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Research Article

SPATIAL DISTRIBUTION OF SOIL SALINITY AND SODICITY IN A SEMI-ARID CLOSED DEVELI PLAIN OF TÜRKİYE

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ABSTRACT. Spatial distribution of salinity and sodicity in the semi-arid closed Develi basin of Türkiye was investigated and assessed by geostatistical methods. Soil samples were taken in 1500 × 1500 m grid system from three different depth segments (D_1 = 0-30, D_2 = 31-60 and D_3= 61-90 cm). Soil saturation paste extracts' electrical conductivity (ECe), sodium adsorption ratio (SAR) and soil reaction (pH) were determined. Classical and geostatistical parameters were obtained and kriging maps were generated to assess spatial patterns of investigated variables. The greatest coefficient of variation (CV) was identified for EC and SAR in D_1 layer (177 and 416%) and the lowest CV was identified for pH in all depths (between 5.3 - 47%). Variation of ECe and SAR for the soil depths was not found significant, but a variation of pH was found significant ($p<0.05$). Develi Plain was exhibited largely saline-sodic characteristics according to the kriging maps of ECe and SAR. In kriging maps, SAR and ECe exhibited similar spatial patterns in all of the soil depths and the variables exhibited a distribution with maximum values at the lower altitudes in the mid-sections of this closed basin.

Keywords: *Closed basin, soil salinity, sodium adsorption ratio, pH, GIS*

INTRODUCTION

Soil salinity and sodicity generate serious land degradation problems worldwide, especially in arid and semi-arid regions. Salinity and sodicity emerge through the accumulation of soluble salts and exchangeable sodium within the surface horizons with the impacts of intrinsic (climate, altitude, topography, parent material, and soil properties) and extrinsic (irrigation, fertilization and land use) factors [1-3]. Salinity and sodicity negatively influence plant growth and development by disrupting soil physical characteristics, nutrient balance, and altering osmatic pressure within soil rhizosphere [4, 5]. Soluble salts limit plant growth in two primary means: (1) altering osmatic potential of soil solution, (2) reducing air and water movement and alleviating soil erosion through dispersion of clays in sodic soils [6-9]. There are two primary stages in reclamation of saline, sodic and saline-sodic soils: i) leaching soluble salts with high quality water, ii) removal of exchangeable sodium from the soil profile through gypsum, sulphur or H_2SO_4 treatments. Since salinity and sodicity exhibit a quite complex variability, excessive leaching water and chemical needs may emerge in problematic sites. Therefore, geostatistics and kriging maps are used to check spatial and temporal distribution of salinity and sodicity and then to determine optimum and monitor success and sustainability of reclamation actions.

Geostatistics and kriging maps are commonly used to model spatial and temporal distribution of various parameters [10]. Geostatistics, which can be defined as tools for studying and predicting the spatial structure of georeferenced variables, offers a set of tools to illustrate spatial variability in a variety of natural phenomena [11-13], as well as the spatial characteristics of soil attributes [14,15]. Soil scientists focused on predicting spatial variability of soil properties using geostatistics and different kriging methods over small to large spatial scale [16-21]. There are also specific studies focusing on spatial distribution and mapping of salinity and sodicity with the aid of geostatistics [22-25].

The majority of the present research site (Develi plain) is composed of Sultan Marsh National Park, one of the largest and most important wetlands in Türkiye. The marsh was designated as a Ramsar site, a Nature Conservation Area, and recently a National Park by Turkish Government [26]. In the 1940s, large drainage channels were opened to dry out Sultan Marsh just to gain agricultural lands and to prevent malaria [27]. However, such drying practices generated serious damages on wetland ecosystem and salinity and sodicity problems emerged in dried lands. Recently a new project (a recovery project) was initiated to close these channels and bring the wetland into its original conditions. Within the scope of this project, water was diverted from Zamantı River into the wetland to get the original water level of the wetland ecosystem. This study was conducted to determine spatial distribution of salinity and sodicity in agricultural and pasture lands of Develi Plain before the implementation of Sultan Marsh Recovery Project with the aid of geostatistical methods to get spatial patterns for different soil depths. In near future, this research outcome will also be used as a reference in the identification and monitoring of the impacts of the recovery project on the salinity and sodicity of the natural and agricultural lands.

MATERIAL AND METHODS

Study Area

Develi Plain is located 45 km South of Kayseri province between 38°08′13″ - 38°20′21″ north latitudes and 35°03′33″ - 35°28′29″ east longitudes. Develi is a closed basin surrounded by Kızılırmak Basin at the north and northeast, Seyhan Basin at the east and south, and Konya Basin at the west. Develi Basin has a surface area of 3190 km^2 and 800 km^2 is constituted by Develi Plain and the lake surfaces in the middle of the basin. Develi Plain is 35 km long in the east-west direction and 30 km wide in the north-south direction. Plain altitude is ranged between 1070 - 1150 m (Fig. 1).

Sultan Marsh and Yay Lake located within Develi Plain are among the most important bird sanctuaries of Turkey. These lakes are fed by Soysallı, Çayırözü, Dündarlı, and Yahyalı streams and springs. Develi Creak, which is one of the branches of the Zamantı River, and Elbiz-Köşkpınar streams are also located within the plain.

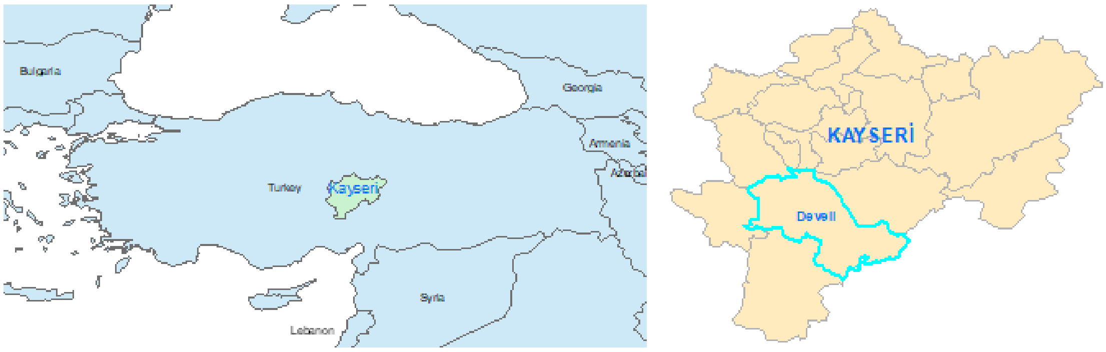

Fig. 1. *Study area*

Climate Characteristics

Develi Basin has a dominant terrestrial climate (steppe climate) with cold and snowy winters and hot and dry summers. However, the climate parameters of the town vary with the altitude. Thus, the climate is mild in lowlands but gets harsh at higher altitudes. For instance, winter months are relatively mild in Develi plain. Annual average precipitation is 317 mm, the annual average temperature is 11°C, and evaporation is 1565 mm [28].

Soil Sampling and Analysis

Soil samples were taken from three different depth segments: D_1 (0-30 cm), D_2 (31-60 cm) and D_3 (61-90 cm) in 1500 × 1500 m grid system (Fig. 2). Because of the water table and hardpans in some parts of the plain, 305, 288 and 243 soil samples were able to be taken from D_1, D_2 and D_3 depths, respectively. Soil samples were air-dried and passed through 2 mm sieve for relevant analyses.

A hydrometer test was used to measure clay, silt and sand content of soil samples following Soil Survey Staff (1996); soil pH and ECe values were measured from soil saturation paste extracts with a pH and EC meter [4,29,30]. Calcium and sodium contents were determined with the aid of flame photometer and Ca+Mg was determined with titration method [31]. Sodium Adsorption Ratio (SAR) was calculated with the use of Eq. 1:

$$SAR = \frac{Na}{\sqrt{\frac{1}{2}(Ca + Mg)}}$$

(1)

where Na, Ca and Mg contents were expressed in meq/l.

Fig. 2. *Sampling design in the study area*

Statistical Analysis

Descriptive statistics (mean, standard deviation, coefficient of variation, minimum and maximum value, skewness, kurtosis) were calculated for each parameter. Data normality was checked with the Kolmogorov-Smirnov test. Experimental data were subjected to analysis of variance (ANOVA) with the aid of SPSS 13 statistical software.

Geostatistical Analysis

The range distance related to spatial variability of the variables was estimated based on an experimental variogram. Variograms helped in relating some of the descriptors of the variogram with the spatial characteristics of variables. Experimental variograms were calculated by taking each point measurement spacing (*h*) for each soil variable (Eq. 2) [32-35]:

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

where, $z(x_i)$ and $z(x_i+h)$ are the values at point x_i and x_i+h; and $N(h)$ is the number of data pairs at h distance.

The empirical variograms were directionally calculated at the angles of 0° (N–S), 45° (NE–SW), 90° (E–W), and 135° (SE–NW). This directional examination of the variogram surfaces indicated no severe anisotropy, and therefore, only omni-directional variograms were obtained by using the best-fitting model through cross-validation method and modeled with isotropic functions to determine spatial-dependent variance within the study area. The performance of spatial interpolation methods can be assessed by 'leave one out' cross-validation. This technique involves temporarily removing the observation of one recorded point from the dataset and re-estimating its value from the remaining data using interpolation. The predicted value is then compared with the observed value from the removed point; accuracy is assessed by calculating the mean squared error (MSE) between observed and modeled values in all points. The values for each measurement point of variables were used to predict the values at unknown points using the ordinary kriging interpolation method by models and parameters of the variograms generated. The software package GS+5 (Gamma Design Software) was used to perform geostatistical computations.

RESULTS AND DISCUSSION

Descriptive Statistics

Variance analysis results for descriptive statistics of ECe, SAR, and pH at three different depths are provided in Table 1. For D_1, D_2, and D_3 depth segments, average ECe values were respectively determined as 6.75, 7.64 and 7.64 dS m^{-1}, average SAR values as 25.4, 22.1 and 19.0, and pH values as 8.35, 8.30 and 8.24. There were large differences between the minimum and maximum values of each depth segment. Such a difference reached to drastic size, especially in D_1 depth. In D_1 depth, ECe values varied between 0.28 to 109 dS m^{-1}, SAR between 0.05 to 1679, and pH between 7 to 10. The coefficient of variation is a measure of the variation of a variable within the research site. The greatest coefficient of variation was observed in D_1 depth for ECe and SAR (respectively as 177 and 416%) and the lowest coefficient of variation was observed in all depths for pH (varied between 4.7-5.3%). Such a great coefficient of variation for ECe and SAR was mainly attributed to the high water table of the research site and the resultant capillary rise and salt accumulation in lower altitudes through salt transport from high altitudes to lower altitudes.

Table 1. *Descriptive statistics, ANOVA and DUNCAN test results for EC, SAR and pH for three different soil depths ($p<0.05$)*

Soil Properties	Depths	n	Mean	S.D	CV	Min	Max	Skewness	Kurtosis	K-S
ECe	D_1	305	6.75	11.8	139	0.28	109.1	3.75	21.11	0.00
LnECe	D_1		0.92	1.31		-1.27	4.70	0.68	-0.63	
SAR	D_1		25.4	103	416	0.05	1679	13.91	217.2	0.00
LnSAR	D_1		1.63	1.78		-3.00	7.43	0.20	-0.65	
ECe	D_2	288	7.64	11.6	134	0.23	71.4	2.45	6.96	0.00
LnECe	D_2		1.02	1.44		-1.47	4.27	0.38	-1.09	
SAR	D_2		22.1	33.4	151	0.21	264	2.64	10.54	0.00
LnSAR	D_2		1.93	1.66		-1.56	5.57	0.02	-1.01	
ECe	D_3	243	7.64	11.4	130	0.32	59.2	2.20	4.90	0.00
LnECe	D_3		1.06	1.41		-1.14	4.08	0.41	-1.03	
SAR	D_3		19.4	30.3	155	0.06	233	2.95	12.16	0.00
LnSAR	D_3		1.94	1.53		-2.81	5.45	-0.02	-0.59	
pH	D_1	305	8.35 a	0.39	4.7	6.99	9.98	-0.08	1.68	0.002
pH	D_2	288	8.30 ab	0.44	5.3	5.45	9.95	-0.40	6.88	0.032
pH	D_3	243	8.24 b	0.40	4.9	7.06	9.85	0.60	2.20	0.171

ECe: Electrical conductivity of soil saturation paste extract (dS.m^{-1}), LnECe: Log-transformed electrical conductivity, SAR: Sodium adsorption ratio, LnSAR: Log-transformed sodium absorption ratio S.D: Standard deviation, K-S: Coefficient of Kolmogorav-Smirnow, *; lower letters indicate difference, CV; Coefficient of variation (%)

Although the variation of soil salinity with the depth was not found significant variation of salt accumulation with altitudes was found significant. The sampling points with an altitude below 1072 m are mostly located within the wetland site. The wetland water elevation is around 1070 m, but the water level fluctuates in the winter and summer months. Average soil salinity of the altitudes between 1070.0 - 1074.9 m was found 15.81 dS m^{-1}, of the altitudes between 1075.0 - 1079.9 m was 6.32 dS m^{-1}, of the altitudes between 1080.0 - 1084.9 m was 2.60 dS m^{-1}, of the altitudes between 1085.0 - 1089.9 m was 2.40 dS m^{-1} and above of the altitudes, 1090 m was found 1.44 dS m^{-1}.

Sodium adsorption ratios (SAR) varied significantly with the altitudes. At low altitudes with high salinity levels, SAR values were also high. The average SAR value was 57.8 for altitudes of between 1070.0 - 1074.5 m, 26.1 for 1075.0 - 1079.5 m, 5.3 for 1080.0 - 1084.9 m, 4.3 for 1085.0 - 1089.9 m, 3.3 for 1090.0 - 1099.9 m and 1.7 for 1100.0 - 1150 m.

Soil reaction (pH) varied significantly with soil depth (Table 1). Soil pH values decreased with increasing soil depths. Higher salinity levels of deeper soil layers might have reduced pH values. Although the difference between the minimum and maximum pH values was high, the low coefficient of variation at all depths was related to the narrow range of expression of pH in the logarithmic scale. The coefficient of variation of EC for the upper soil layer is between 57-85% [24] and between 103-125% [25]. In both studies, complying with the present findings, CV of pH was reported as between 4.7-5.0%.

Soil reaction varied significantly also with altitudes ($p<0.01$). Average pH was 8.25 for altitudes of between 1070.0 - 1074.5 m, 8.41 for 1075.0 - 1079.5 m, 8.31 for 1080.0-1084.9 m, 8.30 for 1085.0 - 1089.9 m, 8.30 for 1090.0 - 1099.9 m and 8.26 for 1100.0 – 1150.0 m.

Table 2. *Pearson correlation coefficients between selected soil properties for D_1, D_2 and D_3 cm soil depth (n=305)*

h	LnECe	pH	LnSAR	C
-0.172**				
0.033	-0.121*			
-0.064	0.661**	0.162**		
-0.194**	0.208**	0.216**	0.058	
0.065	0.108	-0.202**	-0.015	-0.248**
0.136*	-0.265**	-0.063	-0.044	-0.756**
-0.152*				
0.09	-0.197**			
-0.085	0.723**	0.223**		
-0.173**	0.235**	0.126*	0.248**	
0.003	0.109	-0.123	-0.091	-0.2**
0.160*	-0.284**	-0.045	-0.178**	-0.815**
-0.055				
0.093	-0.373**			
-0.183**	0.715**	0.054		
-0.154*	0.265**	0.012	0.407**	
0.061	0.152*	-0.193**	-0.091	-0.221**
0.109	-0.341**	0.107	-0.326**	-0.804**

**: $p<0.01$, *: $p<0.05$, h: altitude, LnECe: Log-transformed electrical conductivity, LnSAR: Log-transformed sodium absorption ratio, C: clay, S: sand, Si: silt

Data normality was assessed through skewness and kurtosis values. Since ECe and SAR data were highly skewed, data normality (pH, ECe and SAR) was checked for all depths with the aid of the Kolmogorov-Simirnov test. ECe and SAR in all depths and pH in D_1 and D_2 depths exhibited log-normal distribution ($p<0.05$). Therefore, log-normal data were used for ECe and SAR in classical statistics and variogram models, raw data were used for differences and kriging maps.

Correlations between the soil properties and altitudes were analyzed separately for three depths and results were summarized in Tables 2, 3, and 4. In D_1 layer, the altitude had significant correlations with soil salinity (r= -0.172) and clay content (r= -0.194) ($p<0.01$) and significant correlations with sand content (r= 0.136) ($p<0.05$). Increasing surface soil salinity levels were observed with decreasing altitudes. The plain is a closed basin and lower altitudes are mostly constituted by wetlands of Sultan Marsh. Salts are transported from higher altitudes to lower altitudes through water flows. In D_2 layer, the altitude had significant correlations with ECe (r= -0.152) and sand content (r= -0.173) ($p<0.05$) and highly significant correlations with clay content (r= 0.160) ($p<0.01$). In D_3 layer, the altitude had significant correlations with SAR (r= -0.183) and clay content (r= -0.154) ($p<0.05$). SAR is an indicator of exchangeable sodium and had highly significant correlations with ECe in all depths (r = 0.661, 0.723 and 0.715, respectively) ($p<0.01$). There were highly significant positive correlations between soil reaction and SAR in D_1 and D_2 depths (r = 0.162 and 0.223), and there were highly significant negative correlations between pH and ECe in all depths (r = -0.121, -0.197 and -0.373, respectively) ($p<0.01$).

Geostatistical Analysis

Variogram parameters for investigated variables at three different segments are provided in Table 3. Since SAR and ECe data exhibited log-normal distribution, variogram models were generated with the use of log-transformed data for all depths. Soil reaction was modeled with the use of raw data for all depths. Because of the least MSE for all variables, the spherical model was used in variogram models (Figure 3). The nugget effect (C_0) indicates the instant variation of the variable in a short distance and presents sampling and analysis errors. The lowest C_0 values were calculated for D_3 depth of all parameters and C_0 values increased toward the upper layers. Such a case indicated that SAR, ECe and pH are influenced more by intrinsic and extrinsic factors (precipitation, evaporation, runoff, capillary rise, drainage, fertilization, etc.) toward the surface. Nugget to sill ratio (C_0/C_0+C) indicates the level of spatial dependence among the sampling points for investigated variables. There was strong spatial dependence between SAR and ECe for each depth (between 31-23%), but pH exhibited a weak spatial dependence for all three depths (between 82-68%) [36].

Table 3. *Parameters of variogram models of SAR (%), ECe (dS m^{-1}), and pH*

Variables	n	Depth	Model	(C_0)	(C_0+C)	(C_0/C_0+C)	Range	MSE*
LnSAR	305	D_1	Spherical	0.93	3.20	29	12500	2.69
LnSAR	288	D_2	Spherical	0.70	2.80	25	13000	2.86
LnSAR	243	D_3	Spherical	0.60	2.35	26	13000	1.75
LnECe	305	D_1	Spherical	0.55	1.75	31	10000	1.60
LnECe	288	D_2	Spherical	0.50	2.10	23	10000	1.70
LnECe	243	D_3	Spherical	0.50	2.00	25	9500	1.65
pH	305	D_1	Spherical	0.123	0.15	82	10000	0.482
pH	288	D_2	Spherical	0.145	0.195	74	12000	0.486
pH	243	D_3	Spherical	0.108	0.160	68	6500	0.460

*; Mean Squared Error, C_0; Nugget effect, C0+C; Sill, C0/C0+C; Nugget to sill ratio (%)

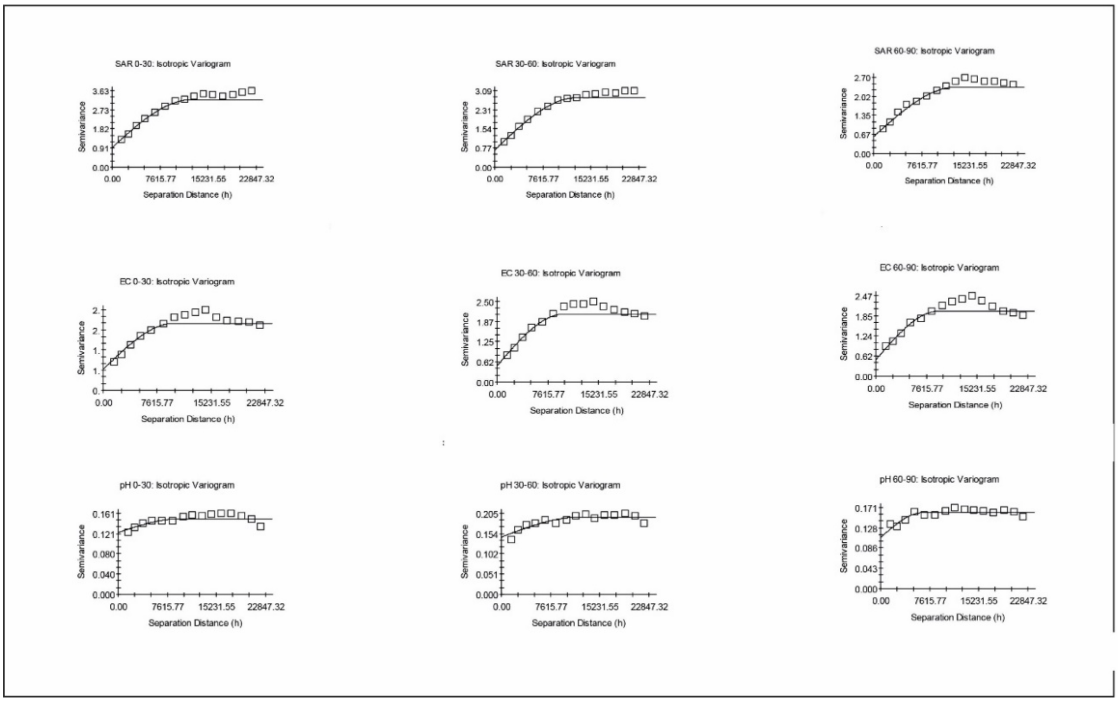

Fig. 3. *Variogram models of ECw, pH and SAR for all depths*

The range indicates the maximum likelihood distance of the variables. SAR at D_2 and D_3 depths (13000 m), ECe at D_1 and D_2 depths (10000 m), and pH at D_2 depth (12500 m) exhibited maximum spatial correlation. The least likelihood distance was observed at D_3 depths of pH and ECe (6500 and 9500 m). The greater likelihood distance of pH and ECe in upper soil layers could be attributed to irrigation, drainage, and fertilization practices potentially influencing the distribution of basic cations and soluble salts in upper layers. Macro topography and altitude may designate likelihood distance not only for pH and ECe, but also for SAR at different soil depths. Altitude was the major concern in soil salinization [37]. As indicated above, classical statistics revealed that salinity varied significantly with altitude and SAR with pH, salinity and SAR increased and pH decreased with decreasing altitudes. A study just 30 km away from the present research site over the pastures of the same basin (28 km^2) and soil samples were taken randomly from 80 points at 0-30 and 30-60 cm depths [25]. Researchers reported maximum likelihood distance for two depths respectively as 2640 and 6060 m for EC and 2000 and 2800 m for pH and related differences between the depth segments directly to changes in microtopography and water table levels. Sampling grid spacing and the number of samples may also influence range values. Sampling spacing may alter the maximum likelihood distance [35, 38]. Transport and deposition of alluvial parent material may result in the different spatial distribution of variables at different depths. Spatial distribution of EC over 3375 ha land size with 200×200 m grid sampling and reported maximum likelihood distance as 700 m [39]. Another work on a 5000 m^2 study area with 10×10 m grid sampling from 0-30 and 30-60 cm soil depths and reported maximum likelihood distance at 0-30 and 60 cm depths respectively as 169 and 150 m for EC and as 210 and 177 m for pH [40].

Kriging

Variogram models and parameters were used to generate Kriging maps for ECe, SAR, and pH at three different depths (Fig. 4, 5 and 6 and Table 4). As indicated before, salt accumulation was observed at low altitudes of the closed basin. The greatest salinity levels were mainly observed around the lake lands with the lowest altitudes and soil salinity decreased with increasing altitudes (Figure 4). The ratio of the area around the base lands with soil salinity level of above 10 dS.m^{-1} was 27.4, 41.5 and 44.5% at D_1, D_2 and D_3 depths, respectively. Around the saline base lands, soil salinity varied between 4-10 dS.m^{-1} and ratio of such area was 42.8, 29.6 and 39.0% at D_1, D_2 and D_3 depths, respectively. At high altitudes, soil salinity was generally below 4 dS.m^{-1} and ratio of such lands was 29.8, 28.9 and 16.5% at D_1, D_2 and D_3 depths, respectively.

Table 4. *Salinity classes at different depths*

	0-30 cm Depth EC_e		
ECe classes*	**ECe ranges (dS/m)**	**Area (ha)**	**Ratio (%)**
I	0-0.65	0.0	0
II	0-1.3	336.5	0.6
III	1.3-3	8437.5	14.8
IV	3-4	8207.9	14.4
V	4-6	11572.7	20.4
VI	6-10	12713.9	22.4
VII	10-20	13922.0	24.5
VIII	20-40	1639.7	2.9
Total		56830.2	100
	30-60 cm Depth EC_e		
ECe classes*	**ECe ranges (dS/m)**	**Area (ha)**	**Ratio (%)**
I	0-0.65	421.2	0.7
II	0-1.3	1670.3	2.9
III	1.3-3	6530.5	11.5
IV	3-4	7826.1	13.8
V	4-6	7973.2	14.0
VI	6-10	8838.3	15.6
VII	10-20	15546.3	27.4
VIII	20-40	8024.2	14.1
Total		56830.2	100
	60- 90 cm Depth EC_e		
EC classes*	**ECe ranges (dS/m)**	**Area (ha)**	**Ratio (%)**
I	0-0.65	713.2	1.3
II	0-1.3	419.5	0.7
III	1.3-3	2548.8	4.5
IV	3-4	5676.0	10.0
V	4-6	10154.7	17.9
VI	6-10	12001.9	21.1
VII	10-20	14325.1	25.2
VIII	20-40	10990.9	19.3
Total		56830.2	100

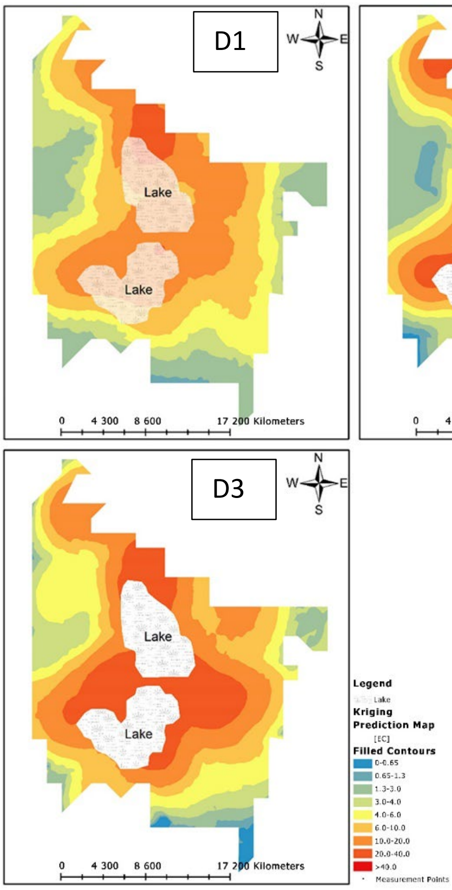

Fig. 4. *Kriging maps of ECe for D_1, D_2, and D_3*

SAR value exhibited similar spatial patterns at three different depths. Greater SAR values were observed in the middle of the research site (base lands) at three depths and lower SAR values were observed around the outer boundaries at higher altitudes. However, at D_1 depth, SAR values were greater than the other depths especially the northern section of the study area (Fig. 5). The ratio of the areas with a SAR value of greater than 13 was 66.6, 71.5 and 68.9% at D_1, D_2 and D_3 depths. Greater SAR values were observed in mid-layer (Table 5). SAR had significant correlations with ECe and pH of D_1 layer, with ECe, pH and clay content of D_2 layer and with ECe, clay and sand content of D_3 layer. With the effect of increasing salinity, calcium probably compounded with carbonates and turned into $CaCO_3$ and precipitated, thus increased Na content and SAR values. There were significant positive correlations between SAR and clay content of D_2 and D_3 layers, and significant negative correlations between SAR and sand content of D_3 layer.

Table 5. *SAR classes at different depths*

SAR classes*	SAR range	Area (ha)	Ration (%)
	0-30 cm Depth SAR		
SAR classes*	**SAR range**	**Area (ha)**	**Ration (%)**
I	0-6.5	532.5	0.9
II	6.5-13	18136.6	31.9
III	13-20	31000.5	54.5
IV	20-30	7160.6	12.06
V	>60	0.0	0.0
Total		56830.2	100
	30-60 cm Depth SAR		
SAR classes*	**SAR range**	**Area (ha)**	**Ration (%)**
I	0-6.5	1946.5	3.4
II	6.5-13	14226.5	25.0
III	13-20	15755.6	27.7
IV	20-30	23171.4	40.8
V	>60	1730.3	3.0
Total		56830.2	100
	60-90 cm Depth SAR		
SAR classes*	**SAR range**	**Area (ha)**	**Ration (%)**
I	0-6.5	1186.5	2.1
II	6.5-13	16481.9	29.0
III	13-20	18791.5	33.1
IV	20-30	19341.1	34.0
V	>60	1029.3	1.8
Total		56830.2	100

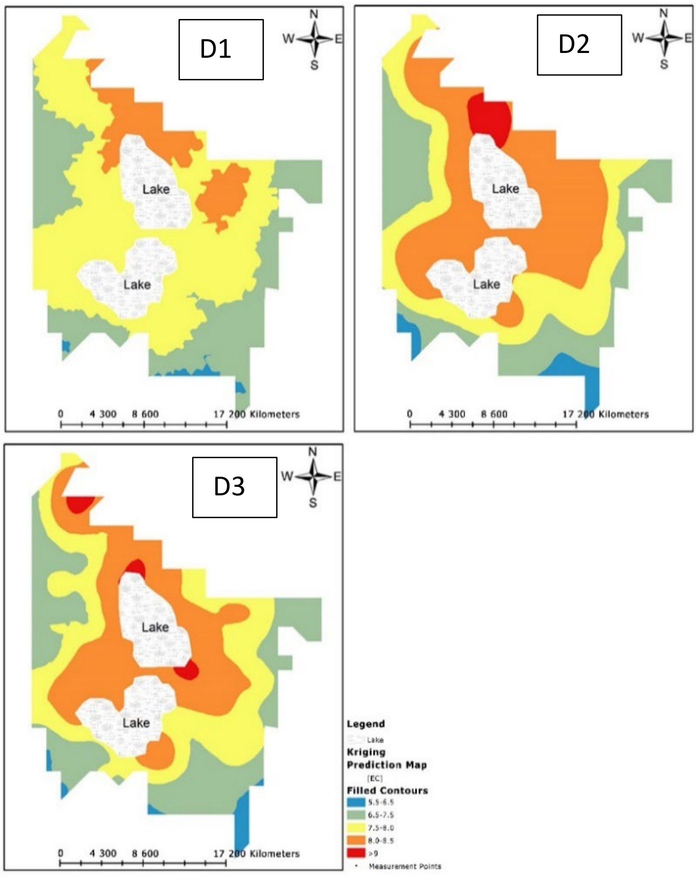

Fig. 5. *Kriging maps of SAR for D_1, D_2 and D_3*

***Table 6.** pH classes at different depths*

pH classes*	pH ranges	Area (ha)	Ratio (%)
0-30 cm Depth pH			
pH classes*	**pH ranges**	**Area (ha)**	**Ratio (%)**
I	6.5-7.5	2932.6	5.2
II	7.5-8	20370.7	35.8
III	8-8.5	13670.3	24.1
IV	8.5-9	18268.2	32.1
V	>9	1588.2	2.8
Total		56830.2	100
30-60 cm Depth pH			
pH classes*	**pH ranges**	**Area (ha)**	**Ratio (%)**
I	6.5-7.5	672.1	1.2
II	7.5-8	27983.0	49.2
III	8-8.5	25162.4	44.3
IV	8.5-9	3012.7	5.3
V	>9	0.0	0.0
Total		56830.2	100
60-90 cm Depth pH			
pH classes*	**pH ranges**	**Area (ha)**	**Ratio (%)**
I	6.5-7.5	1017.4	1.8
II	7.5-8	15866.2	27.9
III	8-8.5	36520.7	64.3
IV	8.5-9	3425.5	6.0
V	>9	0.4	0.0
Total		56830.2	100

The spatial distribution of soil reaction at three depths is presented in Figure 6. In the surface layer, high pH values were generally observed in the eastern sections and partially in the northeastern and western sections of the study area. In lower layers, pH values significantly decreased but intensified within the same sections as the surface layer. The spatial distribution of soil reaction was not complying with the spatial distribution of SAR and ECe. While spatial distribution of SAR and ECe was mostly related to exchangeable Na and soluble Na salts, lime and soil texture were more effective in the spatial distribution of pH.

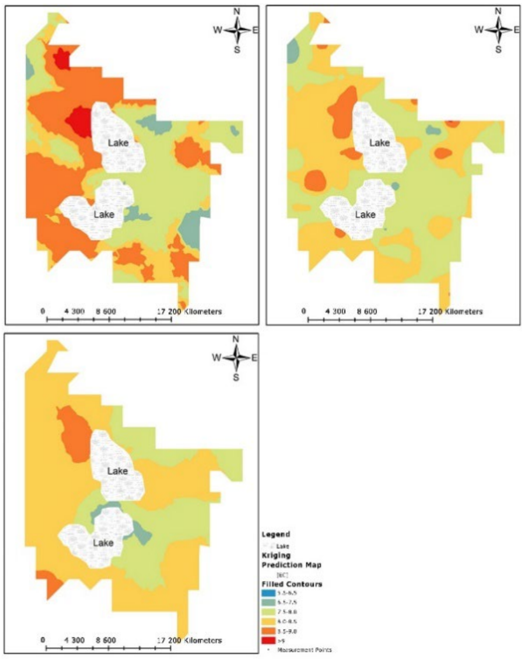

***Fig. 6.** Kriging maps of pH for D_1, D_2 and D_3*

A similar soil salinity and altitude relationship was found in this study which stated that salinity was a major problem in lower altitudes [37]. Lower saline areas had been found in higher altitudes and groundwater depth and its chemical composition were stated as another factor that may affect soil salinity [41]. Soil salinity was correlated to soil properties such as water content, cation exchange capacity, silt, and clay percent [42]. A similar negative relationship between soil pH and EC was found [43].

CONCLUSION

In this study, conducted to determine and map the variations in soil salinity, sodium absorption ratio and soil reaction within Develi closed basin of Türkiye, soil samples in 1500 × 1500 m grid system from three different depth segments (D1= 0-30, D2= 31-60 and D3= 61-90 cm) were taken. Average soil salinity (ECe) of D1, D2 and D3 layers was respectively identified as 6.75, 7.64 and 7.64 dS/m, sodium adsorption ratio (SAR) as 25.4, 22.1 and 19.4 and soil reaction (pH) as 8.35, 8.30 and 8.24. There were significant positive correlations between ECe and SAR and significant negative correlations between ECe and pH. Altitude had significant correlations with ECe, SAR and pH and such correlations varied with the depths. Increasing soil salinities were observed with decreasing altitudes. Therefore, it was concluded that there was a salt transport from higher altitudes toward lower altitudes of the closed basin. The greatest soil salinity was obtained from the soil samples taken from the lowest altitudes. The ratio of the sites with soil salinity greater than 4 dS/m in D1, D2 and D3 layers was respectively calculated as 70.2, 71.1 and 83.5% and ratio of the sites with a SAR of greater than 13 was respectively calculated as 66.6, 71.5 and 68.9%. Develi Plain exhibit largely saline-sodic characteristics. With recent investments in irrigation infrastructure, irrigated lands are continuously increasing. Water is transferred from neighboring watersheds. Therefore, salts are also transported with the irrigation water applied. Such a case may further increase salinity and transport salts to higher altitudes.

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