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ORIGINAL ARTICLE

Assessment of spatial variability in some soil properties as related to soil salinity and alkalinity in Bafra plain in northern Turkey

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Abstract The objectives of this study were to assess the variability in soil properties affecting salinity and alkalinity, and to analyze spatial distribution patterns of salinity (EC) and alkalinity (ESP) in the plain, which was used irrigation agriculture with low quality waters. Soil samples were collected from 0–30 cm, 30–60 cm, 60–90 cm and 90–120 cm soil depths at 60 sampling sites. Soil pH had the minimum variability, and hydraulic conductivity (Ks) had the maximum variability at all depths. The mean values of pH, EC, ESP and Ks increased while the mean values of CEC decreased with soil depth. Values pH, EC and ESP were generally high in the east and northeastern sides. Soil properties indicated moderate to strong spatial dependence. ESP and pH were moderately spatially dependent for three of the four depths, EC exhibited moderate spatial dependence for one of the four depths, CEC had a moderate spatial dependence at all depths, and Ks exhibited a strong spatial dependence. EC, CEC, and ESP were considerably variable in small distances. The spatial variability in small distances of EC, CEC, pH and ESP generally increased with depth. All geostatistical range values were greater than 1230 m. It was inferred that the strong spatial dependency of soil properties would be resulted in extrinsic factors such as ground water level, drainage, irrigation systems and microtopography.

Keywords Spatial variability · Geostatistics · Bafra plain · Soil salinity

1 Introduction

The suitability of soil for plant growth depends heavily on its structural properties and the nutrient concentration of the soil solution. Soil variability in the field is generally defined with classic statistical methods and is assumed to have a random variability. Soil variability occurs as a result of effect and interaction of various processes in soil profile (Parkin, 1993). Soil characteristics generally show spatial dependence (Webster, 1985). Samples close to each other have

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similar properties than those from each other. However, the classical statistic, assuming the measured data independent, is not capable to analyse the spatial dependency of the variables (Vieira *et al.*, 1983).

Geostatistical analysis is used to define the spatial dependency of soil properties both isotropically and anisotropically (Burgess and Webster, 1980; McBratney and Webster, 1983; Bos *et al.*, 1984). In recent years, a wide variety of soil morphological, physical, chemical and biological properties have been studied (Burgess and Webster, 1980; Gajem *et al.*, 1981; Yost *et al.*, 1982; Samra *et al.*, 1988; Yates *et al.*, 1988; Oztas, 1993).

Sustainable agriculture is widely recognized as a potentially viable means of meeting the future food demands of an ever-growing world population as it targets at balance agricultural productivity, economic stability, resource utilization and degradation, and environmental impacts. Soil resource management is one aspect of sustainable agriculture that is needed to overcome limitations to productivity while maintaining or enhancing environmental quality. An overall understanding of soil quality will allow management of the soil resource to ensure sustainable food, fiber, and feed production throughout the world. Currently, there is a global need for tools to evaluate the ramifications of soil resource management upon spatio–temporal changes in soil quality to ascertain sustainability of farm-management practices (Corwin and Lesch, 2005).

Agriculture productivity is threatened due to the lack of an outlet for drainage water, high groundwater level and low quality of water using as irrigation water. It is estimated that the soil quality of 350.000 ha in Turkey may be dominantly affected by perched water and low-quality irrigation water diverted from drainage canals and continued deterioration is expected. The soils in the study area are regularly flooded even after installation of the irrigation scheme. These floods resulted in leaching the readily soluble salts and the rising of groundwater level. Meanwhile, in particular, in Bafra plain low-quality irrigation water diverted from drainage channels or drilling water was used, as irrigation system has not been completed yet. EC values of well water used for irrigation are about 5 dS/m or higher because of seawater intrusion to groundwater as groundwater level was lowered by use of well water. EC of groundwater increased from 4.3 dSm^{-1} to 8.1 dSm^{-1} as a result of this intrusion. The assessment of salinity and alkalinity in soils is needed to establish data of salt-affected soils and to evaluate spatial variability for site-specific management.

The objectives of this study were to examine spatial variability in exchangeable sodium (ESP), electrical conductivity (EC), soil pH, cation exchangeable capacity (CEC) and hydraulic conductivity (K_s) in the soils in Bafra plain right land irrigated area (Turkey), and to assess spatial distribution patterns of these soil properties within this study area.

2 Material and methods

2.1 Description of the study area

The study area lies on the Black Sea coastal region of Samsun (41°30′–41°45′ latitude and 35°30′–36–15′ longitude) in the Northern Turkey. The soils of study area formed from alluvium on different elevations. The current climate in the region is semi-humid. The summers are warmer than winters (the average temperature in July is 22.2 and in January is 6.9°C). The annual average temperature is 13.9°C. The annual precipitation is 722.5 mm most of which falls between September and April (Anonymous, 2004). Soil water and temperature regime are ustic and mesic, respectively.

The groundwater level and drainage greatly differ within the study area due to the differences in elevation, which slightly increases from the seaside and reaches to 10 m within approximately 6 km distance. The study area has been under conventional tillage system including moldboard plough (about 20 cm depth) in fall, cultivator (about 15 cm depths) and disc harrow (about 10 cm depths) subsequent to threshold soil tillage, and under production of maize, pepper, watermelon, cucumber and tomato with sprinkler and furrow irrigations in the summer, and cabbage and leek in the winter.

2.2 Soil sampling and analyses

Soil samples in the 60 sampling sites and 0–30, 30–60, 60–90 and 90–120 cm depths of soil profiles in a representative of 8.187 ha were taken. The samples were air-dried, pass through a 2 mm sieve and analyzed for ESP, CEC, EC and pH. Soluble salts were calculated from the measurement of EC in the soil extraction by the use of a conductivity meter (Rhoades, 1982).

Table 1 Some physical and chemical properties of soils in the study area

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cm3)	Field capacity (%)	SN (%)
0–30	27	31	42	1.52	27	13
30–60	35	31	34	1.38	31	17
60–90	38	29	33	1.44	18	8
90–120	38	28	34	1.45	20	12

ESP was calculated from soluble salts. Soil pH was determined using a glass electrode pH meter (McLean, 1982), and CEC was measured using the sodium saturation method (Rhoades, 1986). Hydraulic conductivity (K_s) was measured based on Darcy's law:

$$K_s = \frac{VL}{At\Delta h} \qquad (1)$$

where K_s = saturated hydraulic conductivity (m s^{-1}); V = volume of water (m^3) discharging the permeameter in time $t\,(s)$; L = core length (0.2 m); A = crosssectional area of core (1.8×10^{-3} m^2); Δh = hydraulic head difference between top and bottom of core (0.1 m); t = time (s).

Data analyses were conducted in three stages: (i) normality tests were applied (Kolmogorov-Smirnov); (ii) distributions were analysed by classical statistics (arithmetic mean, standard deviation and coefficient of variation, CV); (iii) geostatistical parameters, range, nugget and nugget ratio values were calculated for each variable, as a result of corresponding semivariogram analysis.

Values for unsampled locations were interpolated by kriging technique (Isaaks and Srivastava, 1989) and the results were plotted to build surface map for each variable. Normality tests were performed by SPSS (2000) and values of those variables showing lognormal distribution were subjected to log-transformation. Geostatistical software (GS + 5.1, 2001; Gamma Design Software) was used to conduct semivariogram and spatial structure analysis for variables.

The hypothesis justification behind semivariogram analysis was described by Burgess and Webster (1980). Semivariance is defined as the half of estimated square difference between sample values in a given distance (lag) (Trangmar *et al.*, 1985). Estimated semivariance at the lag h is

$$\lambda\,(h) = \frac{1}{2}N\,(h) \sum \left[z\,(xi)\,.z\,(xi+h)\right]^2 \qquad (2)$$

where z is the regionalized variables, $z(xi)$ and $z(xi{+}h)$ are measured sample values at xi and $xi + h$ points. N is the number of pairs separated with distances h (lag space). Model selection for semivariograms was done considering coefficient of variation (r^2) and visual fitting. Nugget variance effect, expressed as the percent of total semivariance, was used to rank spatial dependency of soil variables. The variable was considered strongly dependent if the rate was equal or lower than 25%, moderately dependent if it was between 25 and 75%, and weakly dependent if it was greater than 75% (Cambardella *et al.*, 1994). When the slope of semivariogram was close to zero, the variable was considered random (no spatial dependency) (Cambardella and Karlen, 1999).

3 Results and discussion

Among the soil properties analyzed, the coefficients of variation (CV) for hydraulic conductivity (Ks) were greatest, while that for pH was lowest in all the four layers studied (Table 2). The Ks was relatively more variable in the topsoil (0–30 cm depth) as compared to those in other depths. The CV of the other soil properties except pH was fairly high, indicating that soil properties were generally heterogeneous. In general, the CV obtained for the other soil properties, except EC and CEC, decreased with soil depth. However, the mean values of pH, EC, ESP and Ks increased while the mean values of CEC decreased with soil depth due to that the clay content decreased with soil depth. EC and ESP concentration increased when CEC in the soil solution decreased (Van Asten *et al.*, 2003). The pH values varied from 7.1 to 9.7, having a mean of 8.3 at all the depths. The pH, EC and ESP except Ks and CEC had generally high values in these portions because of the east and northeastern sides had high groundwater level (Figures 2–6). Application of poor quality water would result in increase in pH, EC and ESP. A highly significant positive correlation between soil salinity and water content was found

Table 2 Descriptive statistics for selected properties of soils

Soil property	Depth (cm)	Mean	S.D.	C.V.	Minimum	Maximum
Ph	0–30	8.0	0.4	5.0	7.4	9.4
	30–60	8.2	0.4	5.3	7.6	9.7
	60–90	8.3	0.4	5.3	7.1	9.5
	90–120	8.4	0.4	4.7	7.7	9.3
EC	0–30	1.8	1.0	57.2	0.8	6.0
	30–60	2.4	1.8	74.1	0.6	10.0
	60–90	2.7	1.9	69.1	0.5	11.6
	90–120	2.6	2.2	84.5	0.7	16.0
CEC	0–30	38.2	8.9	23.3	16.5	60.9
	30–60	33.3	11.6	34.7	6.9	60.0
	60–90	26.8	11.8	44.1	8.7	70.0
	90–120	27.4	11.5	41.9	7.8	70.0
ESP	0–30	7.7	7.1	92.2	0.9	39.4
	30–60	8.5	7.8	91.1	0.7	40.9
	60–90	9.5	7.8	81.8	0.9	36.5
	90–120	10.5	8.5	81.1	1.2	42.5
Kh	0–30	0.353	1.00	283.40	0.025	7.15
	30–60	0.561	1.23	219.47	0.030	6.50
	60–90	0.838	2.10	250.81	0.028	13.91
	90–120	0.695	1.68	242.44	0.030	11.05

in a feild with clay Entisol having low infiltration capacity (Miyamoto and Chacon, 2005). Another reason of high values of these soil properties in the lower layers was that the clay content decreased with soil depth (Table 1). Kachanoski *et al.* (1988) found that EC was affected by volumetric water content, increasing with increasing water content when clay content was low.

ESP was inversely related to Ks. Ks was lower in the east and northeastern parts of the plain as compared to rest of the plain due to the higher ESP in these portions (Figures 3 and 5). This inverse relationship between ESP and Ks was appeared to be result of swelling, aggregate slaking, and blocking of water conducting pores by dispersed clay particles. In addition, Ks values decreased when ESP values increased at the toeslope position where poor drainage conditions prevail.

Soil properties differed in spatial dependence (Table 3). Directional experimental semivariograms were fitted in the directions of 0°, 45°, 90° and 135° for each soil property. There were no distinct different among the structures of directional semivariograms for soil properties. Exponential and spherical models were used to define soil properties except Ks, but spatial structure of Ks was generally fitted into linear model. Therefore, all soil properties had a range indicating existence of a spatial structure for them.

Nugget effect was higher for EC, CEC and ESP compared to pH and Ks (Table 3). This indicated that EC, CEC and ESP had spatial variability in small distances. Nugget effect is related to the spatial variability in shorter distances than the lowest separation distance between measurements (Webster, 1985). Meanwhile, the large nugget effect suggested that an additional sampling of these properties at smaller distances and in larger numbers might be needed to detect spatial dependence, and a greater sampling density will result in a more accurate salinity and alkalinity map. The nugget effects of EC, CEC, pH and ESP were generally increased with depth, but Ks that of remained relatively unchanged with depth.

When the distribution of soil properties is moderately or strongly spatially correlated, the mean extent of these distributions is given by the geostatistical range of the semivariogram. A larger range values indicates that observed values of the soil property are influenced by other values of this property over greater distances (Isaaks and Srivastava, 1989). All range values were greater than 1230 m for soil properties (Table 3). Thus, CEC had a range greater than 30 000 m at the topsoil. This indicated that CEC correlated each other over greater distances than other soil property, e.g., pH, which had a range shorter than 1500 m at topsoil.

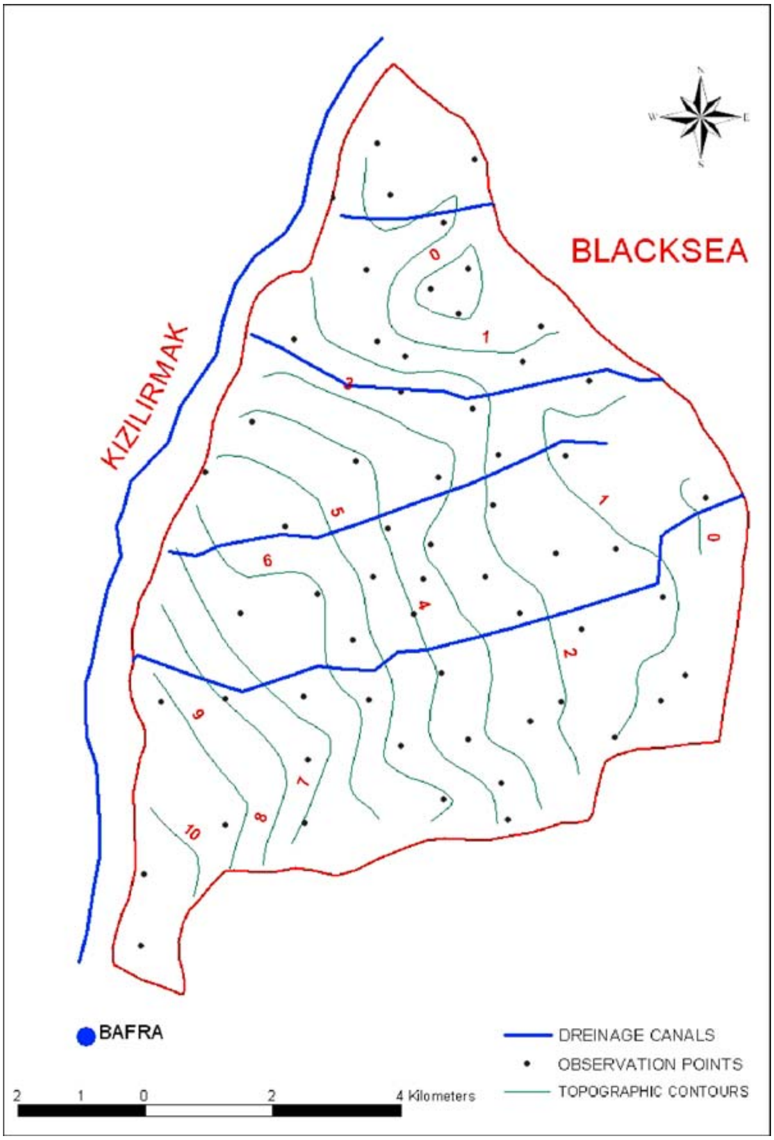

Fig. 1 Location and general layout of the study area of topographic contour map with 1.0 m contour interval. Surface elevations are in meters above mean sea level

Generally, range values of pH and ESP were smaller than that of range values of the other soil properties.

Semivariograms indicated moderate to strong spatial dependence for soil properties (Table 3). Soil properties exhibited both a consistent and non-consistent spatial dependence takes into consideration all depths. Some soil properties occurred having different spatial dependence at each depth that showed both patchy distribution in the topsoil, e.g., pH and EC, and a strong spatial dependence in the subsoil, e.g., Ks and ESP. Cambardella and Karlen (1999) reported a similar consistent and non-consistent spatial distribution according to the sampling depths, e.g., NH_4-N showed three spatial patterns: moderate spatial dependence at 0–10 cm depth, no spatial dependence at 10–20 cm depth, and strong spatial dependence 20–30 cm depth, while pH exhibited a strong spatial dependence at all depths. ESP and pH were moderately spatially dependent for three of the four depths, EC exhibited moderate spatial dependence for one of the four depths, CEC had a moderate spatial dependency at all depths, and Ks showed a strong spatial dependency.

The low nugget variance/total variance rations and small range values for soil properties exhibited patchy distribution. The patchy distribution can be related to the groundwater, fluvial deposition and topography.

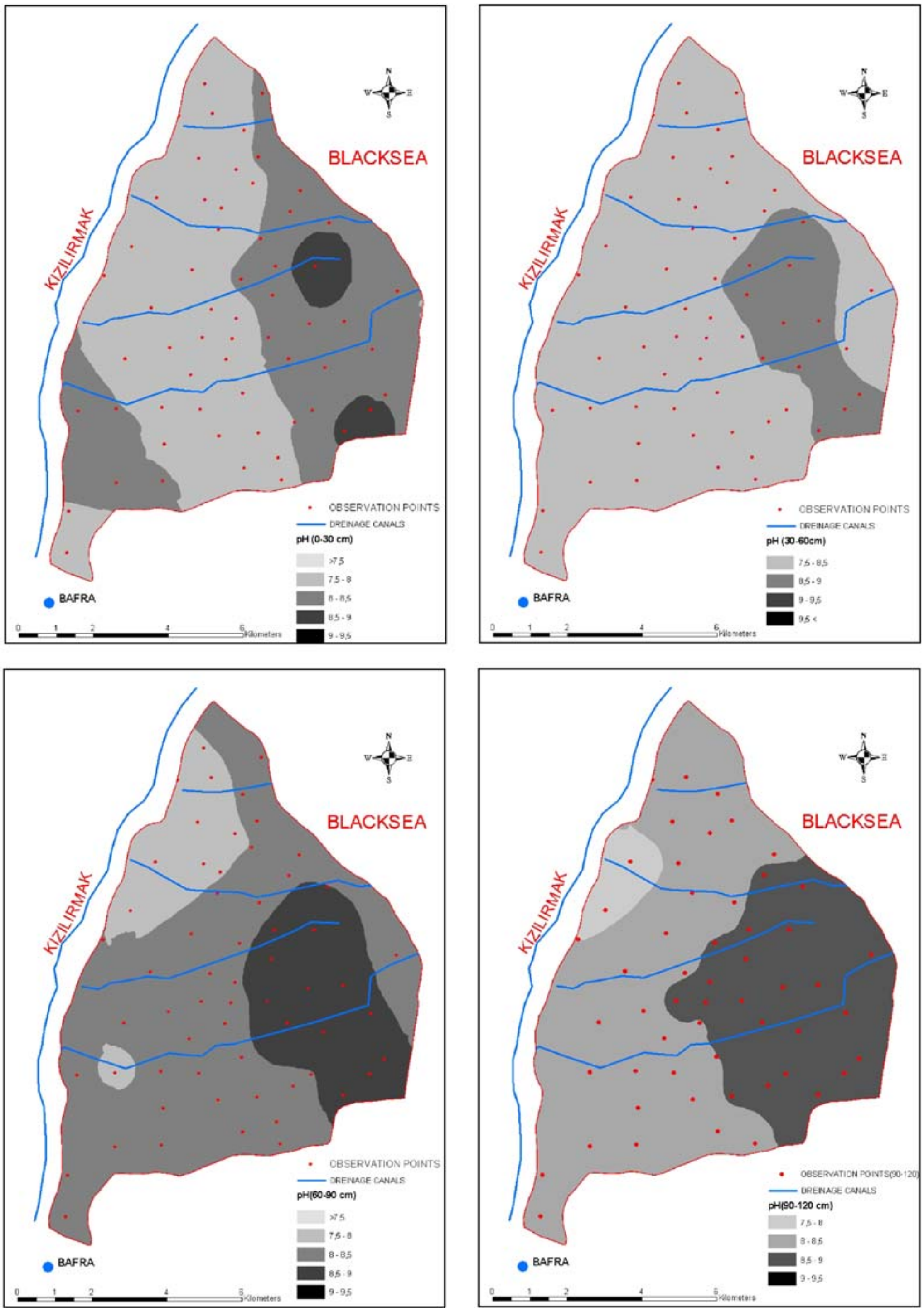

Fig. 2 Distribution maps of pH

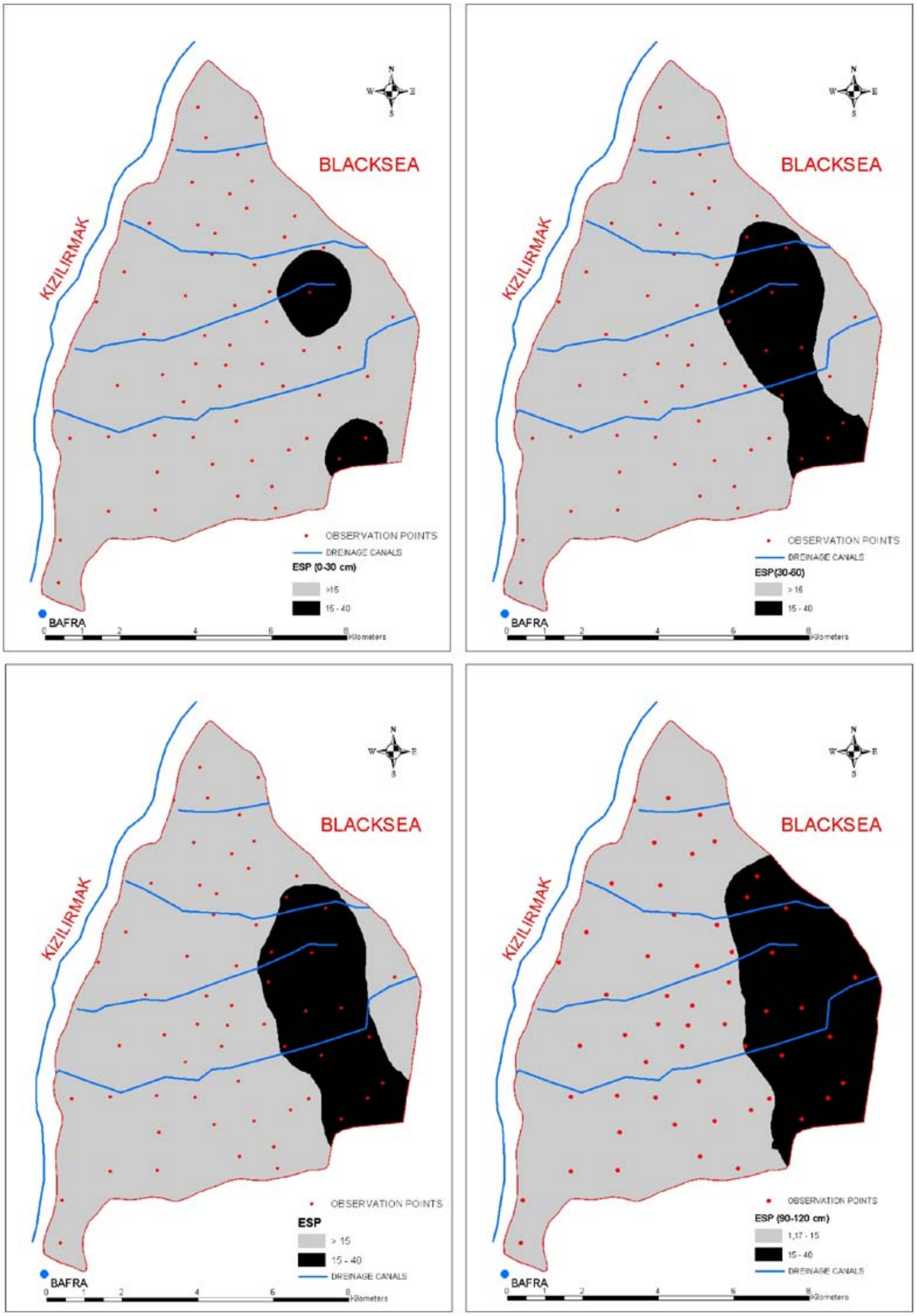

Fig. 3 Distribution maps of ESP

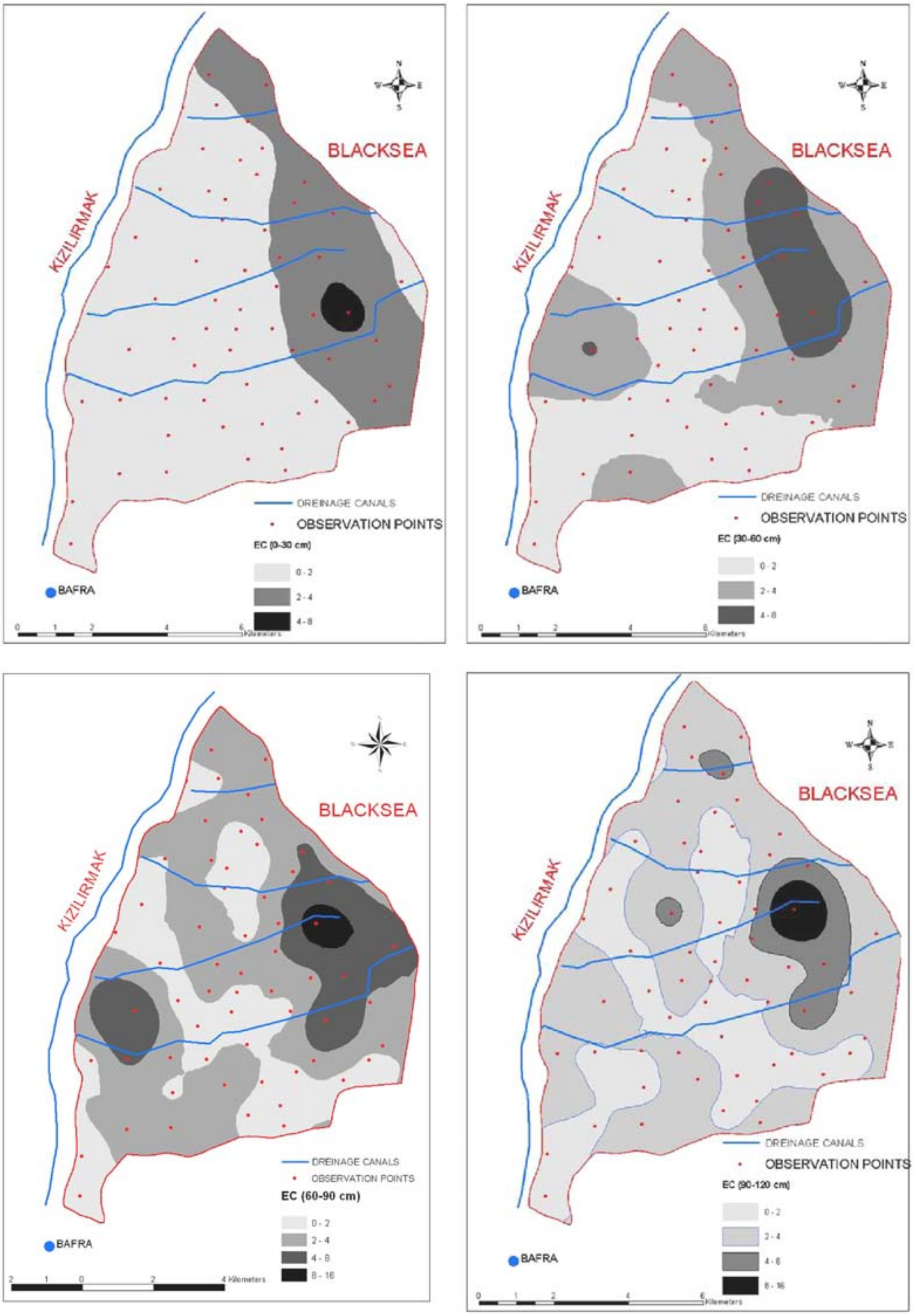

Fig. 4 Distribution maps of EC

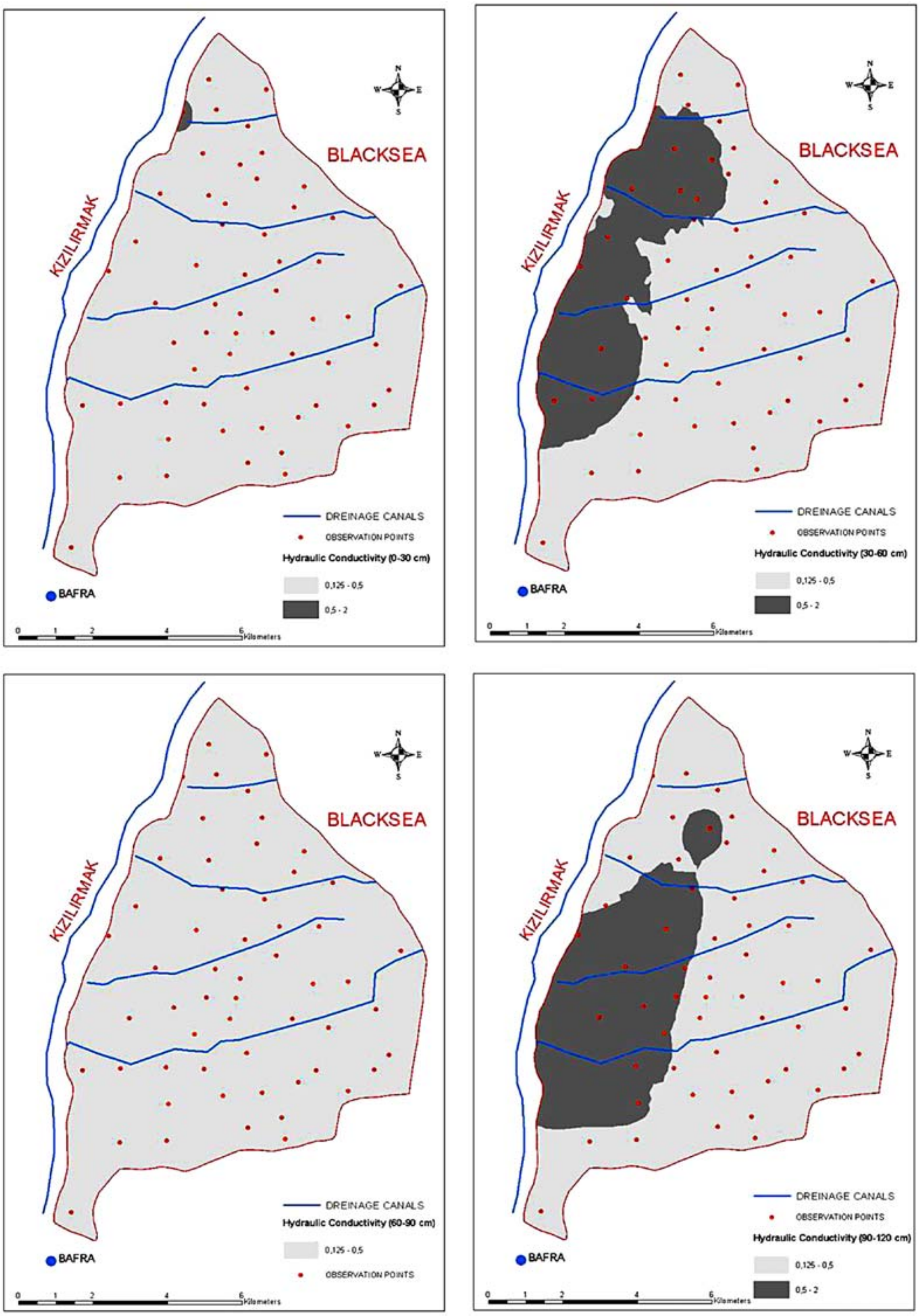

Fig. 5 Distribution maps of Kh

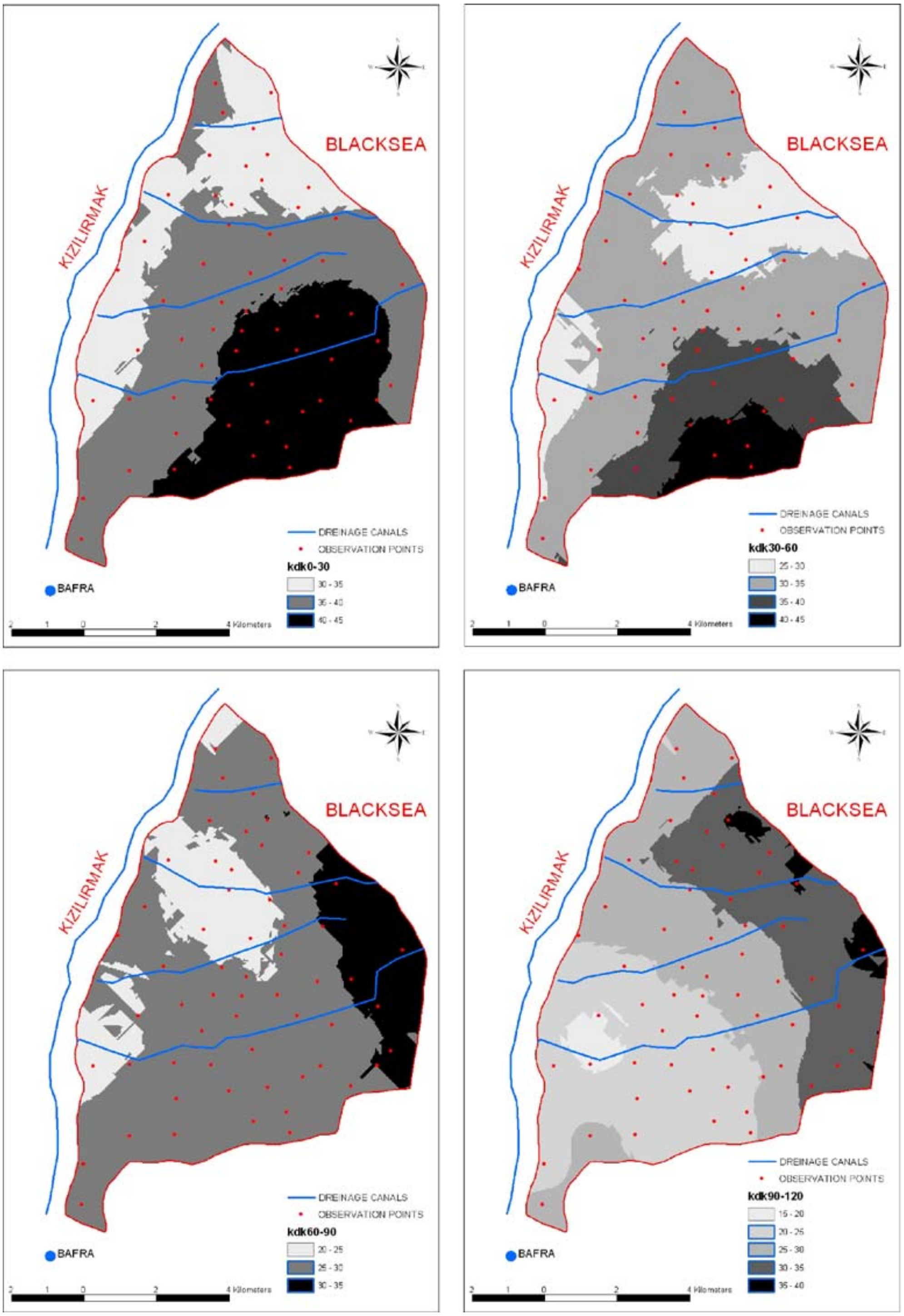

Fig. 6 Distribution maps of CEC

Table 3 Semivariogram models and model parameters for soil properties studied

Soil property	Depth (cm)	Class, model	Nugget (C_o)	Sill (C_o+C_s)	Range (m)	Nugget/Sill (%)	r^2
Ph	0–30	Exponential	0.0159	0.1728	1340.0	9.20	0.917
	30–60	Exponential	0.0001	0.2012	1230.0	0.05	0.801
	60–90	Exponential	0.1100	0.5990	22760.0	18.36	0.923
	90–120	Spherical	0.0924	0.1858	8300.0	49.73	0.752
EC	0–30	Spherical	0.0010	1.1540	3420.0	0.090	0.873
	30–60	Exponential	0.2542	0.5094	11660.0	49.90	0.856
	60–90	Exponential	0.2740	0.5490	26680.0	49.90	0.723
	90–120	Exponential	0.2385	0.5080	21130.0	46.95	0.627
CEC	0–30	Spherical	52.000	188.90	31100.0	27.53	0.591
	30–60	Spherical	99.900	240.10	27300.0	41.61	0.790
	60–90	Exponential	124.00	248.10	31100.0	50.00	0.728
	90–120	Spherical	84.800	264.70	22520.0	32.00	0.721
ESP	0–30	Spherical	7.4000	54.310	3700.0	13.62	0.826
	30–60	Exponential	0.1000	64.420	1310.0	0.15	0.772
	60–90	Spherical	14.000	65.540	4240.0	21.40	0.891
	90–120	Spherical	34.500	82.910	6330.0	41.61	0.754
Kh	0–30	Linear	0.010	4.03	17050.0	0.25	0.814
	30–60	Spherical	0.0026	0.126	22730.0	2.10	0.898
	60–90	Linear	0.0010	0.795	21420.0	0.13	0.964
	90–120	Linear	0.010	3.012	11300.0	0.33	0.926

The study area was located on Kizilirmak terraces having different slopes and drainage (Figure 1). Meanwhile, there were differences in topography of the soil sampling sites. The microtopography is important in the development of very different soil types due to a depression focused recharge and associated discharge of internal water flow in soils (Knuteson *et al.*, 1989). Strong spatial dependency of soil variables may be controlled by intrinsic variations in soil characteristics (Cambardella *et al.*, 1994). The results presented here suggested that extrinsic factors such as ground water level, drainage and irrigation systems would be important factors affecting in strong spatial dependency of soil properties studied.

Soil salinity (EC) and alkalinity (ESP) had generally high values in the east and northeast side of the study area (Figures 3 and 4). Values for ESP and EC ranged between high and very high in the northeast side, suggesting that proper soil management, and drainage techniques should be applied to decrease soil salinity and alkalinity in these localities.

4 Conclusions

The most variable soil property was Ks, with regard to the lowest variable was pH in all the four layers studied. EC and ESP were found inversely related to Ks and CEC. ESP increased when Ks decreased at the toeslope position. In general, soil properties indicated strong spatial dependency in topsoil, while they exhibited moderate spatial dependency in the subsoil. Geostatistical range values for all soil properties studied, were greater than 1230 m, indicating that soil-sampling distance for further sampling designs should be taken as 1230 m. The nugget effects of EC, CEC, pH and ESP were generally higher in topsoil layers than in subsoil layers. The majority of soil properties showed a strong spatial dependency at small distances in the topsoil. This high variability in small distances could be attributed to differences in the fluctuation, drainage, and microtopography.

Results showed that irrigation deteriorated the salinity and alkalinity in the study area and also indicated that 30% of the study area was free of salt, 53% slightly was salty, 16% salty, and 1% extreme salty, 80% was not alkaline, and 20% was alkaline. The most important reasons of salinity and alkalinity were the low quality of irrigation water, extreme water use, and insufficient drainage. In addition the present study suggested that microtopography in the study area could influence the pattern and magnitude of spatial variability in salinity and alkalinity. Recently, the amount of irrigation water used for irrigation was decreased to lower adverse effect of irrigation water on soils. In the study area furrow irrigation applied predominantly. Sprinkle or subsurface irrigation methods should be preferred over furrow irrigation to decrease amount of irrigation water used.

The results of this study include are important depicting the effect of poor management practices on soil quality parameters. The local areas with high salinity and alkalinity or having salinity and alkalinity risk should be continously monitored for depth of groundwater table and groundwater salinity to avoid upward transport of soluble salts with evaporation during irrigation season.

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