Evaluation of Soil Degradation in Northern Sinai (Egypt), Using Remote Sensing and GIS Techniques

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Abstract

Remote sensing documents and thematic maps were used to provide comprehensive views of surface-bound conditions such as soil and vegetation. The current work applies a parametric methodology, adopted from the FAO/UNEP and UNESCO methodology for assessment and mapping of soil degradation at a scale of 1:250,000. The study area is located in the northern part of Sinai peninsula, Egypt, a region with considerable agriculture potential. Satellite MSS, TM imageries and aerial photographs were utilized to provide data on soil conditions, land cover and land use of the study area.

ARC/INFO software was used to manage and manipulate thematic data, to process satellite images and tabular data. ERDAS software is utilized to derive the Normalized Difference Vegetation Index (NDVI) values and IDRISI software for generation of the slope degree. A system is established for rating soil parameters, slope, climate and human activity. The rating values serve as inputs into a modified Universal Soil Loss Equation (USLE) to calculate the present state and risk of soil degradation processes (i.e. water erosion, wind erosion, salinization and physical degradation).

The produced maps and tabular data show the risk and present status of different soil degradation processes. The study area, in general, is exposed to slight hazard of water erosion, but to high risk of wind erosion, slight to high salinization and slight to moderate physical degradation. It is recommended to use a GIS in detailed and very detailed studies for evaluating soil potentiality in agricultural expansion.

Keywords : Soil degradation, Remote sensing, GIS, Egypt, Sinai.

Background and justification

Soil degradation is defined by FAO/UNEP (1983) as "a process which lowers the current and/or the potential capability of soil to produce (quantitatively and/or qualitatively) goods or services." In 1975, UNEP, FAO and UNESCO initiated a project "A world assessment of soil degradation - phase 1" to develop a methodology for assessing soil degradation on a global scale. The methodology was tested in Africa north of the equator and in the Near and Middle East. The results of the assessment were recorded on four maps published at a 1:5,000,000 scale. The maps show clearly that soil degradation occurs over large areas, and that areas which are not degraded then are threatened by degradation in the future. Duly alarmed by these results, FAO and UNEP (1978) provided initiative to refine the original methodology to better serve scientists and managers in assessment of damage already done and future threats to land.

The provisional methodology, published in 1983 has been developed to be scale independent, so that it may be applied at a global level, national planning level, regional / provincial planning level and local project planning level. It is designed to provide mappable data that may potentially be used to plan strategies to conserve the remaining productive soil and to prevent soil degradation in areas not yet affected. The current work aims to assess soil degradation in the north of Sinai applying the above mentioned provisional methodology at 1:250,000 mapping scale. This scale is considered appropriate for planning at national level.

Objectives

The Sinai peninsula covers an area of 61,000 km² which is about 6% of Egypt's total area. It represents a promising and strategic region for economic development. The northern territories of Sinai have considerable potential for agriculture, fisheries and summer resorts. Much of the arable land in this area would eventually be irrigated with Nile river water through the El-Salam canal (HAMMAD, 1986). It is aimed to reclaim and cultivate about 27,000 km² concentrated mainly in wadi El Arish, east of Bitter lakes, and El-Tina plain, in order to create new and stable communities in these areas. The objectives of the study are to assess existing soil degradation and to determine the risk of soil degradation. The most interesting aspects of the research from a remote sensing and GIS practitioner's viewpoint is:

- To test the methodology of assessment of soil degradation at 1:250,000 scale;
- To use digital image processing and GIS techniques to derive input to the assessment model;
- To evaluate the procedures and results.

Concept of soil degradation monitoring and evaluation

Degradation processes are phenomena which cause a decrease in the quality of soils. The risk of soil degradation is the lowering of current or potential productivity, as a result of one or more degradation processes (LAL and STEWART, 1990). The present state of soil degradation is derived from the risk values by introducing the human activity represented by land use and soil management. Although often interacting, the soil degradation processes may be grouped into six categories, which are: water erosion, wind erosion excess of salts, chemical degradation, physical degradation and biological degradation. The current study assesses four of the six degradation processes, excluding only chemical and biological degradation. Soil degradation is expressed in the "provisional methodology" in units appropriate for each process. For example, soil erosion by water or wind is expressed by soil loss in tons/ha/year and salinization by increase of EC in ds/m and physical degradation by increase of bulk density in g/cm^3/year.

The degradation hazard values are then compared to listing of soil degradation classes which exist for all soil degradation processes (FAO / UNEP and UNESCO, 1979).

Assessment methodology and data sources

A parametric formula based on the universal soil loss equation (USLE) was used (SSSA, 1979). Input data values are derived from a combination of direct measures and information of remote sensing and thematic maps. The formula can be written in the general form as:

$$D = f(C, S, T, V, L, M)$$

where, D is degradation, C is climatic aggressivity factor, S the soil factor, T the topographic factor, V the natural vegetation factor, L the land use factor and M the management factor. For each degradation process a similar formula is used. The values of the variables are chosen in such a way that the solving of the equation gives a numeric indication of the degradation rate. The formula describes the processes only approximately and the values assigned to each factor are approximate in the present state of knowledge. Thus, the final results should not be regarded as absolute values for soil loss but as indication of the magnitude of degradation.

ARC/INFO GIS software is used to manage and manipulate the thematic map data, processed satellite images and tabular data sources. ERDAS digital image processing programs are utilized to process the images, including radiometric and geometric correction, and to derive values of Normalized Difference Vegetation Index (NDVI). IDRISI software is employed with ARC/INFO to generate slope values (GAD, 1993 and GAD *et al.* 1994).

Special processing concerns

Most of the data required by the parametric formula were derived from map data sources or published data. The most problematic inputs are the data on management and topography.

The management factor or M value is derived from digitally processed satellite data. The NDVI values are computed for each pixel in two 1024x1024 datasets from 1984 Landsat MSS and 1990 Landsat TM imagery (Plate 12). Iso-clustering classification is used to classify the NDVI images into six vegetation density classes. The classified image is then converted to ARC/INFO format and crossed with the soil coverages. The thus composed dataset is used in establishing a vegetation density rating for each soil polygon, thus deriving a management factor.

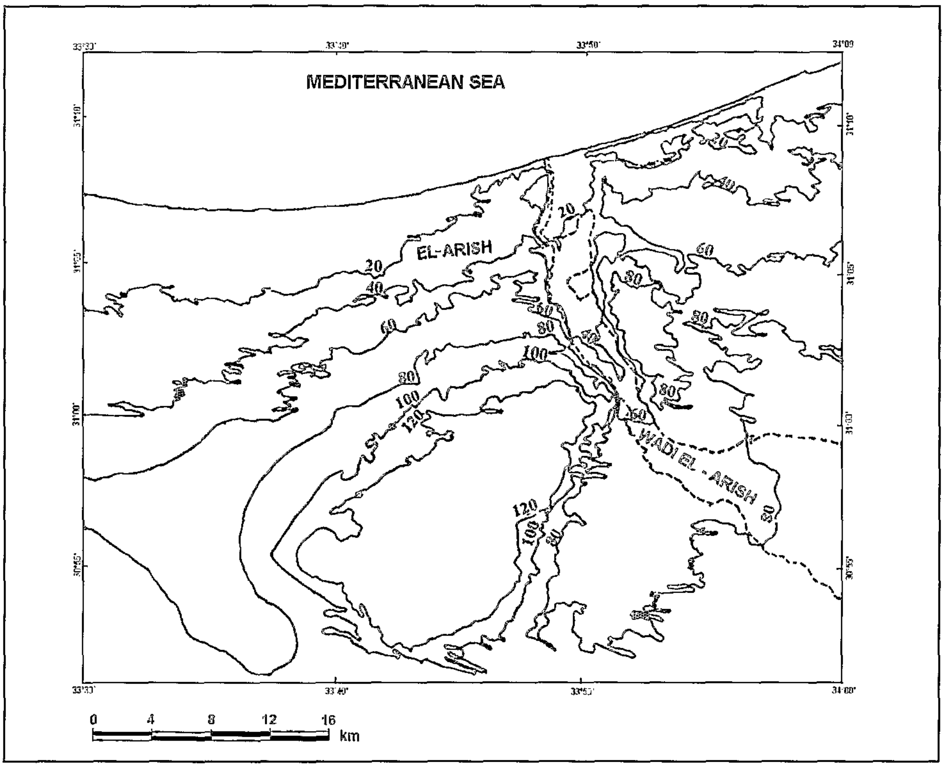

Figure 1. Contour map of the study area.

The other problem involves generating the percent slope data which are used in developing the rating of topography or T factor. A multi-step process is followed. First the digitizing of contour lines from 1:100,000 scale planimetric maps (Fig. 1). ARC/INFO line coverage is developed from digitized data and attributed with appropriate elevations.

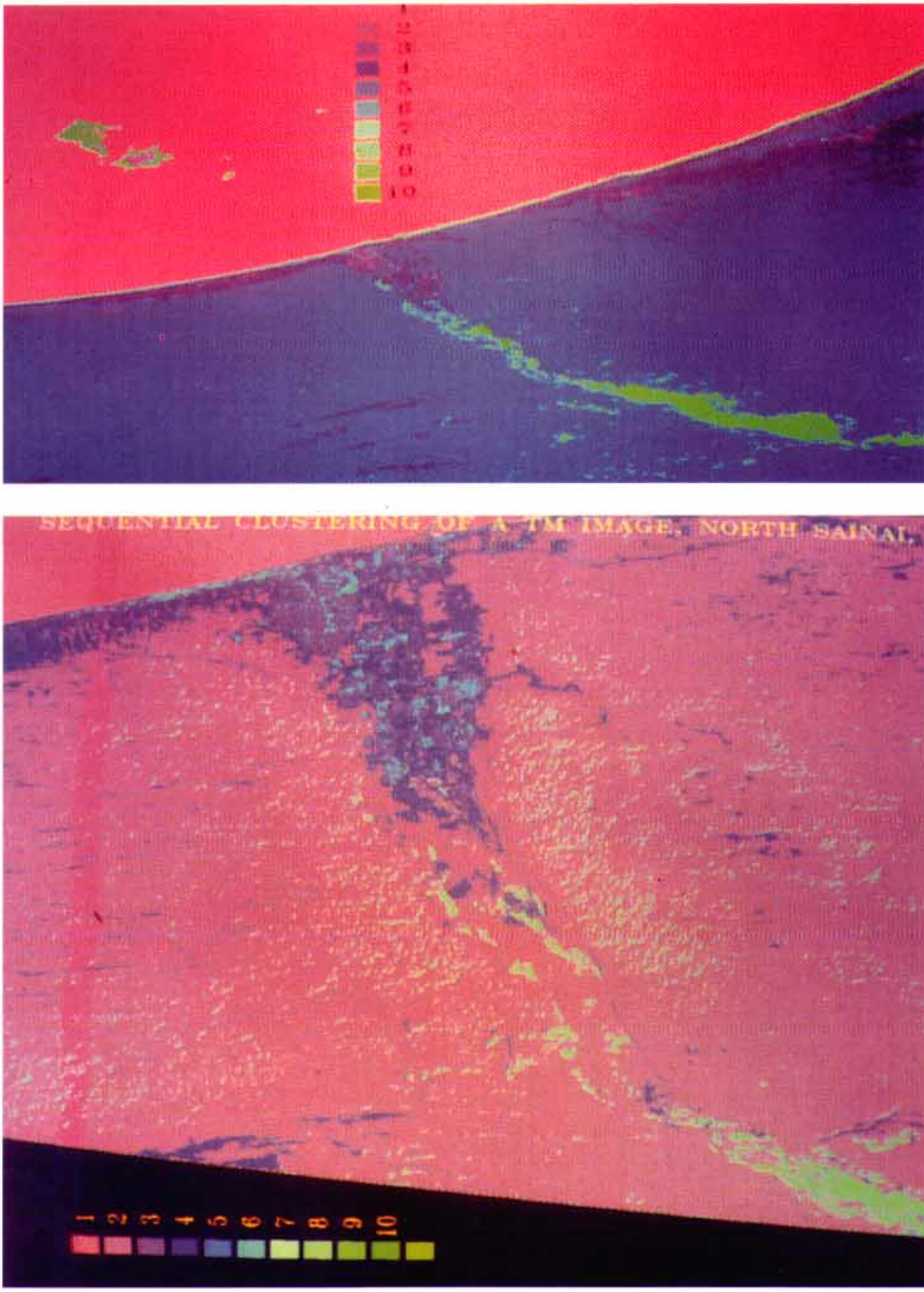

Plate 12. Processed satellite images of study area in Egypt (sequential clustering). A: Landsat MSS image; B: Landsat TM image (p. 448).

Second, contour data are clipped to the digitized soil coverage and exported to IDRISI. A copy of the soil coverage is imported to IDRISI. Third is the development of a digital elevation model (DEM) in IDRISI vector contour data. Fourth, a percent slope value is generated for each cell. The fifth step is to make a composite image of the percent slope data and the soils data. The sixth and final step, uses the histogram to determine the distribution of slope values for each soil unit and to assign a percent slope class to each soil polygon.

Generation of the model

The soils coverages (HAMMAD, 1986 and ABDEL-SAMIE *et al.*, 1982) developed in ARC/INFO are the base for generating the model (Fig.°2). Climatic ratings, soil factors, topographic, vegetation, land use and management ratings are added as attributes to the polygons of the soil coverage. Four soil profiles, representing different soil types in the study area were investigated (for description: appendix). Soil samples were collected and analysed in the laboratory for calculating the soil factor acc. USLE. Computing the parametric equations is then completed for the four soil degradation processes, both for current soil degradation and the risk of soil degradation.

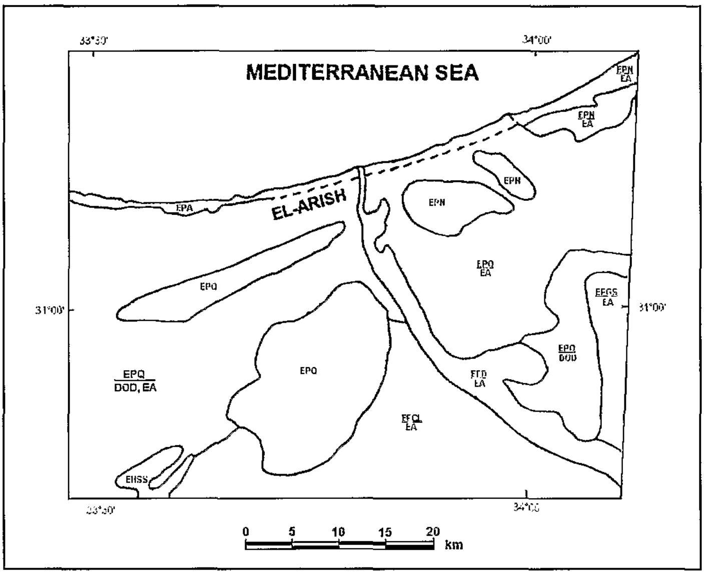

Figure 2. Soil map of the study area (ABDEL-SAMIE *et al.*, 1982).

Soil type	Order	Sub-order	Great group	Soil type	Order	Sub-order	
EPA	Entisols	Psamments	Aquipsamments	EFCL	Entisols	Fluvents	
EPQ	Entisols	Psamments	Quartizipsamments	EFD	Entisols	Fluvents	
EPN	Entisols	Psamments	Normipsamments	EFGS	Entisols	Fluvents	
EHSS	Entisols	Orthents	Haplorethens	DOD	Aridisols	Orthids	Durorthids
EA	Entisols	Orthents	Agrorthens				

Results and discussion

Tables 1 and 2 show the laboratory analyses of the collected soil samples. Determination of the soil factor in the USLE is based on the results of these analysis. The soil erodibility factor for water erosion is calculated from Wischmeier's nomograph (WISCHMEIER *et al.*, 1971). A correlation between soil texture and the wind erodibility was used (KIMBERLIN *et al.*, 1977). Soil texture and depth to ground water have been utilized for rating the soil factor in salinization. The silt/clay ratio is considered as important factor contributing to the physical degradation process.

Table 1. Some physical properties of soil samples in the selected soil profiles.

Profile No.	Depth (cm)	Mechanical analysis (mm) 2> 1	1> 0.5	0.5> 0.25	0.25> 0.125	0.125> 0.063	<0.063	Texture	O.M.	Structure
1	0-30	0	2	46,5	47	2	2,5	sand	0,1	loose
	30-60	0	1	50	46	2	1	sand	nil	loose
	60-100	0	5,5	58	33,5	2	1	sand	nil	loose
	100-150	0	10,5	58,5	25,5	1	1	sand	nil	loose
2	0-40	0	1	11	82	3,5	2,5	sand	0,1	loose
	40-100	0	2,5	26,5	69	1	1	sand	nil	loose
	100-150	0	7,5	18	72	1,5	1	sand	nil	loose
3	0-35	0	3	10,1	35,1	22	9,8	s.loam	0,5	w.subang.
	35-70	0	1	2,9	50	27	17,5	s.loam	0,4	w.subang.
	70-120	0	3,5	5	39,6	31,2	20,7	loam	0,2	mod.subang.
4	0.-65	0	2	39	48	7,5	5.5	sand	0,4	loose
	65-105	0	3	29,2	21,6	13,3	31,9	s.clay	0.5	m.m.subang.
	105-140	0	3,6	32	25,9	14,2	19,3	s.loam	0,3	w.m.subang.
	140-175	0	4,7	33	52,2	0	10,1	sand	0.2	loose

Water erosion

Table 3 shows the values of risk and present status of water erosion and the input parameters for their calculation. The area is generally exposed to a non to slight risk as the sand fraction is dominant in most soil types (Table 1). However, values of water erosion are highest in the Normipsamments soils (EPN) as the topsoil is characterized by a sandy loam texture (Soil profile n°3) as opposed to the other soil units with sandy topsoils.

Table 2. Some chemical properties of soil samples in the selected soil profiles.

Profile No.	Depth (cm)	Ec. mmohs /cm.	$CaCo_3$ (%)	Soluble salts (mEq / l) Cations				Anions			
				Ca	Mg	Na	K	CO_3	HCO_3	Cl	So_4
1	0-30	0,5	6,3	1,7	0,9	2	0,5	0	0,8	2,8	1,5
	30-60	0,4	8,1	1,4	0,5	1,9	0,5	0	0,7	2,4	1,1
	60-100	0,5	10,1	2,1	0,3	1,9	0,4	0	0,7	2,5	1,5
	100-150	0,6	10,2	1,1	0,6	3,5	0,3	0	0,8	3,1	1,6
2	0-40	0,7	2	0,7	0,5	5,8	0,1	0	0,8	4,5	1,8
	40-100	0,8	0,3	0,6	0,4	7,5	0,2	0,5	0,9	6,1	1,2
	100-150	0,9	0,3	0,8	0,3	7,7	0,2	0,5	0,9	6,2	1,4
3	0-35	0,7	43,5	1,6	0,6	4,6	0,2	0	1,2	4,2	1,8
	35-70	1,1	54,5	1,8	1	7,9	0,2	0	1,3	5,8	3,8
	70-120	2,2	52,5	3,4	2,5	17	0,2	0	2,9	16,2	3,9
4	0.-65	0,6	5,5	1,9	0,5	3,3	0,4	0	0,9	3,6	1,6
	65-105	2,5	28,5	2,6	2	21	0,2	0	3,1	18,4	4,4
	105-140	8,3	29,5	17	11,8	69	0,5	0	7,4	72	19,3
	140-175	6,1	23	12	8,9	50	0,4	0	7,4	43,8	19,8

Table 3. Values of risk and present status of water erosion and the input parameters for their computation.

Area (km^2)	ID	Soil-Type	Climatic factor	Soil factor	Topo. factor	Human factor	Risk	Present state
000051.130	1	EPA	16.39	0.03	0.35	0.32	0.1721	0.0551
000062.810	2	EPQ	16.39	0.03	2.00	0.45	0.9834	0.4425
000212.500	3	EPQ	16.39	0.03	2.00	0.45	0.9834	0.4425
000582.190	4	EPQ	16.39	0.03	2.00	0.45	0.9834	0.4425
000017.190	5	EHSS	16.39	0.08	0.35	0.07	0.4589	0.0321
000301.875	6	EFCL/EA	16.39	0.08	0.35	0.07	0.4589	0.0321
000126.560	7	EFD/EA	16.39	0.08	0.35	0.07	0.4589	0.0321
000041.880	8	EPN	16.39	0.14	3.50	0.12	8.0311	0.9637
000014.380	9	EPN	16.39	0.14	3.50	0.12	8.0311	0.9637
000030.310	10	EPN/EA	16.39	0.14	3.50	0.12	8.0311	0.9637
000022.190	11	EPN/EA	16.39	0.14	3.50	0.12	8.0311	0.9637
624514.990	12	EPQ/EA	16.39	0.03	2.00	0.45	0.9834	0.4425
000109.380	13	EPQ/DOD	16.39	0.03	2.00	0.45	0.9834	0.4425
000053.750	14	EFGS/EA	16.39	0.08	0.35	0.07	0.4589	0.0321

Wind erosion

Table 4 shows the values of risk and present status of wind erosion and the input parameters for their calculation. Annual average of wind velocity, in El-Arish station reaches 4.30 knots (2.214 $m.sec^{-1}$). Thus the wind erosivity factor is high (50-150) in the study area. All soil types are characterized by high (50-200 $t.h^{-1}.year^{-1}$) to very high (> 200 $t.h^{-1}.year^{-1}$) risk values of soil loss by wind erosion. Wind erosion in the study area is particularly important because the soils are mostly dry and the vegetation cover is scattered or absent. Cultivation of barley and non conventional crops in some soils reduces the present state of wind erosion hazard. However, wind erosion is more pronounced in the Psamments soils (Quartzipsamments EPQ and Aquipsamments EPA) which are formed on sand dunes.

Table 4. Values of risk and present status of wind erosion and the input parameters for their computation.

Area (km^2)	ID	Soil-Type	Climatic factor	Soil factor	Topo. factor	Human factor	Risk	Present state
000051.130	1	EPA	100	3.50	1	0.70	350	245.00
000062.810	2	EPQ	100	3.50	1	1.00	350	350.00
000212.500	3	EPQ	100	3.50	1	1.00	350	350.00
000582.190	4	EPQ	100	3.50	1	1.00	350	350.00
000017.190	5	EHSS	100	1.75	1	0.15	175	026.25
000301.875	6	EFCL/EA	100	1.75	1	0.15	175	026.25
000126.560	7	EFD/EA	100	1.75	1	0.15	175	026.25
000041.880	8	EPN	100	1.75	1	0.30	175	052.50
000014.380	9	EPN	100	1.75	1	0.30	175	052.50
000030.310	10	EPN/EA	100	1.75	1	0.30	175	052.50
000022.190	11	EPN/EA	100	1.75	1	0.30	175	052.50
624514.990	12	EPQ/EA	100	3.50	1	1.00	350	350.00
000109.380	13	EPQ/DOD	100	3.50	1	1.00	350	350.00
000053.750	14	EFGS/EA	100	1.75	1	0.15	175	026.25

Salinization

Table 5 shows the values of risk and present status of salinization and the input parameters for their calculation. The study area is characterized by hyper arid climatic conditions: the precipitation (P) is less than 1/3 of the potential evapotranspiration (PET) and at least one 12 month period without rainfall. Thus, the proposed climatic index (PET/P) is very high (0.5 $\rightarrow$ 3.3).

The present state and risk values in the Psamments (i.e. EPA, EPQ and EPN) are slight to moderate. The coarse texture and rapid permeability of these soils reduce the risk of salinization. Haplorthents (EHSS) and Fluvents (EFGS, EFD and EFCL) are exposed to a very high risk of salinization. This is related to their shallow soil profiles, fine texture and medium to low permeability. Since Fluvents occur in wadis, valley floors, desert basins and playas, the topographic factor increases the salinization risk. Furthermore, agricultural practices on these soils, especially the excessive application of irrigation water, increase salinization hazard.

Table 5. Values of risk and present status of salinization and the input parameters for their computation.

Area (km^2)	ID	Soil-Type	Climatic factor	Soil factor	Topo. factor	Human factor	Risk	Present state
000051.130	1	EPA	1.50	0.1	1.0	0.7	0.150	0.105
000062.810	2	EPQ	1.50	0.1	1.0	0.5	0.150	0.075
000212.500	3	EPQ	1.50	0.1	1.0	0.5	0.150	0.075
000582.190	4	EPQ	1.50	0.1	1.0	0.5	0.150	0.075
000017.190	5	EHSS	1.50	1.0	5.0	0.7	7.500	5.250
000301.875	6	EFCL/EA	1.50	1.0	5.0	0.7	7.500	5.250
000126.560	7	EFD/EA	1.50	1.0	5.0	0.7	7.500	5.250
000041.880	8	EPN	1.50	1.0	0.1	0.7	0.150	0.105
000014.380	9	EPN	1.50	1.0	0.1	0.7	0.150	0.105
000030.310	10	EPN/EA	1.50	1.0	0.1	0.7	0.150	0.105
000022.190	11	EPN/EA	1.50	1.0	0.1	0.7	0.150	0.105
624514.990	12	EPQ/EA	1.50	0.1	1.0	0.5	0.150	0.075
000109.380	13	EPQ/DOD	1.50	0.1	1.0	0.5	0.150	0.075
000053.750	14	EFGS/EA	1.50	1.0	5.0	0.7	7.500	5.250

Physical degradation

Table 6 presents the values of risk and present status of physical degradation and the input parameters for their computation. All soil types are characterized by non to slight present state hazard. However, the cultivated relatively heavy textured soils are exposed to moderate risk. These soils could be subjected to some interrelated processes, including impermeability and compaction. Cultivation and irrigation practices on vulnerable soils are also factors increasing the risk of physical degradation.

Table 6. Values of risk and present status of physical degradation and the input parameters for their computation.

Area (km^2)	ID	Soil-Type	Climatic factor	Soil factor	Topo. factor	Human factor	Risk	Present state
000051.130	1	EPA	01.64	0.001	1.0	0.3	0.0016	0.0005
000062.810	2	EPQ	01.64	0.001	0.5	1.0	0.0008	0.0008
000212.500	3	EPQ	01.64	0.001	0.5	1.0	0.0008	0.0008
000582.190	4	EPQ	01.64	0.001	0.5	1.0	0.0008	0.0008
000017.190	5	EHSS	10.00	0.100	1.0	0.3	1.0000	0.3000
000301.875	6	EFCL/EA	10.00	0.100	1.0	0.3	1.0000	0.3000
000126.560	7	EFD/EA	10.00	0.100	1.0	0.3	1.0000	0.3000
000041.880	8	EPN	10.00	0.100	0.5	0.3	0.5000	0.1500
000014.380	9	EPN	10.00	0.100	0.5	0.3	0.5000	0.1500
000030.310	10	EPN/EA	10.00	0.100	0.5	0.3	0.5000	0.1500
000022.190	11	EPN/EA	10.00	0.100	0.5	0.3	0.5000	0.1500
624514.990	12	EPQ/EA	01.64	0.001	0.5	1.0	0.0008	0.0008
000109.380	13	EPQ/DOD	01.64	0.001	0.5	1.0	0.0008	0.0008
000053.750	14	EFGS/EA	10.00	0.100	1.0	0.3	1.0000	0.3000

Conclusions and recommendations

Management and planning agricultural expansion in desert areas are essential for self sufficience of food production. However, many degradation processes are active on the soils and causes deterioration in their potential productivity. The evaluation and control of soil degradation and productivity are based on environmental information. GIS techniques are useful in storing, retrieving and manipulating such information.

Furthermore, remote sensing techniques and GIS are useful in updating the status of soil deterioration and providing services to a risk model. It should be advised that the final values generated by parametric equations are not absolute values of soil loss. These values merely give an approximate indication of the likely magnitude of degradation. Additionally better sources of data for the management factor and percent slope information need to be identified.

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Appendix

Field description of profile no. 1

Area	Wadi El-Arish
Location	Close to sea shore
Vegetation	Nuts (fig)
Relief	Undulating
Slope	Slightly steep
Soil classification	Aquipsamments (EPA)

Depth (cm)	Description
0-30	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sand; single grains; loose; diffuse smooth boundary.
30-60	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sand; single grains; loose; diffuse smooth boundary.
60-100	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sand; single grains; loose; diffuse smooth boundary.
100-150	Pink (7.5 YR 7/4, dry), light brown (7.5 YR6/4, moist); sand; single grains; loose.

Field description of profile no. 2

Area	Wadi El-Arish
Location	30 m.east of Lihfin-El-Arish road
Vegetation	V. few desert shrups
Relief	Undulating to hilly
Slope	Sloping
Soil classification	Quartzipsamments (EPQ)

Depth (cm)	Description
0-40	V. pale brown (10 YR 7/6, dry), pale brown (10 YR 6/3, moist) sand; single grains; Loose; diffuse smooth boundary.
40-100	V. pale brown (10 YR 7/4, dry), pale brown (10 YR 6/3, moist) sand; single grains; loose; diffuse smooth boundary.
100-150	V. pale brown (10 YR 7/3, dry), pale brown (10 YR 6/3, moist); sand; single grains; loose.

Field description of profile no. 3

Area	Wadi El-Arish
Location	
Vegetation	Barely
Relief	Undulating
Slope	Sloping
Soil classification	Normipsamments (EPN)

Depth (cm)	Description
0-35	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sandy loam; weak medium sub-angular blocky; sticky; plastic; slightly hard; weavy clear boundary.
35-70	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sandy loam; weak angular blocky; sticky; plastic; hard; diffuse smooth boundary.
70-120	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); loam; angular blocky; sticky; plastic; hard.

Field description of profile no. 4

Area	Wadi El-Arish
Location	300 m east of main road
Vegetation	Barely
Relief	Undulating
Slope	Slightly sloping
Soil classification	Fluvents / Agrorthents (EFD / EA)

Depth (cm)	Description
0-65	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sand; single grains; Loose; abrupt smooth boundary.
65-105	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sand clay loam; angular to sub-angular blocky; v. sticky; v. plastic; diffuse smooth boundary.
105-140	Pink (7.5 YR 7/4, dry), light brown (7.5 YR 6/4, moist); sandy loam; angular to sub-angular blocky; sticky; plastic; clear smooth boundary. 140-175 Pink (7.5 YR 7/4, dry), light brown (7.5 YR6/4, moist); sand; massive.