and rocky terrain	0.4
Drought resistance	1	Very high	Dense forest	0.1
	2	High	Irrigated crops, degraded maquis	0.2
	3	Average	Cereals	0.3
	4	Low	Bare soils and rocky terrain	0.4
Plant cover rate	1	High	Dense forest, irrigated crops	0.2
	2	Average	Cereals, degraded maquis	0.3
	3	Low	Bare soil and rocky terrain	0.5

two-thirds (71.2%); these lands are located in the south-western part of the study area (Fig. 5).

**Management System and Human Influence quality index**

The parameters used to define socio-economic quality index in the study area are: intensity of agricultural land use,

population intensity, livestock intensity, type and influence of road networks (Table 4). The socio-economic quality index will be calculated by the following equation:

$$MQI = ((\text{Weight} * \text{intensity of agricultural land use}) + (\text{Weight} * \text{Population intensity}) + (\text{Weight} * \text{livestock intensity}) + (\text{Weight} * \text{type and influence of road networks})) (5)$$

**Elaboration of the vulnerability map to desertification**

The methodology adopted for the spatialization of vulnerability to desertification is based on the integration of mainly five factors (Soil, Vegetation cover, Climate, and Management System and Human). Each factor has a weight according to

its importance and influence on the gravity of the phenomenon (Table 5).

The analytical method adopted is that of analytic hierarchy process (AHP).

In this method, created by Saaty and Vargas (1991, 2000), AHP is a multi-criteria analysis method that can be used in the quantification of qualitative characteristics, through its weighting.

The method is based on the comparison of different characteristics. Starting from the construction of a square matrix,

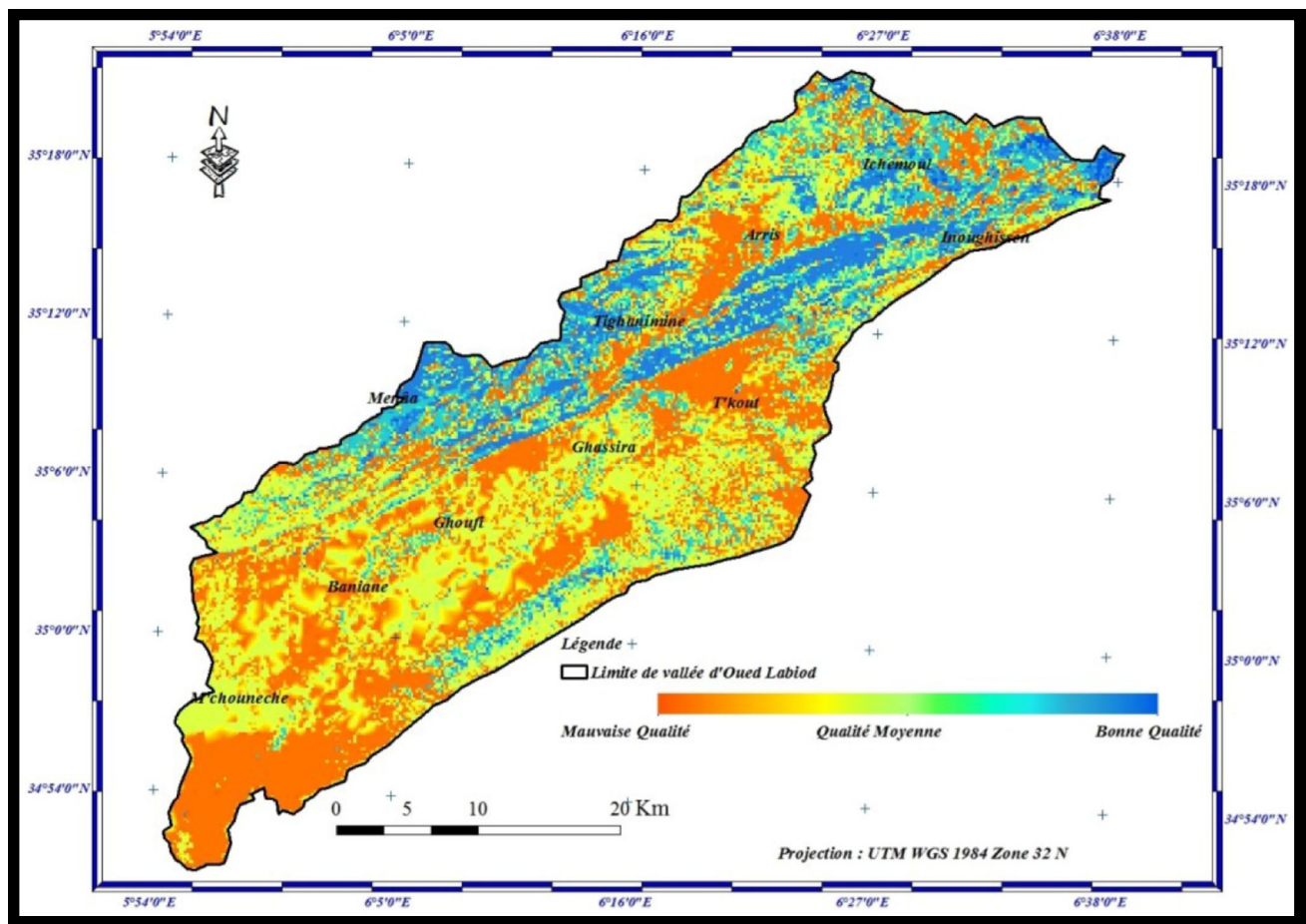


Fig. 5 Map of the vegetation cover quality index of Oued Labiod valley

**Table 4** Classes and affected weights corresponding to the calculation of the socio-economic quality index

Parameters	Classes	Description	Characteristics	Index
Intensity of agricultural land use	1	Low	Bare soils and rocky terrain.	0.2
	2	Average	Cereals, degraded maquis.	0.3
	3	High	Dense forest, irrigated crops.	0.5
Livestock intensity	1	Low	60	0.2
	2	Average	60–85.5	0.3
	3	High	> 85.5	0.5
Population intensity	1	Low	< 34	0.2
	2	Average	34–70	0.3
	3	High	> 70	0.5

we evaluate the relative importance of one characteristic with respect to another, by using an adequate scale. The results issued from the AHP correspond to scores whose sum is equal to 1 (Guellouh et al. 2020).

$$(DSI) = ((Weight * CQI) * (Weight * SQI) * (Weight * VQI) * (Weight * MQI)) \tag{6}$$

The results obtained (Table 6) revealed that over than 45% of the study area is classified as critically endangered areas (highlighted in red color), followed by 33.3% relatively threatened areas and 21.1% low-risk areas (Fig. 6).

### Discussions

The MEDALUS model is one of the most widely used models in monitoring desertification sensitivity in the world. The general methodology is fully described by Kosmas et al. (1999), identifying the vulnerability to desertification of Mediterranean ecosystems by a desertification sensitivity index (DSI). This DSI index is obtained from the geometric mean of four other quality indices taken from environment and man action. The MEDALUS model allows for variation in the number of factors in the calculation of partial quality indicators, and this relates to the availability of objective data and maps. The first three quality indices provide insight into the environmental conditions, while the last one expresses an assessment of the pressure resulting from the anthropogenic

activities. Each of these indices is grouped into different uniform class with a weighting factor assigned to each class; then four layers are evaluated.

The aim of any monitoring and assessment of desertification threats is to understand and predict changes and trends over time and space to promote a suitable management system. Furthermore, the MEDALUS approach can be an efficient tool for managing and protecting fragile arid and semi-arid lands. The approach is also flexible because it allows users to add, remove, and adjust the sub-indicators as necessary (AitLamqadem et al. 2018).

The application of the MEDALUS model in the study area revealed alarming results. Aures, including the study area, constitute an obstacle to the desert’s advance to the north. The causes of desertification in this region are due to a combination of climate change, scarcity of water resources (less rainfall and successive droughts), and high pressure on limited natural resources.

In the watershed of the Labiod valley, the rainfall class “< 300 mm” dominates, due to the importance of the arid and semi-arid climate in the central areas and the southern slopes. The climate in the north and northeast of the region tends to be semi-humid, and this is due to the elevation factor, as the region is ranked as the second highest peak in Algeria (*summit of Cape Kulthum* on the heights of the *Chilia mountains*, 2328 m), and the area is full of forests of Atlas Cedar and Aleppo Pine forming dense vegetation mainly, Atlas Cedar trees varying in age between 150 and 300 years old and with diameters between 60 cm and 80 cm, they now suffer from the symptoms of a serious epidemic disease, and the impacts of desertification and human intervention.

**Table 5** The weight according to each factor

Index	Weights
Management System and Human Influence quality	C 1
Climate quality	C 2
Vegetation cover quality	C 3
Soil quality	C 4

**Table 6** Results of sensitivity to desertification areas

Class	Description	Area (km <sup>2</sup> )	%
1	Critically endangered areas	603.68	45.69%
2	Relatively threatened areas	437.39	33.3%
3	Low-risk areas	277.14	21.1%



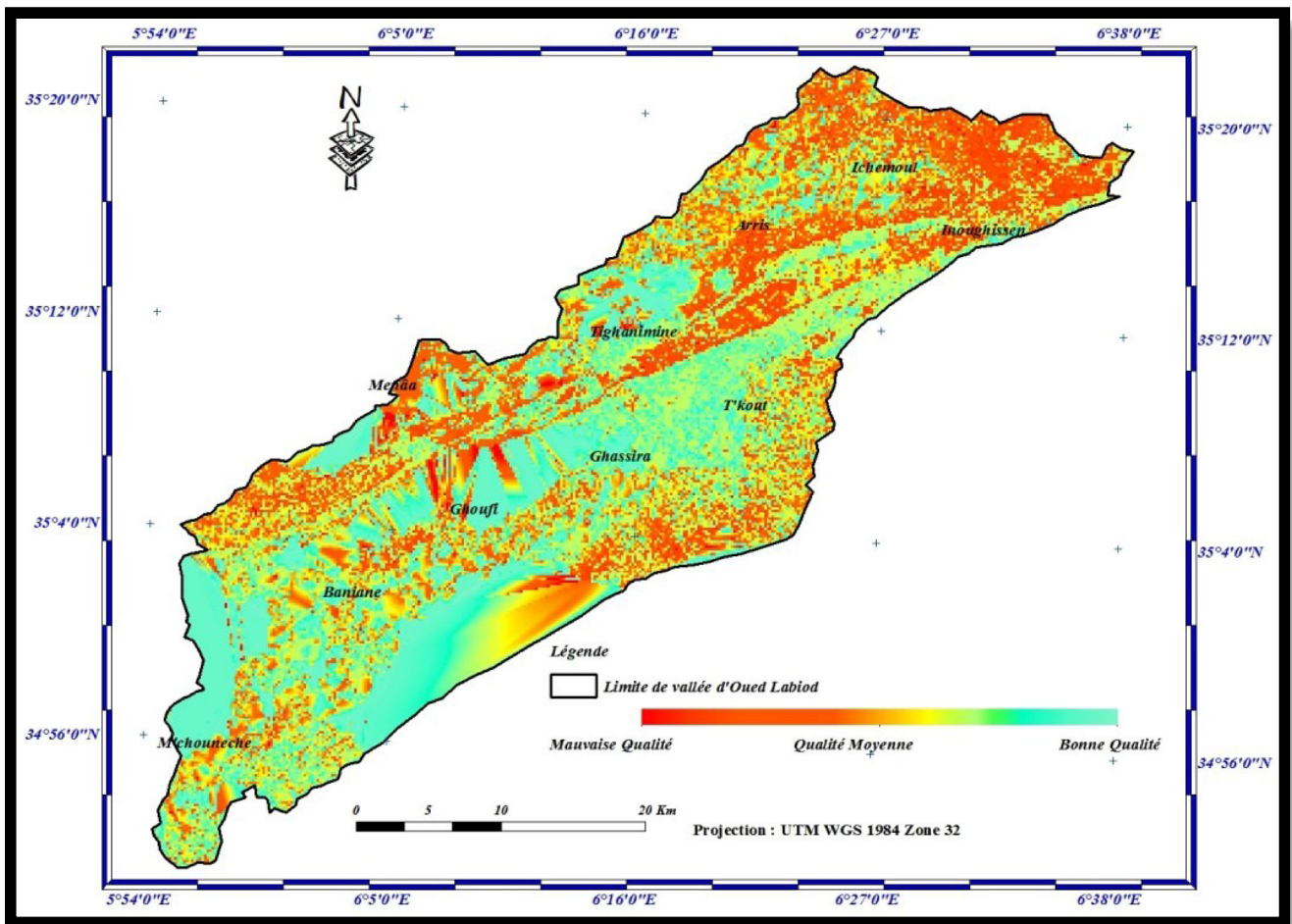


Fig. 6 Map of the socio-economic quality index of Oued Labiod valley

The climate in this area had considerable rainfall. However, this situation has been reversed since 1991. It is predicted that rainfall will decrease from 50 to 105 mm/year on altitudes and the foothills, from 13 to 50 in the low-lying areas towards the desert. Statistical tests reveal breaks around 1991–1994. We notice a severe drought which began in 1991, the results indicate that the spatial pattern of precipitation was first effect of the local climate, and inside the massif, altitude and latitude are the two factors that control this variability that installs and starts to take the form of climate change (Khentouche and Dridi 2019), which speeds up the process of desertification in this region.

The orientation classes “South-West” and “South-East” are the dominant due to the orientation of Saharan Atlas, they represent, approximately 65% of the area. According to the results of the climate quality index, the good quality represent only 25, 83% of the total study area, these areas are generally located in South East and Eastern center of watershed, and are low exposed and protected from the wind action. The poor quality area and moderate quality area covers almost 74, 17% of the total surface, almost half of the total area, are occupied by the poor quality class and the very poor class. These two

classes are characterized by very good exposure to the south wind (sirocco); sirocco wind is more common in spring and autumn, it is associated with very hot, dry and dusty weather, it is a factor which increases the vulnerability of the soil year after year.

The North of the study area is subject to demographic pressure and it is concentrated in the city of Arris, Medina (Ichamoul) and the city of Inoghissen due to historical facts and to the presence of a network of roads, infrastructures and cultivable lands. Poverty and the precarious social situation of populations and rural populations lead to natural resources management abuse and high pressure on limited natural resources, especially forests, as the area is characterized by extreme cold, which leads the population to cut trees to ensure the source of energy and heating. In many cases the forest is deliberately exposed to fires in order to build or expand the areas of agricultural land.

Relatively threatened areas are moderately sensitive lands occupying 33.3% of the total area. These lands are less subjected to desertification than the rest of the classes, but are not immune because if they are poorly managed, in a few years later, they will suffer the

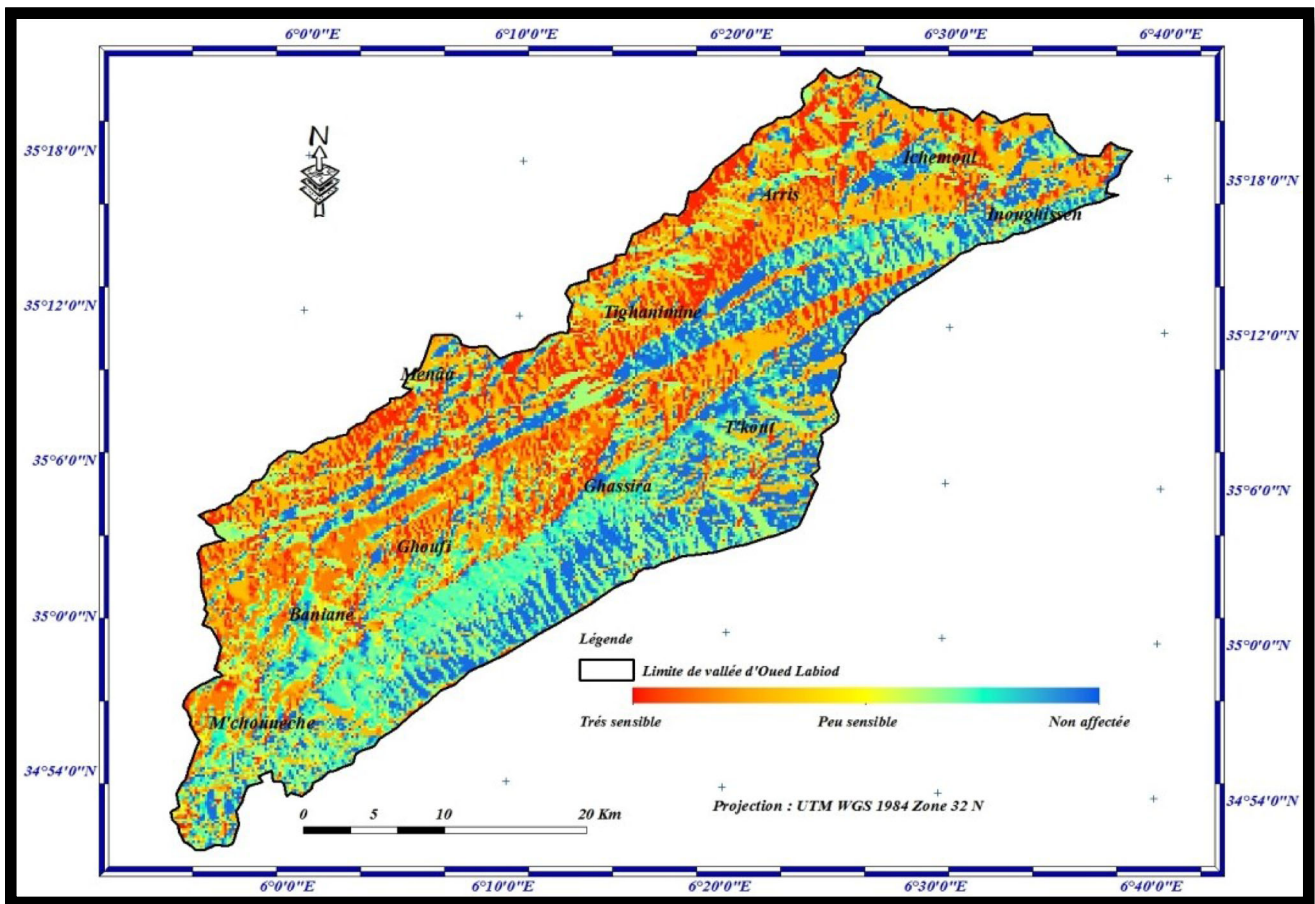


Fig. 7 Map of vulnerability to desertification based on major contributing factors

consequences and will turn into deserted land (Fig. 7). They are superimposed on the zones of para-forest formations; they occupy large areas in the form of discontinuous islets based mainly on holm oak. The maquis are in a very advanced state of aging and are degraded.

The critically endangered areas (very vulnerable, critical) account for 45.69% of the total area. They are generally superimposed on the south facing areas where the vegetation cover is almost zero. This sensitivity is also due to the poor quality of the climate, the poor quality of the soil and to the rapid socialization of these areas (Fig. 7). The populations of these semi-arid zones are generally poor and the agricultural land proper is very small. This obliges them to orient themselves towards the breeding of sheep or goats in para-forest land, and to practice clearing and deforestation of forests to meet in particular the growing needs for fuel wood, construction wood, branches for herds and in farmland or rangelands.

The use of geomatics tools (GIS and remote sensing) still suffers from a number of limitations. These limits are, on the one hand, to the fact that it is impossible to approach all the functions and relations constituting the environment. Then, the availability and viability of the data

collected in the field. Regarding the application of the MEDALUS approach, it is useful to note that the results of the calculation of the desertification sensitivity index are not always easy to verify in the field.

## Conclusion

In this study, attempts were made to map vulnerability to desertification by adapting the MEDALUS method and using GIS tools. The analysis of the results obtained shows the importance of desertification phenomenon which threatens practically almost half (45.69%) of the total study area. Several factors and their articulations in space and time have been the cause of this state of strong sensitivity to desertification, among which the most important factor is respectively climatic deterioration, and socialization by agricultural activity that leads to the destruction of the plant cover protecting soil against erosion.

The results showed the intensity and severity of desertification processes in this area and give us an insight into the evolution of ecosystems, which can be used as an essential tool to help decision-making and planning (i.e., the definition

of priority areas for intervention in the fight against the evolution of land degradation).

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## Declarations

**Competing interests** The authors declare no competing interests.

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