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Soil Fertility Evaluation Using ASLE, Nutrient Index Models and GIS Techniques: A Case Study on Some Soils of Dakahlia Governorate, Egypt

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EVALUATION of soil fertility is an important factor for proper decisions making and strategies to achieve more sustainable agricultural systems. The main objective of this research was to evaluate the soil fertility status using ASLE program, GIS techniques and nutrient index in some soils of Dakahlia Governorate. For this purpose, 15 soil samples were randomly distributed within the studied area at a depth of 0-30 cm. Those were subjected to physiochemical analyses in order to evaluate soil fertility properties and nutrient index using Applied System for Land Evaluation (ASLE) software. Data outputs of the studied area were classified into two classes: (i) Good-C_2 and (ii) Fair-C_3 according to fertility index. Meanwhile, soil rating chart of fertility status was low based on the in their available P, medium in salt index and available K and high in organic carbon and available N according to nutrient index values. The obtained data of this study, therefore, provide insights regarding the potential modeling of soil characteristics data to make the proper decisions for soil fertility management.

Keywords: Soil fertility evaluation, Fertility index, ASLE, GIS, Nutrient index.

Introduction

Soil fertility term is defined by FAO as the ability of soil to sustain nutrients required by plants in adequate quantities and correct proportions (Jin at el., 2011). In other word, soil fertility is one of the components that control its productivity potentials, and the status of this fertility is strongly influenced by management practices (Johnson et al., 2000). Physicochemical properties of soil (*e.g.* pH, OM, and soil texture) are the most important factors, which reflect the fertility of soil and its productivity potentials (Mulder, 2000; NajafiGhiri et al., 2010 and Havlin et.al. 2010). Additionally, the availability of plant nutrients in soil and their status in soil are crucial to justify the fertility of soil (Havlin et al., 2010). Last but least, the fertility of soil has a strong relation with the complicated reactions among organic substances, water and nutrient ions and is largely controlled by the nature and quality of mineral ores (Sushanth et al., 2019). On the other hand, soil fertility controls farmers' options for agricultural production procedures and Agricultural practices (*e.g.* fertilizers application, organic matter management and other conservation systems). Therefore, soil analysis is helpful for better understanding of soil fertility status to increase the crop production and obtaining sustainable yield.

The important role of soil fertility and nutrient management in modern agriculture appears to be an essential step in the management of appropriate fertilizers at specific crop production sites (Bagherzadeh et al., 2018). Soil fertility evaluation is the most important decision-making tool for management of soil nutrients sustainably (Khadka et al., 2017). Fertility management based on soil testing, therefore, is an effective tool for increasing the agricultural soils production that have a high degree of spatial variation resulting from the combined effects of physiochemical processes (Goovaerts, 1998). Consequently, it is very important to study of soil fertility and determine situation of soil characteristics for cultivation of different crops.

The soil fertility index (SFI) of the study area classified to moderate, low and very low (Bagherzadeh, 2018). Several methods were

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used in the field for determination of soil fertility (Bijanzadeh and Mokarram, 2017). ASLE (The Applied System of Land Evaluation) is a computer-based program for arid and semi-arid regions is a useful tool for evaluating soil fertility, land capability and suitability (Ismail & Morsi, 2001 and Ismail et al., 2001). ASLE program compares the characteristics and interactivity of the land units to evaluate soil fertility classes (C1, C2, C3, C4, C5 and C6) (Sayed et al., 2016). A nutrient index is a percent of distribution estimate of soil samples through three categories: low, medium and high classes of nutrient status (Willy et al. 2019). Soil fertility status could be also evaluated using nutrient index (available P, available K and OC) and the soil reaction index. Based on rating chart using the soil reaction index, and nutrient index for organic carbon, available phosphorus and available potassium, soil fertility was evaluated where most of soils are classified as medium (II) to high (III) based on organic carbon. Meanwhile, it were classified as low (I) according to available phosphorus and potassium (Abah and Petja 2015a). There are wide variations in soil fertility status of soils developed on various landforms. NI of available nitrogen, phosphorus and potassium was respectively low, low to high and medium to high (Verma et al., 2005).

The objective of this study, therefore, is to evaluate soil fertility status of the study area using ASLE program, GIS techniques and nutrient index models.

Materails And Methods

Soil sampling and analysis

Fifteen soil samples (depth 0-30 cm) were selected from studied area, which is located between 31° 19´ to 31° 41´ E 30° 48´ to 30° 59´ N in Dakahlia Governorate (Temai Elamded District (126 km^2) and Al-Sembelawaan District (304 km^2) (Fig. 1). Coordinates of samples locations were recorded using the Global Positioning System (GPS). Meteorological data (relative humidity (%), wind speed (kmh^{-1}), temperature (°c) and rainfall (mm)) are represented in Table 1. These samples were air-dried, crushed and sieved through a 2-mm screen and the fine earth (less than 2-mm diameter) was used for physical and chemical analyses as illustrated in Table 2.

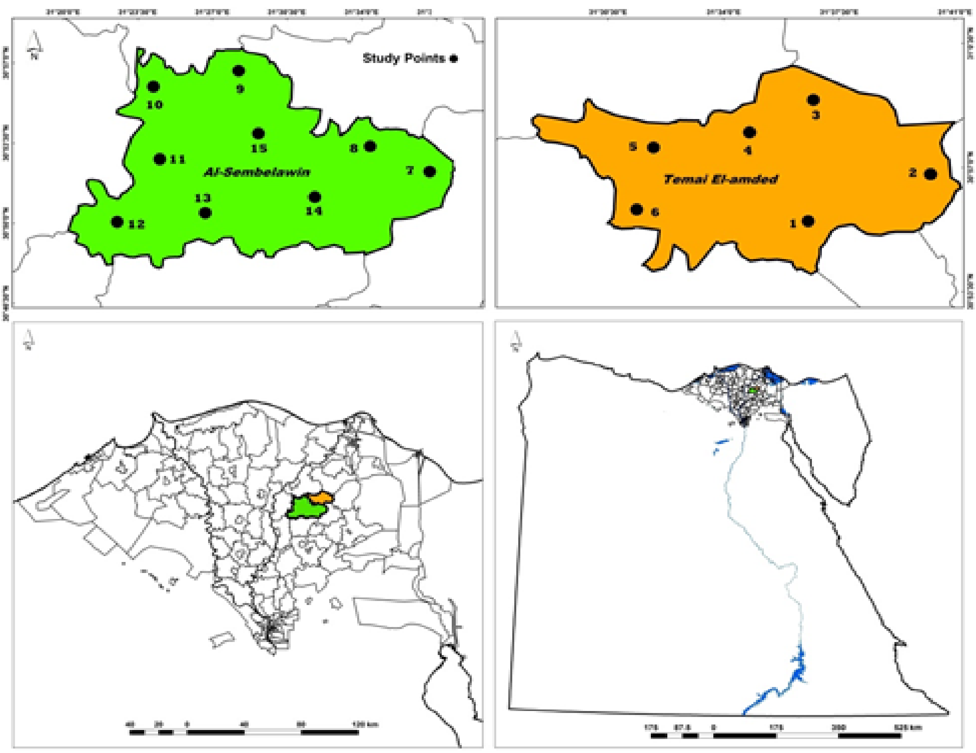

Fig. 1. Location map of the study area and spatial distribution of soil samples

TABLE 1. Average of Climate elements data for the study area

Climate elements	Winter	Summer
Relative Humidity (%)	61	57
Wind Speed (kmh^{-1})	11.4	12
Temperature (°c)		
Maximum	29	36
Minimum	9	19
Rainfall (mm)	4.7	0

Source:https://www.worldweatheronline.com/mansoura-weather-averages/ad-daqahliyah/eg.aspx (2018)

TABLE 2. Parameters and methods adopted for the laboratory analysis

S.N.	Parameters	Methods
1	Physical	
1.1	Mechanical analysis	pipette method (Piper, 1947)
1.2	Bulk density	(Dewis and Freitas, 1970).
1.3	Organic carbon (OC)	Walkley and Black (Hesse, 1971).
1.4	Total soil porosity	Porosity = (1 - Db/ Dr)*100 Where, Db is soil bulk density (g cm-3) and Dr is soil real density (2.65 g cm^{-3}).
1.5	Saturation percentage (SP)	(Richards, 1954).
2	Chemical	
2.1	Soil pH	soil paste (Jackson, 1967).
2.2	Electrical conductivity (EC)	soil paste extract (Hesse, 1971).
2.3	Cation exchange capacity (CEC)	sodium and ammonium acetate (Hesse, 1971)
2.4	Exchangeable cations	1M ammonium acetate of pH 7.0 (Hesse, 1971)
2.5	Available nitrogen	Kjeldahl (Hesse,1971)
2.6	Available phosphorus	(Olsen and Sommers,1982).
2.7	Available potassium	flame photometer (Hesse, 1971).
2.8	Total nitrogen (TN)	TN = 0.026 + 0.067*OC (Rashidi and Seilsepour, 2009).

Soil fertility evaluation

Evaluation of soil fertility was carried out using Applied System for Land Evaluation (ASLE) software, which developed by (Ismail and Morsi, 2001) to calculate the fertility index value. It works as an extension under ArcGIS software package. Several soil physical, chemical are integrated in this model. The outputs are also displays in simple and handy maps that represent the spatial variability in soil fertility for the studied area. Soil fertility classes could be obtained by the program outputs according to Storie (1933 and 1944), as illustrated Table 3.

Soil nutrient index

In order to analyze the soil fertility status, different indices like soil reaction index of pH, and nutrient index with respect to organic carbon, available NPK and EC were calculated based on the specific rating chart in Table 4. The rating charts were used to rate the soil analysis results and nutrient index, respectively. This procedure was used elsewhere in Ravikumar and Somashekar (2013) and Hamissa et al. (1993). Interpretation was done as value given in Table 5. Using the soils rating chart, the nutrient index for soil samples was calculated using equation 1 (Ramamurthy and Bajaj, 1969):

Nutrient Index (NI) = (NL×1 + NM×2 + NH×3) / NT …… Equation 1

where,

NL is number of samples rated low. NM is number of samples rated medium.

NH is number of samples rated high. NT is total number of samples.

TABLE 3. Fertility classes according to (Storie, 1933 and 1944)

Fertility Class	Fertility Index %	Description
C1	> 80	Excellent
C2	< 80 - > 60	Good
C3	< 60 - > 40	Fair
C4	< 40 - > 20	Poor
C5	< 20 - >10	Very poor
C6	< 10	Non agriculture

TABLE 4. Rating chart for analyzed soil nutrient values

Parameter	Category ratings		
Soil pH *	Acidity	Neutral	Alkaline
Range	Below 6	6-8	Above 8
Soil reaction index	I	II	III
EC *	Normal	Critical	Injurious
Range dSm^{-1}	< 1	1-2	> 2
Salt index	I	II	III
Organic Carbon *	Low	Medium	High
Range (%)	< 0.5	0.5-0.75	> 0.75
Nutrient index	I	II	III
Available Nitrogen (N)**	Low	Medium	High
Range ($mgkg^{-1}$)	< 40	40-80	> 80
Nutrient index	I	II	III
Available Phosphorus (P)**	Low	Medium	High
Range ($mgkg^{-1}$)	< 10	10-15	> 15
Nutrient index	I	II	III
Available Potassium (K) **	Low	Medium	High
Range ($mgkg^{-1}$)	< 200	200-400	> 400
Nutrient index	I	II	III

* Ravikumar and Somashekar (2013) & ** (Hamissa et al. 1993).

TABLE 5. Rating Chart of Nutrient index

Nutrient index	Categories	Value
I	Low (L)	< 1.67
II	Medium (M)	1.67 - 2.33
III	High (M)	> 2.33

Ramamurthy and Bajaj (1969) & Ravikumar and Somashekar (2013)

Rersults And Discussion

Soil physical properties in the studied area

Data in Table 6 show the ranges, average values, standard deviations (STDEV) and Coefficient of Variation (C.V) of some soil physical properties of the studied area. Clay percentage varied from 18.9 to 55.18 % (about 35.4 % in average). Soil textures in the studied area varied from Clay to Sandy loam. Saturation percentage (SP) varied from 54 to 72 % with an average value of 66.90 %.SP values were associated with clay content in the studied soils. Bulk Density (BD) ranged between 0.97and 1.51g cm^{-3} with an average of 1.14g cm^{-3} soil. Porosity varied from 43.02 and 63.40% with an average of 57.10 %.

Soil chemical properties in the studied area

Descriptive statistics for the ranges, averages, (STDEV) and (C.V) of some soil chemical properties of the studied area are given in Table 7. Soil pH ranged from 8.39 to 8.7 (about 8.59 in averages). Electrical conductivity (EC) varied from 0.85 to 2.97 dSm^{-1} (about 1.64 dSm^{-1} in average). These data indicate that the studied soils are ranging from non-saline (0.81 -1.20 dSm^{-1}) to slightly saline (1.61 -3.20 dSm^{-1}) according to Dahnke and Whitney, (1988). Salinization is one of the main factors contributing to soil degradation and soil productivity performance (Prapagar et al. 2015). The average exchangeable Ca^{2+} was 27.6 $cmolkg^{-1}$, which varied from 21.89 to 38.44 $cmolkg^{-1}$. Exchangeable Mg^{2+} varied from 14.69 and 27.55 $cmolkg^{-1}$ (about 21.5 $cmolkg^{-1}$ in average). Exchangeable K^{+} varied from 0.7 and 1.7 $cmolkg^{-1}$ (about 1.06 $cmolkg^{-1}$ in average). Exchangeable Na^{+} varied from 1.25 and 4.41 $cmolkg^{-1}$ (about 2.11 $cmolkg^{-1}$ in average). The CEC values ranged between 47.92 and 56.7 $cmolkg^{-1}$ (average about 51.6 $cmolkg^{-1}$). In this regard, it is well known that total exchangeable cations and CEC are two significant concepts in soil fertility and long-term productivity (Hodges, 2010). On the other hand, the ESP values varied from 2.52 and 8.34 % (about 4.04 % in average), which indicates that most of the studied soils were non sodic. Organic matter was low in the studied soils and ranged between 0.75 and 1.66 % with an average of 1.3 %. The low level of organic matter content in the study area is mainly associated with the broad diversity of soil texture and its clay content. There are several reports suggested that organic matter content ranged from <1% (very low) to (low) in soils with low clay content and progressively increased in line with increase of soil clay contents (Plante et al., 2006 and Hartati & Sudarmadji, 2016,). Soil organic matter is the main constitute of fertility index. It is the main pool for nitrogen and carbon supplementation. Additionally, it has a crucial effect on soil bulk density and other physical properties related to water movement and aeration dynamics. The variation of soil organic matter is mainly related to the environmental conditions (*e.g.* precipitation or drought). This variation in soil organic matter will reflect on the bulk density of soil and its related indices (e.g. porosity, hydraulic conductivity and air transfer (Golabi, et al. 2004; Thomas et al. 2006 and GÖL, 2017).

Data in Table 8 illustrate average of some chemical characteristics of the irrigation water. As shown in the Table, the analysis reveals that the irrigation water is medium saline (0.55 dSm^{-1}) where the EC is less than 0.75 dSm^{-1} (United State Salinity Laboratory Staff, 1969). The pH of the irrigation water was 7.74. The irrigation water used was non sodic where the SAR values were 3.00 (United State Salinity Laboratory Staff, 1969). Sodium percentage was low where the Na% was less than 60 % (United State Salinity Laboratory Staff, 1969).

TABLE 6. Ranges of soil physical properties in the studied soil area

Physical Properties	Unit	Min.	Max.	Average	STDEV[1]	C.V[2]
Clay	%	18.9	55.18	35.4	11.1	31.4
Soil Texture	Clay to sandy loam			Clay loam	---	---
Saturation percentage	%	54	72	66.90	6.08	9.07
Bulk Density	gcm^{-3}	0.97	1.51	1.14	0.15	13.301
Porosity	%	43.02	63.40	57.10	5.71	9.99

[1]Standard Deviation , [2]Coefficient of Variation

TABLE 7. Ranges of soil chemical properties in the studied soil area

Chemical Properties		Unit	Min.	Max.	Average	STDEV	C.V
pH			8.39	8.7	8.59	0.09	1.08
EC		dSm^{-1}	0.85	2.97	1.64	0.61	37
Exchangeable Cations	Ca	$cmol\ kg^{-1}$	21.89	38.44	27.6	4.11	14.9
	Mg		14.69	27.55	21.5	3.81	17.7
	K		0.7	1.7	1.06	0.28	26.8
	Na		1.25	4.41	2.11	0.95	45.2
CEC		$cmol\ kg^{-1}$	47.92	56.7	51.6	2.54	4.92
ESP		%	2.52	8.34	4.04	1.72	42.5
Soil Index		%	63.76	85.74	77.68	6.35	8.17
Organic Matter		%	0.75	1.66	1.3	0.23	17.8
Soil Class			C2	C1	- -	- -	- -

C1 Excellent C2 Good

TABLE 8. Average of some chemical properties of the irrigation water

EC dSm^{-1}	pH	Soluble ions ($meqL^{-1}$)								SAR	Na %	RSC $meqL^{-1}$
		Anions				Cations						
		$SO4^{2-}$	Cl^-	HCO_3^-	CO_3^{2-}	K^+	Na^+	Mg^{2+}	Ca^{2+}			
0.55	7.74	1.70	2.80	1.25	N.D.	0.70	3.00	0.83	1.22	2.97	59.41	- 0.8

*The obtained data is an average of four representative water samples.

Soil fertility properties

Data in Table 9 show the ranges, averages, (STDEV) and (C.V) of available NPK, total nitrogen (TN), organic carbon (OC), C/N ratio and fertility index of the studied area. Available nitrogen values were ranged between 78.05 and 199.5 mg kg^{-1} (average about 140 mg kg^{-1}). Available phosphorus ranged between 2.46 and 10.5 mg kg^{-1} (average about 6.55 mg kg^{-1}). Available potassium varied from 186 and 466 mg kg^{-1} (average about 291 mg kg^{-1}). Soil fertility evaluation of phosphorus and potassium indicate that P content was low in some locations and medium in others, while K content is low in some locations and high in others. This also indicates that some soils in the studied area are in need to fertilization with phosphorus and potassium additions (Hamissa et al., 1993). Total (N) ranged between 0.21 and 0.4 %, (about 0.32 % in average), which indicates a very low content. Organic carbon (OC) varied from 0.44 and 0.96 % (average about 0.75 %). The C/N ratio varied from 1.67 and 3.09 (average about 2.39 %), which indicates that nitrogen mineralization is the dominant process in the studied soils.

Data in Table 10 show the ranges, averages, (STDEV) and (C.V) of fertility index and fertility class of the studied area. The fertility index (FI) varied from 48.02 and 64.4 (average about 56.51). Fertility index was fit into 2 classes, which are Good-C2 and Fair-C3 as illustrated in Figures 2 (Thomas et al. 2006). The water index varied from 95.32 and 100 (average about 98.59) and the environmental index varied from 64.86 and 82.58 (average about 75.51) as shown in Figures 2. Fig. 3 illustrates some of the linear relationships between some soil properties and Fertility index % in the studied Soils. It is observed that there are linear relationships among OM, sum of available NPK, C/N ratio, sum (Ca, Mg, K), CEC and soil index with fertility index-FI were significant correlations (r = 0.63, 0.58, 0.36, 0.69, 0.69 and 0.67, respectively)**.**

Nutrient Index (NI)

Data in Table 11 show the nutrient index and categories of some soil parameters of the studied area. Based on the criteria given in Table 5, categories of soil fertility status in the study area were classified into three categories according to nutrient index values, which are high (H), medium (M) and low (L). The nutrient index (NI) varied from parameter to other; this indicates the different soil fertility status from parameter to other. The soil fertility status was low in their available P (1.07). Meanwhile, it was medium at salt index (2.07) and available K (2.07). However, soil reaction index (3.00), organic carbon (2.53) and available N (2.93) were high as shown in Fig. 4.

TABLE 9. Ranges of available NPK, total nitrogen (TN) and C/N ratio in the studied soil area

Soil fertility indices		Unit	Min.	Max.	Average	STDEV	C.V
	N		78.05	199.5	140	36.3	25.9
Available NPK	P	(mg kg^{-1} soil)	2.46	10.5	6.55	2.13	32.6
	K		186	466	291	88	30.3
TN		%	0.21	0.4	0.32	0.06	17.4
OC		%	0.44	0.96	0.75	0.13	17.8
C/N Ratio			1.67	3.09	2.39	0.37	15.5

TABLE 10. Ranges of Soil fertility index in the studied area

Profile No.	Fertility Index	Fertility Class	Water Index	Water Class	Environ. Index	Environ. Class
1	49.24	C3	100	C1	75.48	C2
2	55.89	C3	95.32	C1	76.85	C2
3	61.13	C2	98.02	C1	75.48	C2
4	55.45	C3	98.31	C1	74.67	C2
5	57.45	C3	95.72	C1	76.25	C2
6	58.65	C3	100	C1	75.48	C2
7	52.32	C3	100	C1	75.48	C2
8	59.5	C3	100	C1	64.86	C2
9	64.4	C2	99.16	C1	75.48	C2
10	52.96	C2	97.94	C1	75.48	C2
11	60.26	C2	98.18	C1	75.48	C2
12	48.02	C3	100	C1	75.48	C2
13	58.94	C3	96.15	C1	71.67	C2
14	53.16	C3	100	C1	81.93	C1
15	60.24	C2	100	C1	82.58	C1
Min.	48.02	C3	95.32	- -	64.86	- -
Max.	64.4	C2	100	- -	82.58	- -
Average	56.51	- -	98.59	- -	75.51	- -
STDEV	4.63	- -	1.69	- -	3.99	- -
C.V	8.19	- -	1.72	- -	5.28	- -

C1 = Excellent , C2 = Good, C3 = Fair

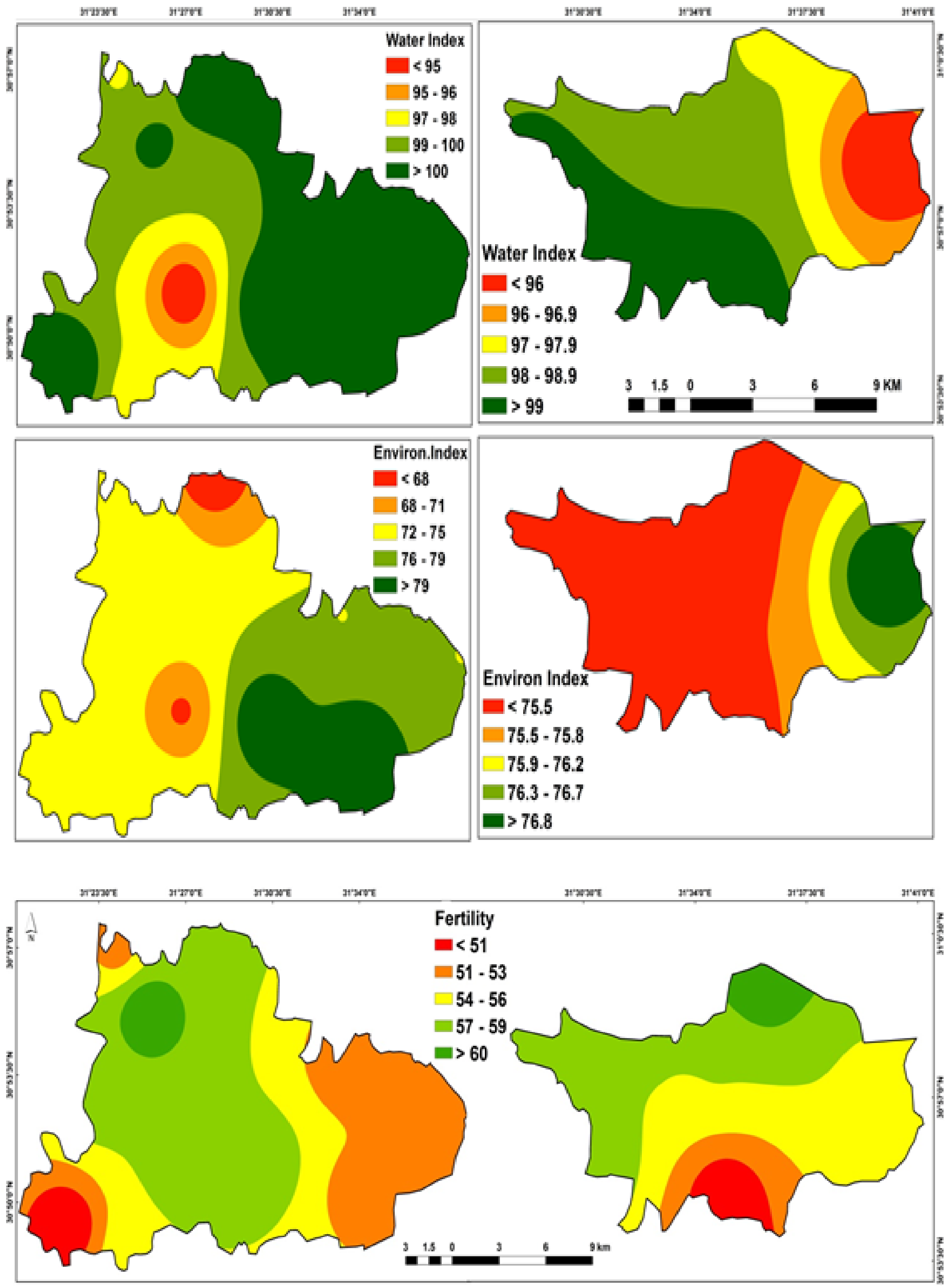

Fig. 2. Water index, environmental index and soil fertility index in the studied area

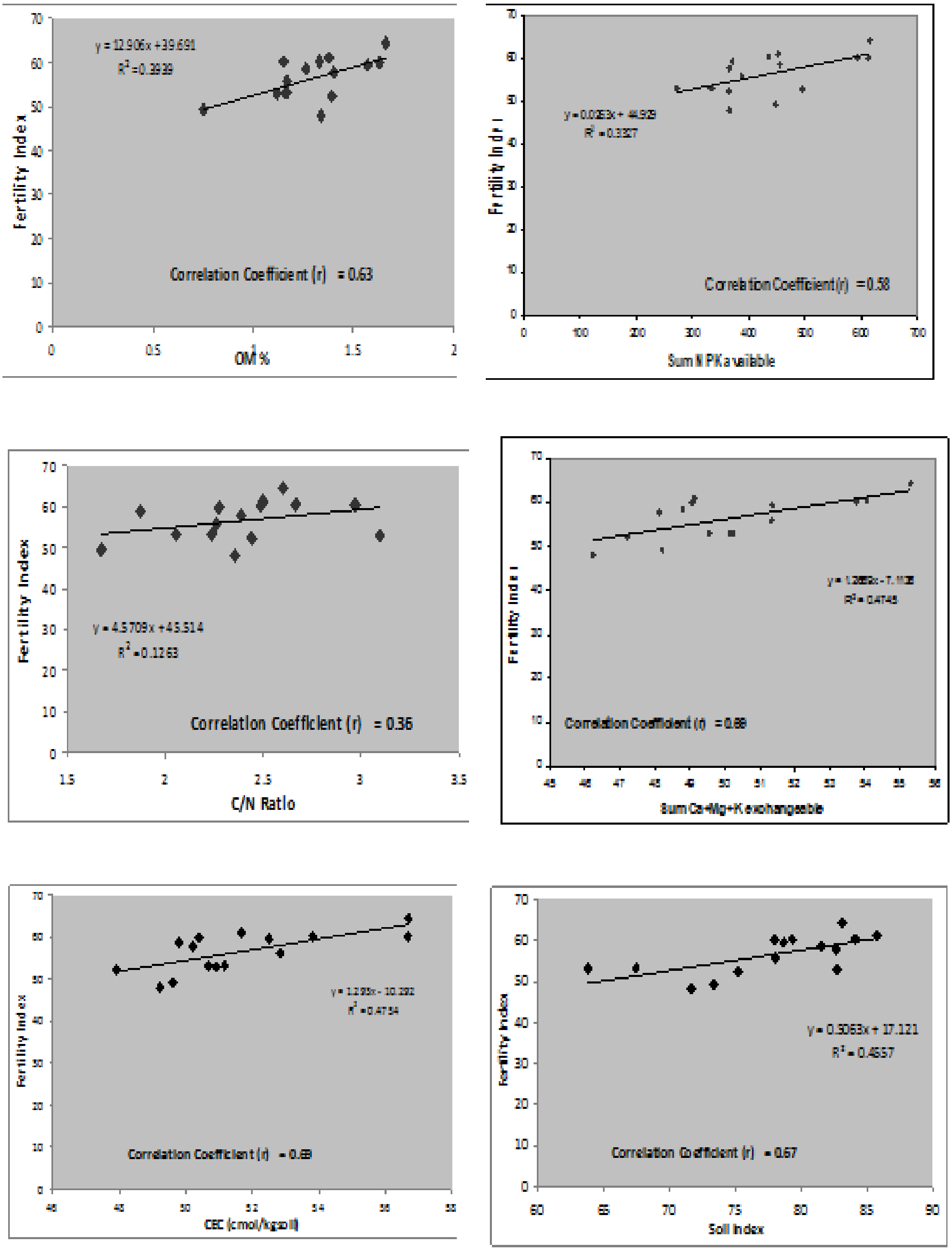

Fig. 3. Linear relationships between some soil properties and FI % in the studied Soils

TABLE 11. Nutrient index of some soil parameters in the studied area

Number of Soil Parameters	Low	Medium	High	Total samples	Nutrient index values	Categories	Nutrient Index
pH	0	0	15	15	3.00	H	III
% distribution of samples	0	0	100	100%			
EC	3	8	4	15	2.07	M	II
% distribution of samples	20	53.33	26.66	100%			
OC	1	5	9	15	2.53	H	III
% distribution of samples	6.66	33.33	60	100%			
Available N	0	1	14	15	2.93	H	III
% distribution of samples	0	6.66	93.33	100%			
Available P	14	1	0	15	1.07	L	I
% distribution of samples	93.33	6.66	0	100%			
Available K	3	8	4	15	2.07	M	II
% distribution of samples	20	53.33	26.66	100%			

H = High, M= Medium, L= Low

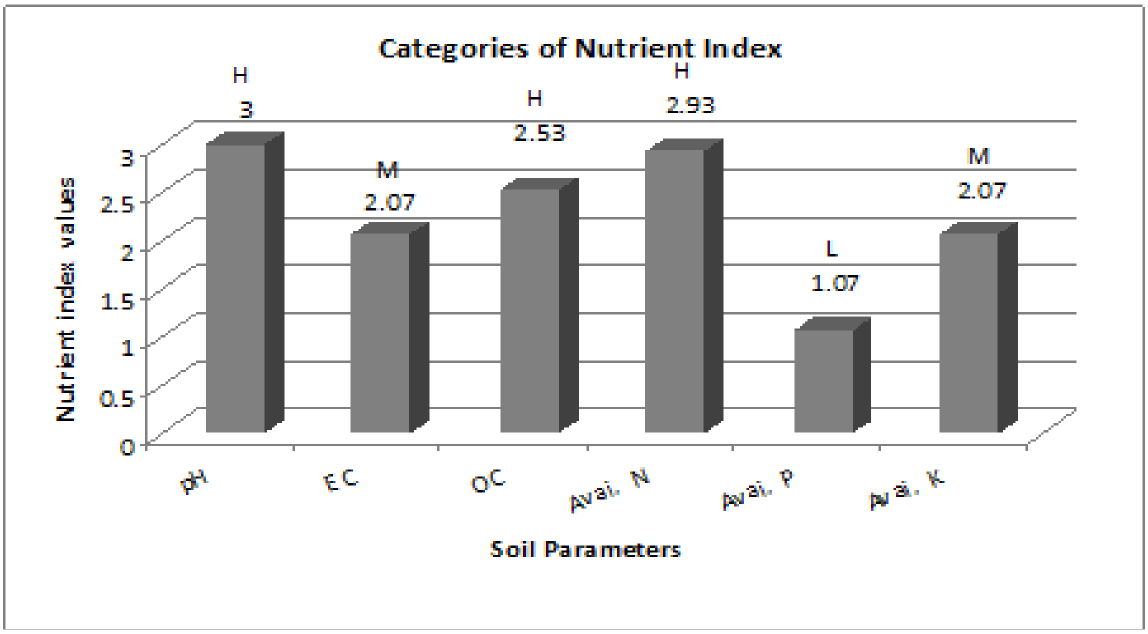

Fig. 4. Nutrient index Categories of soil parameters in the studied area

Conclusions

Routine work for soil fertility evaluation by using ASLE and nutrient index can support decision makes to develop fertility management programs, and helps in improving agricultural practices to increase soil agricultural productivity. Soils in the studied area varied from Good to Fair according to fertility index by ASLE. While Nutrient index of soil parameters varied from low to medium and high. Further investigations should be undertaken in the studied are taking into account other soil properties to develop a coherent approach for soil fertility management to maximize its productive capability potentials and suitability for crops.

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تقييم خصوبة التربة باستخدام نموزجي ASLE و مؤشر العناصر الغذائية وتقنيات نظم المعلومات الجغرافية: دراسة حالة لبعض اراضي محافظة الدقهلية، مصر

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تقييم خصوبة التربة مهم لاتخاذ القرارات والاستراتيجيات الأساسية لتحقيق نظم زراعية أكثر استدامة. الهدف الرئيسي من هذا البحث هو تقييم حالة خصوبة التربة باستخدام برنامج ASLE و GIS ومؤشر المغذيات لبعض أراضي محافظة الدقهلية. وفقًا لذلك . تم اختيار ١٥ عينة من التربة بشكل عشوائي داخل منطقة الدراسة على عمق ٠-٣٠ سم . وتم تحليل بعض خصائصها الفيزيائية والكيميائية وخصوبة التربة ومؤشر العناصر الغذائية. تم إجراء تقييم لخصوبة التربة وحساب مؤشر الخصوبة باستخدام برنامج تقييم الأراضي (ASLE). تم تصنيف بيانات المنطقة التي تم دراستها إلى فئتين جيدة C2 وFair-C3 معتدلة وفقًا لمؤشر الخصوبة بواسطة ASLE . في حين كانت حالة خصوبة التربة استنادًا إلى مخطط تصنيف التربة منخفضة في الفوسفور الميسر. ومتوسط لمؤشر الملوحة والبوتاسيوم الميسر. وكان الكربون العضوي والنيتروجين الميسرمرتفعًا وفقًا لقيم مؤشر العناصر الغذائية. وبالتالي . فإن البيانات التي تم الحصول عليها من هذه الدراسة . توفر نظرة ثاقبة بشأن النمذجة المحتملة لبيانات خصائص التربة لاتخاذ القرارات المناسبة لإدارة خصوبة التربة.