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A Comparison of Methods for Mapping the Environmental Sensitivity Areas for Desertification of a Mediterranean Landscape Using Remote Sensing and GIS Applications

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Abstract:

The irregularity of Mediterranean climate and the impact of anthropic actions accelerate risks of degradation of Mediteranean landscapes. Those risks are more important toward the south-west of Tunisia. The study area is performed on a Dorsalien at jabel Abdeladim watershed delimited by the desert, in the southern part, and characterized by an arid climate.

Land degradation usually is described by the natural resource that is being depleted (e.g., soil, vegetation, forest, environment) or the process it operates (e.g., water erosion, wind erosion, excess of salts, deforestation, or chemical, physical, or biological degradation). Main method of the research was to compare two approchs based on mapping segments landscape and the environmental sensitivity areas for desertification at scale 1: 10 000, using remote sensing and GIS technologies and thus to evaluate degradation processus in this region. This research undertakes a spatial context using GIS systems, adapting a parametric evolution indexes method, based on arid landscape parameters. It was assisted by elaborating the digital land resources database using Aster satellite image and thematic layers.

Investigation has confirmed that comparison of landscape gradation risks map is suitable and an effective method for the environmental sensitive area map of Abdeladim watershed, In fact, the study region is threatened by serious problems of desertification and erosion despite the sustainable management practices in Jbel Abdeladim.

Finally, this work constitutes a fundamental source for perspectives of research and development in the assessment and evaluation of landscape degradation and presents a new approach to arrest the reality and the management of Tunisian landscapes and their involvements in social, economic and environmental sectors.

Key words: degradation, landscape segment, desertification sensitivity index, GIS, remote sensing, Tunisia.

1. Introduction

For several decades, the Mediterranean landscapes are affected by socio-economic reorganization manifested by the rural exodus and the decline of traditional agro-pastoral. This reorganization has a variable gap that varies from south-west to north-east of the Tunisian Dorsal, essencially after watershed management since 1993. The study site is situated in the Tunisian region of Djebel Chambi and represents the Jebel is a limit to the southern end of the Ridge with the Algerian border. The asymmetry of this region on both sides of the ridge line is explained by the presence of large oriental glaze steep slopes occupied by steppe vegetation. On the north side, to look more diverse, Djbel plateau overlooking the Bou Diriès (1000-1100 m) characterized by Aleppo pine woodlands that extend to the plain Fusan (750 m). The grain acreage associated with a few olive groves mark the landscape of the platter is sulking when the small watershed of Abdeladim cleared and grazed since the Neolithic.

The watershed of Abdeladim has a bowl-shaped almost ideal teardrop limited relief woodlands. His media seem to be divided into regular rings around a point just upstream of the reservoir. It belongs to the semi-arid bioclimatic winter costs lower altitude with a rainy season stretching from October until April. Its rainfall regime has two characteristics: a large inter-annual and monthly or daily aggression.

In 2013 almost two thirds of the total area of the watershed is occupied by field crops (wheat and barley). The remaining area consists of coniferous and scrub rosemary. The natural vegetation is exposed to high human pressure since antiquity: clearing, logging, overgrazing,... where the natural resource degradation and erosion risk exposure. Mindful of these effects, the population of the watershed has long been applied to the development of some anti-erosion crafts such as benches. According Riyahi (2005) two dry stone sills, only, are located on the ravine that drains the slopes of Jebel Ashawar.

Figure1. Localisation of landscape's Abdeladim extracted from Google earth

2. Materials and Methods

To determine the degree of landscape degradation we have to combine two complementary methods. The first one treats the spatial analyse landscape and the second deals with the identification of sensitive areas.

2.1. Landscape analysis

Analyze landscape is from a general view, distant, and gradually move towards the surface of the earth. It was then discovered three sets of landscape units nested inside each other (Richard and., *al* 1977): the "landscape", the "segments of the landscape" and "geons" (the latter units, the smaller ones, are what might be called of "elementary natural environments). The perception implementation is very broad (it takes into account the terrain, soil, vegetation cover, land occupation, etc..). But, for reasons of practical efficiency, it is mainly based on methodical analysis systems topographic slope (the measure of a slope provides the simplest criterion, the most universal and most permanent of the dynamics of the landscape). The segment is characterized by its geomorphologic and pedologic significance, represented in topography, relief form and soils in addition to land cover.

Richard (2003) slope systems determine the most changement of spatial states in the field and the slope inflexion presents the most landscapes discontinuities. The facts of this factors are combined to those human actions who accentuate, perturbed or replace precedent variations.

The segment of landscape is a polysemic concept which have several levels of definition and understanding: the concept gradually enriched as the analysis progresses from description to interpretation ... The concept of segment may then, amount to two more specialized concepts. The first is that of "ecological aspect" defined by C. White-Pamard (1986), based on a splitting space similar to the segmentation and corresponds to areas of "isopotentialités" natural for human activities. Across the ecological facets, an "average" human behavior can be defined, an equilibrium, whereas at larger scale such behavior can sometimes seem totally incomprehensible. The second concept is that of "active zones and contributory" defined by B. Ambroise (1998) in the flow of water. This concept characterizes the "zones", extend generally varies over time (at both the year that the event), where at least a given process is active and contributes to the overall flow of the basin. In each period, any "zone" active for one or the other process is generating to pay if it is then connected to the stream.

The final definition of landscape segment amounts to a diagnosis on the global dynamics. Proven in many parts of the globe, a model with "seven units" defined by Filleron (1995), has been selected for the study of Mediterranean landscapes and used in researchs made by Riyahi (2005) and Khebour-Allouche (2007) who have defined units of Abdeladim landscape and then the landscape segments were digitized using GIS technology (Table1). With this method we can't delimit and better understand the organization spatial of landscapes in segments and their hydrodynamic behaviour at the level of the watersheds (Temple-Boyer, 2007).

Therefore after gathering existing digital data about components and features of landscape, three thematic layers were selected and intersected: hydrographic system, slope gradient, soil texture, soil depth, cover vegetation of the Abdeladim watershed on the scale 1/10 000. After intersection of thematic layers, seven number of segments landscape areas was obtained with average of 642 ha. These units represent more or less homogeneous morphodynamic units that govern vertical or lateral fluxes of water and soil.

Table 1. Landscape segments

	Samples of slope systems	**Main** **lateral organizations**	**Water and matter Balances** ***Interpretations***
Acroeder	Convex slopes differing strong or very strong: *isolated rocky peaks…*	Mosaic structures often very diverse and very contrasting	**Erosive** **to very erosive**
Supraeder		Uniform or central	***Autonomous***

	Slopes subaplanies low or very low: *summits of hills, "ridges"…*	structures in marquetry ("by patchy") *Many legacies* Peripheral structures in halos	***(with low erosive toward the edges)***
Ectaeder	Convexo-concave slopes close (confined) very heavy to heavy *"Hills connection", cornices (ledge)…*	Lateral differentiations triangular "Chevron": • *incoming: Complex / developed* • *Highlights: Single / undeveloped*	**Erosive** **(in surface)**
Metaeder	Subrectilignes slopes expanded high to low: *sections of "watershed"* *of "rise" ...*	*Geons more developed* *and complex downstream*	***Trans-erosive*** ***to*** ***Trans-accumulative***
Cataeder	Steep slopes (Networked tree): *"Notches", ravines .*	Homogeneous structures *Geons poorly developed / very simple*	***Erosive*** ***to very erosive***
Infraeder	Slopes very low to zero (Networked tree): *"Bottoms", floodplains ...* …	Mosaic structures often very diverse and very contrasting	***Accumulative***
Endoeder	Convergent slopes very low to zero: *endorheic bowls..*	Structures halos often very diverse and contrasting	***Very*** ***accumulative***

2.2. Sensitive areas

The identification of sensitive areas is based on the hypotheses of MEDALUS project model (Giordano et al., 2007). The model applies a geometrical average of some quality indexes, in order to provide sensitivity diagnosis. It assumes that each index has only a limited capacity to influence the final value of ESA index and only when several parameters have a high score, an area can be assigned to high sensitivity class.

The following three quality indices were computed;

– Soil Quality Index (SQI),
– Vegetation Quality Index (VQI)
– Climatic Quality Index (CQI)

The methodology is based on classification of each quality index obtained as geometric mean of available environmental and anthropogenic parameters. The available parameters are quantified in relation to their influence on the desertification process assigning score to each (Figure1). The scores assigned to different parameters range between 1 (best value) and 2 (worst value). The final overall ESA index is obtained as a geometrical average of the quality indexes (E.C, 1999).

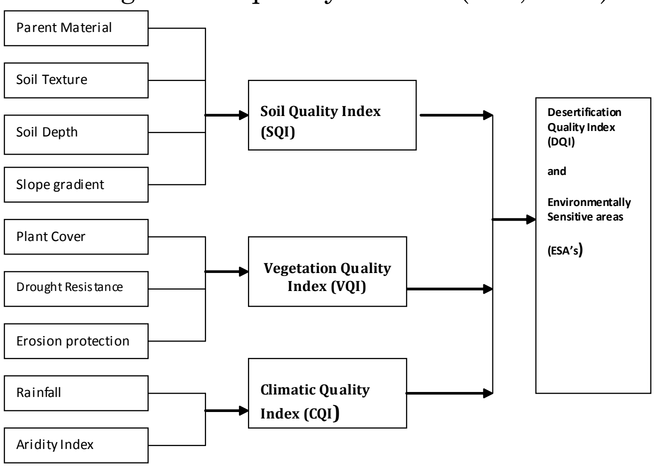

Figure 2. Flow chart of mapping Environmentally Sensitive Areas (ESA's)

2.2.1 Mapping Soil Quality Index (SQI)

Soil quality indicators for mapping ESA's can be related to water availability and erosion resistance (Briggs et al., 1992). A number of four soil parameters were considered at the current investigation (i.e. parent material, soil texture, soil depth and slope gradient).

$$SQI=(Ip * It * Id * Is)^{1/4} \quad (3)$$

Ip index of parent material, *It* index of soil texture, *Id* index of soil depth, *Is* index of slope gradient).

Tables 2 to 5 demonstrate the assigned indexes for different categories of each parameter. The soil Quality Index (SQI) was calculated on basis of the following equation, and classified according to categories shown in Table 6.

Table 2. Classes, and assigned weighting index for parent material

Class	Description	Score
Coherent: Limestone, dolomite, non-friable sandstone, hard limestone layer.	Good	1.0
Moderately coherent: Marine limestone, friable sandstone	Moderate	1.5
Soft to friable: Calcareous clay, clay, sandy formation, alluvium and colluvium	Poor	2

Table 3. Classes, and assigned weighting index for soil depth

Class	Description	Score
Very deep	Soil thickness is more than 1 meter	1
Moderately deep	Soil thickness ranges from <1m to 0.5 m	1.33
Not deep	Soil thickness ranges from <0.5m to 0.25 m	1.66
Very thin	Soil thickness 0.15 m	2.00

Table 4. Classes, and assigned weighting index for soil texture

Texture Classes	Description	Score	
		Areas dominated by water erosion	Areas dominated by wind erosion
Not very light to average	Loamy sand, Sandy loam, Balanced	1	1
Fine to average	Loamy clay, Clayey sand, Sandy clay	1.33	1.66
Fine	Clayey, Clay loam	1.66	2
Coarse	Sandy to very Sandy	2	2

Table 5. Classes, and assigned weighting index for Slope gradient

Classes	Description	Score
< 6%	Gentle	1
6 – 18 %	Not very gentle	1.33
19 – 35 %	Abrupt	1.66
> 35 %	Very abrupt	2

Table 6. Classification of soil quality index

Class	Description	Range
1	High quality	< 1.13
2	Moderate quality	1.13 to 1.45
3	Low quality	> 1.46

2.2.2. Mapping Vegetation quality index (VQI)

Vegetation quality, according to Basso et al. (2000) is assessed in terms of three aspects (i.e. erosion protection to the soils, drought resistance and plant cover). The Aster satellite image is the main material used to map vegetation and plant cover classes using Erdas Imagine 8.3. Adapted rating values for each of erosion protection, drought resistance and vegetal cover classes were adapted on basis of OSS (2003) as shown in Table 6. Vegetation Quality Index was calculated according the following equation, while VQI was classified on basis of the ranges indicated in Table 7.

$$VQI=(IEp * IDr * IV c)^{1/3} \quad (4)$$

Where: *IEp* index of erosion protection, *IDr* index of drought resistance and *IV c* index of vegetation cover).

Ranking of different elements is based upon the magnitude of vegetation fundamental role in erosion protection, drought resistance and soil capacity protection. The perennial cultivation provides a very high capacity to reduce the kinetic energy caused by the impact of soil erosion driving forces. Furthermore, the plant root system increases the stability of the soil, thus a value of (1) was assigned to rank each of *IEp*, *IDr* , and *IV c*. Gradual relative lower capacity are provided by other vegetation classes (e.g. Halophytes, orchards, Saharan vegetation, etc.), thus relatively higher values are assigned for different sensitivity indices.

Table 7. Classes, and assigned weighting index for different vegetation parameters

Class	Description	I_{Ep}	I_{Dr}	I_{Vc}
1	Perennial cultivation	1	1	1
2	Halophytes	1.33	1	1.33
3	Temporal and orchards, mixed with crop land	1.66	1.33	1.66
4	Saharan vegetation < 40%	2	1.66	1
5	Saharan vegetation > 40%	2	1	1

Table 8. Classification of vegetation quality index (VQI)

Class	Description	Range
1	Good	< 1.2
2	Average	1.2 to 1.4
3	Weak	1.4 to 1.6
4	Very weak	> 1.6

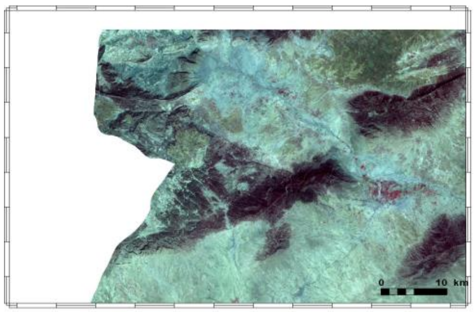

Figure 2. The Aster Abdeladim image

2.2.3 Mapping Climatic quality index (CQI)

The aim of the climatic quality index (CQI) in the current investigation is to assess the water availability to vegetation. Climatic quality is assessed by using parameters that influence water availability to plants such as the amount of rainfall, air temperature and aridity, as well as climate hazards, which might inhibit plant growth (Thornes,1995). Table 8 reveals the classification categories of climatic quality index according to OS (2003).

$$CQI = P / PET \quad (5)$$

Where: P is average annual precipitation and ETP is average annual Potential Evapo-Tanspiration

Table (9) Classification of Climatic quality index (CQI)

Class number	**Climatic zone**	**P/PET**	**CQI**
1	Hyper-Arid	< 0.05	2
2	Arid	0.05 – 2.0	1.75
3	Semi-Arid	0.20 – 0.50	1.50
4	Dry Sub-Humid	0.50 – 0.65	1.25
5	Humid	> 0.65	1

2.2.4. Mapping Environmentally Sensitive Areas (ESA's) to Desertification

ArcGIS9.3 software was used to map ESA's to Desertification (Kosmas et al, 1999) by integrating all data concerning the soil, vegetation and climate. Different quality indices were calculated and displayed as GIS ready maps from which class areas were deduced. The Desertification Sensitivity Index (DSI) was calculated in the polygonal attribute tables linked with the geographic coverage according to the following equation;

$$DSI=(SQI * VQI * CQI)^{1/3} \quad (6)$$

3. Results

3.1. Mapping landscape segments

Figure3 shows the highest area proposition of metaeder segment with 400,305 ha and the acroeder segment presents 104,374 ha. Therefore, it is clear that the spatially disperse of other segments classes is heterogeous and the propotion vary from 2% to 6% of the total watershed area. From example, segments with a hight risk of erosion such as acroeder, ectaeder and supraeder presents 25% but segment with low risk of erosion infraeder and endoeder ocuped a weak surface, les then 9%.

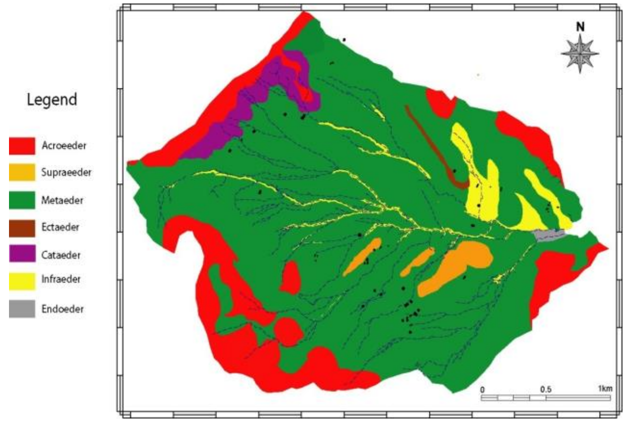

Figure 3. Map of segment landscapes'Abdeladim watershed

3.2. Mapping Soil Quality Index (SQI)

Soil is the dominant factor of the terrestrial ecosystems in the arid and semi arid and dry zones, particularly through its effect on biomass production. Four soil parameters, related to water availability and erosion resistance, were considered (parent material, soil texture, soil depth and slope gradient).

Table10 and Figure 4 show that there's a variability of parent material nature. The study site is dominated by moderately coherent parent material (62,5%), related to continuous soil erosion.

Table10. Distribution of parent materiel classes and assigned scores in the Abdeladim

Class	Score	Area (ha)	%
Soft to friable	2	108,797	16,94
Moderately coherent	1.5	400,305	62,35
coherent	1	131,429	20,47
Retenue		1,469	0,228
Total		642	100

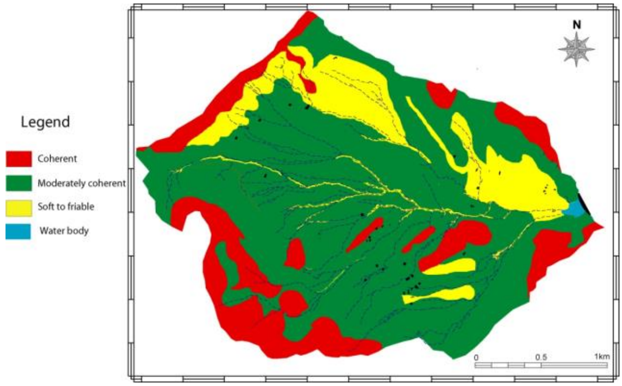

Figure 4. Nature of parent material in Abdeladim watershed

Table 11 and Figure 5 show that 83,73% of the Abdeladim study site is distributed between fine to medium textured soils. It could be outlined that vicinity of study site from the wind blown and water eroded materials resources were important factors for the dominance of most sensitive soil textural classes.

Table11. Distribution of soil texture classes and assigned scores in the Abdeladim.

Class	Score	Area (ha)	%
Coarse	2	104,374	16,25
Medium	1.33	274,662	42,78
Fine	1.66	261,495	40,74
Retenue		1,469	0,228
Total		642	100

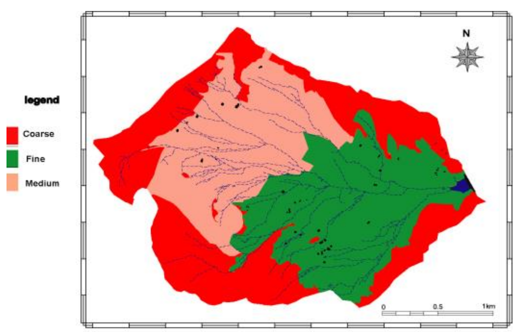

Figure. 5. Categories of soil texture as contributing in soil quality index

The Abdeladim area include 71.45% of its soils characterized by a moderately soils (Table12 Figure6).

Table 12. Distribution of soil depth classes and assigned scores in the Abdeladim.

Class	Score	Area (ha)	%
Very thin	2	122,41	19,06
Moderately deep	1.33	458,748	71,45
Very deep	1	17,122	2,66
Deep	1.66	42,25	6,58
Retenue		1,469	0,228
Total		642	100

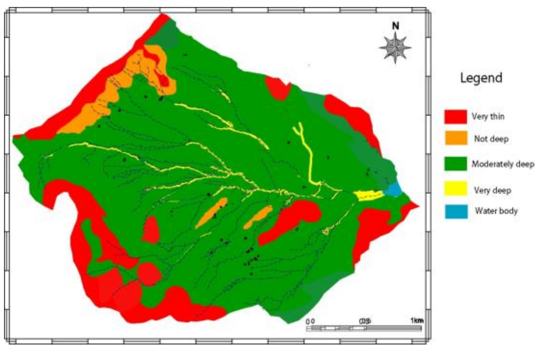

Figure. 6 Categories of soil depth as contributing in soil quality index

The slope gradient (Table13 and Figure7) was classified, on basis of topographic maps and digital elevation model (DEM). Show that Abdeladim watershed contains four classes of slope gradient with a quasi equal propotions.

Table 13. Distribution of slope gradient classes and assigned scores in the Abdeladim territory.

Class	Score	Area (ha)	%
Very abrupt	2	126,524	19,708
Abrupt	1.66	129,001	20,094
Not very gentle	1.33	215,731	33,604
Gentle	1	169,25	26,363
retenue		1,469	0,228

Total		**642**	**100**

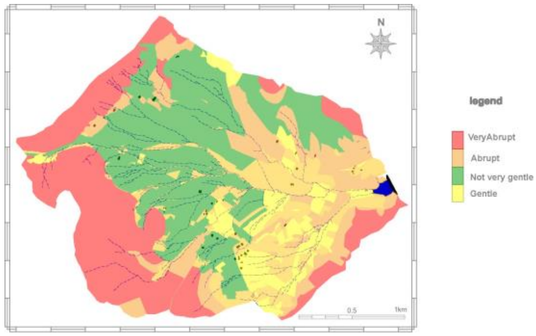

Figure. 7 Categories of slope gradient as contributing in soil quality index

Calculating the soil quality index (Table14 Figure7) reveals that the study area is characterized by moderate and low soil quality. The moderate quality soils exhibit 50% of Abdeladim watershed

Table 14. Areas of different categories of Soil Quality Index (SQI) classes (Areas dominated by water erosion)

Class	**Score**	**Area (ha)**	%
Low quality	1.4–1.6	**207,116**	**32,26**
Moderate quality	1.2–1.4	**433,379**	**67,50**
Retenue		**1,469**	**0,228**
Total		**642**	**100**

These least sensitive soils are located in an interference landscape at the vicinity of the high or table land. Such landscape conditions encourages the sensitivity to land degradation.

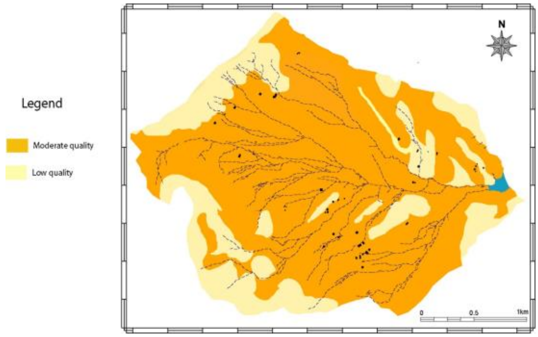

Figure 8. Soil quality Index map (SQI) of Abdeladim watershed

3.2 Mapping Vegetation quality index (VQI)

Calculating the vegetation quality index, on basis of the previous parameters reveal that that the 53.07% of the vegetation cover is very weak and sensitive to desertification. The good vegetation index class, which may resist desertification, represents only 17.31% of the vegetation cover (Table15 & Figure 10).

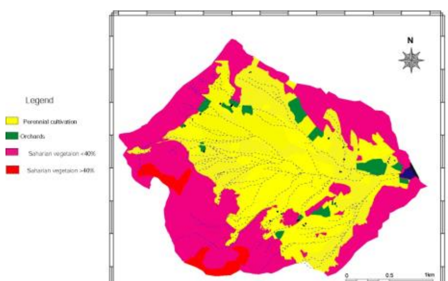

Fig. 9. Vegetation cover classes, based on the hybrid classification of ETM image

Table15. Areas of different vegetation quality index (VQI) classes in the Abdeladim.

Class	Score	Area (ha)	%
Week	**1.4–1.6**	**340,705**	**53,07**
Average	**1.2–1.4**	**111,16**	**17,314**
Good	**<1.2**	**188,63**	**29,381**
Retenue		**1,469**	**0,228**
Total		**642**	**100**

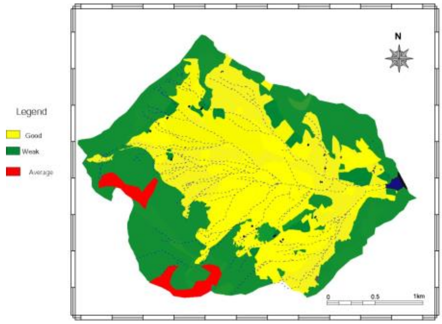

Figure 10 Vegetation Quality Index (VQI) of Abdeladim watershed

3.3 Mapping Climatic quality index (CQI)

The Abdeladim watershed have an average of a precipitation of 347mm/a and the PET is inferior to 1200 mm/an. So the climatic quality index is inferior to 0,289. That's why all the field have a weak climatic index (Figure 11).

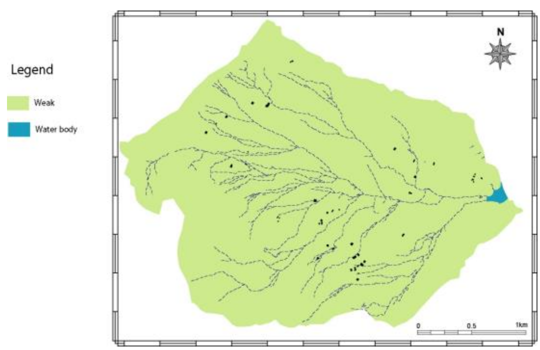

Figure 11. Climatic Quality Index (VQI) of Abdeladim watershed

3.4 Mapping Environmentally Sensitive Areas (ESA's) to Desertification

Table 16. Figure 12 show the distribution of ESA's. It is clear that most of the Abdeladim territoriy is very sensitive to desertification (53%); these moderately and low sensitives classes are distributed between the right and the left bank of the watershed.

Table 16. Areas of different categories of Desertification Quality Index (DQI) classes (Areas dominated by wind erosion)

Class	Score	Area (ha)	%
Low sensitive areas	1.3–1.4	118,697	18,48
Moderately sensitive areas	1.4–1.5	182,202	28,38
Sensitive areas	1.5–1.6	339, 632	52,902
Retenue		1,469	0,228
Total		642	100

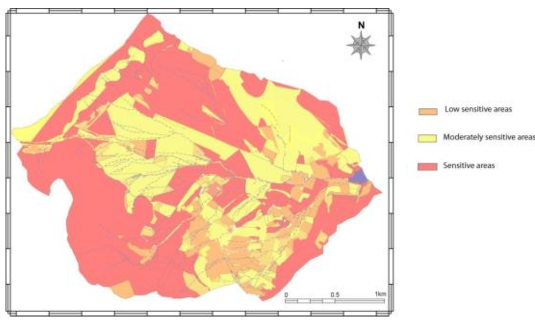

Figure 22. Environmentally sensitive areas (ESA's) for desertification inAbdeladim watershed

4. Discussion

The results of the work carried out in this article and allow us to evaluate the degradation degree of the Abdeladim landscape with two methods. It was found that nearly 25% of the segment landscapes with a highest erosion risks belongs the class of sensitive areas to desertification. Therefore, the accumulative segments are based at the class of low sensitive areas to desertification. However, 60% segments ranging from moderate erosion belong senSitive, low and moderate areas to desertification. More then 50% of the Abdeladim watershed area is threatened by land degradation risks.

This indicates that all segment landscapes with a heighest risk of erosion are located at the class of sensitive areas to desertification and there one accumulative are based at the class of low sensitive areas to desertification. Therefore, segment landscapes characterised by a trans-erosive hydrodynamics can belong in three classes of sensitive area to desertification with the highest average of units in the class of sensitive areas.

5. Conclusion

It can be concluded that the Abdeladim landscape is mostly very sensitive areas to desertification. However, as various environmental conditions may control the desertification sensitivity, some areas with perennial cultivation and orchards may be exposed to relatively moderately or less sensitivity. Assessment of segments landscape and desertification sensitivity is rather important to plane combating actions and to improve the employment of natural resources. The merely quantitative aspect of desertification sensitivity demonstrates a clearer image of the risk state, thus, reliable priority actions can be planned.

Remote sensing, in addition to thematic maps, may supply valuable information concerning the soil and vegetation quality. However, field validation is rather important for reliable information. The Geographic Information System (GIS) is a valuable tool to store, retrieve and manipulate the huge amount of data needed to compute and map different quality indices to desertification.

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