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ASSESSMENT THE SOIL PROPERTIES AFFECTING SALINITY AND SODICITY OF BAFRA PLAIN USING MULTIVARIATE STATISTICAL TECHNIGUES

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Abstract: Multivariate statistical techniques are useful for characterizing and estimating dynamic soil properties. Multivariate statistical techniques of cluster analysis (CA) and factor analysis (FA)/principal component analysis (PCA) were employed to comprehend the complex relationships between salinity, sodicity and some soil properties in irrigated part of Bafra Plain, Turkey. Seventy eight soil samples were randomly collected from 0–30 and 30–60 cm depths on September 2008. Cluster analysis grouped the sampling sites into three clusters based on similarity of soil properties. FA suggested a four-factor model that explained over 80.32% of the total variations in soil properties of 0-30 cm depth, with factor 1 comprising exchangeable sodium percentage (ESP), Na and EC; factor 2 comprising Mg, cation exchange capacity (CEC) and clay content; factor 3 comprising pH; and factor 4 comprising exchangeable Ca and Mg contents. FA suggested a three-factor model that explained 70% of the total variations in soil properties of 30-60 cm depths, with factor 1 comprising ESP, Na, pH and EC; factor 2 comprising CEC, clay and Mg concentrations; and factor 3 comprising Ca and K concentrations. The results demonstrated that cluster and principle component analyses are both useful in monitoring the soil degradation and help decision makers to take necessary precautions in advance.

Key words: Cluster analysis, principle component analysis, Soil, Salinity, Sodicity.

1. INTRODUCTION

While not as dramatic or immediate as earthquakes or large-scale landslides, excessive soil salinity is a severe environmental hazard and has considerable adverse impacts on productivity of agricultural plants. Under arid or semi-arid conditions and in regions with poor natural drainage, there is an increased potential for salt accumulation in soils at hazardous levels. Accumulation of salts increases the osmotic potential of soil solution which in turn affects water movement and restricts water uptake by plants (Metternicht & Zinck, 2004).

The applications of multivariate analytical methods such as cluster analysis (CA), factor analysis (FA), and principle component analysis (PCA) to environmental data have tremendously increased and yielded meaningful information. CA and FA/PCA have been widely used in soil surveys, researches (Webster & Oliver, 1990) and in the assessment of water quality (Kim et al., 2005; Zhao & Cui, 2009; Akbal et al., 2011) as an alternative or complement to other soil and water classification methods (Visconti et al., 2009). Perez-Sirvent et al., (2003) used PCA to investigate temporal changes in the chemical properties of slightly-to-moderately saline calcareous soil solutions, and some recent studies have applied multivariate analysis and GIS techniques in urban soil assessment (Facchinelli et al., 2001; Manta et al., 2002; Li et al., 2004; Zhang, 2006).

In the present study, CA was used to group sampling sites by soil characteristics, and FA/PCA ratio was used to identify the principle factors affecting soil characteristics and plot their spatial distributions to locate potentially problematic areas for plant growth in the Bafra Plain, Turkey.

2. MATERIAL AND METHODS

2.1. Study area

The study area is located within the Black Sea Coastal Region of the Samsun province (between 41º30'- 41º45' latitude and 35º30'-36º15' longitude) in the northern Turkey (Fig. 1). Soils are formed over alluvial deposits of Kizilirmak River at various elevations and classified as Typic Ustifluvents, Chromic Haplusterts and Vertic Haplustepts. The climate is semi-humid with mean annual precipitation of 802.6 mm most of which falls between September and April and an average annual temperature of 14.4ºC (Arslan, 2012). The Kizilirmak River is the major source of irrigation water in the Bafra Plain and groundwater and drainage water are also used in the areas of water scarcity.

2.2. Soil sampling and Laboratory analysis

Seventy eight soil samples from 0-30 cm and 30-60 cm depths were collected in September 2008. Sampling sites were located at irregular intervals, and each sampling location was recorded with a global positioning system (GPS). Soil samples were air-dried and passed through a 2 mm sieve prior to physical and chemical analyses.

Electrical conductivity (EC) is the most common measure of soil salinity and is indicative for the ability of an aqueous solution to carry an electric current. Electrical conductivity measurements of extracted soil saturation paste were performed using a conductivity meter (Rhoades, 1982). Salinity classification was performed based on electrical conductivity, as follows: non-saline: 0-0.98 dSm^{-1}; very slightly saline: 0.98-1.71 dSm^{-1}; slightly saline: 1.71-3.16 dSm^{-1}; saline: 3.16-6.08 dSm^{-1} and very saline: $\geq$ 6.08 dSm^{-1} (Soil Survey Staff, 1993; Janzen, 1993; Smith & Doran, 1996). Soil pH was measured using a pH meter with glass electrode, and soils were classified according to pH as either mild (7.4-7.9), moderate (7.9-8.4), high (8.5-9.0), or very high ($\geq$ 9.0) (Bruce & Rayment, 1982).

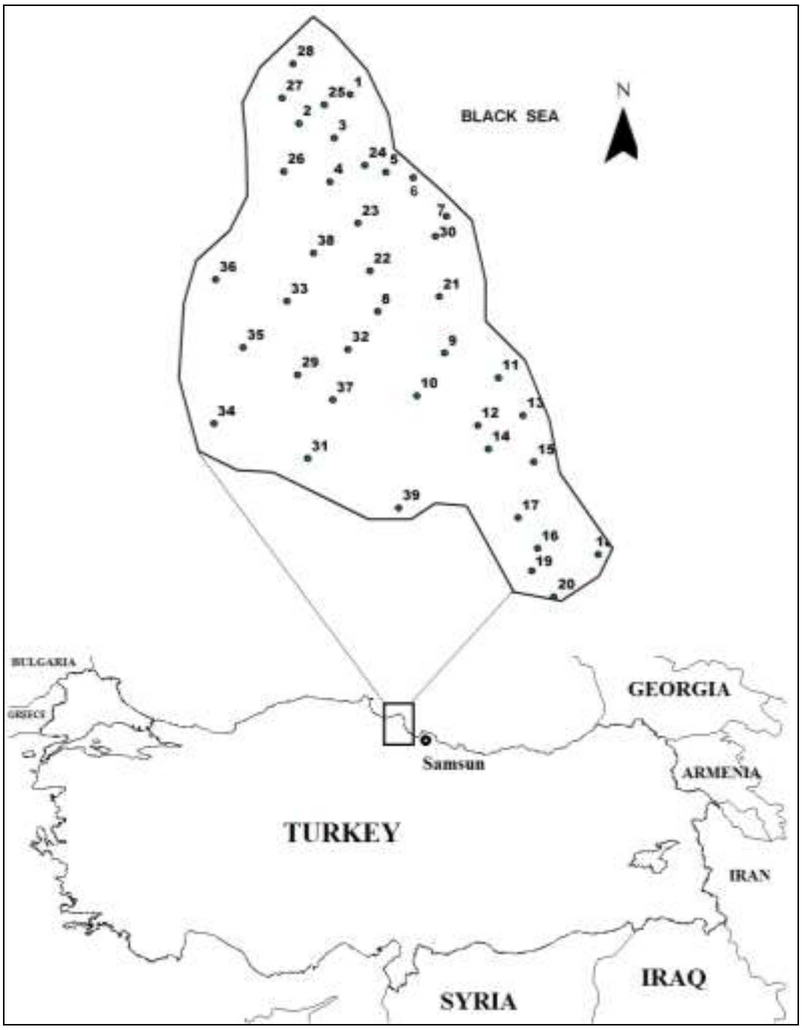


Figure 1. Location of Study Area and Distribution of Sampling Points

Soil texture was determined with a method described by Bouyoucos (1951). Exchangeable Ca and Mg contents were analyzed by EDTA titration, with Eriochrome black T used as an indicator. Na and K contents were measured by flame photometry. Exchangeable sodium percentage (ESP) was calculated as follow:

$$ESP = \frac{Na^{+}}{CEC} * 100 \quad (1)$$

Where:
ESP is the exchangeable sodium percentage (%), Na is the measured exchangeable Na (meq100g^{-1}) and CEC is the cation exchange capacity (meq100g^{-1}).

The classification of soil for ESP values were as non-sodic (ESP < 6%), sodic (6% to10%), very sodic (10% to15%), excessively sodic (15% to 25%) and extremely sodic (ESP > 25%) (Isbell, 1995). Cation Exchange Capacity (CEC) was determined with the sodium saturation method (Rhoades, 1982). CEC depends on soil texture and organic matter content, and CEC increases with increasing clay and organic matter content of soils. Clay content affects soil salinity and sodicity due to the high surface-area-to-volume ratio of clay particles (Rhoades, 1982).

2.3. Spatial Analysis

Geostatistical methods were applied to determine the spatial distribution of the soil properties. The spatial structure of variables was characterized using experimental semivariogram, expressed as;

$$\lambda(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[z(x_i) - z(x_{i+h}) \right]^2 \quad (2)$$

where, z(xi) and z (x i+h) are the variables of interest at locations xi and x i+h respectively, and N(h) is the number of pairs on the locations separated by a distance h (Isaaks & Srivastava 1989). Theoretical semivariogram (covariance) models are used to predict the values of factor scores at unsampled locations. The geostatistical analyses were carried out with ArcGIS 10.1 software.

2.4. Multivariate Analysis

Multivariate statistics are widely used to identify and evaluate soil properties and groundwater quality in environmental studies. The multivariate techniques enable to simplify, organize and classify the data to draw out useful meaning. The method can also be used to clarify the temporal and spatial variations due to relations of natural and human factors with the seasonality. The data obtained for the soil samples were analyzed with cluster and factor /principle component analyses.

2.5. Cluster analysis (CA)

Cluster Analysis describes a number of multivariate techniques whose primary purpose is grouping objects based on their characteristics. Objects are grouped into clusters so that objects in the same cluster are more like one another compared to the objects in other clusters. Tariq et al., (2005) and Morrison et al., (2011) successfully used cluster analyses to classify soil samples by grouping samples according to the similarities. Menció & Mas-Pla (2008) also proved that CA method is an extremely powerful grouping mechanism. Thus, the CA was applied to group the soil samples based on EC, pH, clay content, ESP, CEC, exchangeable Na, Ca, K and Mg contents.

2.6. Factor Analysis (FA)/Principle Component Analysis (PCA)

Factor analysis (FA) is a multivariate statistical technique examines the underlying patterns or relationships within a large number of variables and summarizes information in a smaller set of factors or components for predictive purposes. Principle component analysis (PCA) is the most frequently employed approach to transform the original variables into new and uncorrelated variables (axes) or principal components. Variations in data can be concisely accounted for in PCA (Pop et al., 2009). The amount of variance explained by an individual factor is referred to as an “Eigenvalue”. Factors possessing the highest Eigenvalues are responsible for explaining the greatest variation in data. Liu et al., (2003) classified factor loading as “strong”, “moderate” and “weak”, corresponding to absolute values of >0.75, 0.50-0.75 and 0.30-0.50, respectively. PCA have been used to assess soil salinization and alkalinization (Mohamedou et al., 1999; Dawes & Goonetilleke, 2006; Vance et al., 2002; Visconti et al., 2009; Sha-Sha et al., 2011). Utilizing PCA to classify soil samples based on exchangeable sodium percentages and spontaneous or mechanical dispersion, Sha-Sha et al. (2011) used an Eigenvalue of >1 to distinguish factors that explained higher total variation in the data compared to individual soil properties. Eigenvalue of <1 was used to distinguish factors explaining lower total variation than individual soil properties.

Because of the wide variations in measurement scales and numerical ranges of the original variables, the present study used the Z-test to standardize the raw data, eliminating the effects of different units of measurement and making the data dimensionless. Z-scores for all chemical variables were calculated using the following formula:

$$Z_i = \frac{x_i - \bar{x}}{S} \quad (3)$$

where $\bar{x}$ and S represent the mean and standard deviation of the variable, and z_i and x_i represent the standard score and the value of the variable in sample i.

3. RESULTS AND DISCUSSION

Descriptive statistics of physical and chemical soil properties (0-30 cm and 30-60 cm) are given in Table 1 and 2, respectively. Mean clay contents were 48.6% and 48.7% at 0-30 cm and 30-60 cm depths and ranged from 15.1 to 83.1% for surface and 18.0 to 80.5% for subsurface soils. Electrical conductivity (EC), pH and exchangeable sodium percentage (ESP) values exceeded the threshold values for healthy plant growth. Average EC values (2.16 dSm^{-1}) indicated that soils were slightly saline though maximum values of EC showed some saline and very saline spots in study area. Average organic matter content of soils was slightly higher than the 2.0% in Bafra Plain (Sağlam & Dengiz, 2012). Coefficient of variability (CV) is an important parameter in describing the variability of a soil property. The variability of soil properties was ranked a CV ≤15% as the least, 15% < CV ≤ 35% as moderate, and CV >35% as the most variable (Wilding, 1985). The relatively large CV values of clay and sand contents, ESP, K and Na contents at surface and subsurface indicated the high variability's at local scale.

The soil pH at surface and subsurface can be classified as low variable (3.28 and 4.79%).

The soil pH at surface and subsurface ranged from moderate to high/very high, and ESP ranged from non-sodic to very sodic. The ESP and pH values increased with depth whereas EC remained the same throughout the soil profile.

3.1. Cluster Analysis (CA)

Cluster Analysis was separately applied to each soil depth. Soil characteristics were classified into nine dimensional spaces (clay, EC, pH, CEC, ESP, Ca, Na, K and Mg), and the results were represented as a dendrogram. Soils at 0-30 cm depths were classified into three groups with significant differences in soil properties (Table 3, Fig. 2a). Soils in group 1 and group 2 were very slightly saline and soils in group 3 were saline. Soils in all three groups were sodic and had moderate pH values. Soils in group 1 had the lowest EC, CEC, Na and Mg values of the three groups. The ESP, clay and Ca contents of soils in group 1 were significantly higher than those in group 2. Soils in group 3 with the exception of pH had the highest values for all parameters tested.

Soils at 30-60 cm depths were also classified into three groups with significant differences in soil properties (Table 4, Fig. 2b). The ESP had the most significant variations among the different properties examined. Soils in group 1 had the lowest EC, pH, ESP, Na and Mg values of the three groups. But ESP values in Group 1 also slightly exceeded the threshold value of 6%. Soils in group 3 had the highest values for all parameters tested, except for Mg. Soils in group 1 were very slightly saline, sodic and had moderate pH values. Soils in group 2 were very sodic, soils in group 3 were excessively sodic and consisted of heavy clayey soils. Both sodicity and pH represented problems at varying degrees for all soil groups tested.

The results indicated that cluster analysis can be of significant use in classifying soils into meaningful groups. Parameters in different groups can easily be interpreted to provide an understanding of site conditions.

3.2. Principle Component Analysis (PCA) and Factor Analysis (FA)

Factor analysis was carried out on the data sets of 9 soil attributes, and the soil attributes were compared to identify the sources of variation. Eigen values, percentages of variance and cumulative percentages for the four factors identified are given in table 5.

FA yielded four factors with Eigenvalues of >1 explaining 80.32% of the total variances in the data set for 0-30 cm depths (Table 5). The spatial distribution of the scores for factor 1 (salinity-sodicity), factor 2 (soil texture), factor 3 (sodicity) and factor 4 (Ca) were shown in Figures 3a, 3b, 3c and 3d, respectively. For each factor, higher values were indicated by darker colors and lower values were indicated by lighter colors. Factor 1 explained 35.50% of the total variance, with strong positive loadings on ESP, Na and EC.

Table 1. Descriptive statistics of soil samples for 0-30 cm depth (N = 39).

Parameter	Minimum	Maximum	Mean	Stand Dev	CV (%)
Clay (%)	15.5	83.1	48.6	17.98	36.99
Silt (%)	11.5	42.3	27.1	9.10	33.54
Sand (%)	5.0	70.4	24.3	15.61	64.34
EC (dSm^{-1})	0.72	7.02	2.16	1.18	54.63
pH	7.41	8.76	7.92	0.26	3.28
ESP (%)	2.90	27.72	9.76	5.55	56.86
CEC (meq100 g^{-1})	25.87	54.42	38.10	7.02	18.43
Na (meq100 g-1)	1.20	16.02	4.06	3.39	83.50
K(meq100 g-1)	0.13	6.02	1.10	1.16	105.45
Ca(meq100 g-1)	17.60	38.83	27.64	5.20	18.81
Mg(meq100 g-1)	6.40	22.20	13.23	4.43	33.48

EC: Electrical conductivity, CEC: Cation exchange capacity, ESP: Exchangeable sodium percentage

Table 2. Descriptive statistics of soil samples for 30-60 cm depth (N = 39).

Parameter	Minimum	Maximum	Mean	Stand Dev	CV (%)
Clay (%)	18.0	80.5	48.7	17.61	36.20
Silt (%)	12.5	47.9	28.4	8.90	31.36
Sand (%)	6.5	68.7	23.0	15.81	68.83
EC (dSm-1)	0.51	4.68	2.16	0.99	45.83
pH	7.56	9.43	8.15	0.39	4.79
ESP (%)	2.49	35.91	12.39	8.57	69.17
CEC (meq100 g-1)	26.20	65.98	38.76	8.93	23.04
Na (meq100 g-1)	0.88	24.69	5.38	5.27	97.96
K(meq100 g-1)	0.10	3.96	0.82	0.70	85.37
Ca(meq100 g-1)	14.60	41.20	25.39	5.88	23.16
Mg(meq100 g-1)	5.20	24.20	13.79	5.62	40.75

EC: Electrical conductivity, CEC: Cation exchange capacity, ESP: Exchangeable sodium percentage

Table 3. Mean parameter values for groups (0-30 cm)

Groups	EC	pH	ESP	CEC	Clay	Na	Ca	Mg
Group 1 (n=20)	1.67	7.92	8.77	34.80	44.91	2.61	28.83	10.31
Group 2 (n=10)	2.03	7.97	8.45	34.88	41.48	3.58	22.08	15.52
Group 3 (n=9)	3.37	7.87	13.42	49.01	64.77	7.79	31.19	17.17

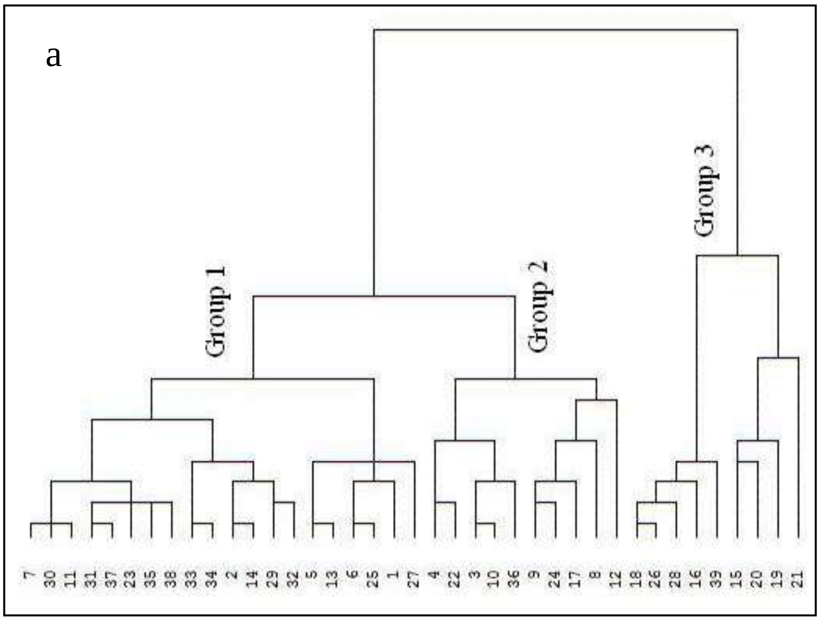
All values in meq $100g^{-1}$ soil except pH, EC (dSm^{-1}) and clay (%)

Table 4. Mean parameter values for groups (30-60 cm)

Groups	EC	pH	ESP	CEC	Clay	Na	Ca	Mg
Group 1 (n=12)	1.39	8.08	6.06	35.92	48.83	2.62	29.05	11.83
Group 2 (n=14)	2.02	8.14	12.48	32.34	33.76	3.27	21.67	12.59
Group 3 (n=13)	3.02	8.24	18.13	48.28	64.52	10.21	26.02	16.88

All values in meq $100g^{-1}$ soil except pH, EC (dSm-1) and clay (%)

Factor 1 represents sites with salinity and sodicity problems caused by excessive irrigation and lack of drainage. Excessive salinity and sodicity represented the greatest problem in the northeast area of the study region (Sites 21, 15, 19 and 27) and the smallest problem in the southwest area (Sites 36, 35, 39 and 34) (Fig. 3a). Factor 2 explained 16.97% of the total variance, with strong positive loadings on Mg and CEC and moderate loading on clay. Factor 2 is related to soil texture, with higher CEC values expected in soils with high clay content.



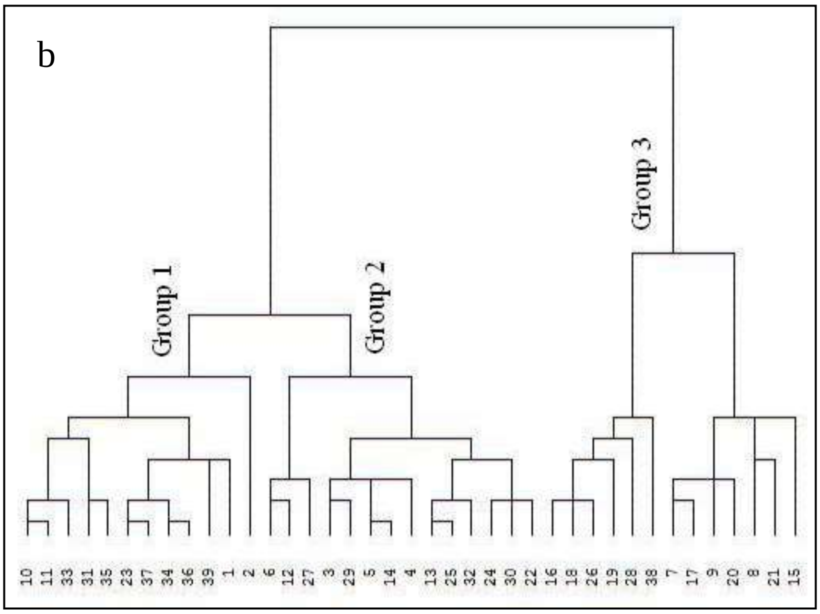


Figure 2. Cluster Analysis identification of soil groups for 0-30 cm (a) and 30-60 cm (b)

Table 5. Rotated factor patterns of four factors after varimax rotation (0-30 cm)

Parameters	Factor 1	Factor 2	Factor 3	Factor 4
ESP	**0.938**	-0.084	0.154	0.000
Na	**0.874**	0.357	0.172	-0.052
pH	**0.804**	0.235	-0.421	-0.096
EC	-0.001	**0.836**	-0.126	-0.324
CEC	0.389	**0.810**	0.039	0.278
Clay	0.115	**0.635**	0.356	0.342
Mg	0.043	0.043	**0.941**	-0.095
Ca	0.042	0.212	0.080	*0.729*
K	0.192	0.239	0.273	*-0.699*
Eigenvalue	3.195	1.527	1.342	1.165
Total variance (%)	35.50	16.97	14.91	12.94
Cumulative variance (%)	35.50	52.47	67.38	80.32

Bold and italic values indicate strong (> 0.75) and moderate (0.75 – 0.50) loadings, respectively

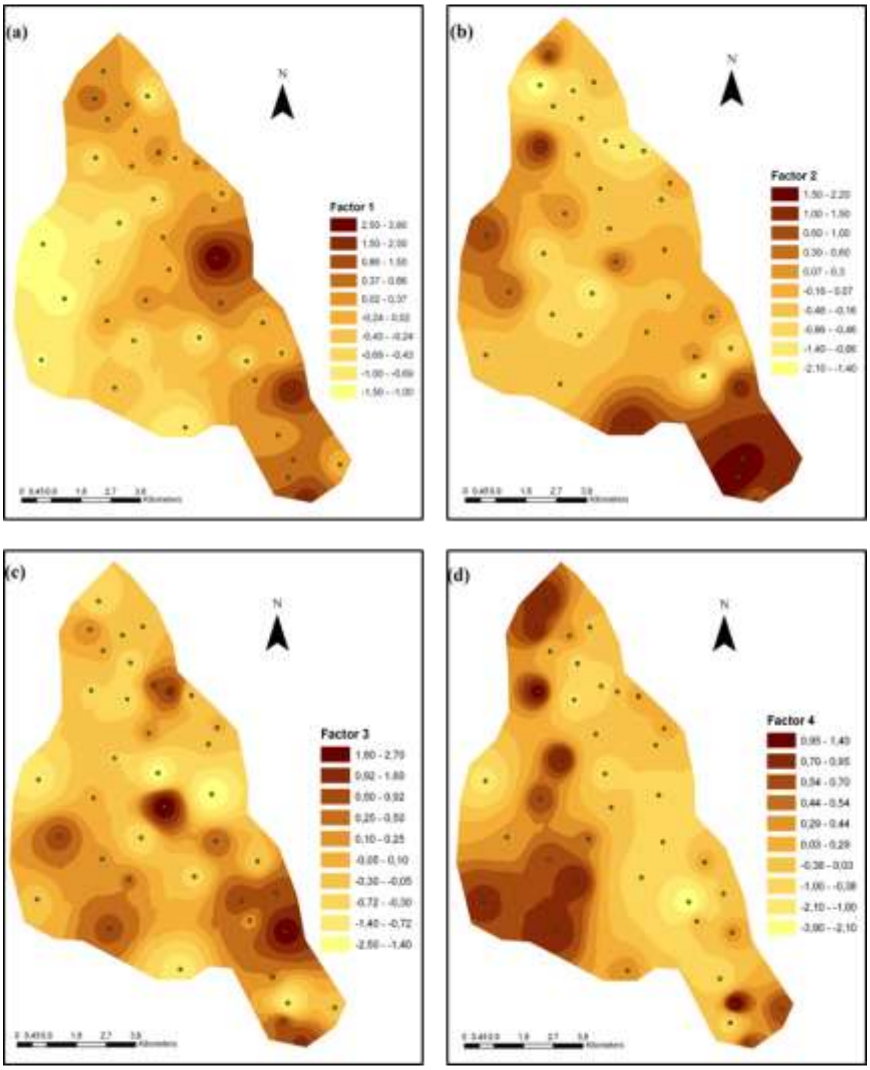


Figure 3. Spatial distribution of scores for Factor 1 (a) Factor 2 (b) Factor 3 (c) and Factor 4 (d) (0-30 cm)

Table 6. Rotated factor pattern of three factors after varimax rotation (30-60 cm)

Parameters	Factor 1	Factor 2	Factor 3
ESP	**0.937**	0.089	-0.113
Na	**0.881**	0.382	0.072
pH	**0.755**	-0.285	-0.080
EC	*0.653*	0.393	0.090
CEC	0.170	**0.826**	0.247
Clay	0.095	**0.771**	0.139
Mg	-.0002	*0.730*	-0.395
Ca	-0.215	0.171	**0.786**
K	0.107	-0.022	*0.701*
Eigenvalue	3.174	1.900	1.279
Total variance (%)	35.27	21.11	14.21
Cumulative variance (%)	35.27	56.38	70.59

Bold and italic values indicate strong (> 0.75) and moderate (0.75 – 0.50) loadings, respectively

Factor 3, which explained 14.91% of the total variance, has positive strong loadings on pH, indicating areas with pH problems. The highest scores for Factor 3 were located at sites 8, 15, 5, 10 and 12 (Fig. 3c). Factor 4 explained 12.94% of the total variance, with a moderate loading of Ca, and had the highest scores at sites 16, 26, 38, 37, 28 and 27. Factor Analysis yielded three factors with eigenvalues of >1 explaining 70.59% of the total variance in the data set for 30-60 cm depths (Table 6).

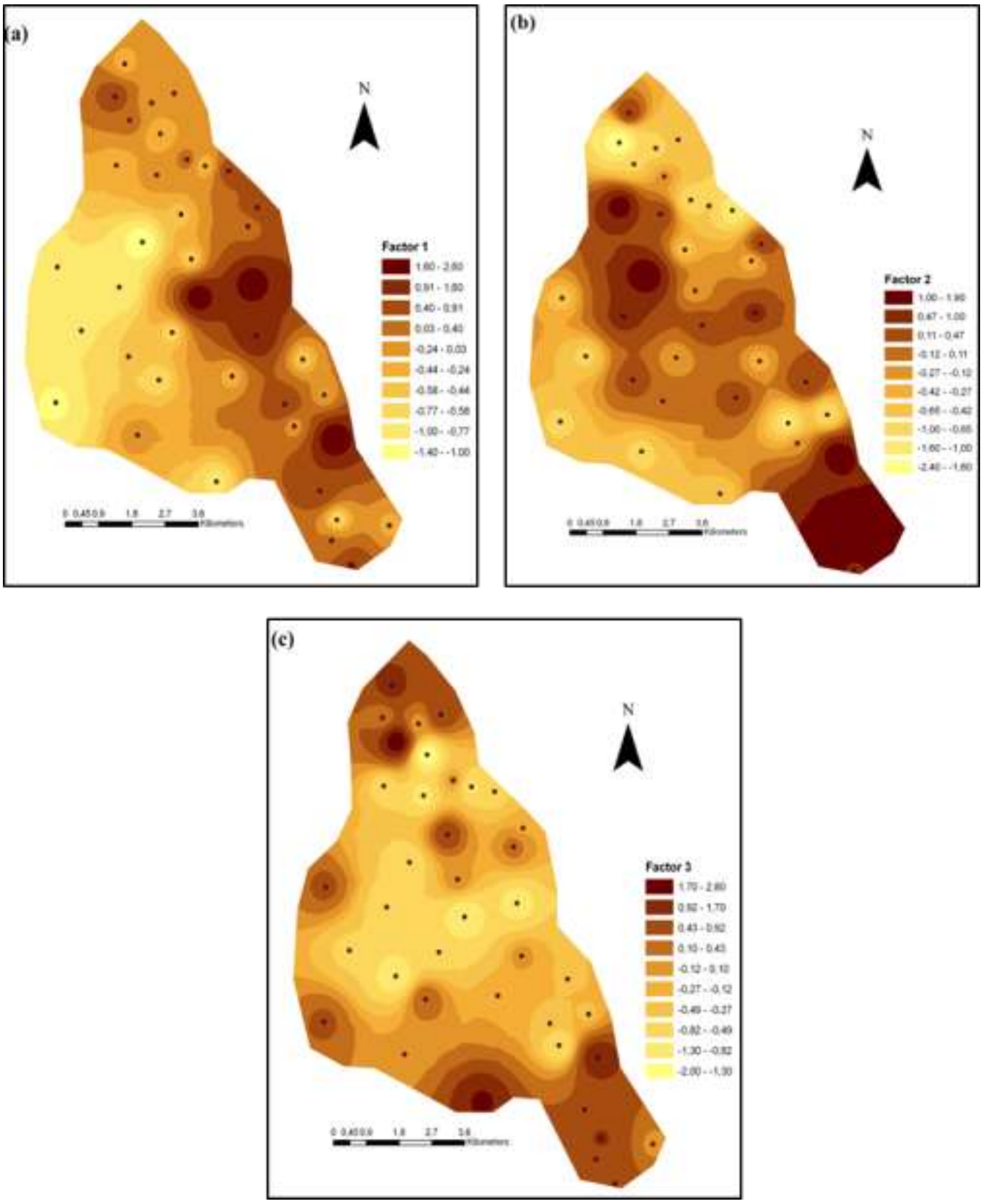


Figure 4. Spatial distributions of scores for factor 1(a), factor 2(b) and factor 3(c) (30-60cm)

The spatial distribution of the scores for factor 1 (salinity-sodicity), factor 2 (soil texture) and factor 3 (Ca) were shown in figures 4a, 4b and 4c, respectively. For each factor, the higher values were indicated by darker colors and lower values were indicated by lighter colors. Factor 1 explained 35.27% of the total variance, with strong positive loadings on ESP, Na and pH and moderate loading on EC. Factor 1 represents sites with salinity, sodicity and pH problems due to excessive irrigation and lack of drainage. Factor 2, which explained 21.11% of the total variance, was related to soil texture and correlated strongly with CEC, clay and moderately with Mg. Factor 3, which explained 14.21% of the total variance, had strong positive loadings on Ca and moderate loading on K.

4. CONCLUSIONS

Soils from 39 sampling locations were evaluated with cluster and factor/principal component analyses. Cluster analysis grouped the sample sites into 3 clusters, all of which presented varying degrees of problems for plant growth, namely, salinity and sodicity. Factor analysis/principal component analysis showed that soils at 0-30 cm depths were affected by four main factors which explained 80.32% of the total variance of the 9 variables tested. Factor analysis/principal component analysis showed that soils at 30-60 cm depths were affected by three principal factors that explained 70.59% of the total variance of the variables tested. The CA and PCA proved that the soil surface quality in study area is greater than that of the subsoil. The results demonstrated that cluster and principle component analyses are useful in monitoring the soil degradation and help decision makers to take necessary precautions in advance. Thus, multivariate statistical methods might be integrated into the future studies on soil degradation and pollution risk assessments of soil environments.

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