

Assessment and mapping of desertification sensitivity in some of the western desert oases, Egypt, based on Remote Sensing and GIS

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Abstract

The United Nations convention to combat desertification, issued in September 1994, has defined desertification as "*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities*". Recently, different models were developed to scope on the quantitative approach of desertification assessment. A number of three oases, located in the Middle Western desert of Egypt were investigated. ETM and SRTM satellite images, geologic and soil maps were used as main sources for calculating the Environmental Sensitivity Areas Index (ESAI) for desertification. The results show that the areas characterized by low desertification sensitivity represent 7.3% of the Bahereya oasis, while those of moderate sensitivity represent 92.7 and 0.8% of Bahereya and Kharga oases respectively. The whole Dakhla oasis is exhibited by sensitive and very sensitive environmental sensitive areas for desertification. It can be concluded that implementing the maps of sensitivity to desertification is rather useful in the desert oases as they give more likely quantitative trend for frequency of sensitive areas. Land use can be adopted, on basis of the environmental sensitivity indices for desertification. The integration of different factors contributing to desertification sensitivity may lead to plan a successful combating. The usage of space data and GIS proved to be suitable tools to fulfill the needed large computational requirements. They are also useful in visualizing the sensitivity situation of different desertification parameters.

Keywords: Remote sensing, GIS, Environment, Desertification, Oases, Egypt

تتبع وتخريط الحساسية البيئية للتصحّر لبعض واحات الصحراء الغربية بمصر باستخدام الاستشعار من البعد ونظم المعلومات الجغرافية

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الملخص العربي

تعرف مبادرة الأمم المتحدة لمواجهة التصحر الصادرة في سبتمبر ١٩٩٤ عملية التصحر بأنها "تدهور الأراضي بالمناطق الجافة والشبه جافة والشبه رطبة والناجمة بفعل عوامل مختلفة تشمل التغير المناخي وأنشطة البشر". تم حديثاً تطوير نماذج رياضية تتناول المفهوم الكمي لتحليل التصحر. تعد واحات الصحراء الغربية مناطق واعدة للتنمية المستدامة بما فيها التنمية الزراعية ، لذا فان تحديد الحساسية البيئية للتصحّر بمناطق الواحات يمكن أن يدعم اتخاذ القرار لصيانتها وتنميتها. أختير لإجراء البحث الحالي ثلاثة من واحات الصحراء الغربية المصرية حيث استخدمت صور القمر الصناعي من نوعية ETM ونوعية SRTM والخرائط الجيولوجية وخرائط التربة والبيانات المناخية كمصدر أساسي للبيانات المستخدمة في تخريط استخدامات الأراضي والنموذج ثلاثي الأبعاد وحساب دلائل الحساسية البيئية للتصحّر. تشير النتائج الى أن المناطق ذات الحساسية البيئية المنخفضة للتصحّر تمثل ٧,٣% من الواحات البحرية بينما تمثل المناطق المتوسطة الحساسية ٩٢,٧ و ٠,٨٠% من أراضي الواحات البحرية والخارجة على الترتيب. تتصف كل أراضي الواحات الداخلة بحساسية بيئية عالية الى عالية جداً للتصحّر. يمكن الخلاصة أن إنتاج خرائط الحساسية البيئية للتصحّر لها أهمية فائقة بواحات الصحراء حيث تؤدي الى التصور الكمي لتأثير عمليات التصحر. يمكن تطويع استخدامات الأراضي على ضوء دلائل الحساسية البيئية للتصحّر يمكن أن يؤدي التكامل بين العوامل المساهمة في الحساسية البيئية للتصحّر الى التخطيط الناجح لمجابهة عمليات التصحر. ان استخدام البيانات الفضائية ونظم المعلومات الجغرافية أثبت كفاءتها كأدوات لحسابات دلائل الحساسية البيئية التي تتطلب امكانيات حسابية عالية ، كما أنها تقدم المفهوم المرئي لوضع الحساسية البيئية للتصحّر.

Introduction

The word oases is commonly used to describe a place characterized by a sustainable life features, inserted among severe environmental conditioned areas. The Oases can be defined as isolated fertile areas, usually limited in extent and surrounded by desert. They are depressions in desert regions which comprise springs, wells and trees, reflecting the beauty, charm and diversity of nature. The term “oases” was initially applied to small areas in Africa and Asia typically supporting trees and cultivated crops with a water supply from springs and from seepage of water originating at some distance. However, the term has been expanded to include areas receiving moisture from intermittent streams or artificial irrigation systems. Thus the floodplains of the Nile and Colorado rivers can be considered vast oases, as can arid areas irrigated by humans. In Egypt, there are some oases located at the western desert, most known ones are Fayoum, Kharga, Dakhla, Paris, Frafrah, Bahereya, Siwa and the Qattara Depression.

Desertification is the consequence of a set of important processes, which are active in arid and semi-arid environment, where water is the main limiting factor of land use performance in ecosystems (Batterbury and Warren, 2001). Environmental systems are generally in a state of dynamic equilibrium with external driving forces. Small changes in the driving forces, such as climate or imposed land use tend to be accommodated partially by a small change in the equilibrium and partially by being absorbed or buffered by the system. Desertification of an area will proceed if certain land components are brought beyond specific threshold, beyond which further change produces irreversible change (Nicholson et al. 1998). Environmentally Sensitive Areas (ESA's) to desertification in desert oases exhibit different sensitivity status to desertification for various reasons. Low rainfall is generally the main constraint supporting severe desertification sensitivity. However, availability of ground water and preferable soil and landscape conditions may sustain a satisfactory vegetation cover causing drought resistance (Ferrara et al, 1999).

2 Location and Environment of study areas

In this study, a number of three desert oases (i.e. Bahereya, Dakhla and Kharga) located at the middle of western desert, Egypt, are considered (Fig. 1). The Bahereya oasis lies 360 km. south of west Giza and 180 km. west of Assyut. It belongs administratively to the Giza Governorate and is known by the existence of iron oars. The other two oases belong, administratively, to the New Valley Governorate. The Kharga oasis is the capital of the New Valley Governorate, lying 232 km. south of Assyout in a natural elongating in N-S excavation. It is characterized by its numerous monuments, springs and tourist sites such as ponds of fish in Bulaq village. The water temperature in Bulaq wells, south of Kharga, reaches 39°. The Dakhla oasis is the second provincial capital of the New Valley Governorate, located 200 km. northwest of Kharga. It contains several wells in which the temperature reaches 43° C. It is a collection of fourteen different settlements, dominated on its northern horizon by a wall of rose-colored rock.

Fertile cultivated areas growing rice, peanuts and fruits are dotted between sand dunes along the roads from Farafra and Kharga.

The desert climate is recognizable in all oases, the difference in day and night temperature degrees are vast especially in winter. The difference in day and night humidity is also noticed, and more expressed in summer time.

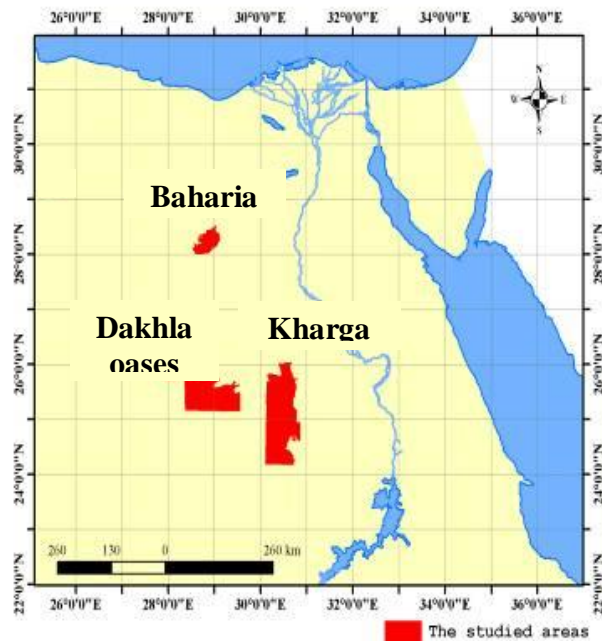


Fig. (1) Geographic location of studied western desert oases

3. Methodology

The soil and vegetation quality indexes (SQI and VQI) were computed, the climatic quality index was neglected as the arid desert climate is similar in the studied oases. Fig. (2) demonstrates the main flow chart of concepts and studied steps performed in the current study. The main input data for calculating these indices include a mosaics of LANDSAT ETM and SRTM images and the geologic map of Egypt, produced by CONOCO, 1990. The satellite images were processed using the ERDAS IMAGINE 8.3 system. Different enhancement and classification techniques were tried to specify the optimal ones for the study purposes. Computational and map editing functions were performed using Arc GIS 9 to find out the environmental sensitivity areas (ESA's).

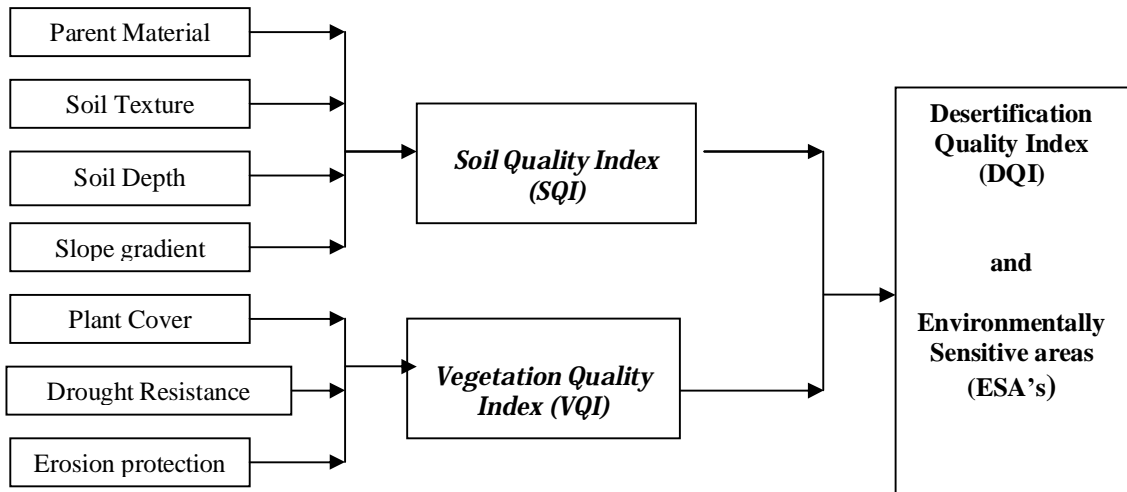


Fig. (2) Flow chart of mapping Environmentally Sensitive Areas (ESA's)

2.1 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 (i.e. parent material, soil texture, soil depth and slope gradient) following Medalus project methodology (European Commission, 1999). Weighting factors were assigned to each category of the considered parameters, on basis of Gad and Loffy (2007). The soil Quality Index (SQI) was computed on basis of the following equation

$$SQI = (I_p * I_t * I_d * I_s)^{1/4}$$

Where I_p index of parent material, I_t index of soil texture, I_d index of soil depth, I_s index of slope gradient).

2.2 Mapping Vegetation quality index (VQI)

Vegetation quality was evaluated according to Basso et al (2000) in terms of three aspects (i.e. erosion protection to the soils, drought resistance and plant cover). The TM satellite images mosaic covering the studied oases (Fig. 2) is the main material used to map vegetation and plant cover classes. Rating values for erosion protection, drought resistance and vegetal cover classes were adapted on basis of OSS (2004). Vegetation Quality Index was calculated according the following equation, while VQI was classified on basis of the ranges indicated in the European Commission (1999).

$$VQI = (I_{Ep} * I_{Dr} * I_{Vc})^{1/3}$$

Where: I_{Ep} index of erosion protection, I_{Dr} index of drought resistance and I_{Vc} index of vegetation cover).

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

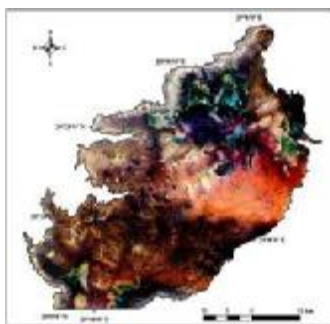
ArcGIS9 software was used to map ESA's to Desertification (Kosmas et al, 1999) by integrating all data concerning the soil and vegetation. Different quality indices were calculated and displayed as GIS ready maps from which class areas were deduced. The Desertification Sensitivity Index (DSI) was computed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

$$DSI = (SQI * VQI)^{1/2}$$

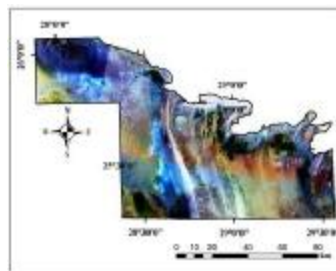
Classification of (DSI) was done according to the values of Medalus project Mediterranean desertification and land use- Manual –Table (1) (European Commission, 1999).

Table (1) Ranges and classes of desertification sensitivity index (DSI)

Classes	DSI	Description
1	> 1.2	Non affected areas or very low sensitive areas to desertification
2	1.2 < DSI < 1.3	Low sensitive areas to desertification
3	1.3 < DSI <1.4	Medium sensitive areas to desertification
4	1.3 > DSI <1.6	Sensitive areas to desertification
5	DSI > 1.6	Very sensitive areas to desertification



(A) Baharyia oasis



(B) Dakhla oasis



(C) Kharga oasis

Fig. (2) LANDSAT image of the studied oases

3- Results and discussions

3.1 Soil Quality Index (SQI)

Table (2) shows the classification of the soil parent material in the Bahereya, Dakhla and Kharga oases regarding their sensitivity to desertification. The results show the variability of parent material nature of the three studied oases. While the moderately coherent Marine limestone and friable sandstone characterized by moderate sensitivity class cover 93.4% of the Bahereya, its frequency in Kharga oases reaches only 17.8%. The Dakhla oases parent material splits between the coherent (51.2%) and the soft to friable (48.8%) attaining good and poor sensitivity classes respectively. The Kharga oasis is dominated (55%) by poor parent material which is more sensitive to the desertification processes. It may be outlined that the southern oases include more sensitive parent material that the northern ones.

Table (2) nature of parent material and assigned scores

Parent Material classes	Oases	Area (sq km)	Area %	Score	Class
1) Coherent: Limestone, dolomite, non-friable sandstone, hard limestone layer.	Bahereya	91.3	4.7	1.0	Good
	Dakhla	4844.8	51.2		
	Kharga	3268.23	27.2		
2) Moderately coherent: Marine limestone, friable sandstone	Bahereya	1803.2	93.4	1.5	Moderate
	Dakhla	0.0	0.0		
	Kharga	2144.28	17.8		
3) Soft to friable: Calcareous clay, clay, sandy formation, alluvium and colluvium	Bahereya	35.9	1.9	2.0	Poor
	Dakhla	4617.78	48.8		
	Kharga	6606.19	55.0		

The slope gradient, as shown in table (3) was classified, on basis of topographic maps and digital elevation model (DEM). The majority (88.5%) of the Bahaereya Oasis, situated northwards is characterized by a gentle slope class, inducing less sensitivity to the desertification process. The slope gradient in Kharga oases mostly ranges between not very gentle to a very abrupt covering areas representing 37.3 to 18.9% of its terrain respectively. An area representing 24.4% is characterized by a gentle sloping landscape. In general, it can be outlined that the oases inserted in the table land of the western desert, as Kharga, attain more rugged landscap causing more sensitivity to most desertification processes.

Table (4) shows that the soils in the three oases are mostly characterized either by a very shallow or very deep soil depth. In particular, the Dakhla oases, include 45.1% of its soils characterized by a very shallow depth, while the Bahereya include 93.5% very deep soils. The soil texture was assessed on basis of the geomorphology, deduced from the ETM satellite mosaic. Table (5) shows that the most sensitive coarse textured soils dominates the Dakhla and Kharga oases, covering 77.8 and 75.6%

respectively. The rest of the soils are characterized by very light to average soil texture. The soils of Bahereya oases are dominated (95%) by fine to average texture which characterizes them by less sensitivity to desertification. It could be outlined that vicinity of Kharga and Dakhla oases from the great sand sea and their vertical location as interior oases in the western desert were important factors for the dominance of most sensitive soil textural classes.

Table (3) Distribution of slope classes and assigned scores

Slope class	Slope %	Oases	Area (sq km)	Area %	Score
Gentle	< 6%	Bahereya	1708.2	88.5	1.00
		Dakhla	4022.10	42.51	
		Kharga	2928.50	24.4	
Not very gentle	6 to 18 %	Bahereya	130.9	6.8	1.33
		Dakhla	287.35	3.04	
		Kharga	4495.50	37.3	
Abrupt	18-35%	Bahereya	0.0	0.0	1.66
		Dakhla	5153.12	54.46	
		Kharga	2331.98	19.4	
Very abrupt	> 35 %	Bahereya	91.3	4.7	2.00
		Dakhla	0.0	0.0	
		Kharga	2262.72	18.9	

Table (4) distribution of soil depth classes and assigned scores

Class of soil depth	oases	Area (km ²)	%	Score
Very shallow (> 0.25 m)	Bahereya	91.3	4.7	1
	Dakhla	4271.7	45.1	
	Kharga	4594.7	38.2	
Shallow (0.25 to 0.50 m)	Bahereya	17.8	0.9	1.33
	Dakhla	0.0	0.0	
	Kharga	0.0	0.0	
Deep (0.50 – 1.00 m)	Bahereya	18.1	0.9	1.66
	Dakhla	881.4	9.3	
	Kharga	4313.2	35.9	
Very deep (> 1m)	Bahereya	1803.2	93.5	2.0
	Dakhla	4309.5	45.6	
	Kharga	3110.8	25.9	

Table (5) Distribution of soil texture classes and assigned scores

Class	Description	Oases	Area (km ²)	%	Score
Very light to average	Loamy, Sandy, Sandy-loam, balanced	Bahereya	5.27	0.3	1.00
		Dakhla	2101.9	22.2	
		Kharga	2928.5	24.4	
Fine to average	Loamy clay, Clayey-sand, Sandy clay	Bahereya	1833.9	95.0	1.33
		Dakhla	0.0	0.0	
		Kharga	0.0	0.0	
Average	Clay, Clay-Loam	Bahereya	0.0	0.0	1.66
		Dakhla	0.0	0.0	
		Kharga	0.0	0.0	
Coarse	Sandy to Very sandy	Bahereya	91.3	4.7	2.00
		Dakhla	7360.7	77.8	
		Kharga	9090.2	75.6	

Calculating the soil quality index (SQI) as shown in table (6) and (figs 4A-C) reveal that only the Kharga oasis include 24.4% of its soils characterized by high quality which may have least sensitivity to desertification. The moderate quality soils exhibit 94.4, 42.5 and 1.5% of Bahereya, Dakhla and Kharga oases respectively. These soils are located at the middle part of the oases characterized by lowest altitude and deep soil profiles. The majority of the oases soils range between the moderate and low quality.

Table (6) Areas of different categories of Soil Quality Index (SQI) classes

Class	Description of soil quality	Range of SQI	Oases	Area (Km ²)	%	Score
1	Good Quality	< 1.2	Bahereya	0.0	0.0	
			Dakhla	0.0	0.0	
			Kharga	2928.5	24.4	1.11
2	Moderate Quality	1.2 to 1.4	Bahereya	1821.3	94.4	1.6818
			Dakhla	4023.7	42.5	1.2
			Kharga	182.3	1.5	1.28
3	Low Quality	1.4 to 1.6	Bahereya	109.2	5.6	1.2447
			Dakhla	5438.9	57.5	1.0
			Kharga	8907.9	74.1	1.68
4	Very Low Quality	> 1.6	Bahereya	0.0	0.0	
			Dakhla	0.0	0.0	
			Kharga	0.0	0.0	

3.2 Vegetation Quality Index (VQI)

The ETM satellite images were classified and field validation was performed to convert the unsupervised classes to vegetation type. Different vegetation types were given score values evaluating vegetation cover type, erosion protection and drought resistance, and hence calculating the vegetation quality index (VQI). Table 7 and Figs. 5A-C) reveal that the Bahereya and Dakhla oases attain the largest areas (91 and 96.6% respectively within the average VQI class, while rest of the area (8.3 and 3.4 % respectively) within the good class. The reverse situation is noticed in the Kharga oasis where 97.1% of its area is characterized by very week vegetation quality and 1.2% by average one. Geographic locations of different oases influence the vegetation quality which contributes to the desertification sensitivity. Where the Baharia oases is situated at the north low lying altitudes, near from ground water and existence of sulphur springs, the vegetation quality is adapting. Also, the existence of several wells and fertile alluvial soil at the Dakhla oases sustain vegetation quality characterized by average. The Kharga oases is mostly situated at 350 m elevated plateau, thus ground water is rather deep resulting in weak vegetation type quality.

Table (7) Areas of different vegetation quality index classes

Class	VQI range	Oases	Area (km ²)	%	Score
Good	<1.2	Bahereya	159.2	8.3	1.19
		Dakhla	329.1	3.4	1.00
		Kharga	000.0	0.0	
Average	1.2-1.4	Bahereya	1763.3	91.7	1.22
		Dakhla	9313.3	96.6	1.26
		Kharga	138.7	1.2	1.21
Week	1.4-1.6	Bahereya	000.0	0.0	
		Dakhla	000.0	0.0	
		Kharga	202.0	1.7	1.54
Very week	>1.6	Bahereya	000.0	0.0	
		Dakhla	000.0	0.0	
		Kharga	11674.6	97.1	1.81

3.3 Environmental Sensitivity Areas (ESA's)

The desertification sensitivity index was computed in for each pixel in the geographic coverage of the three oases, on basis of Medalus project methodology, using both SQI and VQI values. Table (8) shows the output of the calculation, whereas Figs. (6A-C) demonstrate the geographical extension of each Environmental Sensitive Areas (ESA's). The desert oases, in general, lie within the sensitive and very sensitive areas to desertification. However, some locations as most of the Bahereya oases and some spots in Kharga Oases may be classified as moderately sensitive due to existence of sufficient vegetation cover or shallow water resources. It may be pointed out that

comprehensive environmental conditions should be considered to determine the desertification sensitivity in desert oases precisely

Table (8) Occurrence of Environmentally Sensitive Areas (ESA's)

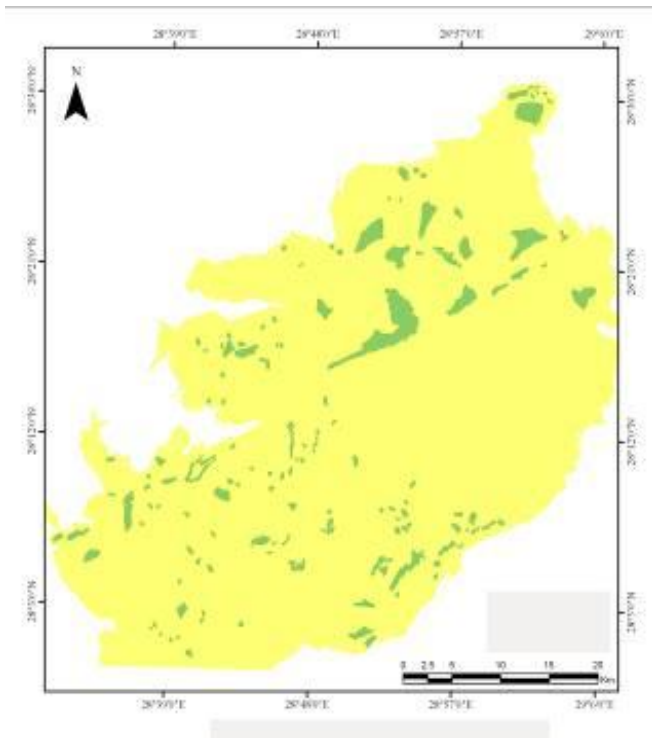
Classes	DSI	Description	Oases	Area (Km ²)	%
1	> 1.2	Non affected areas or very low sensitive areas to desertification	Bahereya	140.29	7.3
			Dakhla	0.0	0.0
			Kharga	0.0	0.0
2	1.2 < DSI < 1.3	Low sensitive areas to desertification	Bahereya	0.0	0.0
			Dakhla	0.0	0.0
			Kharga	0.0	0.0
3	1.3 < DSI < 1.4	Medium sensitive areas to desertification	Bahereya	1790.69	92.7
			Dakhla	0.0	0.0
			Kharga	92.32	0.8
4	1.3 > DSI < 1.6	Sensitive areas to desertification	Bahereya	0.0	0.0
			Dakhla	2149.85	22.7
			Kharga	2894.26	24.1
5	DSI > 1.6	Very sensitive areas to desertification	Bahereya	0.0	0.0
			Dakhla	7306.80	77.3
			Kharga	8986.46	75.1

4. Conclusions

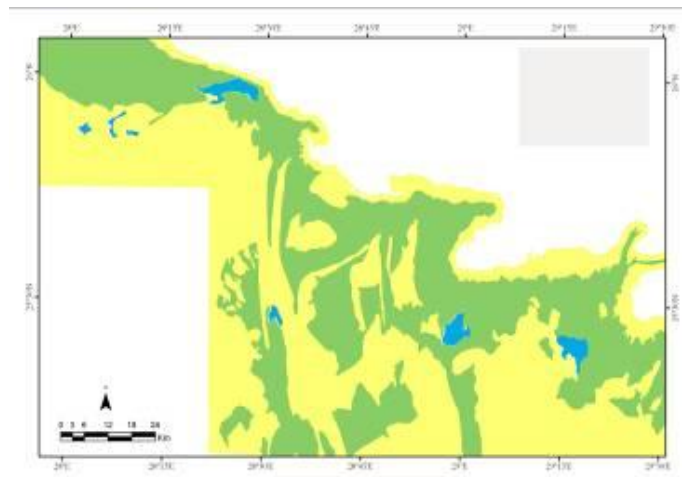
It can be concluded that the desert oases are mostly very sensitive areas to desertification. However, as various environmental conditions may control the desertification sensitivity, some areas within the oases may be exposed to relatively less sensitivity. Assessment of desertification sensitivity is rather important to plan 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.

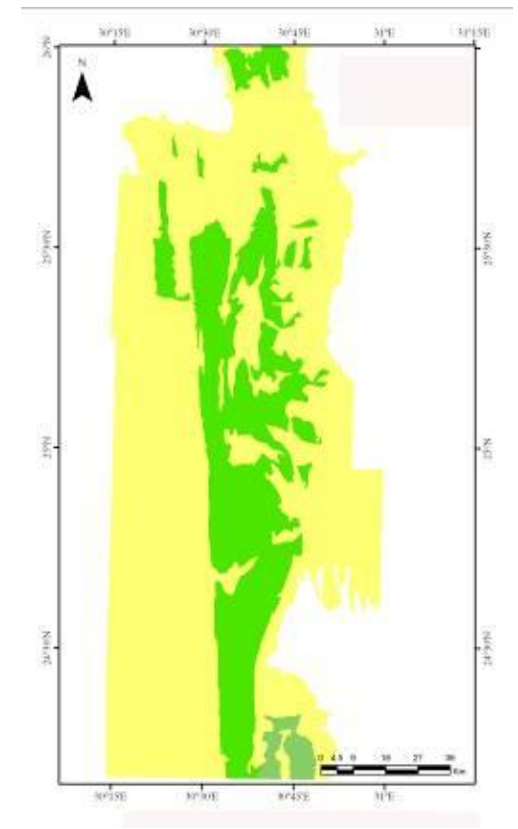
The Dakhla and Karga oases are susceptible to a high to very high desertification sensitivity. The majority of Bahererya oases is moderately sensitive due to satisfactory vegetation cover, in addition to near sub-surface water resources. Action measures are essential for the sustainable agricultural projects located in the desert oases due high desertification sensitivity. Multi scale mapping of ESA's are needed to point out the risk magnitude and causes of degradation in problematic areas.



(A) Bahereya oasis



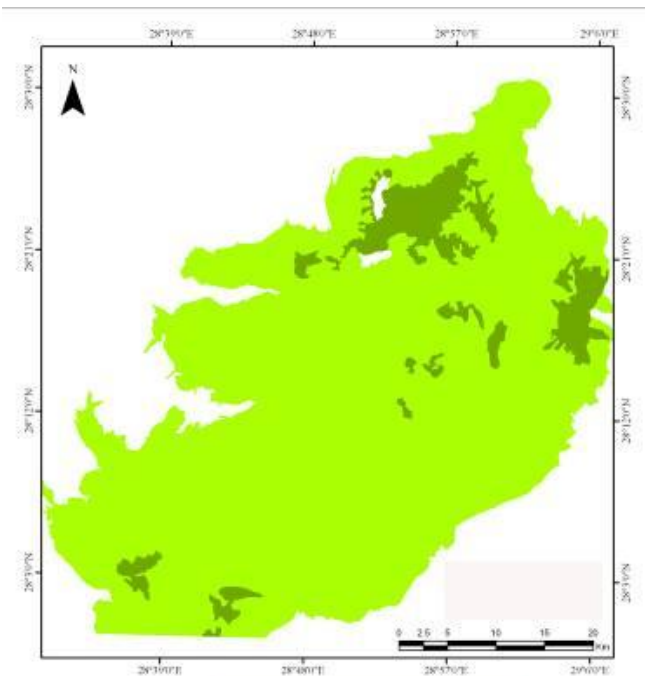
(B) Dakhla oasis



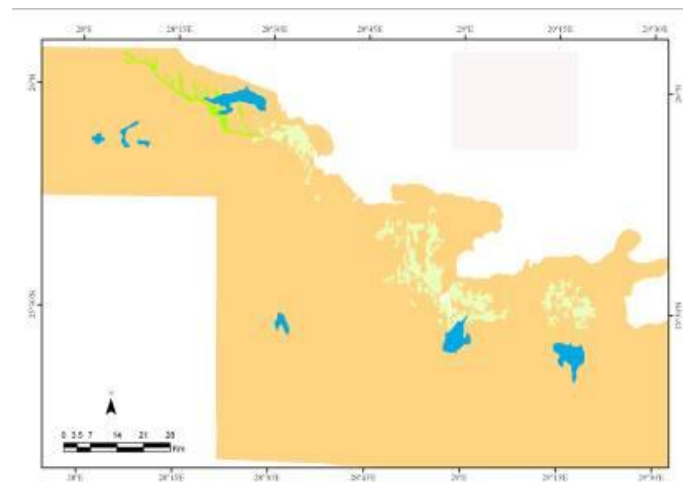
(C) Kharga oasis



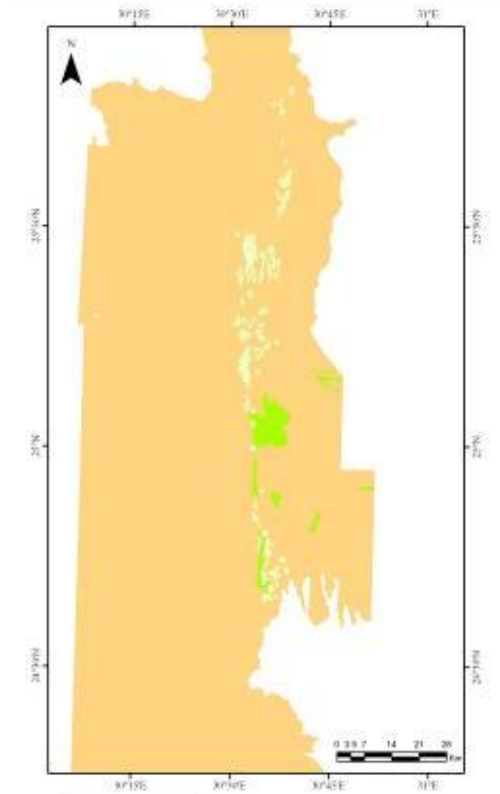
Fig. (4) Soil Quality Index classes of different oases



(A) Bahereya oasis



(B) Dakhla oasis

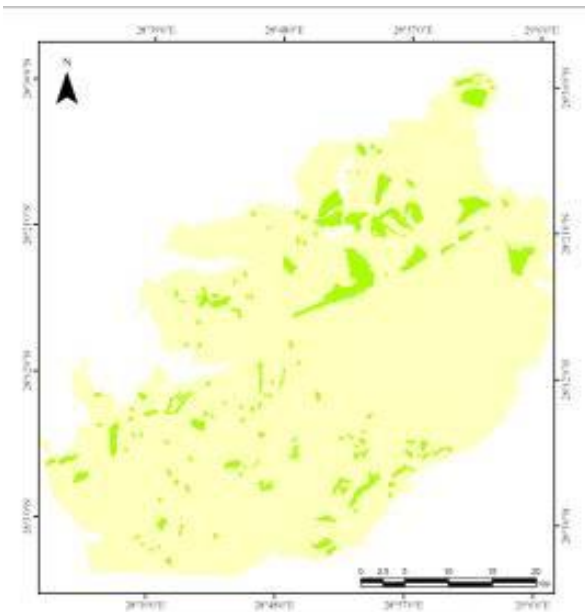


(C) Kharga oasis

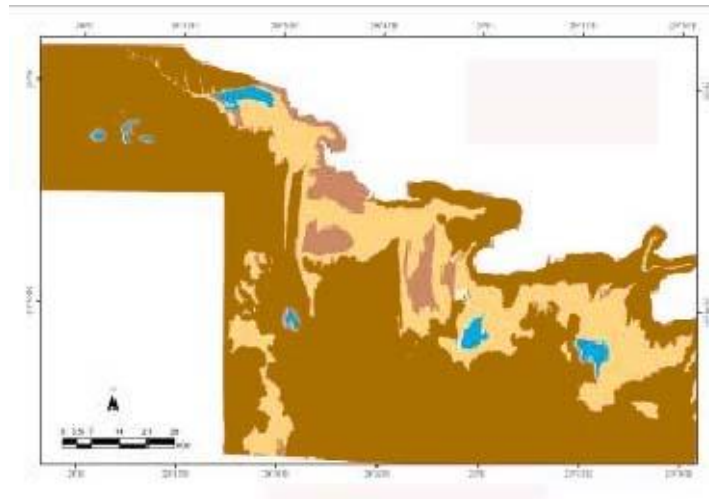
Vegetation Quality Index (VQI)

- Good
- Average
- Very weak
- Others**
- Salt marshs

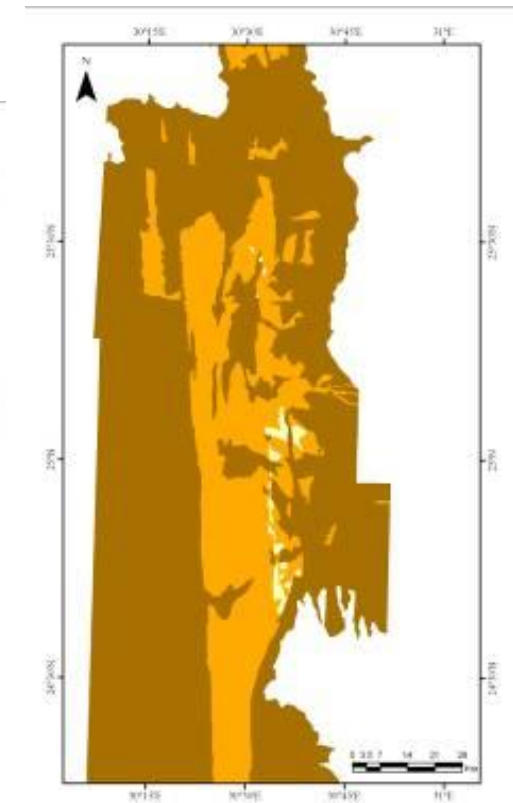
Fig. (5) Vegetation Quality Index classes of different oases



(A) Bahereya oasis



(B) Dakhla oasis



(C) Kharga oasis

Desertification Sensitivity Index (DSI)






-  Low sensitive areas to desertification (Score: 1.2 to 1.3)
-  Medium sensitive areas to desertification (Score: 1.3 to 1.4)
-  Sensitive areas for desertification
-  Very sensitive areas for desertification
-  Salt Mashes

Fig. (6) Environmentally sensitive areas (ESA's) for desertification in the Kharga oases.

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