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DELINEATION OF SITE-SPECIFIC MANAGEMENT ZONES USING MULTIVARIATE ANALYSIS AND GEOGRAPHIC INFORMATION SYSTEM TECHNIQUE

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ABSTRACT

The basic objectives of this study were: 1) The ability to characterize the spatial variability across a soil for selected soil properties using GIS technique and 2) identification of site-specific management zones using selected soil properties using PCA and cluster analysis. 120 geo-referenced representative soil samples obtained from Sahl Al-Hussainiyah, El-Sharkia Governorate, Egypt, (from 0 to 0.60 m depth). These samples were prepared and analysed for soil characteristics, such as soil pH, electrical conductivity (ECe), calcium carbonate ($CaCO_3$), soil organic matter (OM), available N, P, K, soil cations exchange capacity (CEC), and bulk density (BD). Using semi-variogram analysis and ordinary kriging, spatial distribution pattern varies from moderate to strong spatial dependence for most soil characteristics. Using PCA and cluster analysis, site-specific management zones were identified in the study area. For further analysis, four PCs with eigenvalues > 1 were used, with PCs explaining 73.19 percent of the variance. Four MZs were defined based on cluster analysis using an agglomerative hierarchical clustering technique. The differences between these MZs were statistically significant ($p < 0.05$). 3.01 (466.56 ha), 36.47 (5658.9 ha), 31.02 (4813.54 ha), and 29.5 percent (4577.8 ha) of the total area is MZ1, MZ2, MZ3, and MZ4 (15516.8 ha).

***Keywords**: Site-specific management zones, Precision agriculture, Spatial distribution,Principal component analysis, Cluster analysis

INTRODUCTION

Soil characteristics differ from spatial characteristics because of the cumulative effect of the physical, chemical, and biological processes in the soil environment along with human/animal activities (Goovaerts, 1998). The main key to site-specific soil management for sustainable crop production by differential nutrient addition is a thorough understanding of the spatial distribution of soil properties and their mapping (Behera and Shukla, 2015; Bogunovic *et al.,* 2017; Brevik *et al.,* 2016; Shukla *et al.,* 2017). The spatial distribution of soil characteristics can be evaluated using geostatistical approaches, such as ordinary kriging (Behera *et al.,* 2018; Mueller *et al.,* 2003). Saito *et al.,* (2005) revealed that the values in un-sampled locations can be predicted through geospatial modeling techniques by observing the spatial correlation analysis between the expected and sample points and decreased estimation errors and associated costs. A technique to resolve soil heterogeeity (Ortega and Santibαñez, 2007; Peralta *et al.,* 2015; Xin-Zhong *et al.,* 2009) is known to be the classification of heterogeneous soil into different zones with homogeneous characteristics through the delineation of the soil management zone (MZ). Geo-statistics, principal component analysis (PCA), and cluster analysis are methods used by many researchers to delineate soil MZs in various agroecosystems, including different crops for site-specific soil management (Davatgar *et al.,* 2012; Nawar *et al.,* 2017; Shukla *et al.,* 2017; Tripathi *et al.,* 2015). The concept of a “management zone” was created primarily to improve agricultural inputs in response to the significant expansion of soil variation (Ali and Ibrahim, 2016). In a sector that has similar yield-limiting variables, site-specific management zones are called homogeneous sub-areas (Doerge, 1999; Khosla and Shaver, 2001). The main objective of site-specific management is to spatially manage soil variability by adding inputs according to the site-specific requirements of a specific soil and crop (Fraisse *et al.,* 2001). In principle, using the management zone delineation method, the agricultural field can be divided into management zones that represent the general difference in soil characteristics, so there are considerable attempts to delineate management zones (Ali and Ibrahim, 2016). Many studies have attempted to describethe association between the topography of the agriculture field and soil nutrient content suchas nitrogenpage19 (Bruulsema *et al.,* 1996; Cassel *et al.,* 1996) as well as the difference in yield (Verity and Anderson, 1990). The objectives of this study were a) to characterize the spatialvariability across a soil for selected soil properties using GIS technique, b) tothe identification of site-specific management zones using selected soil properties in the studyarea using PCA and cluster analysis and attempting to find out the limiting factors tosoil productivity in the study area.

MATERIALS AND METHODS

Study area and soil sampling

The study was conducted in Sahl Al-Hussainiyah, Sharkia Governorate, Egypt,bounded by 31°47’30'' & 32°11’30'' E and 30°44’30'' & 31°11’30'' N (Figure 1). Basedon Port Said and Ismailia meteorological station It was found that the maximumtemperatures varied from 31.9 to 37.1°C in August; meanwhile, the lowest was 9.7 to13.1°C in January with an average annual 22.5°C and 22.8°C, respectively with awide difference between summer and winter months. The annual precipitation variedfrom 33.3 to 73.3 mm. the precipitation is not distributed evenly throughout the rainyseason. The highest precipitation was recorded in November and December (rangedfrom 7.7 to 18 mm). The values of relative humidity varied from 58 to 72%. The windvelocity ranged between 14.2 and 18.7 km h^{-1} at Port Said station was recorded inSeptember and March, respectively. According to Ismailia station, it was 10 and 17.1 kmh^{-1} in November and March, respectively.

A total of 120 geo-referenced representative soil samples (from 0 to 0.60 mdepth) were collected using a hand auger and prepared to analyzed (air-dried,Crushed, and then passed through a 2 mm sieve). The GPS device was used to record thelatitude and longitude of each sampling point. Soil pH, EC_e, $CaCO_3$, OM, available N,available P, available K, CEC, and BD were analyzed according to the protocol described by (Richards, 1954; Baruah and Barthakur, 1997 and van Reeuwijk, 2002).

Statistical, geostatistical, principal component and cluster analysis

The descriptive statistics revealing, minimum, maximum, mean, and standarddeviation, was done using theXLSTAT software version 2016. The normality distribution ofsoil properties was tested using the Shapiro-Wilk test. The relationship between pairs of soil properties has been revealed by the Pearson correlation coefficient. ArcGIS 10.4.1software was used and a semi-variogram was used to evaluate the spatial distributionpattern of each soil property. semi-variogram was calculated using the following Eq. 1 (Behera *et al.,* 2018).

$$\gamma(h) = \frac{1}{2N(H)} \sum_{\alpha=1}^{N(h)} [Z(X_\alpha + h)]^2 \qquad (1)$$

where γ(h), N (h), $z(x_\alpha)$ and z (x_α + h) represent semi-variance for the lag distance h,several sample pairs separated by the lag distance h, measured value at α th samplelocation and measured value at point α + h th sample location, respectively.

Many criteria were used to evaluate different semi-variogram models likespatial dependence (SDC), Mean error (ME), Root-Mean-Square error (RMSE), Mean Standardized error (MSE), Root-Mean-Square Standardized error (RMSSE), and Average Standard Error (ASE). Generally, the best fit model which have the mean error ”ME”, mean standardized error “MSE” and average standard error “ASE” values closeto zero and root mean square error “RMSE” close to one(Gundogdu and Guney, 2007). Cambardella *et al.,* (1994) reported that the semi-variogram model is classified based on nugget to sill ratio, spatial dependence (SDC), to strong (<0.25), moderate (0.25 – 0.75) and weak (> 0.75).

Interpolation mapping was carried out using the ordinary kriging method, a reliablemethod than other methods based on MSE (Meul and Van Meirvenne, 2003), to determine the soil characteristics values at un-sampled locations. Moreover, it is an unbiased predictor for the random process as well as reducing the influence of outliers (Triantafilis *et al.,* 2001).

Using Kaiser Meyer Olkin (KMO) and Bartlett’s sphericity test(Hutcheson and Sofroniou, 1999), data adequacy and appropriateness for principal component analysis (PCA) were assessed. In order to address multicollinearity among variables and reduce the number of variables by generating new variables, main component analysis was carried out (Rahayu *et al.,* 2017). The key components of the new variables are called (PCs). In performing cluster analysis, these PCs will be used to assess management zones (Behera *et al.,* 2018). The number of PCs is dependent on the Eigenvalue, while PCs with an Eigenvalue greater than 1 are retained (Kaiser, 1960). To classify the study area using agglomerative hierarchical clustering, new variables created from PCA were used (AHC). AHC is a multivariate test method used to test data in various clusters with a common characteristic (Abdel-Fattah, 2020). The method of agglomeration used was Ward’s hierarchical clustering method.

RESULTS AND DISCUSSION

The studied soil properties

Table 1 shows the summary statistics of some of the soil properties under study It is clear from the results that the properties of the soil varied greatly. The mean values of pH, EC, $CaCO_3$, OM, ava. N, ava. K, ava. P, CEC and BD were 7.61±0.38, 9.43±3.79dSm^{-1}, 3.55±1.61%, 0.6±0.15%, 42.39±13.95 $mgkg^{-1}$, 0.69±0.15 $mgkg^{-1}$, 2.59±1.59$mgkg^{-1}$, 47.96±10.81 $cmol_c kg^{-1}$, 1.31±0.10Mgm^{-3}, respectively. According to Baruah and Barthakur (1997) these results show that the studied soil is located within the

Table 1: Descriptive statistic summary of the selected soil char characteristics in current study

	N	MAX	MIN	MEAN	SD	Shapiro-Wilk
pH	120	8.33	6.89	7.61	0.38	0.001
EC, dSm^{-1}	120	18.15	3.39	9.43	3.79	<0.0001
$CaCO_3$, %	120	6.71	0.34	3.55	1.61	0.002
OM, %	120	0.85	0.06	0.60	0.15	0.001
Ava. N, $mgkg^{-1}$	120	71.40	21.00	42.39	13.95	0.000
Ava. K, $mgkg^{-1}$	120	0.99	0.37	0.69	0.15	0.015
Ava. P, $mgkg^{-1}$	120	7.39	0.14	2.59	1.59	0.000
CEC, $cmol_c kg^{-1}$	120	74.61	22.50	47.96	10.81	0.788
BD, Mgm^{-3}	120	1.75	1.08	1.31	0.10	<0.0001

pH : Soil potential of hydrogen, EC : Soil electric conductivity
OM : Soil organic matter Ava. N : Available nitrogen
Ava. K : Available potassium Ava. P : Available phosphorus
CEC : Cation exchange capacity BD : Bulk density

low category for OM, ava. N, ava. K and ava. P. concerning soil pH, the studied soil fell into the normal category, while it falls into the high category of salinity expressed as dSm^{-1}.based on FAO (1979) the studied soil is considered non-calcareous soil due where the $CaCO_3$ percentage is less than 15%. These findings agree with many studies carried out in the same study area (AbdElghany *et al.,* 2019, Ali *et al.,* 2014, Ibrahim *et al.,* 2015, Mohaseb *et al.,* 2019, Nasef *et al.,* 2009, and Shaban *et al.,* 2010). Table 1 shows that all soil properties do not follow a Normal distribution, where the value of p of the Shapiro-Wilk Test is less than 0.05 except for the CEC property (p>0.05). So, before making spatial distribution of soil properties by ordinary kriging (OK) method the data was transformed using the Box-Cox method (Box and Cox, 1964).

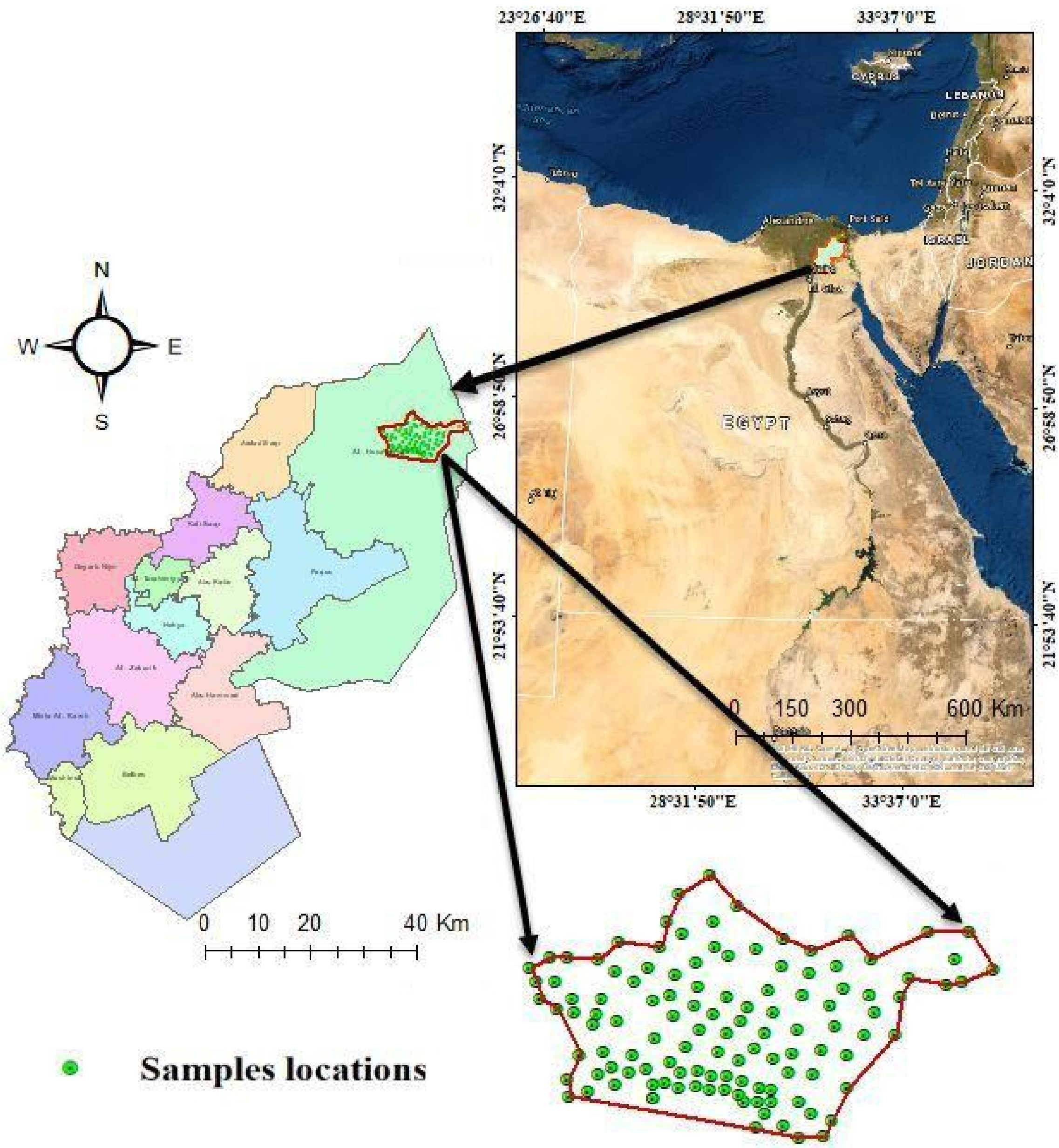

Fig. 1: Study area and locations of samples

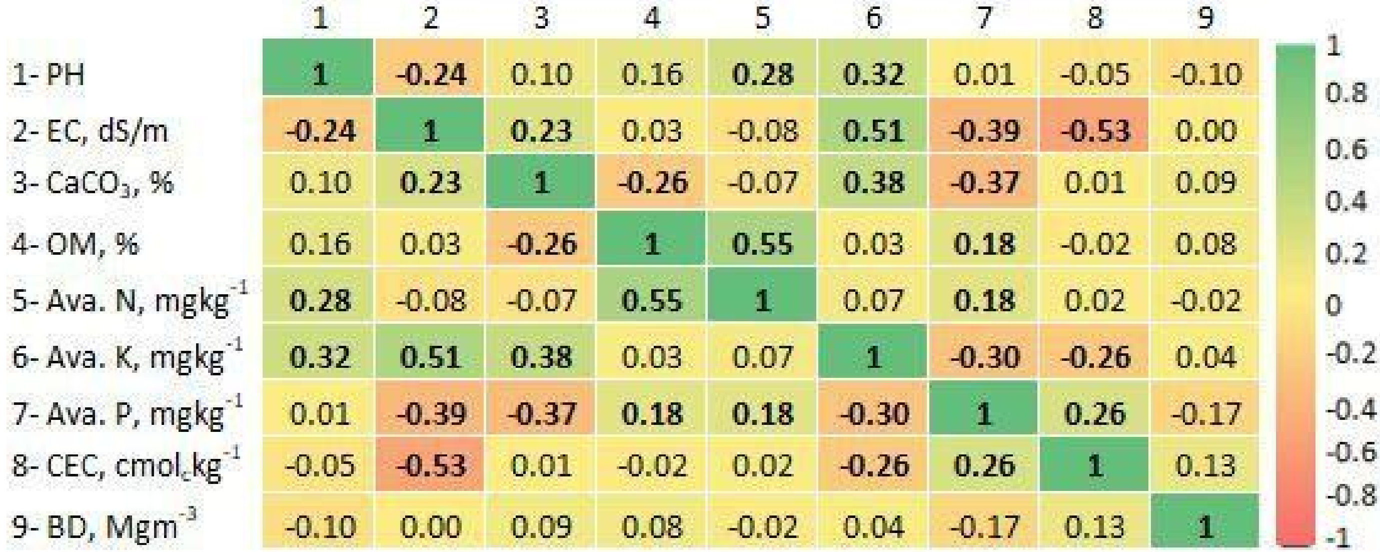

Fig. 2: Correlation matrixof the soil properties

Correlation matrix between soil properties

Figure 2 shows the correlation map of the understudied soil properties. The values in bold are different from 0 with a significance level alpha = 0.05. Observed from results in Figure 2 that found positive significant correlations between pH with ava. N (r = 0.28) and ava. K (r = 0.32), While there was a negative association between pH and EC (r = -0.24). on the other hand, found positive significant correlations between EC with $CaCO_3$ (r = 0.23) and ava. K (r = 0.51), While there was a negative association between EC with ava. P (r = -0.39) and CEC (r = -0.53). The correlation was positive significant between $CaCO_3$ and ava. K (r = 0.38) and its was negative significant between $CaCO_3$ with OM (r = - 0.26) and av. P (r = -0.37). There is also a positive significant relationship between OM with ava. N (r = 0.55) and ava. P (r =0.18). The association between ava. N and Av. P was positive and significant (r = 0.18). While there was a negative association between ava. K with Av. P (r = -0.30) and CEC (r = -0.26) and positive association between ava. P and CEC (r = 0.26). All other soil properties pairs have no statistically significant correlations. Loeppert and Suarez (1996) observed that the relation between pH and $CaCO_3$ of soils was a significant positive as well as between essential plant nutrients, N, P, K and OM had significant ($P<0.01$) positive correlations. Also, Srinivasan *et al.,* (2017) mentioned that there are positive correlations between soil OM content and available P as well as K.

Semi-variogram parameters and mapping soil properties using ordinary kriging

The spatial distribution pattern of the different soil characteristics was specified using ArcGIS 10.2.1 program using Ordinary Kriging (OK) for Interpolation mapping to estimate values of soil properties for un-sampled locations. Based on many criteria such as (SDC, ME, RMSE, MSE,

Table 2: Semi-variogram parameters of the soil properties of the study area

Model	Ph	EC	$CaCO_3$	OM	Ava. N	Ava. K	Ava. P	CEC	BD
	K-Bessel	Stable	Exponential	K-Bessel	Exponential	Stable	Exponential	K-Bessel	Stable
Nugget	0.00	0.00	1.23	0.00	0.00	0.00	0.80	70.48	0.00
Partial sill	15.94	15.78	2.14	0.03	215.44	0.02	1.92	46.63	0.01
Sill	15.94	15.78	3.37	0.03	215.44	0.02	2.72	117.11	0.01
Nugget/ Sill	0.00	0.00	0.37	0.00	0.00	0.00	0.29	0.60	0.11
Major Range	4582.15	6852.02	12581.25	2963.95	2705.00	4213.28	4891.50	2880.50	1582.72
SDC	Strong	Strong	Moderate	Strong	Strong	Strong	Moderate	Moderate	Strong
ME	0.01	0.01	-0.01	0.00	-0.23	0.00	-0.02	-0.12	0.00
RMSE	3.26	3.44	1.26	0.14	11.90	0.09	1.33	9.92	0.09
MSE	0.00	0.00	-0.01	0.00	-0.02	0.00	-0.01	-0.01	0.01
RMSSE	0.94	0.97	0.96	1.11	1.02	0.89	1.02	1.03	1.24
ASE	3.45	3.55	1.34	0.13	11.73	0.10	1.31	9.59	0.08

SDC : spatial dependence, ME : Mean error, RMSE : Root-Mean-Square error, MSE : Mean Standardized error
RMSSE : Root-Mean-Square Standardized error, ASE : Average Standard Error

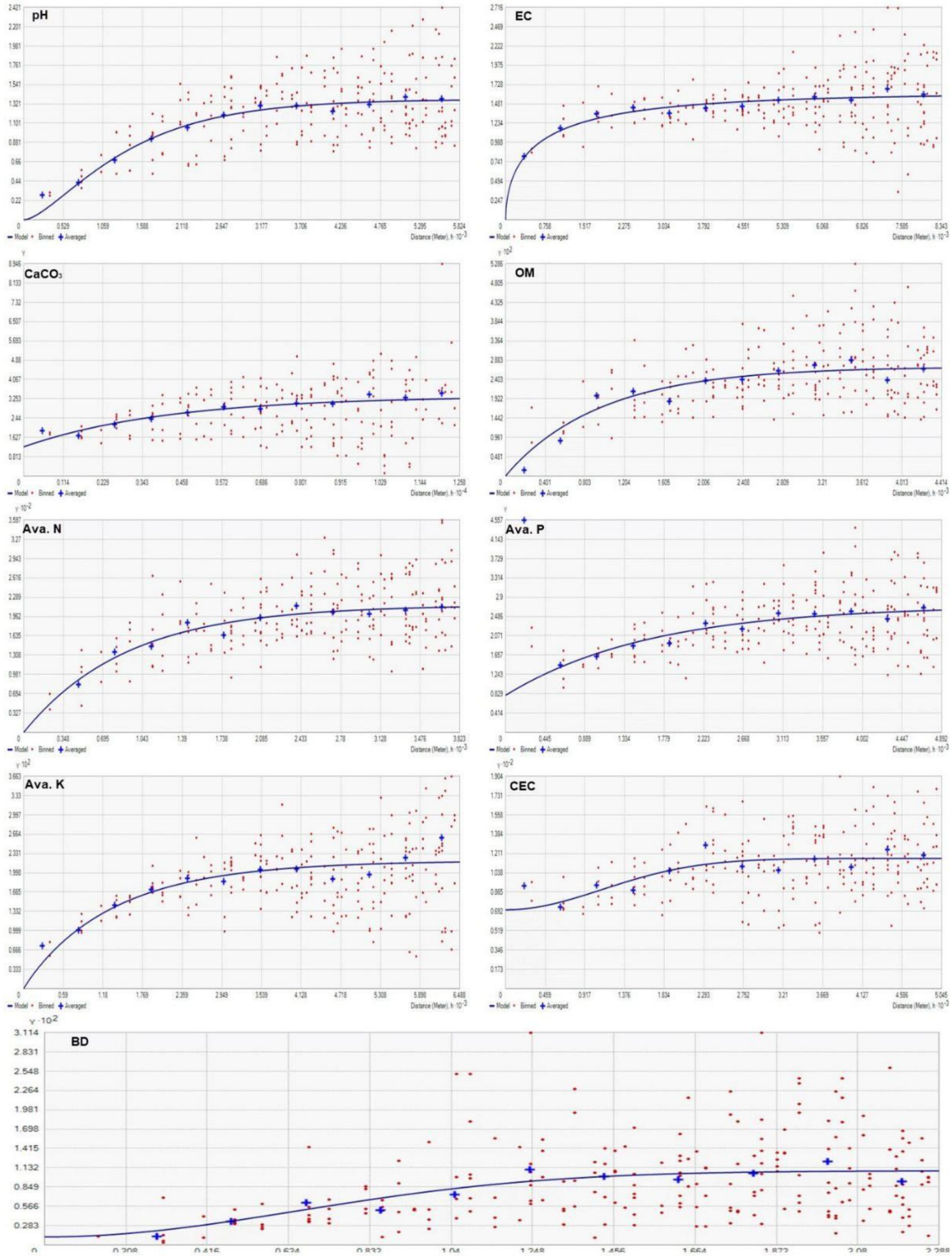

Fig. 3: Semi-variogram parameters of the soil properties of the study area

RMSSE, and ASE), the Semi-variogram was evaluated (Table 2 and Figure 3). The best fit model of EC_e, ava. K and BD was a Stable model, whereas the K-Bessel model was the best fit model of pH, OM, and CEC, while the Exponential model was used with $CaCO_3$, ava. N and ava. P as a best-fit model (Table 2 and Figure 3). The nugget values of all the studied parameters were very small, varied from 0 to 1.23, except the nugget value of CEC was large (70.48). whereas the sill values were varied from 0.01 to 215 (Tasfahunegn *et al.,* 2011). Zhang *et al.,* (2007) reported that Large nugget values indicated that the soil indicators were affected by ecological practices over a small scale and selected sampling distance could not capture the spatial dependence well. Whereas, sill values indicating the

Table 3: Summarization of PCA results

	PC1	PC2	PC3	PC4
Eigenvalue	2.37	1.78	1.29	1.14
Variability (%)	26.35	19.81	14.37	12.66
Cumulative %	26.35	46.16	60.53	73.19
Factor loadings				
PH	-0.007	0.590	0.500	-0.430
EC, dS/m	0.782	0.120	-0.436	0.149
$CaCO_3$, %	0.574	-0.064	0.575	-0.026
OM, %	-0.261	0.742	-0.217	0.364
Ava. N, $mgkg^{-1}$	-0.251	0.787	0.035	0.148
Ava. K, $mgkg^{-1}$	0.690	0.420	0.220	-0.086
Ava. P, $mgkg^{-1}$	-0.713	0.106	-0.140	-0.175
CEC, $cmol_c kg^{-1}$	-0.555	-0.233	0.559	0.192
BD, Mgm^{-3}	0.082	-0.063	0.306	0.838

PCs : Principal components
pH : Soil potential of hydrogen
EC : Soil electric conductivity
OM : Soil organic matter
Ava. N : Available nitrogen
Ava. K : Available potassium
Ava. P : Available phosphorus
CEC : Cation exchange capacity
BD : Bulk density

variance of the sampled population at large separation distance if the data have no trend, were also higher for available CEC (117.11) and ava. N (215.49). The variation in nugget and sill values of the studied soil indicators was observed by (Tasfahunegn *et al.,* 2011). Based on Cambardella *et al.,* (1994), Nugget to sill ratio values was classified to <0.25 for strong spatial dependence (attributed to intrinsic factors), 0.25-0.75 for moderate spatial dependence (attributed to both intrinsic and extrinsic factors) and > 0.75 for weak spatial dependence (attributed to extrinsic factors). Nugget to sill ratio values was less than 0.25 for all the studied soil properties except CEC, indicating the strong spatial dependence for all the studied soil properties, whereas spatial dependence for CEC was moderate. Behera *et al.,* (2018) mentioned that the strong spatial dependence of the soil characteristics is controlled by inherent soil properties such as Mineral composition and texture of the soil whereas extrinsic factors influence moderate and weak spatial dependence of soil properties such as agricultural practices including tillage and fertilizer application. The range value of the semi-variogram varied from 1582.7 for BD to 12581.25 for $CaCO_3$ (Table 2). Large range value indicating that measured soil characteristics were affected by natural and Human factors over a greater distance than soil properties having smaller ranges (Behera *et al.,* 2018; López-Granados *et al.,* 2002). The cross-validation technique was used to measure accurate predictions for soil characteristics (Table 2). Generally, (Gundogdu and Guney 2007) reported that the best fit model which have to mean ME, MSE, and ASE values close to zero and RMSE close to one. The spatial distribution maps of the different soil characteristics were generated using ordinary kriging (Figure 4). The spatial distribution map revealed that about 24.76, 14.39, 16.40, 27.36 and 17.09% of the study area were having soil pH values of > 7.17, 7.17 to 7.41, 7.41 to 7.66, 7.66 to 7.89, and > 7.89 respectively. About 9.15, 28.09, 26.49, 15.46 and 20.81% of the study area were having soil EC value of < 6.70, 6.71 to 8.17, 8.18 to 9.73, 9.74 to 11.44 and > 11.45 dSm^{-1} respectively. Concerning $CaCO_3$, about 22.62, 22.35, 12.57, 27.50 and 17.96% of the study area were having $CaCO_3$ value of < 2.3, 2.31 to 2.92, 2.93 to 3.76, 3.77 to 4.52 and > 4.53% respectively. Concerning organic matter, about 6.52, 19.98, 21.56, 28.92 and 23.02% of the study area were having organic matter value of < 0.43, 0.44 to 0.52, 0.53 to 0.61, 0.62 to 69 and > 0.70% respectively. about 30.28, 18.80, 25.74, 23.29 and 15.75% of the study area were having ava. N value of < 30.28, 30.29 to 37.93, 37.94 to 45.58, 45.59 to 52.64 and > 62.64 $mgkg^{-1}$ respectively. About 14.08, 21.72, 31.70, 21.15, and 11.35% of the study area were having ava. P-value of < 1.61, 1.62 to 2.43, 2.44 to 3.31, 3.32 to 4.30 and > 3.41 $mgkg^{-1}$ respectively. About 22.87, 22.22, 21.19, 20.95 and 12.77% of the study area were having ava. K value of < 0.53, 0.54 to 0.63, 0.64 to 0.74, 0.75 to 0.82 and > 0.83X $mgkg^{-1}$ respectively. About 14.50, 28.36, 25.70, 18.57 and 12.88% of the study area

Table 4: Average values of the soil characteristics in different site-specific management zones

Property	Soil management zones				Pr> F	Signi-ficant
	MZ1	MZ2	MZ3	MZ4		
Soil pH and electric conductivity (ECe, dS m^{-1})						
pH	7.81a	7.79a	7.36b	7.15c	0.00	Yes
ECe	8.916 b	9.50b	12.50 a	6.92c	0.00	Yes
Calcium carbonates (%) and organic matter (%)						
$CaCO_3$	2.18c	4.32b	4.99a	2.13c	0.00	Yes
OM	0.66a	0.64a	0.43b	0.59a	0.00	Yes
Available nutrient (mg kg^{-1})						
N	49.97a	47.19a	27.30b	34.23b	0.00	Yes
P	3.28a	2.21b	1.36c	3.82a	0.00	Yes
K	118.0b	125.0a	127a	99c	0.00	Yes
Cation exchange capacity (CEC) and bulk density (BD)						
CEC, $cmol_c$ kg^{-1}	43.51c	48.84b	45.87bc	54.28a	0.00	Yes
BD, Mg m^{-3}	1.24b	1.35a	1.31a	1.31a	0.00	Yes
Area, ha	465.54	5646.59	4803.07	4567.84	Total area = 15483.04 ha	

Different letters within each column indicate significant difference between the management zones at 0.05 level.
SMZs : Site-specific management zones,
pH: Soil potential of hydrogen
EC : Soil electric conductivity
OM : Soil organic matter
Ava. N : Available nitrogen
Ava. K : Available potassium
Ava. P : Available phosphorus
CEC : Cation exchange capacity
BD : Bulk density

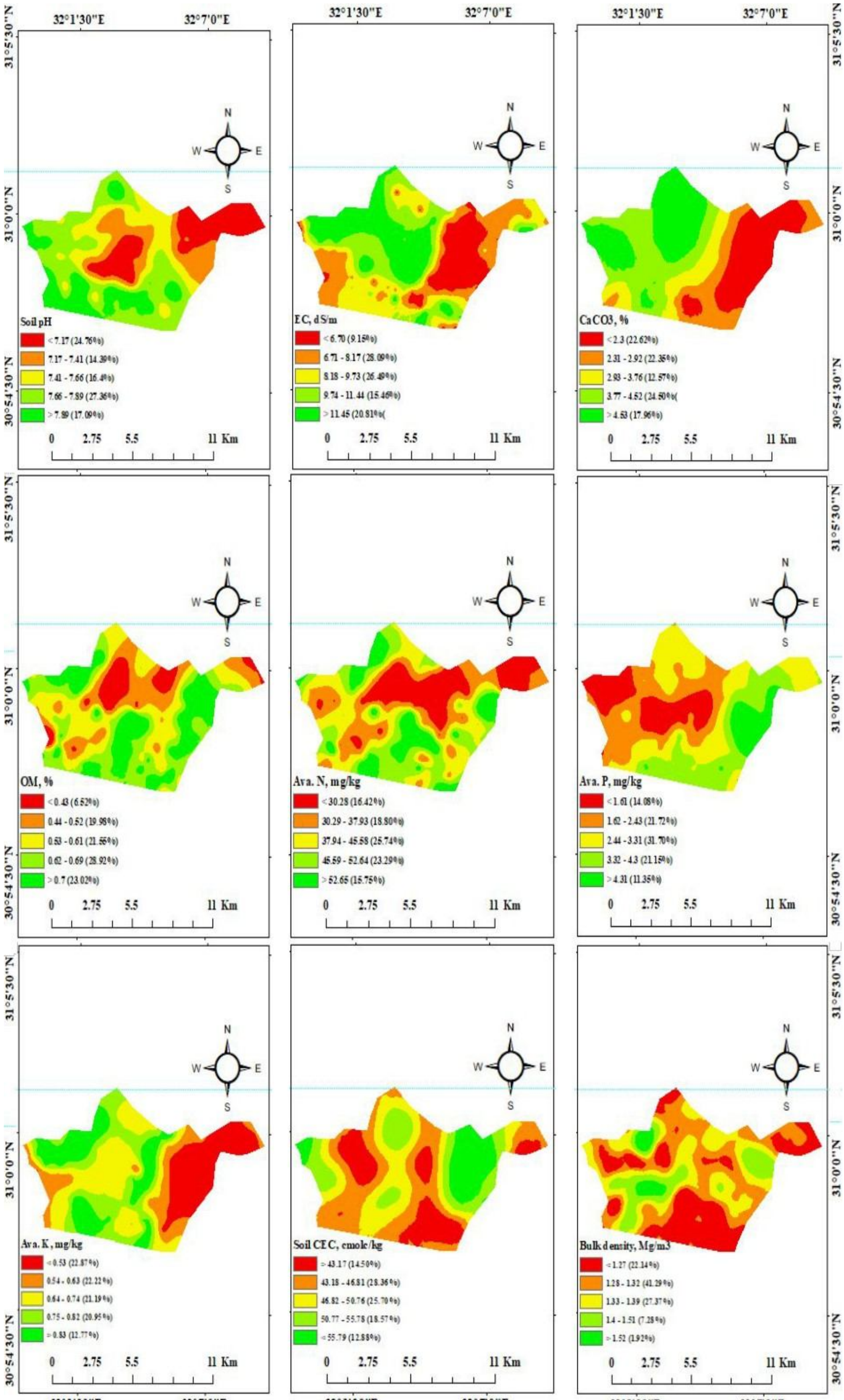

Fig.4: Spatial distribution maps of soil characteristic of the study area using krigingmethod

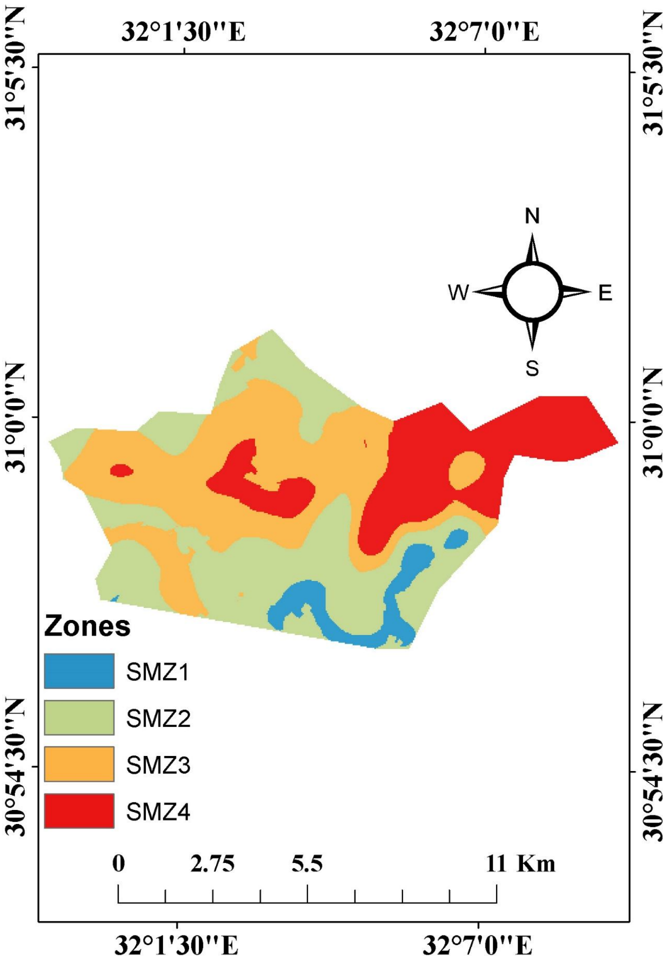

Fig. 5: Site-specific management zones of the study area

were having CEC value of < 43.17, 43.18 to 46.81, 46.82 to 50.76, 50.77 to 55.78 and > 55.79 $cmol_c kg^{-1}$ respectively. About 22.14, 41.29, 27.37, 7.28 and 1.92% of the study area were having BD value of < 1.27, 1.28 to 1.32, 1.33 to 1.39, 1.40 to 1.51 and > 1.52 Mgm^{-3} respectively. Vasu *et al.,* (2017) mentioned that maps of spatial distribution able to identify and delineate the problematic zones, therefore it considers Powerful tools in site-specific management. The spatial distribution of soil characteristics provides a lot of site information that is used for various purposes for environmental forecasting, precision agriculture, and natural resource management.

Principle components analysis (PCA) and cluster analysis

Principal Component Analysis was carried out to Address Multicollinearity among variables and reducing their number (Rahayu *et al.,* 2017). The new variables are called principal components (PCs). These PCs will be used in performing cluster analysis to determine management zones (Behera *et al.,* 2018). The number of PCs depends on the Eigenvalue, whereas, PCs that have Eigenvalue greater than 1 are kept (Kaiser, 1960). Therefore, the PCs were kept even the fourth PC (Table 3). These PCs can explain 73.19% of the variability, where the PC1, PC2, PC3, and PC4 can explain 26.35, 19.81, 14.37, and 12.66% of the total variance, respectively (Table 3). According to the factor loadings values (Table 3), which measures the relationship between different soil parameters and Generated PCs, observed that the soil EC, $CaCO_3$, and ava. K was strongly correlated with PC1. The pH, OM, and ava.N was strongly correlated with the PC2. The CEC was correlated strongly with PC3 where as BD was related strongly with PC4.

Site-specific management zones delineation

Factor scores of PCs for each sample, which resultant from PCA, were used to carry out the cluster analysis using agglomerative hierarchical clustering (AHC) technique to classify the data into different clusters having the common trait. The data were divided into 4 clusters (Figure 4). These clusters were used to divide the study area into 4 zones and mapping the management zones map (Figure 4). The characteristics of each MZ were shown in Table 4. One-way ANOVA test followed by DUNCAN test as a posthoc test to compare between the different MZs (Table 4). The results of ANOVA (Table4) revealed that there are statistically significant differences between the different MZs ($p<0.05$). MZ1, MZ2, MZ3, and MZ4 were 3.01 (466.56 ha), 36.47 (5658.9 ha), 31.02(4813.54 ha), and 29.5% (4577.8 ha) of the total area (15516.8 ha). There were statistically significant differences between different soil properties in different MZs. The highest pH was in MZ1 (7.81) with no significant difference between it and the MZ2 (7.79) and MZs can be arranged according to soil pH values as follows, MZ1 =MZ2 > MZ3 > MZ4, while the soil EC followed the order MZ3 (12.5 dSm^{-1})> MZ4(6.92 dSm^{-1}) > MZ2 (9.5dSm^{-1}) = MZ1 (dSm^{-1}) without no significant between MZ1 and MZ2. The content of soil $CaCO_3$ followed the order MZ3 (4.99%) > MZ2 (4.32%)> MZ1 (2.18%) = MZ4 (2.13) without no significant between MZ1 and MZ4. Regarding soil content of organic matter, the highest value was recorded with MZ1(0.66%) while the lowest value was recorded with MZ3 (0.43%) without statistically significant differences between MZ1 (0.66), MZ2 (0.64%), and MZ4 (0.59%). The concentration available N, P and K was the highest in MZ1 (49.97$mgkg^{-1}$), MZ4 (3.82$mgkg^{-1}$), MZ3 (0.77 $mgkg^{-1}$), respectively and the lowest in MZ3 for available N (27.30$mgkg^{-1}$) and P (1.36 $mgkg^{-1}$) whereas MZ4 for available K (0.49 $mgkg^{-1}$). Soil CEC and BD ranged from 43.51 $cmolckg^{-1}$ in MZ1 to 54.28 $cmolckg^{-1}$ and 1.24 Mgm^{-3} in MZ1 to 1.35 Mgm^{-3} in MZ2, respectively. It is clear from these results that the limiting factors for crop production are the low concentration of nutrients and organic matter in the soil and the high concentration of soil salinity in the MZs, in varying degrees, between different MZs. therefore, efforts must be done to improve these limitations of crop production. Therefore, these crop production restrictions must be improved by adding appropriate nitrogen, phosphate, and potassium fertilizers with an interest inorganic fertilizer as well as soil leaching process to reduce the concentration of salts tothe acceptable limit for crops. These findings are in agreement (Nasef *et al.,* 2009; Shaban *et al.,* 2010; Ali *et al.,* 2014; Ibrahim *et al.,* 2015; AbdElghany *et al.,* 2019; Mohaseb *et al.,* 2019) who all proved that the study area responds significantly to nitrogenous, phosphorous, and potassium fertilization, as well as demonstrated that conducting soil leaching process leads to a decrease in soil salinity and this is reflected in the increased crops yield. Therefore, following this approach in delineating the MZs will benefit those working in the agriculture field in determining the required quantities of mineral and organic fertilizers, as well as calculating the leaching water requirements for each MZ without extravagance where each MZ has requirements and quantities different from the other.

CONCLUSIONS

The study confirmed that this methodology can be used in the delineation of site-specific management zones using multivariate analysis and geographic information system techniques. The study revealed a large variation in the soil characteristics values in Sahl Al-Hussainiyah, El-Sharkia Governorate, Egypt. Based on the cluster analysis technique and PCA were used, four MZs were identified. there were Statistically significant differences between these MZs ($p < 0.05$). MZ1, MZ2, MZ3, and MZ4 were 3.01 (466.56 ha), 36.47 (5658.9 ha), 31.02 (4813.54 ha), and 29.5% (4577.8 ha) of the total area (15516.8 ha). The results revealed that there are statistically significant differences between the different MZs ($p < 0.05$). the limitation factors for crop production are the low concentration of nutrients and organic matter in the soil and the high concentration of soil salinity in the MZs, in varying degrees, between different MZs. therefore, efforts must be done to improve these limitations of crop production. Therefore, these crop production restrictions must be improved by adding appropriate nitrogen, phosphate, and potassium fertilizers with an interest in organic fertilizer as well as soil leaching process to reduce the concentration of salts to the acceptable limit for crops.

Declaration of competing interest

The author(s) declare no conflict of interest

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