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Geostatistical Approach for Land Suitability Assessment of Some Desert Soils

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DUE TO the rapid growth of population in Egypt and the scarcity of land and water resources, the effective management of these resourceshas become a very urgent necessity to achieve the sustainable agricultural development. Consequently, land suitability assessment is an important tool to manage these resources appropriately. The objective of this study was to use geostatistical approach and geographical information system (GIS) to evaluate the land suitability for some essential cropsin Toshka region, Egypt.Soil parameters such as gravel content, soil texture, pH, EC, $CaCO_3$, ESP and CEC were determined, at 1.0 km grid soil sites. Afterward, the geostatistics approach using ordinary kriging interpolation and semivariogram were applied to produce a spatialized and detailed map for each soil parameter. Gaussian, Exponential and Spherical geostatistical models were used to define the spatial variability of soil properties based on RMS, MSE and RMSSE. Also, based on Storie equation the kriged interpolated maps were incorporated in the model builder within GIS environment to achieve the land suitability assessment. The results illustrated that, most of the investigated area are unsuitable (N) for vegetable crops. However, the study area is more promising for field crops where 42.71 % and 11.20 % of the total area are moderately suitable (S2) for barely and alfalfa crops respectively. Furthermore, the results confirmed that, some of orchids crops are very suitable for the study area whereas 6.80 % and 37.81 % of the studied area are highly suitable (S1) and moderately suitable (S2) for olives respectively. On the other hand, the results revealed that the results indicated that, the most limiting factor in the investigated area are EC, pH, calcium carbonate content, CEC and soil texture. Finally, it can be concluded that the geostatistical approach and GIS are powerful and effective tools for land suitability studies and consequently for sustainable planning of land use.

Key words: Geostatistics, GIS, Land Suitability, Storie, Toshka

Introduction

Land is a basic natural resource input to the most production activities of human and also for many alternative and competing uses. As a result,land is becoming so scare in many areas of the world especially in the developing countries (FAO, 2011). Due to the rapid growth of population, Egypt suffers from a very massive population crisis. Given to the limited and scarcity of land and water resources, this crisis has created a very great pressure on these resources. Consequently, the effective and professional management of land and water resources in Egypt is indispensable to insure food needs and sustainable agricultural development (Abdel-Hamid et al., 2010). Therefore, land suitability assessment is the most important tool that can manage these resources appropriately. Land suitability evaluation is an essential prerequisite process for sustainable agricultural management (Dedeoğlu et al., 2018). It includesthe evaluation of soil, terrain, the socio-economic, market, climate conditions and infrastructures criteria.Actually, land suitability assessment is an examination procedure or

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description technique of the degree of land suitability for a particular utilization type or evaluation of the potential land productivity (Sys & Debaveye, 1991 and Rossiter, 1996). Land suitability evaluation is a matching of land attributes with the crop requirements to measure the land quality for a particular land use (FAO, 1976, 1983; Mustafa et al., 2011 and Das & Sudhakar, 2014). Several techniques have been designed and developed for land suitability and capability evaluation (Storie, 1973 and FAO, 1976). Many researches have been implemented the aforementioned methods in many countries such as China (Xingwu et al., 2015), Egypt (Sawy et al., 2013; Rashed, 2016; Abd - Elrahman et al., 2017; Elnaggar, 2017; Aldabaa et al., 2018; Yousif. 2018; Yousif, 2019 and Yousif & Ahmed, 2019) and Turkey (Dengiz, 2013), but it is still discussed and debated that these techniques of which give the best outcomes (Li et al., 2013 and Yousif et al., 2020). Geographic information system (GIS) is a system that incorporates geographical data with attributes data to map, analyze, and solve real-world problems using spatial and statistical methods (Burrough and McDonnell, 1998). Geostatistical technique can provide more useful, dependable and efficient tools to predict soil properties in unsampled and unknown locations and to describe spatial relationship of data using variogram analyses (Webster and Oliver, 2007). The kriging is the most strong and effective interpolation method used in geostatistical applications (Chiles and Delfiner, 1999; Davis, 2002 and Mevlut, 2016). However, there are many researchers have been used GIS and geostatistics techniques as decision tool in several agricultural applications such as evaluation of croplands (Da Silva et al., 2015), delineation of agricultural fields (Chang et al., 2014), soil quality assessment (Wang and Shao, 2013), soil spatial variability assessment (Yousif, 2017) and land suitability evaluation (Emadi et al., 2010). Even though geostatistics technique has not been much used afor land suitability evaluation, but this approach was recommended by some studies for suitability classifications and sustainable land use management in semiarid environments (Emadi et al., 2010 and Denton et al., 2017). The investigated area, which lies southwest of Egypt is considered as one of the most promising areas for horizontal expansion and agricultural development. Therefore, soils of Toshka were studied by different land evaluation systems such as Storie index, ASLE program, MicroLEIS (Abd El-Aziz, 2018 and Salah, 2018)). These studies were showed that most common limitation factors for crop production in Toshka area are the shallow soil depth, highcontent of gravel, soil texture, low soil fertility and soil pH (Abbas et al., 2010; Fayed et al., 2010; Sherif, 2016; Aldabaa et al., 2018; Salah, 2018 and Mohamed et al., 2019). However, the conventional assessment of land suitability is based on evaluating the sampled sites without taking in consideration the unsampled ones. On the other hand, using geostatistical interpolation method improves this assessment by creating continuous data of each soil properties at sampled and unsampled sites. For this reason, the main objective of this study is to evaluate the land suitability of some areas of Toshka region, Egypt for some essential crops using geostatistical approach and GIS. Defiantly, this research helps to build databases for the investigated soils, which significantly helps the decision makers and contributes to better investment process.

Materials and Methods

Study Area

The investigated area is located southwest of Aswan city, near to Toshka lake, Egypt. It locates between 31° 37' 03" to 32° 00' 16" E and 22° 54' 05" to 23° 14' 28" N, covering an area of about 617.21 km^2 (146953.73 Fadden) as illustrated in Fig. 1. The climate of the investigated area is characterized by hyperarid conditions (desertic) over the year, while there is no rainfall in Toshka. The mean annual temperature varied from 9.2 to 25.3 °C and between 42.3 and 44.1 °C in the winter and the summer respectively. The relative humidity fluctuated between 14 and 38 %. The mean annual wind speed ranged from 2.3 to 3.1 $msec^{-1}$. According to the atlas of desertification, the aridity index of Toshka is lower than 0.05 which indicates that the hyperarid climate is common, (Middleton and Thomas, 1992). The geological structure of the studied area is characterized by quaternary deposits (sand sheets), sabaya formation (sandstone, ferrous sandstone with conglomerate), kiseiba formation (shale and sandstone of upper cretaceous) and some basement rocks like highly weathered gneiss and magmatic rocks (Moneim et al., 2014). Three datasets n22_e031_1arc_v3, n23_e031_1arc_v3 and n23_e032_1arc_v3 of SRTM (Shuttle Radar Topographic Mission) were downloaded to extract the digital elevation model (DEM) of the studied area with 30 m spatial resolution (USGS, 2019). The common slope gradient of the investigated area is fluctuating between level (0.2 - 1 %) and very gently sloping (1.0-2.0 %) as shown in Fig. 2.

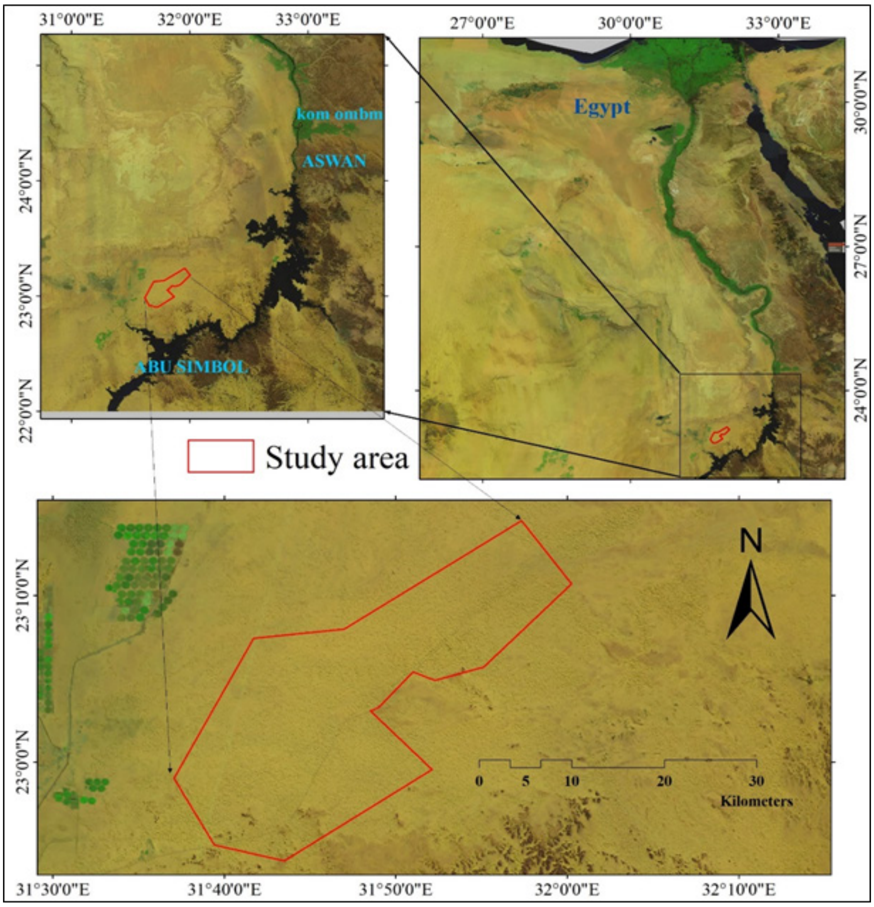

Fig. 1. Location of the study area

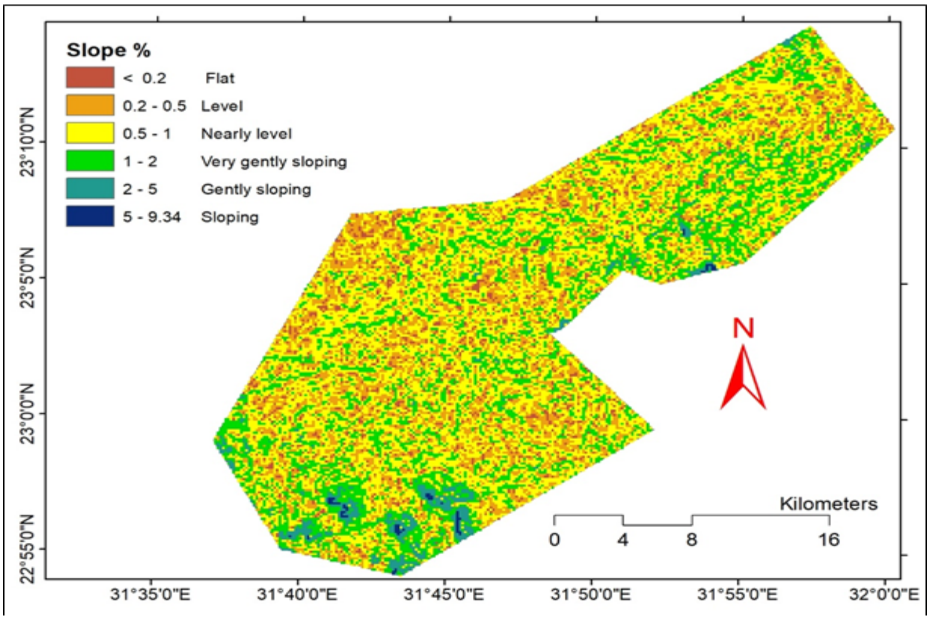

Fig. 2. Slope map of the studied area

Soil Sampling and Laboratory work

Through a huge project carried out by DRC (2014),a grid system of 1.0 km intervals and consequently 594 soil profiles were dig at the intersection sites as illustrated in Fig. 3 and soil samples were collected and prepared for laboratory analysis. Soil chemical and physical analysis (gravel content, particle size distribution, Soil pH, electrical conductivity (EC), calcium carbonate, exchangeable sodium percent and cation exchangeable capacity) were determined according to USDA (2014).

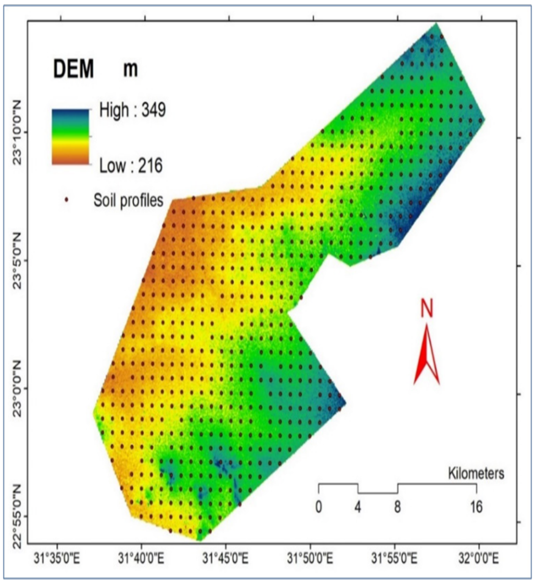

Fig. 3. Digital elevation model and grid system of soil profiles

Statistical and Geostatistical analyses

Classical statistical analysis was implemented using SPSS 26 software (SPSS, 2019) to investigate the distribution of each soil parameter. This analysis is a preconditional step before geostatistical analyses. Some statistical parameters were calculated such as Range, average, min, max, standard deviation (SD), variance, coefficient of variation (CV), Skewness and Kurtosis for all measured soil parameters.

Geostatistical approach was utilized to examine the variability of the soil parameters. The geostatistics approach comprises of calculation the experimental semivariogram and the prediction at un-sampled locations. Measuring the spatial correlation using semivariogram is the most advantage of geostatistics (Webster and Oliver, 2007). The semivariogram of each soil parameter was achieved using the average squared differences among all pairs of values according to this equation (Webster and Oliver, 2007):

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

where: γ(h) is the semivariance for the interval distance class h,

N(h) is the number of pairs of the lag interval,

Z(xi) is the measured sample value at point i, and

Z(xi + h) is the measured sample value at position (i + h).

The Kriging estimatorwas used to interpolate the spatial data of soil properties. Ordinary kriging is the most commonly method used in geostatistical approach. The general equation of the kriging estimator method is as follows (Webster and Oliver, 2007):

$$Z^*(x_o) = \sum_{(i=1)}^{N} \lambda_i Z(X_i)$$

where, $Z^*(X_O)$ is, estimated variable at X_O location,

$Z^*(X_i)$ is values of inspected variable at Xi location,

λi is the statistical weight that is offered to Z (Xi) sample located near XO, and

N is the number of observations in the neighborhood of inspected point.

There are many models in geostatistical analysis but spherical, exponential, and Gaussian are the most commonly used (Webster and Oliver, 2007). The validation and suitability of each model was tested via some parameters like root mean square error (RMS), mean standardized error (MSE) and root mean square standardized error (RMSSE)(Webster and Oliver, 2007).

Land Evaluation

Crop requirements were defined as shown in Table 1 according to the frame work of land evaluation (Sys et al., 1993). In this study, land suitability evaluation was achieved using Storie method as per land evaluation guidelines (Sys et al., 1991) according to the following equation:

$$I = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \ldots\ldots\ldots$$

where: I is suitability index

A, B, C and D .... are the rating of soil properties.

The suitability classes are defined according to the value of suitability index:

Suitability class	Land index
S1 (Highly suitable)	100 - 75
S2 (Moderately suitable)	75 - 50
S3 (Marginally suitable)	50 - 25
N (Unsuitable)	25 - 0

All the kriging interpolation maps were converted to raster layers with pixel size of 150 m using Arc-GIS 10.5. All of these raster layers used as in input parameters in the model builder withinArc-GIS 10.5 (Allen, 2011) to produce the suitability maps. Model builder started with the raster layers of all soil parameter as inputs, then each raster was reclassified according to Sys et al., (1993) and finally, Storie equation was performed using raster calculator tool in Arc-GIS to produce the suitability map for each crop Fig. 4. Land suitability was examined for three groups of crops vegetable crops (onion, tomato, potato), field crops (wheat, barley, alfalfa) and orchids crops (mango, olives and guava). The methodology of this study is summarized as illustrated in Fig. 5.

TABLE 1. Crop requirements for land suitability (Sys et al. 1993)

Crop	Suitability class	Soil depth	Gravel	Texture	Slope	EC	pH	$CaCO_3$	ESP	CEC
		cm	%	class	%	dS/m		%	%	
Potato	S1	> 60	0-3	L-SCL-SL	0-4	0-3	6.3-7	0-10	< 25	16-24
	S2	60-40	3-15	LS	4-8	3-5	7-8	10-15	25-35	16
	S3	40-20	15-35	-	8-16	5-6	8-8.2	15-30	35-45	16
	N	< 20	>35	S	> 16	>6	> 8.2	>30	> 45	
Tomato	S1	>100	0-15	L - SCL	0-4	0-5	6.6-7.5	0-5	0-15	16-24
	S2	100-75	15-35	LS	4-8	5-8	7.5-8	5-10	15-35	16
	S3	75-50	35-55	-	8-16	8-10	8-8.2	10-25	35-55	16
	N	<50	>55	-	> 16	>10	>8.2	>25	>55	
Onion	S1	> 50	0-15	L-SCL-SL	0-4	0-2	6.7-7.8	0-5	0-20	16-24
	S2	50-30	15-35	LS	4-8	2-3	7.8-8	5-10	20-35	16
	S3	30-20	35-55	S	8-16	3-5	8-8.2	10-20	35-55	16
	N	< 20	>55	-	> 16	>5	>8.2	>20	> 45	-
Barley	S1	>50	0-15	L	0-4	<12	7.2-8	<30	< 25	16-24
	S2	50-20	15-35	LS -SCL	4-8	16-Dec	8-8.2	30-40	25-35	16
	S3	20-10	35-55	SL	8-16	16-20	8.2-8.5	40-60	35-45	16
	N	<10	>55	S	> 16	>20	>8.5	>60	> 45	-
Alfalfa	S1	>75	0-15	SL-SCL-L	0-4	0-5	7.4-8	0-15	0-20	16-24
	S2	75-50	15-35	LS	4-8	5-9	8-8.2	15-25	20-35	16
	S3	50-20	35-55	S	8-16	9-12	8.2-8.5	25-35	35-50	16
	N	<20	>55	-	> 16	>12	>8.5	>35	>50	-
wheat	S1	>50	0-15	L	0-8	0-3	7.2-8	3-30	0-20	16-24
	S2	50-20	15-35	SCL	8-16	3-5	8-8.2	30-40	20-35	16
	S3	20-10	35-55	SL	16-30	5-6	8.2-8.5	40-60	35-45	16
	N	<10	>55	-	>30	6-10	>8.5	>60	>45	-
Olive	S1	>120	<35	L-SL-SCL-LS	0-8	0-12	7.2-8	-	0-25	16-24
	S2	120-100	35-55	-	8-16	12-16	8-8.2	-	25-35	16
	S3	100-80	55-75	-	16-25	16-20	8.2-8.5	-	35-45	16
	N	>80	>75	-	>25	>20	>8.5	-	>45	-
Guava	S1	>50	0-15	L	0-4	0-2	6.8-7.8	-	0-15	16-24
	S2	50-30	15-35	SCL-SL	4-8	2-3	7.8-8	-	15-20	16
	S3	30-10	35-55	LS	8-16	3-4	8-8.2	-	20-25	16
	N	<10	>55	S	> 16	>4	>8.2	-	>25	-
Mango	S1	>100	0-15	L-SL-SCL-CL	0-4	0-4	6.4-7.8	0-5	0-15	16-24
	S2	100-75	15-35	-	4-8	4-6	7.8-8	5-10	15-20	16-10
	S3	75-50	35-55	S	8-16	6-8	8-8.2	10-25	20-25	10-8
	N	<50	>55	-	> 16	>8	>8.2	>25	>25	<8

S1 (Highly suitable) ; S2 (Moderately suitable) ; S3 (Marginally suitable) ; N (Unsuitable).

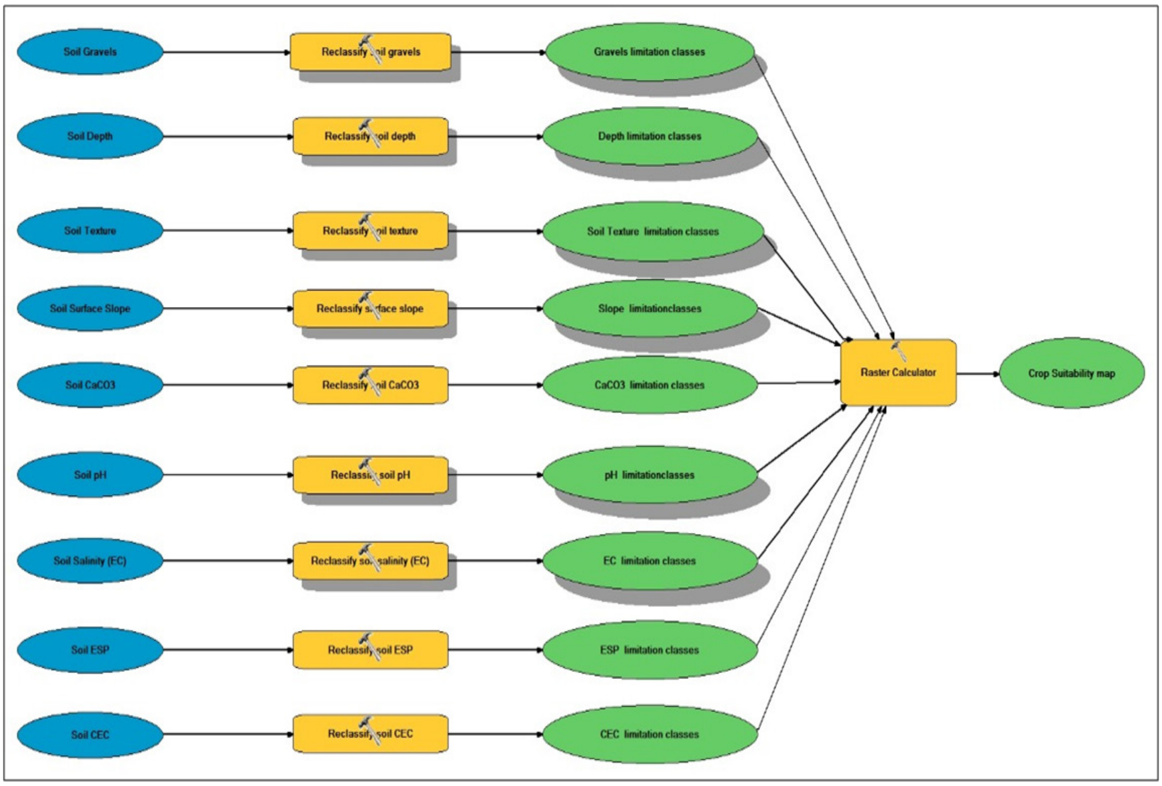

Fig. 4. Land suitabilty process model in Arc-GIS

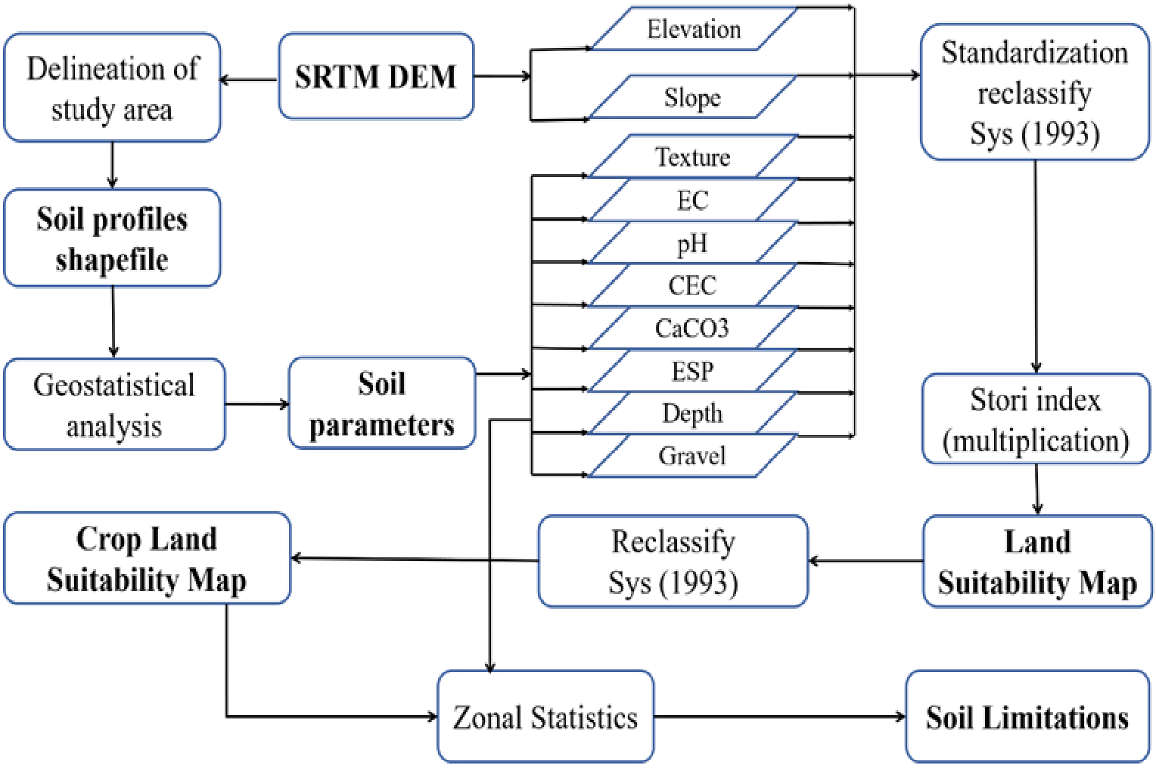

Fig. 5. Summary of the methodology used in the study

Results and Discussion

Descriptive statistical analysis of soil properties

The descriptive statistical analyses were performed using SPSS version 26. The summary of descriptive statistical analysis of the investigated soil parameters is presented in Table 2. It can be noted that the gravel content is ranged between 0.00 and 64.00 %, the coefficient of variance (CV) is 79.76 % with stander deviation (SD) 10.70. Soil depth is varied from 20 to 150 cm, the CV is 31.11 % with SD 29.45.Where the $CaCO_3$ content ranged between 0.19 and 91.07 %, the CV is 89.35 % with SD 5.32. Soil pHvaried between 7.35 and 9.69, the CV is 4.25 % with SD 0.34.WhileEC is ranged between 0.16 and 30.72 dSm^{-1}, the CV is 129.74 % with SD 2.09. Exchangeable sodium percent (ESP) was fluctuated between 9.27 and 14.43, the CV is 0.12 % with SD 0.35.While CEC is varied between 3.49 and 8.47 cmol (p+) kg^{-1}soil, the CV is 17.53 % with SD 0.9.As illustrated in Table 1 the coefficient of variationfor EC, calcium carbonate and gravel content were the greatest, while soil pH and ESP have the lowest values of CV. In generally, the CV of other soil parameters were moderately high which generally indicate that there is a heterogeneous in the investigated area. Most of soil parameters have a positively-skewed distribution except the percent of sand and soil depth which have a negatively-skewed. However, the positive skewness indicates that the mean and the median is greater than the mode while the negative values indicates opposite. Likely, all kurtosis values are positive except for soil depth with negative value. A distribution with a positive kurtosis value shows that the distribution has heavier tails than the normal distribution while a negative kurtosis value shows that the distribution has lighter tails than the normal distribution.

Geostatistical analyses

In order to create the thematic layers of soil properties, the interpolation was generated by ordinary kriging method. Figure 6 shows the spatial distribution patterns of soil characteristics obtained through the different models. Experimental semivarograms of some investigated soil properties are shown in Fig. 7 and the parameters are illustrated in Table 3. Different geostatistical models such as Gaussian, Exponential and Spherical were used to define the spatial variability of soil properties. The performance of ordinary kriging interpolation and the efficiency of geostatistical model for each soil property was checked by some parameters like RMS, MSE and RMSSE as illustrated in Table (3). Results showed that spherical model was suitable for most of soil properties (Sand, EC, ESP, Depth and CEC), then followed by exponential model which was suitable for gravel, silt and $CaCO_3$ content. Finally, the Gaussian model was suitable for Clay content and soil pH. The root mean square standardized error (RMSSE) is close to one and the mean standardized error (MSE) is close to zero for all the studied soil properties. This referred that, this method of interpolation (ordinary kriging) was appropriate and reliable to predict the spatial distribution of the studied soil properties. Geostatistical range values of soil characteristics were greater than 1822 m which indicate that soil-sampling distance for any further sampling designs should be taken as 1800 m. The wide range value indicate that the observed values of the soil property are affected by some other values of this variable over greater distances compared with soil variables which have smaller ranges (Emadi et al., 2010). However, the soil depth had the highest effective range value with 13950.95 m, while the calcium carbonate content had the lowest value with 1822.25 m (Table 3).

TABLE 2. Descriptive statistical analysis of some soil characteristics

	Unit	Range	Min.	Max.	Mean	Std. Dev.	C.V.	Skewness	Kurtosis
Gravel	%	64.00	0.00	64.00	13.42	10.71	79.76	1.31	1.92
Clay	%	24.90	0.00	24.90	8.47	4.48	52.87	0.32	0.48
Silt	%	41.17	4.01	45.18	16.67	7.07	42.41	0.46	0.31
Sand	%	51.08	42.71	93.79	74.86	9.24	12.34	-0.86	0.91
CaCO3	%	90.89	0.19	91.07	5.95	5.32	89.35	7.91	112.36
EC	$dS\ m^{-1}$	30.56	0.16	30.72	1.61	2.09	129.74	6.68	71.19
pH	−log(H+)	2.34	7.35	9.69	8.06	0.34	4.25	1.30	3.76
Depth	cm	130.00	20.00	150.00	94.65	29.45	31.11	-0.14	-0.04
ESP	%	5.16	9.27	14.43	9.51	0.35	3.72	6.68	71.19
CEC	cmol (p+) kg^{-1}soil	4.98	3.49	8.47	5.39	0.94	17.53	0.92	0.91

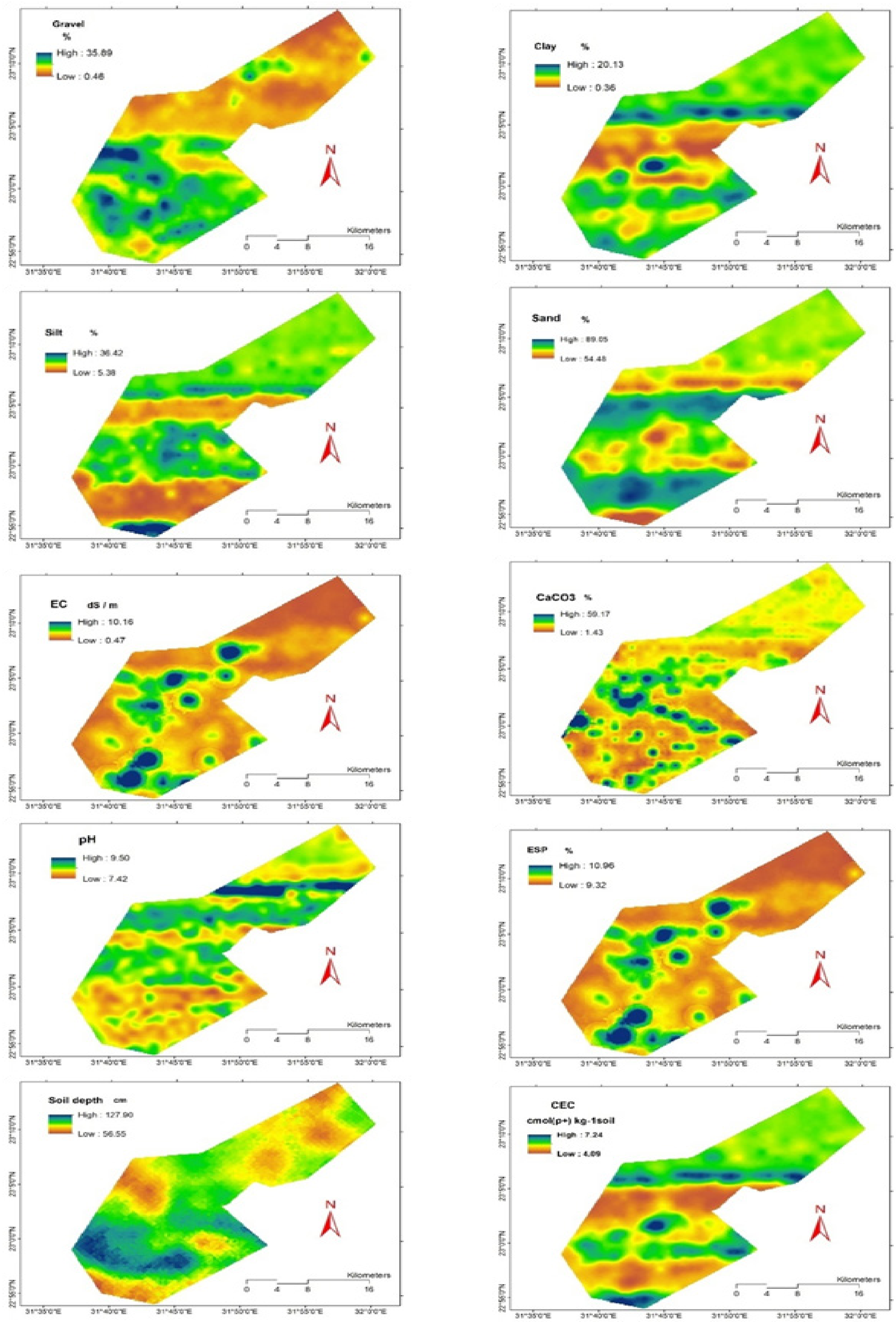

Fig. 6. Geostatistical spatial variability of soil properties

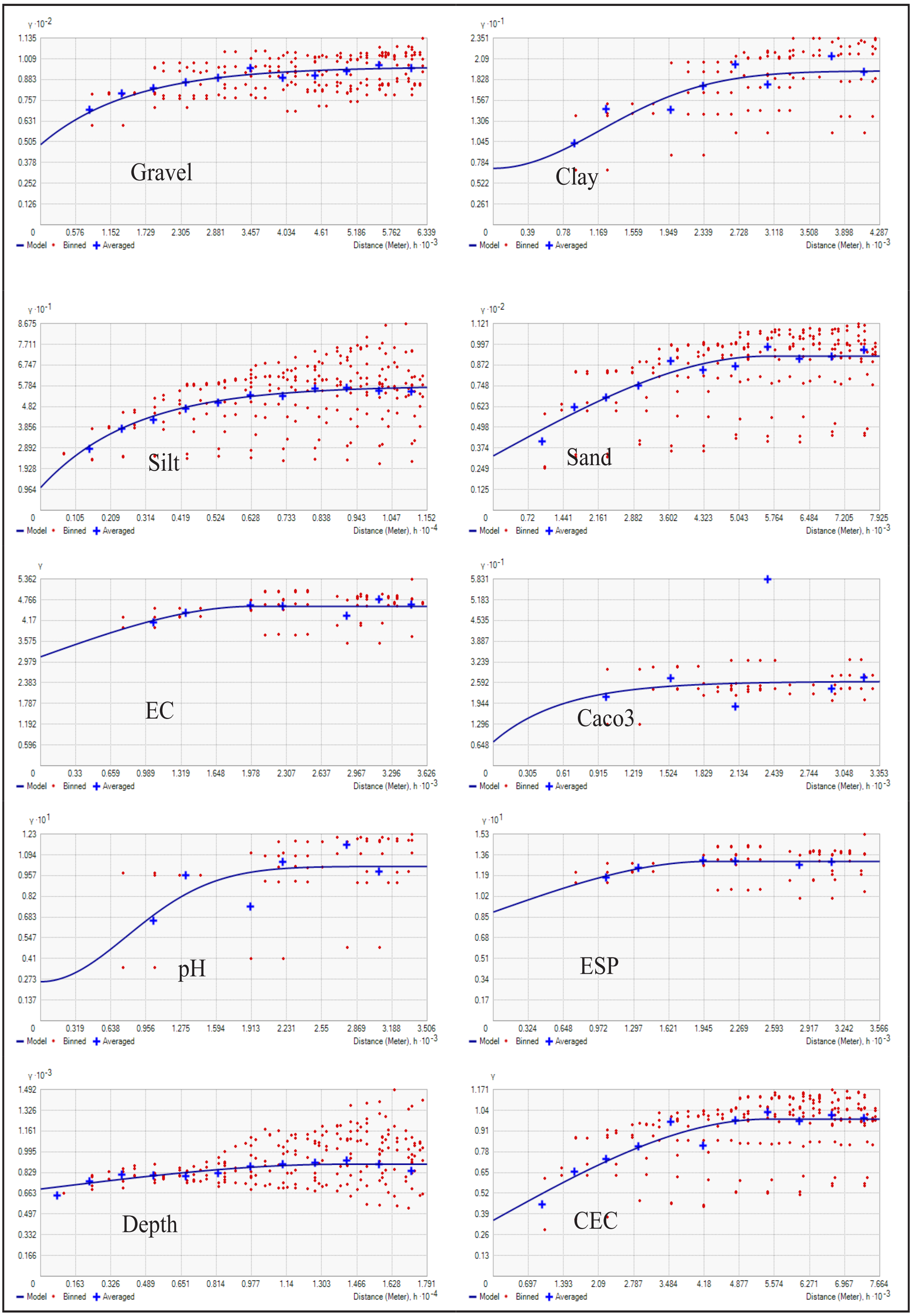

Fig. 7. Experimental semivariograms of soil properties

The spatial dependence of soil properties is varied from strong to weak. A strong dependence is due to the inherited factors, like texture, parent materials and topography. On the other hand, a weak spatial dependence is due to the orthic factors such as cultivation methods and fertilization, while a moderate spatial dependence is controlled by both inherited and orthic factors (Cambardella et al., 1994; Yasrebi et al., 2009; Kılıç et al., 2004 and Kavianpoor et al., 2012). Spatial dependency was moderate for most of investigated soil variables while silt percent and soil pH indicated as a strong spatial dependency but soil depth was the odd variable which indicated a weak spatial dependency.

Land suitability evaluation

Taking the GIS-based modelling for land evaluation process in consideration, each pixel in the database is considered as an alternative to be assessed in its quality or suitability for a specific land and each raster layer represents a standard for the process. Accordingly, in the current study, the kriging layers of soil properties (Figure 6) were used as input layers in the model builder within Arc-GIS environment in order to produce suitability maps for some crops. Suitability of the investigated soils were examined for nine crops, vegetable crops (onion, tomato and potato), field crops (wheat, barley and alfalfa) and orchids (mango, olives and guava) as illustrated in Fig. 8 and Table 4.

Vegetable crops

The results of land suitability as presented in Fig. 8 and Table 4 referred that most of the study area are unsuitable (N) for vegetable crops. Whereas 88.66 % (547.21 km^2) of the study area is unsuitable (N) for potato while 11.34 % (70 km^2) is marginally suitable (S3). For tomato 79.70 % (491.9 km^2) and 20.24 % (124.95 km^2) of the investigated area are unsuitable (N) and marginally suitable (S3) respectively. With regarding to onion crop 78.04 % of the studied area (481.66 km^2) and 21.55 % of the investigated area (133.03 km^2) are unsuitable (N) and marginally suitable (S3) receptively. While 0.41 % (2.51 km^2)and 0.06 % (0.36 km^2) of the area is moderately suitable (S2) for onion and tomato cultivation, respectively.

Field crops

On the other hand, the field crops were more suitable than vegetables whereas 42.71 % (263.58 km^2) and 11.20 % (69.15 km^2) of the area are moderately suitable (S2) for barley and alfalfa, respectively. Marginally suitable (S3) covers 64.30 % (396.84 km^2), 46.50 % (287.03 km^2) and 20.91 % (129.05 km^2) of the studied area for alfalfa, barley and wheat respectively. Also results indicated that 79.09 % (4.88.14 km^2), 24.50 % (151.22 km^2) and 10.79 % (66.59 km^2) are unsuitable (N) for wheat, alfalfa and barley respectively.

Orchid's crops

Regarding the orchids, three crops were examined and the olives is the highly suitable crop in the study area. However, 6.80 % of the investigated area (41.98 km^2) is highly suitable (S1) for olive production. While 37.81 % (233.36 km^2), 14.26 % (88.01 km^2) and 2.97 % (18.35 km^2) of the study area are moderately suitable (S2) for olive, guava and mango cultivation respectively. But 41.50 % (256.12 km^2), 31.50 % (194.43 km^2) and 27.35 % (168.78 km^2) of the total area are marginally suitable (S3) for guava, mango and olive cultivation respectively. Finally, 65.53 % (404.43 km^2), 44.24 % (273.08 km^2) and 28.04 % (173.08 km^2) of the studied area are unsuitable (N) for mango, guava and olive crops respectively.

Soil limitations

Soil limitations were delineated using zonal statistics between crop suitability map and the maximum limitation of each soil parameter as shown in Table 5. It wasquite observed that the investigated area suffers from some soil limitations for the production of different examined crops. In general, coarse soil texture, high soil pH and low CEC were the most common and strong limiting factors for all the investigated crops in the studied area. Results indicated that, the main limiting factor for vegetable crops are increasing soil salinity and excess of calcium carbonate content where the slope gradient and gravel content are slightly limiting factors. Calcium carbonate and gravel content were strong limiting factors for the field crops where soil salinity and slope gradient were limiting factors for alfalfa and wheat crops. Orchids or fruit crops were affected by a little soil limiting factors where the suitability of guava and mango crops were restricted by excessing of soil salinity and slope gradient as presented in Table 5.

TABLE 3. Geostatistical analyses and Semivarograms parameters of soil properties

Soil attribute	model	RMS	MSE	RMSSE	Range	Nugget	Partial Sill	sill	Nugget /Sill ratios	Spatial dependence
Gravels	Exponential	0.874	0.003	0.984	4464.03	48.75	47.34	96.09	50.73	moderate
Clay	Gaussian	0.333	0.006	1.014	2917.25	7.11	12.25	19.36	36.73	moderate
Silt	Exponential	0.499	0.002	0.975	8331.99	10.57	47.28	57.85	18.28	strong
Sand	Spherical	0.686	-0.002	0.953	5615.52	32.68	59.86	92.54	35.32	moderate
EC	Spherical	0.210	0.001	0.974	1996.61	3.13	1.45	4.58	68.37	moderate
CaCO3	Exponential	0.561	-0.003	1.096	1822.25	7.45	18.87	26.33	28.32	moderate
PH	Gaussian	0.026	-0.001	0.973	1911.19	0.03	0.08	0.10	24.86	strong
ESP	Spherical	0.355	0.001	0.974	1992.17	0.09	0.04	0.13	68.23	moderate
Depth	Spherical	0.710	0.005	0.977	13950.95	697.10	197.88	894.98	77.89	weak
CEC	Spherical	0.710	0.002	0.950	5442.65	0.35	0.63	0.98	35.63	moderate

TABLE 4. Land suitability classes of the investigated area

Suitability class		Unsuitable (N)		Marginally suitable (S3)		Moderately suitable (S2)		Highly suitable (S1)	
Crops		Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetable crops	Potato	547.21	88.66	70.00	11.34	-	-	-	-
	Tomato	491.9	79.70	124.95	20.24	0.36	0.06	-	-
	Onion	481.66	78.04	133.03	21.55	2.51	0.41	-	-
Field crops	Barley	66.59	10.79	287.03	46.50	263.58	42.71	-	-
	Alfalfa	151.22	24.50	396.84	64.30	69.15	11.20	-	-
	Wheat	488.14	79.09	129.07	20.91	-	-	-	-
Orchids crops	Olive	173.08	28.04	168.78	27.35	233.36	37.81	41.98	6.80
	Guava	273.08	44.24	256.12	41.50	88.01	14.26	-	-
	Mango	404.43	65.53	194.43	31.50	18.35	2.97	-	-

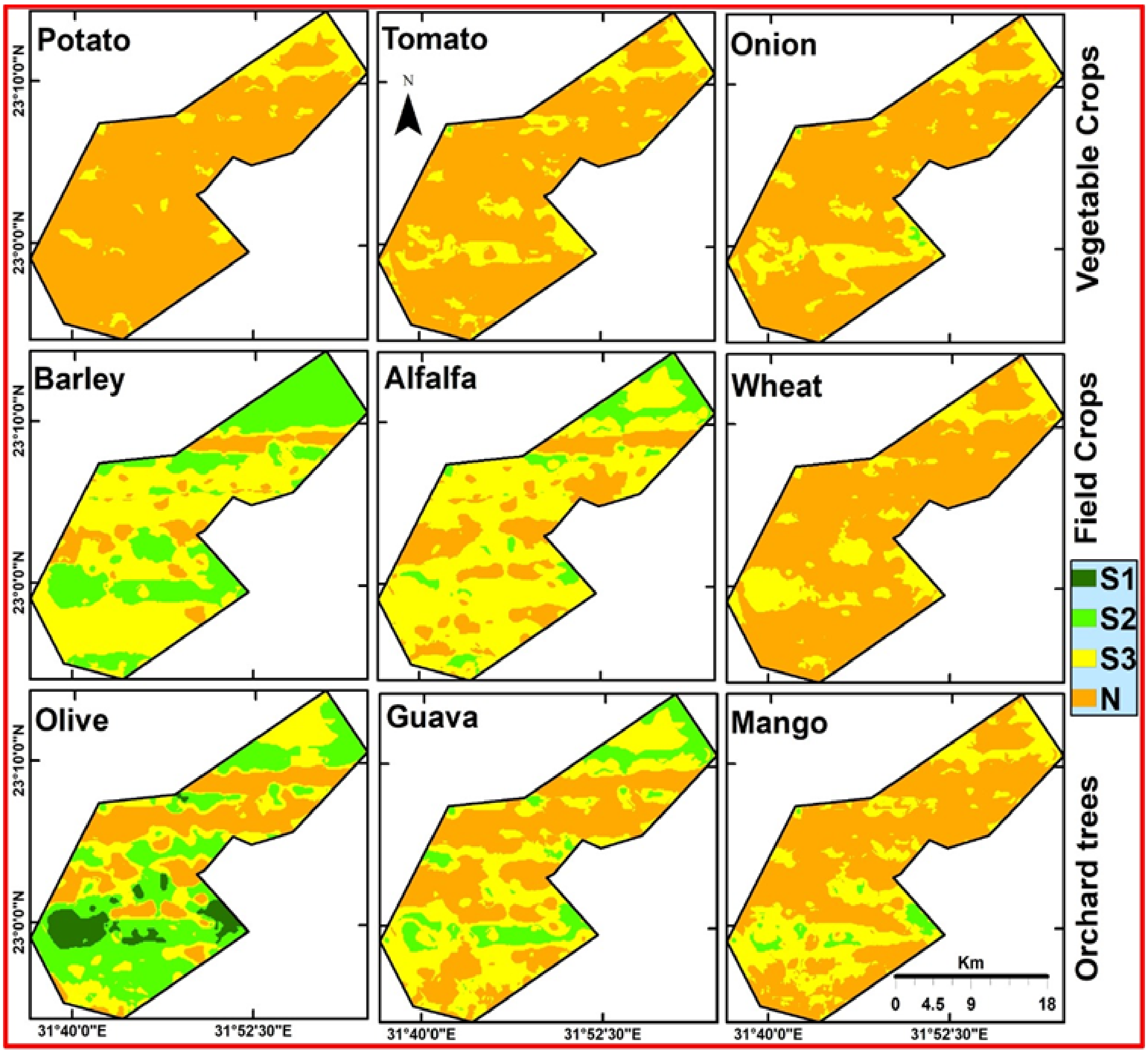

Fig. 8. Land suitability maps of the studied crops

Conclusion

Assessment of land suitability can provide sufficient information about soil conditions and the limitations that can affect the crop growth and productivity. Mostof the studied area (more than 480 km^2) are unsuitable (N) for vegetable crops. However, the study area is more promising for field crops where 263.58 km^2 and 11.20 km^2 area moderately suitable (S2) for barely and alfalfa crops. Some of orchids crops are very suitable (olives) for the study area whereas 41.98 km^2 are highly suitable (S1) for olives. On the other hand, the soil limitations for the investigated crops were excess of soil salinity (EC), high soil pH, highly calcium carbonate content, low CEC and coarse soil texture. Therefore, appropriate land management is required to increase the suitability for the examined crops. Finally, the present work confirmed that geostatistical approach and GIS are powerful and effective tools for land suitability studies and consequently for sustainable planning of land use.

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تقييم صلاحية بعض الاراضى الصحراوية باستخدام منهج الاحصاء الأرضى

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نظرا للزيادة السكانية المطردة ونـدرة الموارد الأراضية و المائية فى مصر، أصبحت الإدارة الفعالة لهذه الموارد ضرورة ملحة للغاية لتحقيق التنمية الزراعية المستدامة. ومن هذا المنطلق يعد تقييم صلاحية الأرض للاستخدام من اهم الأدوات التى تساعد فى إدارة هذه الموارد بشكل مناسب.تهدف هذه الدراسة الى استخدام منهج الاحصاء الأرضى geostatistical approach وبرنامج نظم المعلومات الجغرافية GIS لتقييم صلاحية الأراضي لبعض المحاصيل الأساسية بمنطقة توشكى بمصر.الجدير بالذكر أن استخدام هذه التقنية يعمل علي استنباط خصائص التربة في المناطق التي لم يتم الحصول علي عينات أرضية منها لذا من المتوقع أن تعطي بيانات أكثر دقة مقارنة بالطرق التقليدية لتقييم الأراضى. بنظام شبكى بفاصل ١ كم تم حفر القطاعات الأرضية و تقدير بعض صفات التربة مثل قوام التربة ، نسبة الحصى ، الأس الهيدروجيني pH، التوصيل الكهربائىEC، كربونات الكالسيوم، نسبة الصوديوم المتبادل ESP و السعة التبادلية الكاتيونية CEC .تم دراسة دالة التباين النصفى و الاختلافات المكانية لصفات التربة وعمل خرائطها باستخدام منهج الإحصاء الأرضى (طريقة ordinary kriging) من خلال برنامج نظم المعلومات الجغرافية Arc-GIS. تم دمج خرائط صفات التربة التى أعدت باستخدام طريقة kriging من خلال نظم المعلومات الجغرافية (model builder) لتقييم صلاحية الارضى لبعض المحاصيل باستخدام معادلة ستورى Storie. أظهرت نتائج الدراسة أن معظم المساحة المدروسة (٨٠ ٪) غير مناسبة لمحاصيل الخضر (N). بينما اظهرت المنطقة صلاحية اكثر للمحاصيل الحقلية حيث أن ٤٢,٧١٪ و ١١,٢٠٪ من إجمالي المساحة متوسطة الصلاحية (S2) لمحاصيل الشعير والبرسيم على الترتيب. كما أكدت النتائج أن محاصيل الفاكهه اكثر ملائمة لمنطقة الدراسة حيث أن ٦,٨٠٪ و ٣٧,٨١٪ من منطقة الدراسةعالية الصلاحية (S1) ومتوسطة الصلاحية (S2) للزيتون على الترتيب. وتبين من خلال الدراسة ان زيادة الملوحة ، القوام الخشن ، زيادة محتوى كربونات الكالسيوم وارتفاع رقم الاس الهيدروجينى pH هى اهم معوقات استخدام الاراضى بمنطقة الدراسة. ومن ثم ، يمكن استنتاج أن منهج الاحصاء الأرضى geostatistical approach ونظم المعلومات الجغرافية GIS تعتبر أدوات قوية وفعالة لدراسات صلاحية الاراضى وبالتالي المساهمة فى التخطيط المستدام لاستخدام الأراضي.