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Desertification risks: Sensitivity and Limits of the MEDALUS Method in Semi-arid Areas (Center of Tunisia)

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Abstract

Environmental indicators are essential tools for tracking environmental risks especially land use degradation. Supporting the environmental evaluation and research items needs usually a heavy and costly field work. For these reasons, some methods and indicators of risks have gained in importance in many countries and in international reports. As part of their commitment to transparency to real information, public authority increasingly uses a reduced number of indicators or select existent methods to report on major environmental issues. These economic and time justifications cannot nor ignore or hide the disadvantages of these methods apart from their validation areas especially in arid countries. The study concerned the application of a European method for the evaluation of the risks of desertification namely “the Mediterranean Desertification and Land Use or MEDALUS method”, which had deserved more researches to adapt it to the arid conditions. Indeed, testing this method to the desertification risks evaluation of the agricultural land-use in Tunisia has showed its limits. The review of parameters used and the re-calibration of the risks levels to the agricultural units have improved the results of this method in arid conditions. This improvement was limited about 10% (land degradation risks has reduced from 90.5% to 81% of surface studied) when adapted soil quality index to local conditions and re-calibration of risks levels were applied. But these results do not prevent that validation of the method would improve analyzes and understanding of this phenomenon in local conditions.

Keywords**:** Land-use; soil qualities; desertification risks; evaluation methods.

1. Introduction

Desertification and/or land degradation processes are characterizing by scientists and developer amenagists after droughts threatened areas. Besides, this attribution was affected by the United Nations Convention to Combat Desertification (UNCCD) to “the degradation of the land in arid, semi-arid and dry-sub-humid areas”. It was considered as a result of several factors including among other climatic change and human activities. The dominant symptomatic character of this definition does not account for the underlying processes of the phenomenon [1].

Desertification does not refer to the expansion of existing deserts nor should be used to describe cyclic phenomena but however it must characterize a state of continues degradation of the ecosystem [2].

On the fact of coming from area highly affected by severe aridity, we consider the desertification as a severe stage of soil degradation beyond the resilience of the ecosystem involving an irreversible situation of stable land-cover [3] have demonstrated that several soil parameters (of about thirty) had high correlation coefficients for this phenomenon in comparison with vegetation factors. Study in Morocco[4] shows several factors exacerbate this phenomenon such as the climate dryness, the geological and morphological characteristics of the terrain, the irrational use of space, population growth and the over-exploitation of vegetation and water resources Consequently, indicators of this ecological phenomenon must consider the state of irreversibly soil infertility as rocky deserts or highly sodic soils for example. The most useful indicators, however, are those which indicate the potential risk of desertification while there is still time and scope for remedial action [5].

Indicators, developed from some methods, are already widely used to set targets for and to monitor different ecological factors and deduce environmental consequences. However, results of researches can be also used to understand this complex phenomenon by the general population.

Tunisia and the majority of Mediterranean countries are subjected to the climatic aridity which involves social and environmental problems, especially in the countries of the Mediterranean south shore, and concerns all citizen activities whatever the system of production [5]. Priority of even Mediterranean countries is given to set up a program for acquisition data operating over long periods and specially in threatened areas to follow-up this phenomenon. A best monitoring and evaluation of ecological factors would optimize the high expenditure and means necessary to estimate a quantitative effect of this desertification. In this way, we are working on application of some methods with aims to select a simplified land degradation indexes with our edge availabilities. Indeed, specific properties directly linked to soil and vegetation degradation status, such as chemical properties, organic matter content, mineralogical content, soil crusting, runoff, vegetation content and type, are reasonably analyzed from field prospection and combined with spatial modeling of land degradation to improve model of dynamic functioning and drought simulation in Tunisia.

Highlights of this paper were to evaluate the desertification index in the middle region of Tunisia, through the integration of different factors involved in this ecological phenomenon (Mediterranean Desertification and Land Use) including among of the bioclimatic conditions: climate, vegetation, soil and management. It is important to underline that the degrees of reliability and the limits of sensitivity to desertification (MEDALUS) [7] have been verified when this method is applied under arid conditions in the region of Kairouan, in central Tunisia.

2. Framework and context of the study

The risks of desertification are especially potential in arid region where the potential evaporation exceeds precipitations to ensure vegetation water needs and to preserve the soil structure. Our study area is characterized by a strong deficit between the average annual precipitation and the total actual evapotranspiration and consequently a continuous exhaustion of natural resources without however carrying out any change in the development policy.

To characterize and to preserve our natural resources, the research policies have developed and carried out various activities concerning the risks of environmental degradation through disappearance of some indigenous vegetal species. These tasks are often carried out in partnership with international authorities support and cooperation on biodiversity and climate change subjects. Different approaches are used to assess land sensitivities to desertification; some integrated models combine man and the environment to produce synthetic indices [8], other models use measurable or observed field indicators (vegetation cover, soil salinity, etc.) [9]. The present method (MEDALUS) is based on an original model which parameters are evaluated in the field and it continues to be the most used especially in southern European regions. Indeed, this method identifies ecologically sensitive areas [11] by integrating soil, vegetation, climate and management factors [12]. Each factor is represented by indices calculated through a combination of sub-indices. The output map corresponds to the sensitive areas of desertification.

Thus, the framework of this research was a scientific international cooperation to test the MEDALUS method in the south Mediterranean countries to warn desertification risks. The research was carried out in an arid area named Oueslatia located in Kairouan province (center of Tunisia).

In fact, desertification is considered as the consequence of several processes which are active in arid and semi-arid environments, where water is the main limiting factor of land use performance and consequently, the wind erosion and the soil salinization are the degradation indexes to the desertification phenomenon [13].

Application of MEDALUS needs analysis of the biophysics factors (geology, geomorphology, pedology, bio-climate, vegetation) and anthropic affects like the management activities in the region. Results of this analyses would permit understanding and fighting against the threat of desertification in the Mediterranean region.

3. Materials and methods

Studied area covers a surface of about 12000 ha and constitutes a sub-watershed of the main river in the region (called Maarouf River, Figure 1). Soils parentmaterial are from superior and middle of Cretaceous era with calcareous formation impregnated by argillites and sand facies at lower level [14]. Pedologic formations have been evolved in arid bioclimatic conditions where soils identified are affected to Xerorthents and Calciorthids soils great groups [15]. In these conditions, the average of annual temperature is higher than 15°C and temperature at the hottest month (august) is higher than 35°C and at the coldest month (January) is about 6.8°C. Rainfall in this region of Kairouan is very irregular with a minimum observed in July (2.15mm) and a maximum in October with 57.2mm [16]. Considering the importance of climatic information, these data are presented in table 1.

Table 1.
Climatic data of study area (Kairouan station 1990 – 2000.)

	Average rainfall	**Monthly temperature**			**Average actual evapotranspiration**	**Monthly average humidity**
		Mean	Max	Min		
January	47.16	15	17.0	6.8	38.6	29.1
February	20.48	15.3	18.9	7.6	46.6	22.4
March	29.75	15.4	20.4	8.4	77.5	19.5
April	30.88	17.4	23.6	11.2	105.0	19.3
May	22.91	21.8	28.8	14.9	159.9	14.8
Jun	4.51	26.7	33.9	19.4	203.7	13.4
July	2.15	29.2	36.7	21.7	218.9	13.8
August	14.16	30.1	37.3	22.9	189.1	15.7
September	31.4	26.2	32.1	20.3	123.2	22.2
October	57.22	21.7	27.3	16.1	83.6	21.6
November	35.12	16.6	21.7	11.6	51.3	24.6
December	30.2	12.6	17.8	7.5	40.6	33.2
Annual	**325.9**	**20.7**	**26.3**	**14.0**	**1338.0**	**20.8**

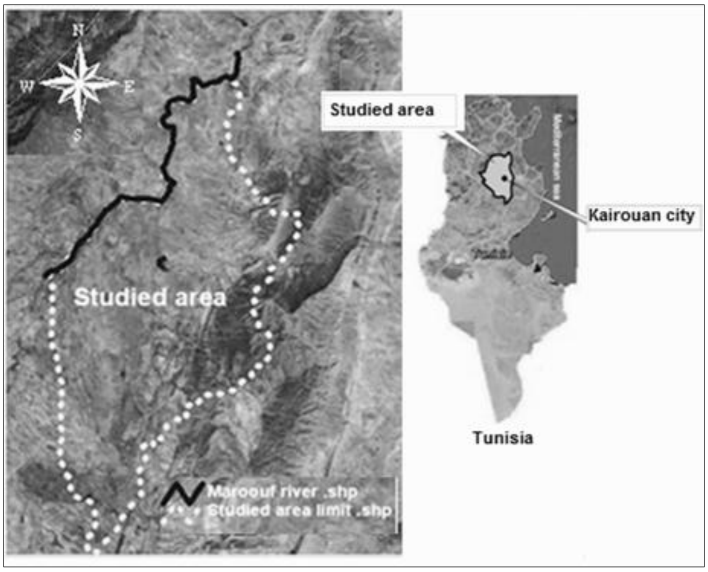

Figure 1: Study site area

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Four biophysics indicators are necessary for the MEDALUS method application which are the vegetation quality index (VQI), the soil quality index (SQI), the climatic quality index (CQI) and the management quality index (MQI). Each indicator is dependent of others parameters which are identified and affected by scores of desertification sensitivity degree by bay of the four equations from (1) to (4). The regional degree of the desertification sensitivities is calculated taking account of all these equations to determine another index named Environmentally Sensitive Areas (ESA in equation 5).

$$VQI = (\text{Fire risk} \times \text{Erosion protection} \times \text{Dryness resistance} \times \text{covering})^{1/4} \quad (1)$$

$$SQI = (T \times R \times FR \times Pr \times P \times D)^{1/6} \quad (2)$$

where we consider the score of soil texture (T), bedrock type (R), stoniness proportion (FR), soil depth (Pr), slope level (P) and drainage quality (D).

$$CQI = (\text{Rain fall} \times \text{Aridity} \times \text{Exposure})^{1/3} \quad (3)$$

In CQI, the aridity value is calculated by Bagnouls-Gaussen method for bioclimatic indexes cited by [16].

$$MQI = (\text{Intensity of land use} \times \text{conservation policy})^{1/2} \quad (4)$$

From these equations, the regional degree of the desertification sensitivities is calculated as fellow:

$$ESA = (VQI \times SQI \times CQI \times MQI)^{1/4} \quad (5)$$

Each indicator of this method was carried out by algebraic analyses of different maps named "raster mode". All these scores (VQI, SQI, MQI and CQI) are represented as map format (Figure 2) and combined by MEDALUS method (equation 5) allowed to have a level of desertification sensitivity where each small area should be characterized by his aridity degree.

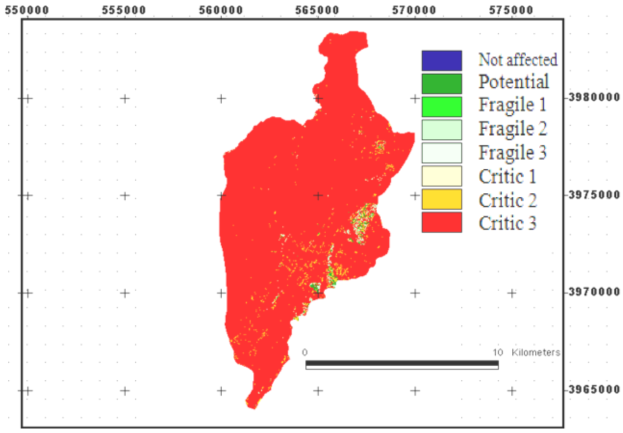

Figure 2: Map of desertification risks according to standard MEDALUS method

The application of this methodology has focused to firstly quantify the environmental effects of different parameters especially edaphic one and to improve monitoring and evaluation of the soil degradation and the desertification process in arid region.

All acquired information is originated from multiple sources with different data formats. The used data are topographic, geological and geomorphological maps. Moreover, we used recent satellite images in order to update the soil occupation and the vegetation cover. Necessary corrections are added for the gray levels of these satellite images in reflectivity values for the land use cartography because the reflectance of the natural surface is the relationship between its luminance and the solar illumination received by this area [17].

The field observations and the pedological analyses of profiles are also acquired data in this study and were integrated in a database geo-referenced in order to proceed to a spatial modeling for the desertification sensitivity analysis.

Our focus is specially to show the realism of the application of this method in Tunisian condition and which means to correct and to improve the valorization of this method.

4. Results and discussions

According to as well parameters retained as limits quantified granted to each factor of MEDALUS method applied in the north of the Mediterranean shore, the results show that 90.5% of the study area are in a critical condition to the desertification affects. This first standard evaluation reveals that soils with a high quality occupied by annual crops are very sensitive to desertification compared to less good quality soils but occupied by natural vegetation as forest or shrubby cover (Figure 2). However, our study deserves more critics in particular related ones to a lack of the number of the measured stations and only one weather station for the climatic indicator is unfortunate not representative of the whole climate of the zone.

Moreover, all indicators of this phenomenon are already widely used to set targets for natural resources protection such as edaphic resources, forester and other ecological ones but it is necessary to be vigilant for a strict using or standardizing these indicators [18]. In fact, making scientific research understandable by the different contributors of the ecosystem's management could help to better use of these methods identified in others conditions, in order to carry out the most important elements that it should contain. The interest remains important for the modeling of these factors to get a good illustration and practical recommendations.

Under the Tunisian semi-arid conditions, other parameters related especially to better characterization of the soil quality index are very important to land use sensitivity. The organic matter content is considered very important to improve the structure, stability and hydro-dynamism of soils [19]. In the north of Africa, the limestone formations (rich with CaCO3) especially the quaternary ones are omnipresent and the bicarbonate of calcium and the organic matter contents should be very important for the soil evolution [20]. To validate this method under Tunisian biophysics environment (especially edaphic conditions) a pedological map was elaborated after a field prospection (Figure 3) and the soil typology was referred to the American soil classification in soil taxonomy [15].

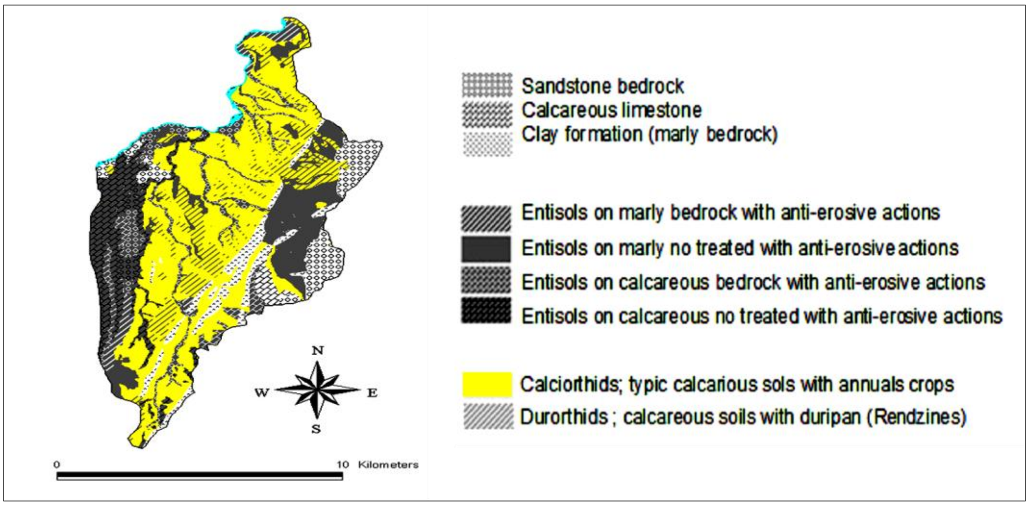

Figure 3: Pedological map of the studied area

The dominance of calcareous soils in the study area was the reason to review the SQI equation and to add two very important parameters related to the $CaCO_3$ and organic matter soil contents and a new equation of the Soil Quality Index Modified (equation 6, Figure 3) noted SQI_{TUN} has tested for the study area conditions.

$$SQI_{TUN} = (T \times R \times FR \times Pr \times P \times D \times CaCO_3 Total \times MO)^{1/8} \quad (6)$$

Basis on this new equation, the soil sensitivity to the desertification phenomenon has been tested and the result was reported in the figure 4.

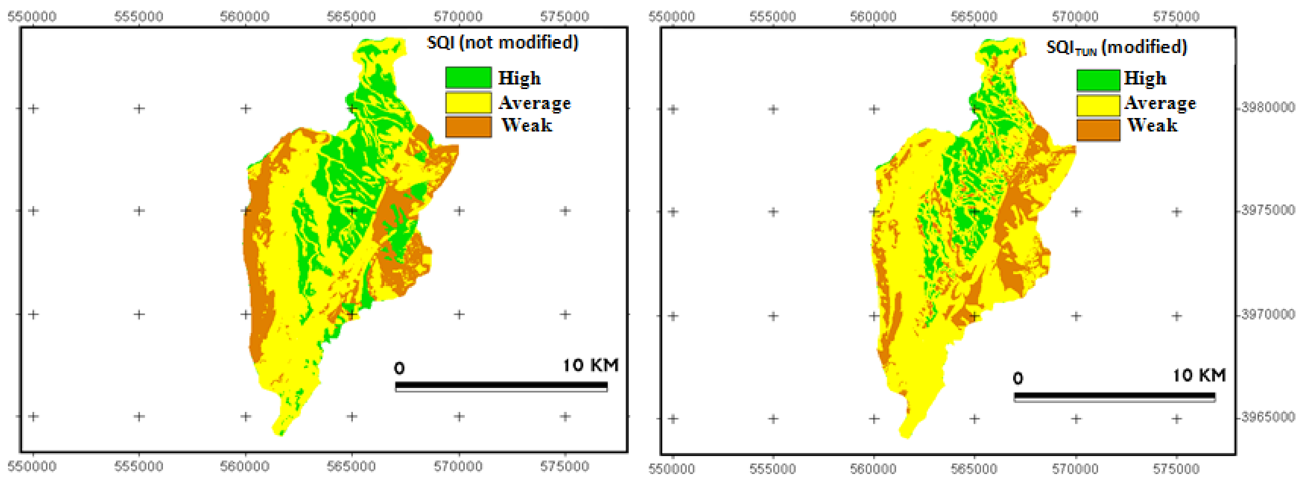

Figure 4: Maps of SQI and SQI_{TUN} (modified) according to standard MEDALUS method

Testing the MEDALUS method with the new equation of the SQI_{TUN} has involved a certain modification of the sensitivity areas (Figure 5 and 6) and has decreased the fragile units to desertification when the organic matter and bicarbonate soils content are used in soil Quality index. These two edaphic factors have limited the threatened areas and results have showed that if the organic matter content decreases, the soils sensitivity increases with the soil bicarbonate content.

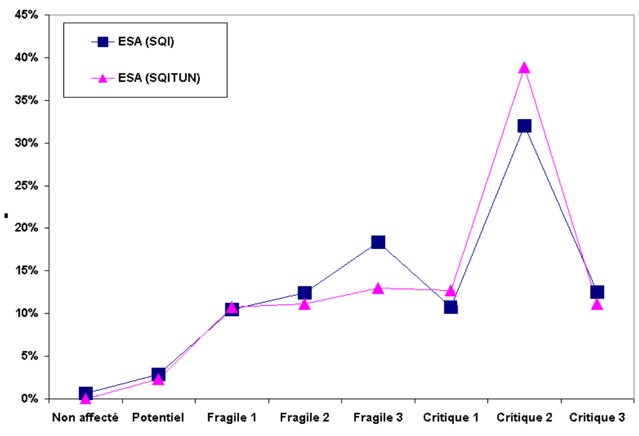

Figure 5: comparison between the quantitative sensitive areas according to standard (SQI) and modified (SQI_{TUN}) by MEDALUS method

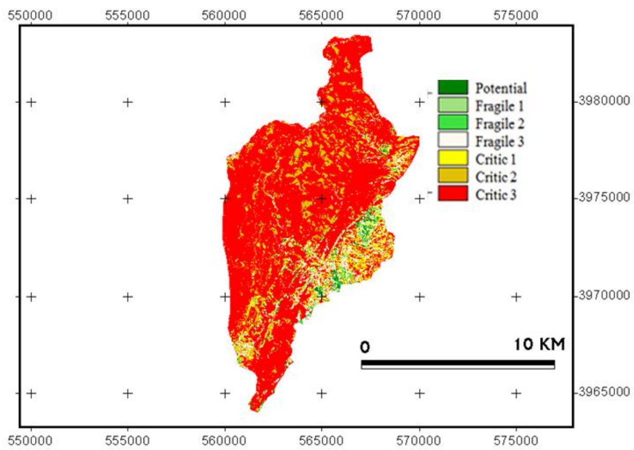

Figure 6: Map of desertification risks according to standard MEDALUS method (with SQI) for the study area

Moreover, of the adoption of the new edaphic parameters to evaluate the soil sensitivity, another test with new limits of the ESA intervals has been adopted to the Tunisian conditions and especially for the limits of the non-affected area, potential, fragile and critical. These changes suggested are carried in the table 2. New maps are then produced (Figure 7) by the application of the ESA equation with new limits of sensitivity units testing the two soil quality indexes (SQI_{TUN} and SQI) to illustrate the land sensitivity to the drought condition in Tunisia. The total surface threatened by the desertification (fragile and critical levels), which was equal to 90.5% according to the standard MEDALUS, is reduced to 86% and 81% of the studied area respectively with SQI and SQI_{TUN} utilization.

Table 2
Classes of ESA units according to standard and modified MEDALUS method

Sensitivity units	Limits of standard ESA values	Values limits ESA adapted for the study area
Critic	> 1.38	> 2.40
Fragile	1,23 – 1,38	1.55 – 2.40
Potential and no affected	< 1.23	< 1,55

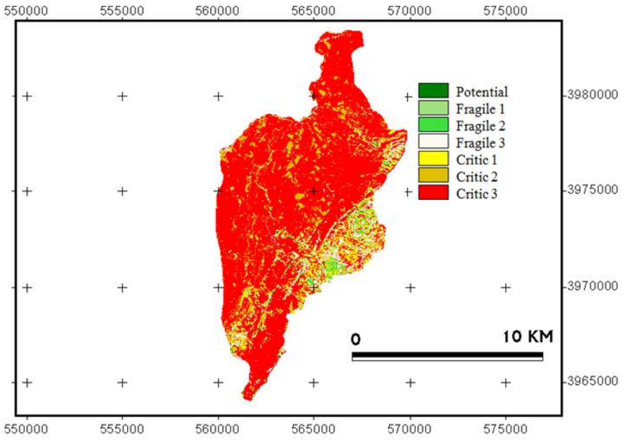

Figure 7: Maps of desertification risks for the study area according to the new limits of ESA and using SQI_{TUN}.

5. Conclusion

To conclude this study, compared to study conducted in Morocco [4]. the MEDALUS model gives us the same problems of desertification evaluated in the studied area in Tunisia. It is important to highlight that the analyses of the desertification and/or the bioclimatic aridity requires a special attention during these last years in all over the world and particularly in Africa with the dryness which prevailed in these areas. Tunisia has not escaped to this phenomenon which still makes object of research and the controversies with several evaluation methods. The adaptation of the MEDALUS method to the semi-arid context (Tunisia) comes in this strategy and was tested according two steps:

1. The first is related to the soil quality index which should include the organic matter content and the total secondary carbonate, two soil parameters largely determining in the differentiation of the soil units' behaviors (Figure 6) and consequently to the land degradation.
2. The second has consisted to adapt the sensitivity intervals of ESA units to local appreciation according the standard MEDALUS method and have new threatened zones limits to define the priority of protection against desertification phenomenon (Figure 7).

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