IDENTIFICATION OF REGIONAL SOIL QUALITY INDICATORS AND LAND EVALUATION OF SIWA OASIS

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ABSTRACT

Identification of soil quality indicators in Siwa oasis is an important issue since it has a unique geographic setting and contains different patterns of soils, water resources, and land uses. For this purpose, soil and water samples that cover the oasis were collected, and analyzed for main chemical and physical characteristics. Data were analyzed using factor analysis to assess the soil quality indicators. Also, land capability evaluation was calculated using ALES-Arid software.

Five quality factors were identified by factor analysis, and could be used as quality indicators in this region, namely: texture, salinity, organic matter, fertility management, and infiltration.

The analysis of land capability showed that, generally, the oasis faces problems related to low soil fertility and the main limiting parameters are EC and OM. Meanwhile, most of water quality index in Siwa oasis are conditionally suitable and the main limiting factors are Na, Cl, and SAR. The overall evaluation showed low capabilities of the oasis, and the use for agriculture should follow proper management for good production.

Abbreviations: organic matter (OM), cation exchange capacity (CEC), salinity expressed as electrical conductivity (EC), saturated hydraulic conductivity (K_s), texture (T), sodium adsorption ratio (SAR), soil moisture retention at -30 (SMR30) and at – 1500 k Pa (SMR1500), and water holding capacity (WHC),soil index(SI), fertility index(FI), water index (WI, and final land evaluation index(FILE)

INTRODUCTION

Siwa oasis is considered one of the most promising oasis in the western desert of Egypt for its historical, demographical and economical settings. It has a great potential for agricultural development, since about 17,000 feddan (7140 ha) were found suitable for agricultural development, beside the existing cultivated area. The distinguished geographic unit of Siwa oasis leads to consider it as a regional scale unit for assessing soil quality. Therefore, the valid characterization of this area will be a useful tool for proper management and development. Many investigators (Balba, 1992; and Abdel Samei, 2000) provide the basis for land management recommendations towards a better utilization of national resources and the enhancement to achieve sustainable agricultural development.

Geostatistical analysis is a reliable tool to characterize the spatial distribution of soil attributes. It has been applied by many researchers to describe the spatial variability by the semivariogram that predicts the values of soil attributes at un-sampled locations by different Kriging techniques (Trangmar *et al.*, 1985; Bahnassy, 2002; and Banerjee and Gelfand, 2002). The importance of spatial distribution of soil quality indicators has been increasingly recognized in predictive models (Giltrap and Hewitt, 2004)

Understanding the behavior of soil attributes in the soil environment is the key of concern prior to consider them as indicators of soil quality. Soil quality has been defined as "the capacity of a soil to function within ecosystem and land use boundaries, sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994). Soil functions that soil quality influences include the ability to (i) accept, hold, and release nutrients and other chemical constituents; (ii) accept, hold, and release water to plants and surface and groundwater recharge; (iii) promote and sustain root growth; (iv) maintain suitable soil biotic habitat; and (v) respond to management and resist degradation (Larson and Pierce, 1991). Maintaining or improving soil quality can provide economic benefits in the form of increased productivity, more efficient use of nutrients and pesticides, and improvements in water and air quality.

Because of its importance, a quantitative assessment of soil quality is needed to determine the sustainability of land management systems as related to agricultural productions practices, and evaluating sustainable agricultural and land use policies. Bahnassy et al. (2001), studied the effect of different management practices on the suitability of Sugar beet region for cultivating wheat, corn and rice, as well as predicting the situation of soil attributes after 5 and 10 years. However, soil quality cannot be measured directly, but must be inferred from soil quality indicators. Soil quality indicators are measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions and are sensitive to changes in land use management, or conservation practices. However, many soil attributes are highly correlated. Fayed (2003) compared and analyzed the changes in soil quality under different crop pattern and management practices in sandy soils at El-Bostan region, western desert, Egypt, and found that cultivation tends to improve soil quality classes. Seybold et al. (1997) reported that correlated soil attributes do not vary independently to changes in management, but respond as a group, integrating many complex interactions among biological, chemical, and physical soil processes. Single attribute indicators do not reflect interacting change in soil quality that may

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occur with changes in management because of correlation among soil attributes.

Multivariate statistical analysis, such as factor analysis, provides techniques for studying the relationships among correlated variables. Brejda et al. (2000a) analyzed 20 soil attributes using factor analysis and identified five soil quality indicators in the northern Mississippi valley loess hills.

The objectives of this study aimed at assessing the land resources of Siwa oasis through (i) characterization the spatial distribution of soil attributes, (ii) identifying soil quality factors, and their significance variations and (iii) evaluating the capability of soil based on these factors, which can be used as soil quality indicators.

MATERIALS AND METHODS

Geographical settings

Siwa oasis is located in the western desert of Egypt about 306 km southwest Marsa Matrouh city, and 65 km east of the Libyan border (Fig. 1). It is one of the most important depressions (~17 m below sea level) in Egypt. Average annual temperature ranges from 11.9 to 30°C. Ground water is the only source of drinking and irrigation with an average discharge of $190\times10^3 m^3 day^{-1}$ (AODA, 1977).

Soil sampling and land use

Soil samples were collected from the top 20 cm of 60 different locations that cover the oasis (Fig 1). The samples were geo-located using GPS, with locational error of 5-7 m. The dominant land use is agriculture; mostly cultivated with olive, dates, and alfalfa.

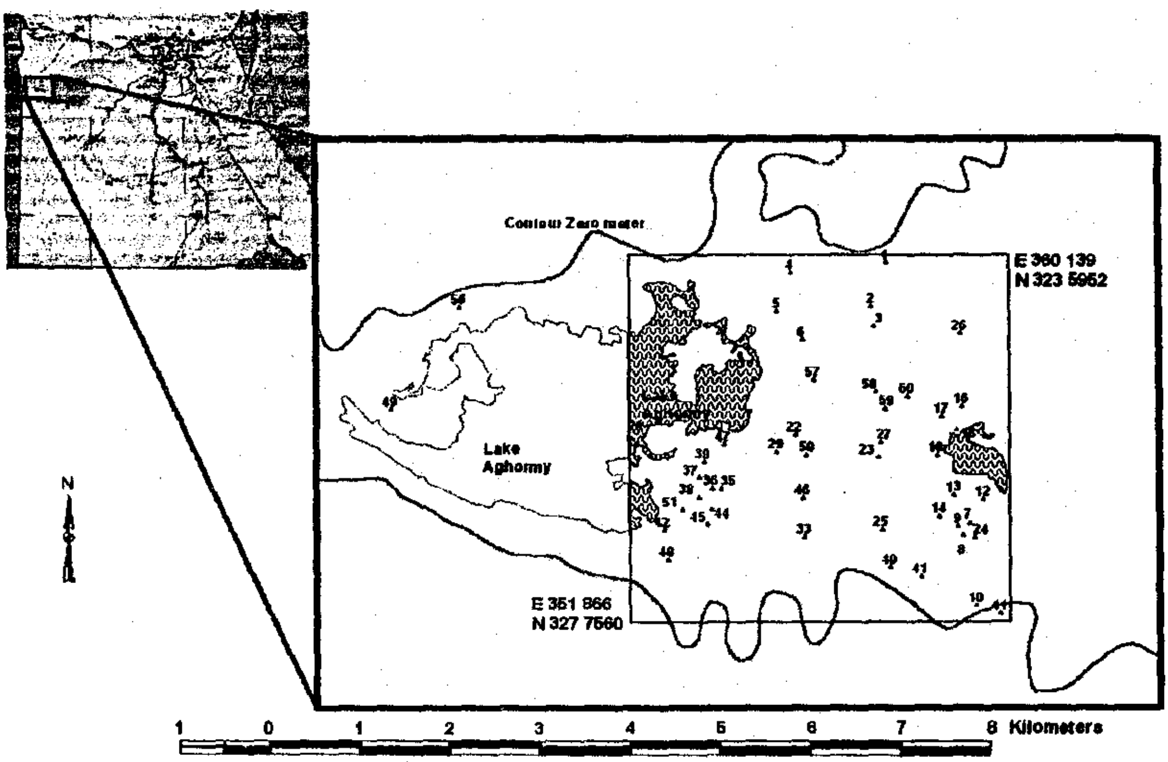
Soil analysis

Soil samples were analyzed for some physical parameters including: sand, silt and clay contents, SMR30 and SMR1500, and K_s according to Klute (1991). Samples were also chemically analyzed for pH (1:2.5 soil: water ratio), EC, OM, CEC, and soluble cations and anions including Ca, Mg, Na, K, Cl, and HCO_3, according to Page *et al.* (1982). SAR and WHC values were accordingly calculated from measured data.

Water analysis

Water samples were collected in glass bottles from the artesian well located in each site, and stored in refrigerator for further analysis. Chemical analyses were performed including: EC, pH, soluble cations and anions, and B according to standard methods of water analysis (Lenore et al., 1999) and SAR values were accordingly calculated.

Fig. 1: Map of sample locations, Siwa oasis



GIS Input

The locations of soil samples were formatted as a comma-delimited of soil sample-number, easting, northing. Avenue script gps 2shp. Ave. was used to import the data into Arc View GIS software (ESRI, 1999) as point data. Moreover, topographic maps at scale 1:25,000 were used to digitize the contour line representing sea level (zero elevation) as a line, and the outline of the main lake as polygon using Terra soft GIS software (Digital Resource System, 1991).

The Linkage between Geostatistics and GIS

The estimates from Kriging technique (Gamma Design, 2001), and the associated error were exported to Arc View GIS software (ESRI, 1999) for better visualization, mapping, and printout.

Statistical analysis

Factor analysis

Factor analysis was used to group the 18 soil attributes into statistical factors based on their correlation structure using PROCFACTOR in (SAS Institute, 1989). Factor analysis was performed on standardized variables using the correlation matrix (Table1) to eliminate the effect of different measurement units on factor loadings. Factor loadings are the simple correlations between the soil attributes and each factor (Sharma, 1996). The 18 soil attributes analyzed were sand, silt, clay, K_s, SMR30, SMR1500, WHC, pH, EC, Ca, Mg, Na, K, HCO_3, Cl, OM, SAR, and CEC.

Because factor analysis was performed on standardized values of the soil attributes, each variable had a variance of one with a total variance of 18 for entire data set. Eigenvalues are the amount of variance explained by each factor (Sharma, 1996). Factors with eigenvalues greater than one were retained for interpretation, because factors with eigenvalues less than one explained less variance than individual soil attributes. The retained factors were subjected to a varimax rotation. A varimax rotation redistributes the variance of significant factors to maximize the relationship between interdependent soil variables (SAS Institute, 1989).

Communalities estimate the portion of variance in each soil attribute explained by the factors. A high communality for a soil attribute indicates a high proportion of its variance is explained by the factors. In contrast, a low communality for a soil attribute indicates much of that attribute's variance remains unexplained. Less importance should be ascribed to soil attributes with low communalities when interpreting variable associations represented by each factor.

Variogram

The variogram (or as named semivariogram) is defined as half of the average squared difference between two attribute values separated by vector h, for one variable (Burrough and McDonnell, 1998):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{Z(x_i) - Z(x_i + h)\}^2$$

where $N(h)$ is the number of pairs at lag h, $Z(x_i)$ is the value of the attribute at location (x_i) and $Z(x_i + h)$ is the value of the attribute at location $(x_i + h)$ separated by distance h. The separation vector h is specified with some direction and distance (lag) tolerance. This variogram is used to characterize the spatial dependence of soil attributes and then fitting them to one of the known models, i.e. linear, spherical, exponential, and Gaussian (McBratney and Webster, 1986).

Kriging

The Kriging technique is optimal method providing linear estimator $Z'(x_o)$ in a sense that the weights of local averaging are chosen to give unbiased estimates while keeping the estimation variance at minimum (El-Haris, 1987; and Banerjee and Gelfand, 2002):

$$Z'(x_o) = \sum_{i=1}^{n} w_i Z(x_i)$$

where w_i is the weight factor related to spatial dependence, n is the number of points. The lack of bias conditions yields:

$$\sum_{i=1}^{n} w_i = 1$$

The parameters from experimental variogram (nugget, sill, and range) were needed in Kriging to perform interpolation.

Cross Validation

Cross validation is a technique that is used to compare estimated and true values using the information available in the data set. The sample value at a particular location is temporarily discarded from the sample data set; the value at the same location is then estimated using the remaining samples. Once the estimate is calculated, it is compared to the true sample value that was initially removed from the sample data set. This procedure is repeated for all samples. The error (e) expressed as (Issaks and Srivastava, 1989):

$$e = Z'(x_i) - Z(x_i)$$

where $Z'(x_i)$ is the estimated value and $Z(x_i)$ the true value. Mean square error (MSE) is calculated from the formula:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} e^2$$

Table 1: Variogram types and parameters for some soil attributes of Siwa oasis.

Variable	Model	Nugget (Co)	Sill (C1)	Range (a)	R^2	Lag (m)
SAND	Exponential	8.6	247	431	0.931	1600
Ks	Exponential	0.01	17.05	289	0.981	2500
OM	Exponential	0.56	2.23	380	0.810	5000
CLAY	Gaussian	0.1	104.4	328	0.804	1500
WHC	Gaussian	0.04	9.53	375	0.864	1500
CEC	Gaussian	0.1	212	484	0.993	2000
EC	Gaussian	9.6	108	900	0.951	2000
SAR	Gaussian	0.1	46.95	726	0.998	3500

Land evaluation

Agriculture Land Evaluation System for Arid region (ALES-Arid) is a new approach for land capability and suitability evaluation (Ismail et al., 1994). ALES-Arid is described as a land use decision support system which is linked directly with integrated database and complied indirectly with GIS (Abdel-Kawy, 2004). Through ALES-Arid program, land evaluation algorithms are expressed in notation forms that can be recognized by a calculating device. According to Storie (1964), six productivity classes are identified as: C_1= excellent (80 – 100%); C_2= good (60 – 80%); C_3= fair (40-60%); C_4= poor (20 – 40%); C_5= Very poor (10-20%); and C_6= non-agriculture (<10%). The calculation of capability index by ALES-Arid is an indication of land capability according to multiplication method. Three main groups of parameters were included: a) soil physical and chemical analysis, b) soil fertility parameters, and c) water irrigation parameters. Each group consists of number of characteristics (or qualities) which are evaluated as index that takes value of each characteristic was calculated from its index. The next step is multiplying the logarithmic mean of its characteristics, and then the anti-logarithmic value (capability index) was calculated. The final index of land evaluation (F.I.L.E.) was calculated based on soil, fertility, and water indexes according to:

F.I.L.E.=3/(1/SI + 1/FI + 1/WI)

and the classes given (F) followed similarity as productivity classes.

RESULTS AND DISCUSSION

The Variogram Models

The spatial dependence between neighboring points i.e. the average rate of change over distance, and interpolation based Kriging, are all depend on the variogram. The estimation of a valid variogram is critical for geostatistics. Kriging depends on an accurate variogram for estimating weights for interpolation. Using incorrect variograms can leads to unfavorable precision of the kriged estimates.

The variogram analysis (Table 1) reveals that the spatial dependence of the soil attributes throughout the study area are exponential for K_s, sand and OM and Gaussian for EC, CEC, SAR and WHC, which formulated as follows:

$$\gamma(h) = C_o + C_1\{1 - \exp(-\frac{h}{a})\} \quad \text{.... Exponential}$$

$$\gamma(h) = C_o + C_1\{1 - \exp(-\frac{3h^2}{a^2})\} \quad \text{..... Gaussian}$$

El-Menshawy (2003) used the geostastical analysis of some soils in Siwa oasis, and reported that the variogram model was spherical for depth and % $CaCO_3$; Gaussian for EC and SAR and exponential for OM and total sand content.

The nugget indicates that the inherited variability for each property. It is clear that EC and sand have the highest inherited variability since Co is 9.6 and 8.6, respectively. The sill represents the maximum variance for each variable, where sand, CEC, EC, and Clay have the highest variances. The range is considered as the distance where the correlation between the sample pairs is high, and where interpolation is worthwhile. EC have the highest range (900 m), followed by SAR (726 m), and finally Ks has the lowest interpolation distance (McBratney and Webster, 1986; Isaaks and Srivastava,1989).

Bi-Variate Statistics

The data illustrated in Table 2 showed significant correlations ($P<0.05$) between soil attributes pairs. K_s showed negatively correlations with all attributes except sand, HCO_3, OM, and CEC, but was only higher significant with clay, and significant with silt, SMR30 and WHC. Also, sand showed highly negative significant correlation with all soil attributes except pH and only significant correlation with OM and Cl concentration and not significant with K and HCO_3. Also, highly positive correlations were found between each of silt, clay, or EC and other soil attributes except K, CEC, and HCO_3. The pH showed only negative highly significant correlation with OM which was not significant with all other attributes.

Multivariate Statistical Characterization

Each of the first five factors had eigenvalues greater than one (Table 3) and were retained for interpretation. These five factors explained >90% of the variance in EC and Na, and 80% of the variance in sand, clay, SMR30, SMR1500, SAR and HCO_3 as indicated by their communalities (Table 3).

Table 2: Correlation matrix among soil physical and chemical attributes of Siwa oasis.

Soil attribute	K_s	Sand	Silt	Clay	SMR 30	SMR 1500	WHC	pH	EC	Ca	Mg	Na	K	Cl	HCO_3	OM	SAR
Sand	0.343**																
Silt	-0.294*	-0.887**															
Clay	-0.343**	-0.947**	0.712**														
SMR 30	-0.261*	-0.734**	0.640**	0.717**													
SMR 1500	-0.202	-0.727**	0.668**	0.694**	0.924**												
WHC	-0.266*	-0.568**	0.462**	0.582**	0.841**	0.608											
pH	-0.191	0.010	-0.052	-0.007	-0.019	-0.41	0.044										
EC	-0.181	-0.613**	0.517**	0.616**	0.387**	0.406**	0.271*	-0.116									
Ca	-0.185	-0.648**	0.555**	0.646**	0.578**	0.490**	0.568**	-0.131	0. 764**								
Mg	-0.160	-0.680**	0.481**	0.745**	0.540**	0.459**	0.518**	-0.91	0.731**	0.745**							
Na	-0.174	-0.515**	0.511*	0.465**	0.370**	0.348**	0.316*	-0.117	0.918**	0.662**	0.699**						
K	-0.108	-0.138	0.096	0.163**	0.350**	0.444**	0.112	-0.163	0.128**	0.125	0.072	0.097					
Cl	-0.160	-0.316*	0.370**	0.246**	0.257*	0.250*	0.205	-0.017	0.600**	0.454**	0.496**	0.744**	-0.061				
HCO_3	0.213	0.075	-0.056	-0.075	-0.139	-0.087	-0.153	-0.0 70	-0.013	-0.043	-0.046	-0.033	0.038	-0.015			
OM	0.052	-0.280*	0.155	0.337**	0.323*	0.308*	0.289*	-0.345**	0.223	0.277*	0.311**	0.128	0.332**	-0.098	-0.095		
SAR	-0.162	-0.462**	0.479**	0.407**	0.359**	0.350**	0.293*	-0.154	0.870**	0.574	0.625**	0.967**	0.185	0.646**	-0.013	0.151	
CEC	0.131	-0.383**	0.211	0.456**	0.218**	0.196	0.144	-0.056	0.576**	0.440**	.425**	0.432**	0.040	0.345**	-0.068	0.235	0.349**

However, the first five factors explained < 50% of the variance in K_s, pH and CEC, therefore, less importance should be ascribed to those attributes when interpreting the factor.

Based on the soil attributes that comprised them, all of the factors identified using factor analysis contributes to one or more soil functions proposed by Larson and Pierce (1991), and therefore are considered to be soil quality factors.

The first factor had high positive loading (0.86-0.83) on clay, EC, Ca and Mg and a moderate positive loading (0.79 – 0.74) on silt, SMR30, SMR1500, WHC, Na and SAR. Sand had a weak negative loading (-0.88) on the first factor. This factor was termed the soil texture factor because it had high positive loadings for clay (0.86) and silt (0.77) and high negative loading for sand (-0.88). Grouping CEC with the texture factor resulted from the stronger correlation between CEC and clay ($r = 0.46^{**}$). The texture factor contributes to the ability of the soil to accept, hold, and release water to plants and for surface and ground water recharge, and respond to management and resist degradation (Larson and Pierce, 1994).

The second factor had positive loading (0.46-0.55) for EC, Na, Cl, and SAR, and was termed the salinity factor. The salinity factor contributes to plant growth, promote and sustain root growth, and maintain suitable soil biotic habitat.

The third factor had positive loadings for OM (0.65) and K_s (0.51) and was termed the organic matter factor. The soil organic matter factor contributes to the ability of the soil to accept, hold, and release nutrients, water and other chemical constituents to plants.

The fourth factor had moderate positive loading for K (0.51) and HCO_3 (0.47) and was termed the fertility management factor. The fertility management factor is important in supplying K and P to the plant and promoting root growth.

The fifth factor had high positive loadings on HCO_3 (0.74) and positive loadings on K_s (0.41) and was termed the calcic-infiltrations factor.

It is better to state that some potentially important soil quality indicators were not included in this study, such as total nitrogen and available phosphorous. The reason is that these factors are considered changeable by many variables such as mineral fertilizer application, temperature, moisture content, and microorganisms. Despite the limitation, the set of 18 soil attributes used in these studies included most of the indicators recommended in minimum date sets proposed by Larson and Pierce (1991).

With factor analysis using the covariance matrix, soil attributes with large variances can unduly influence the determination of factor loadings (Johnson and Wichern, 1992). There is no reason to believe that soil attributes with large variances are potentially more important as soil quality indicators. Schipper and Sparling (2000) stated that soil attributes with large variability may be poor soil quality

Table 3: Rotated factor loadings and communalities of a five factor model of physical and chemical soil attributes of Siwa oasis.

	Factor					
Soil attribute	1	2	3	4	5	Communalities
K_s	-.313	.206	0.510	-.173	.408	.597
Sand	-.877	.246	0.130	7.552E-02	-.200	.892
Silt	.770	-.178	-0.179	.116	.181	.702
Clay	.855	-.262	-0.066	-.184	.181	.871
SMR30	.786	-.508	-0.017	9.792E-02	2.20 E-02	.887
SMR1500	.745	-.481	0.054	.219	3.79 E-02	.838
WHC	.657	-.430	-0.121	-7.92 E-02	2.244 E-02	.638
pH	-.101	-0.01	-0.712	-3.04 E-02	7.336 E-02	.534
EC	.831	.460	0.066	-5.11 E-02	-5.15 E-02	.909
Ca	.825	.109	0.053	-.118	6.750 E-02	.713
Mg	.829	.159	0.037	-.174	8.447 E-02	.751
Na	.791	.545	-8.85E-03	.1444	-.135	.962
K	.242	-.324	.470	.509	-.342	.761
Cl	.563	.548	-.213	1.76	-7.71 E-02	.699
HCO_3	-.102	.171	.229	.468	.737	.855
OM	.350	-.277	.651	-.284	-.173	.734
SAR	.742	.501	5.977E-02	.244	.186	.899
CEC	.498	.299	.169	-.469	5.960 E-02	.590

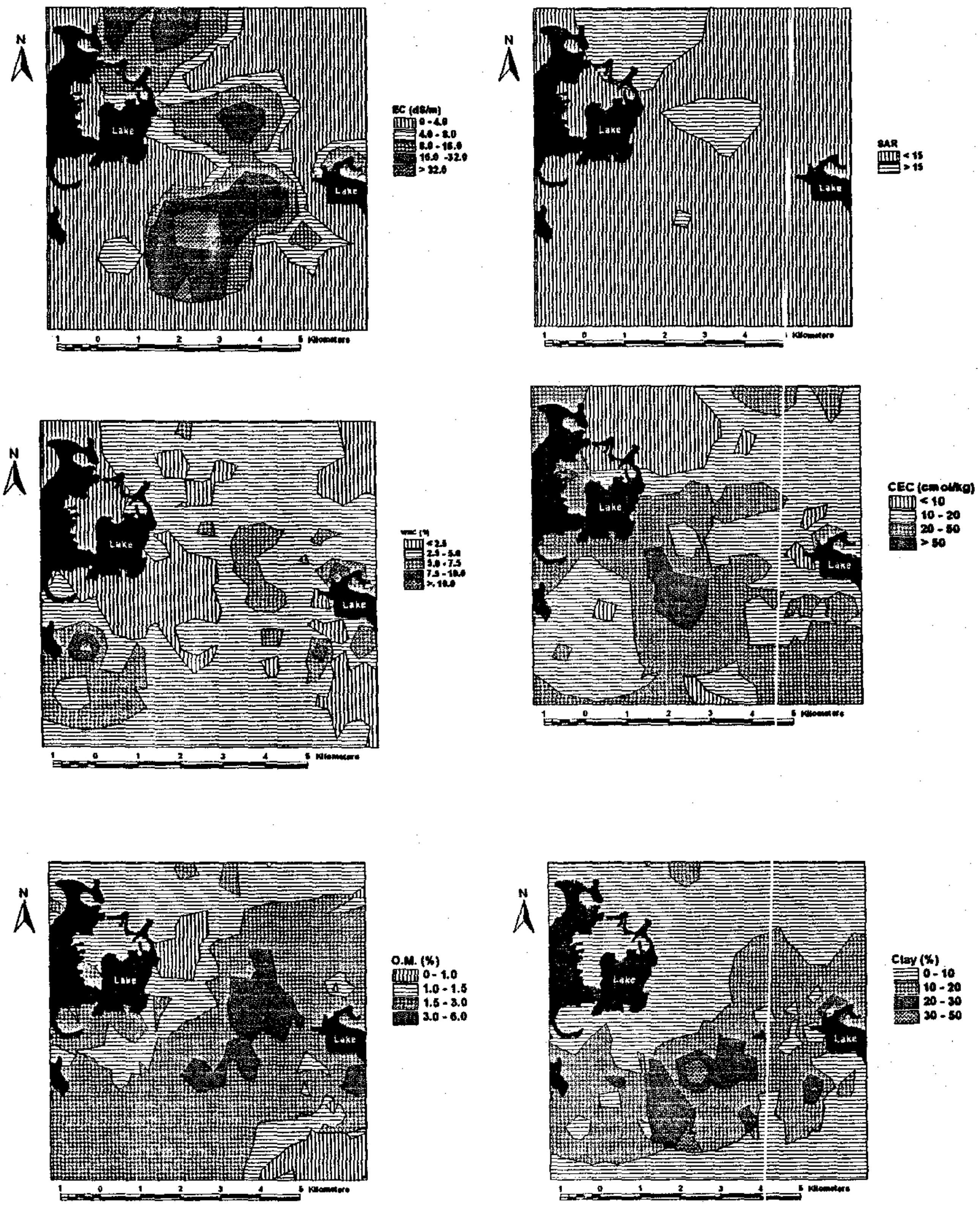


Fig. 2: Spatial distribution of soil salinity, sodium adsorption ratio, water holding capacity, cation exchange capacity, organic matter, and clay content for the studied area.

Table 4: Land capability classes, indices, and limitations of Siwa oasis.

ID	Soil class	Soil Index	Fertility class	Fertility index	Water class	Water index	Final evaluation class	F.I.L.E.[1]
1	C3 (T,WHC,K_s)	51.69	C6(OM)	8.00	NS1 (Na,Cl)	17.95	F5	15.00
2	C3 (T,WHC,CEC)	47.82	C5 (OM)	17.83	NS1 (Na,Cl)	18.80	F4	23.04
3	C3 (T,WHC,CEC)	41.02	C3 (OM)	46.00	NS1 (Na,Cl)	19.17	F4	30.54
4	C5 (T,WHC,CEC,EC_e)	12.05	C4 (OM)	35.67	NS1 (Na,Cl)	19.13	F5	18.37
5	C4 (T,WHC,K_s,CEC)	25.36	C5 (OM)	19.50	S1	99.09	F4	29.76
6	C4 (T,WHC,CEC,EC_e)	26.48	C6(OM)	2.33	NS1 (Na,Cl)	18.51	F6	5.76
7	C3 (T,WHC)	54.84	C2	71.83	NS1 (SAR,Na,Cl)	16.02	F4	31.72
8	C4 (T,WHC,CEC)	25.98	C6(OM)	2.33	S4 (Na,Cl)	20.06	F6	5.80
9	C4 (T,WHC,CEC)	27.56	C5 (OM)	11.50	NS1 (ECw,Na,Cl)	13.75	F5	15.31
10	C3 (T,WHC,CEC)	45.57	C6(OM)	2.33	S1	98.26	F6	6.50
11	C4 (T,WHC,CEC)	32.09	C4 (OM)	23.00	S4 (Na,Cl)	36.86	F4	29.48
12	C2(T,WHC)	61.66	C2	69.00	S4 (Na,Cl)	36.44	F3	51.59
13	C3 (T,WHC)	40.52	C5 (OM)	12.66	NS1 (Na,Cl)	19.56	F5	19.38
14	C3 (WHC,ECe)	55.83	C4 (OM)	39.67	NS1 (Na,Cl)	18.79	F4	31.14
15	C4 (WHC,ECe)	36.73	C3	52.33	NS1 (Na,Cl)	19.08	F4	30.38
16	C4 (T,WHC,CEC,EC_e)	34.19	C6(OM)	2.83	S4 (Na,Cl)	20.14	F6	6.94
17	C3 (T,WHC,CEC)	47.46	C4 (OM)	37.33	NS1 (Na,Cl)	19.34	F4	30.13
18	C3 (T,WHC,CEC)	48.74	C3	55.17	S4 (Na,Cl)	29.19	F3	41.15
19	C4 (T,WHC,CEC)	38.39	C4 (OM)	28.67	NS1 (Na,Cl)	19.91	F4	26.99
20	C4 (T,WHC)	35.85	C6(OM)	4.00	NS1 (ECw,SAR,Na,Cl)	13.76	F6	8.56
21	C4 (T,WHC,CEC)	21.28	C5 (OM)	11.50	NS1 (Na,Cl)	18.82	F5	16.04
22	C3 (T,WHC,CEC)	43.72	C5 (OM)	10.83	NS1 (Na,Cl)	19.17	F5	17.92
23	C2(WHC,ECe)	60.07	C4 (OM)	27.50	NS1 (Na,Cl)	19.81	F4	28.99
24	C5 (T,WHC,Ks,CEC)	16.98	C4 (OM)	28.67	S3 (Na,Cl)	42.57	F4	25.58
25	C3 (T,WHC,CEC)	48.6	C4 (OM)	39.67	S4 (Na,Cl)	29.67	F3	37.74
26	C4 (T,WHC,CEC)	36.11	C4 (OM)	28.67	NS1 (Na,Cl)	19.31	F4	26.23
27	C3 (T,WHC,CEC)	46.72	C1	100	NS1 (Na,Cl)	19.86	F3	36.69
28	C4 (T,WHC,K_s)	32.20	C4 (OM)	20.67	S4 (Na,Cl)	20.31	F4	23.32
29	C3 (T,WHC)	41.60	C5 (OM)	13.16	NS1 (Na,Cl)	19.48	F5	19.82
30	C4 (T,WHC,CEC)	26.53	C5 (OM)	13.83	S4 (SAR,Na,)	21.54	F5	19.18
31	C3 (WHC,CEC,ECe)	46.84	C4 (OM)	26.50	S4 (Na)	38.56	F4	35.29
32	C3 (T,WHC,CEC)	43.88	C6(OM)	2.33	NS1 (Na,Cl)	19.29	F6	5.95
33	C3 (T,WHC)	49.83	C4 (OM)	28.67	NS1 (Na,Cl)	19.18	F4	28.01
34	C4 (T,WHC,CEC)	31.01	C5 (OM)	14.33	NS1 (Na,Cl)	18.67	F5	19.28
35	C3 (T,WHC,CEC)	42.37	C4 (OM)	25.33	NS1 (Na,Cl)	19.18	F4	26.04
36	C3 (T,WHC,CEC)	50.89	C4 (OM)	31.67	S4 (Na,Cl)	20.04	F4	29.67
37	C3 (T,WHC,CEC)	43.41	C4 (OM)	33.33	NS1 (Na,Cl)	19.92	F4	29.06
38	C3 (T,WHC,Ks)	44.13	C1	98.17	NS1 (Na,Cl)	19.23	F4	35.36
39	C3 (T,WHC,CEC)	47.62	C4 (OM)	23.00	NS1 (Na,Cl)	19.01	F4	25.62
40	C4 (T,WHC,CEC)	38.67	C5 (OM)	12.66	NS1 (Na,Cl)	19.63	F5	19.26
41	C4 (T,WHC,CEC)	27.58	C5 (OM)	14.33	S4 (Na,Cl)	20.00	F5	19.23
42	C2(T,WHC)	61.26	C5 (OM)	13.83	NS1 (Na,Cl)	19.89	F4	21.60
43	C3 (T,WHC,CEC)	50.03	C5 (OM)	10.33	NS1 (Na,Cl)	18.87	F5	17.67
44	C3 (WHC,CEC)	52.31	C6(OM)	5.66	NS1 (Na,Cl)	19.27	F5	12.11
45	C3 (T,WHC,CEC)	46.45	C3 (OM)	49.33	NS1 (Na,Cl)	19.31	F4	32.06
46	C4 (WHC,EC_e)	34.48	C2	72.33	NS1 (Na,Cl)	19.88	F4	32.21
47	C3 (T,WHC,Ks)	48.37	C4 (OM)	34.5	NS1 (Na,Cl)	19.59	F4	29.79
48	C3 (T,WHC)	48.80	C4 (OM)	32.17	NS1 (Na,Cl)	19.71	F4	29.32
49	C3 (T,WHC,CEC)	41.56	C4 (OM)	20.67	NS1 (SAR,Na,Cl)	17.66	F4	23.24
50	C3 (T,WHC,CEC)	47.80	C3	54.33	NS1 (Na,Cl)	18.94	F4	32.56
51	C2(T,WHC,CEC)	66.26	C4 (OM)	39.00	S4 (Na,Cl)	31.48	F3	41.38
52	C3 (T,WHC)	52.95	C5 (OM)	15.50	NS1 (ECw,Na,Cl)	17.73	F4	21.46
53	C4 (T,WHC,CEC)	31.88	C5 (OM)	15.50	NS1 (Na,Cl)	19.26	F4	20.30
54	C4 (T,WHC,CEC)	36.68	C6(OM)	5.50	S4 (SAR,Na)	34.19	F5	12.59
55	C4 (T,WHC,CEC)	30.11	C6(OM)	8.00	S4 (ECw,Cl)	31.81	F5	15.82
56	C3 (T,WHC,CEC)	46.96	C5 (OM)	17.17	NS2(SAR,Na,Cl)	9.57	F5	16.30
57	C3 (T,WHC)	50.16	C4 (OM)	20.67	S4 (Na,Cl)	20.30	F4	25.52
58	C3 (T,WHC,CEC)	43.69	C3	56.83	S4 (Na,Cl)	20.05	F4	33.20
59	C3 (T,WHC,CEC,)	53.20	C3	56.33	NS1 (Na,Cl)	19.27	F4	33.92
60	C3 (T,WHC,)	54.68	C3 (OM)	42.50	S4 (ECw,Na,Cl)	28.11	F4	38.76

indicators because they may be too imprecise for detecting changes in soil quality following changes in soil quality following changes in land use or soil conservation.

The five soil quality factors identified in the Siwa oasis were close to the five soil factors identified in Mississippi valley loss hills, (Brejda et al., 2000b).

Soil Attributes Mapping

The maps of spatial distribution of some attributes were focused on the center of the oasis (Fig.2), where the data points are more intensive and well-distributed to have reliable mapping.

The map of soil salinity showed that the center of this area suffer from high salinity 8 - <16 dS m^{-1} and very high salinity >16 dS m^{-1}, while toward the east and west directions, soil tends to be non saline < 4 dSm^{-1}.

In spite of the high range of salinity in the mapped area, the spatial distribution of SAR showed that most of the area is less than 15. Only, small area in the north of the map has SAR more than 15.

The texture distribution illustrated that clay contents of soils ranged between 10-20%. This low range of clay contents affect the CEC, which ranged between 20 and 50 c mol kg^{-1}, while small area had higher values (>50 cmol kg^{-1})

Concerning the spatial distribution of WHC, the map showed that the areas with low contents of clay, have WHC in the range of 2.5-5 %. In contrary, increasing clay content in the middle and south of the map, did not match with increasing WHC. This may be due to the high infiltration rate of soil in this area.

The spatial distribution of OM showed that lower values 0 – 1.0 % located towards the north of the area, while in the middle to the south, great portion ranged between 1.5 and 3.0 %. Only a small portion had high OM in the range of 3.0 - 6.0 % that mainly due to the repeated application of different sources of OM.

In comparison among CEC, OM, and clay content maps, it was noticed that the area higher in clay content was higher in CEC. This means that the source of CEC is the clay minerals rather than the OM.

Land capability evaluation

Land capability classes and limiting parameters for SI, FI, WI, and FILE according to FAO (1979) and Ismail *et al.*, (2001) are presented in Table (4). The data showed that, for most studied sites, the capability of soil belonged to class C3 and C4, the SI ranged between 54.7 and 21.3%. The main limiting parameters are T, WHC, CEC, and K_s. However, three sites belonged to C2 and their indices ranged between 60.1 and 66.3%. The limiting parameters are WHC and EC. It means that most of the soils of Siwa oasis have low capability and might be used for agriculture with caution, as the ecosystem is so fragile.

Generally, the studied area has a problem related to low soil fertility. Therefore, poor nutrition status can be easily detected as indicated by limited FI which ranged between 20-50 % which reflect FI between 3 and 4 (fair & poor). The main limiting fertility parameter was soil OM. Two sites were excellent (C1 class) in fertility, and their FI ranged between 100 and 71.8%. This may be due to OM application. On the other hand, ten sites were belong to class C6 (non-agriculture) and the limiting parameter was also OM. Soil attributes may be obtained from soil data bases and are used with other land characteristics to derive the distribution of land capability (Sys *et al.*, 1993). Yehia, (2004) used ALES-Arid program and reported that land capability in Wadi El-Natrun classified as S_2 and S_3 and the main limitations are soil and erosions risk.

The water quality index indicated that most of the wells are potentially not suitable for irrigation (NS1), and the limiting parameters are Na, Cl and SAR. The same parameters also limited the capability use for the other wells, which belonged to S3 (marginally suitable) and S4 (conditionally suitable). It worth to mention that the wells in sites 5 and 10 were excellent, and their WI were 99.1 and 98.3 %, respectively. So, these wells considered highly suitable for irrigation purposes.

The distributions of final evaluation classes of the oasis were found: F3= fair (8.3%), F4=poor (55.0%), F5= very poor (26.7%) and F6= non agricultural (10.0%). The results confirmed the previous observations of low capabilities of Siwa oasis soils. These soils should be used with caution and suitable management.

Finally, we can conclude that the soil quality indicators observed by the factors analysis (texture, salinity, organic matter, fertility, and infiltration) are the same factors that limited the land capability evaluation in Siwa oasis.

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الملخص العربى

تحديد دلائل جوده الأرض وتقويم الأراضى الزراعية فى واحة سيوه

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التعرف على دلائل جودة الأرض هي من المواضيع الهامة التى تسترعى إنتباه الباحثين في الأونة الأخيرة ويمكن تطبيقها بشكل جيد فى واحة سيوة حيث أن لها وحده جغرافيه فريدة لاحتوائها على نوعيات مختلفة من مصادر الأرض والمياه. ولتحقيق ذلك فقد تم أخذ عينات من الأرض والمياه تغطى معظم منطقة الواحة ، وتم تحليل بعض الصفات الكيمائية والطبيعية ذات الارتباط بجودة الأرض ، وتم تحليل النتائج إحصائياً باستخدام برنامج factor analysis وذلك لتحديد دلائل جودة الأرض ، وكذلك تم حساب تقويم قدرة الأرض الإنتاجية باستخدام برنامج ALES-Arid .

وقد أظهرت النتائج أنه يوجد خمس عوامل محددة يمكن استخدامها فى منطقة واحة سيوة للتعرف على جوده الأرض وهى: القوام – الملوحة – المادة العضوية – إدارة التسميد – التسرب.

كما أوضح برنامج ALES-Arid أن الواحة بصفة عامة تعانى من مشاكل خاصة بانخفاض الخصوبة فيها وأن العوامل المحددة للإنتاج فيها هى المادة العضوية. وبالنسبة لتقويم جوده المياه فى المنطقة قد أظهرت التحاليل أن معظم الآبار مناسبة للاستخدام الزراعى ولكن مع وجود محظورات معينة وأن العوامل المحددة لجودة المياه هى تركيز الصوديوم الذائب، الكلوريد الذائب، ونسبة الصوديوم المدمص. والتقييم العام للواحة يوضح قدرة متدنية مما يستلزم معه استخدام إدارة مناسبة عند الاستزراع للحصول على الإنتاجية الجيدة.