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# Probability mapping of saline and sodic soils in the Harran plain using a non-linear kriging technique

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## Abstract

In the Harran Plain, southeastern Turkey, soil salinisation causes land degradation threatening the sustainability of agricultural production. According to a recent survey, approximately 18000 ha area has been affected by soil salinity and sodicity at various levels. Determining the distribution of saline and sodic soils in the study area is the first step for effective management of these soils. Over 200 soil samples have been randomly selected across the plain and analyzed for selected soil salinity and sodicity variables in soil salinity laboratory. Indicator kriging (IK), a non-linear interpolation technique, was used to map the probability levels of occurrence of saline and sodic soils across the plain. The results of IK showed the probability distributions of risky areas under different types of soil salinity classes; nonsaline, saline, saline – sodic and sodic.

**Keywords**: Harran Plain, saline-sodic soils, indicator kriging, probability distribution



## Introduction

Salinisation and alkalinisation of soils degrade soil physical,chemical and also biological quality (Andrews et al., 2004; Muhammed et al., 2008) eventually reducing the crop yield. Around 20 % of irrigated lands across the world are reported to have been affected by soil salinity and alkalinity at varying levels (Tanji, 2002). The secondary salinisation, accumulation of salts in root zone, may occur in arid and semi arid areas which is under irrigation. One such example can be given for the Harran plain which is located in southeastern Turkey. After the Harran plain was opened to irrigation as a part of multibilion GAP development project, it faced with problems such as salinisation and alkalinisation at its lower lying areas where groundwater level is closer to surface (less than 2 m) under heavy clay soil accompanied with poor drainage conditions and semi-arid climate with evaporation rates as high as 1400 mm per year as compare to precipitation which is around 400 mm per year. In addition, poor management methods, such as low water use efficiency exagerates the problem in the area (Cullu, 2003; Kendirli, 2005; Bilgili, 2011). Monitoring salinity and alkalinity regularly is significant for an efficient management and also for delineation of hot spots of affected soils. Performing this with traditional laboratory analyses can be tedious and can hinder the efficient management of this type soils. Instead, inverse distance weighting, splines and various kriging methods such as ordinary kriging, regression kriging, cokriging and kriging with external draft have been used to achieve this goal (Ardahanlıoglu, 2000; Cetin and Kırda, 2003). These all estimated values of salinity at unsampled locations using points at neighboring locations (Webster and Oliver, 2007). In some cases, rather than exact estimations, delineating of hot spots can be more useful for determination of management zones. In these

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case, indicator kriging (IK) can be used (Goovaerts, 1997). IK maps the probability of occurence of variables i.e. soil contaminants (Dash et al., 2010) or ground water depth (Demir et al., 2009). Overall goal of this research was to test the use of Indicator kriging in delineating the salt affected areas and to produce the probability maps of different soil salinity groups such as nonsaline, saline, saline-sodic and sodic in the Harran Plain.

## Materials and Method

The study was caried out in the Harran Plain. The study area is under semiarid climate conditions with long terms average evaporation, rainfall and temperatures values of 17 °C, 365 mm and 1850 mm, respectivelly. The elevation in the plain shows high variability ranging from 358 m at south to 470 at north (Bilgili et al., 2006). Over 200 soil samples collected across the Harran plain were analyzed for various soil salinity parameters including soil electrical conductivity EC ($dS.m^{-1}$) and also for soil exchangeable sodium percentage (ESP). In order to determine the ESP, exchangeable cations and Cation Exchange Capacity (CEC) of soil samples (meq 100 $g^{-1}$) were determined (Richard, 1954). ESP was calculated using the formula below;

$$ESP = 100 \times (Exchangeable\ Na/CEC)$$

Indicator Kriging (IK)

Indicator kriging is a non-linear kriging estimation method (Goovaerts, 1997). Before running indicator kriging, samples were coded as 1 or 0 according to certain threshold (Figure 1). In calculating thresholds, soils were grouped into four different classes based on their ESP and EC values (Richard, 1954). I.e. soils with EC > 4 and ESP < 15 were classified as saline and samples meeting these conditions were coded as 1 and the others as 0. The coding of other groups were performed similarly using different thresholds; soils with EC < 4 and ESP < 15 were grouped as nonsaline, soils with EC > 4 and ESP > 15 as saline-sodic and soils with EC < 4 and ESP > 15 as sodic (Richard, 1954).

$$I(x;Z_k) = \begin{cases} 1 \; if \; Z(x) \le Z_k \\ 0 \; otherwise \end{cases}$$

here Z(x) is the concentration of soil EC or ESP value at location of x. $Z_k$ is the threshold value for variable of interest. In indicator kriging, the probability of occurence of each parameter is mapped by finding the conditional cumulative distribution function (ccdf) for the threshold values ($Z_k$) at unsampled location (xo) using the equation below;

$$F(x_o;Z_k|(n)) = prob\{Z(x_o)|Z_k|(n)\}$$

here $F(x_o;Z_k \le (n))$ is an estimation of the ccdf value. The ccdf for each threshold value at any unsampled location ($x_o$) can be predicted by linear combination of transformed values (Goovaerts, 1997):

$$[F\{x_o;Z_k|(n)\}] = \sum_{\alpha=1}^{n} \lambda_\alpha(Z_k) I(x_\alpha;Z_k)$$

$\lambda_\alpha$ are weigths and found by calculating indicator variograms for transformed values;

$$\gamma_L(h;Z_k) = \frac{1}{2N(h)} \sum_{\alpha=1}^{N(h)} \{I(X_\alpha;Z_k) - (X_{\alpha+h},Z_k)\}$$

Experimentel variograms for indicator transformed values are estimated and fitted using an appropriate model. More detail about indicator kriging can be found in Goovaerts, 1997 and Webster and Oliver, 2007. Calculation of variograms and indicator kriging were performed using programming language software (R Development Core Team, 2006). Before indicator kriging were run, grids of 200 by 200 meter covering the study area (Harran Plain) were formed and estimations were performed at each grid point.

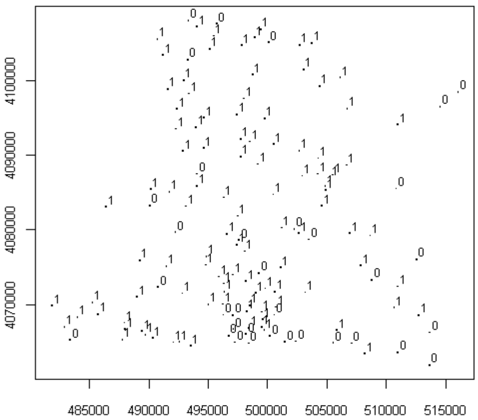


Fig. 1. An example of indicator coding based on threshold value

# Results

The concentrations of soil EC (dS $m^{-1}$) and ESP showed a wide range and a skewed distribution (Figure 2). Indicator variograms were calculated seperately for each soil salinity classes; nonsaline, saline, saline-sodic and sodic. The indicator variogram parameters and fitted variograms were given in Table 1 and Figure 3, respectivelly. Variograms were fitted using either spherical or exponential models (Table 1). The range values showing the distance over which samples in different salinity groups are spatially dependent ranged from 493 to 2387 m. The values for nugget to sill ratio showing the quality of spatial distribution changed from 0.11 to 0.36.

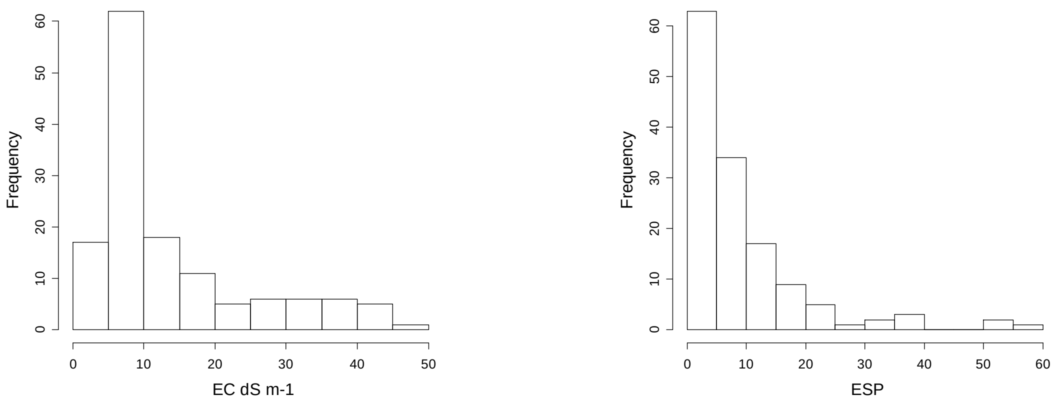


Fig.2. Distribution of soil EC (dS $m^{-1}$) and ESP

The probability of exceeding the threshold values at series of desired grid locations were determined using indicator kriging method and the probability maps were shown in Fig. 3.

Table.1. Variogram parameters ($c_o$: Nugget and $c+c_o$: Sill ) and models used to fit experimental indicator variograms estimated for each salinity classes

| | $c_o$ | c | Range | $c+c_o$ | $c_o /(c+ c_o)$ | Model |
|---|---|---|---|---|---|---|
| Nonsaline | 0.06 | 0.11 | 2387 | 0.17 | 0.36 | Spherical |
| Saline | 0.01 | 0.08 | 826 | 0.09 | 0.11 | Exponential |
| Saline-sodic | 0.03 | 0.07 | 3646 | 0.10 | 0.27 | Spherical |
| Sodic | 0.01 | 0.05 | 493 | 0.06 | 0.16 | Exponential |

# Discussion

The spatial quality of indicator variograms changed from good to moderate indicated by low nugget to sill ratio ($c_o /(c+ c_o) < 0.25$ and $0.25 < c_o /(c+ c_o) < 0.75$, respectively; Cambardella et al., 1994). The quality of the spatial structure affects the quality of variograms and therefore the accuracy of the estimations using kriging models (Leenaers et al., 1990).

IK showed the probability levels of occurence of different soil salinity groups (Figure 4). The probability of occurence of saline and saline-sodic soils were high in southeastern regions of the plain indicating the soils affected by saline and saline-sodic conditions were located in these areas. This is mostly due to low elevation and existing topographycal conditions of these areas which favor the accumulation of ground water with excess irrigation. A different pattern were observed for soils in sodic group. The high probability of occurence of sodic soils were obtained in some spots located in northern parts as well as southeastern part of the study area. In addition, the amount of areas affected by alkalinity was less compare to other groups. This is mostly because of relatively high amount of gypsum existing in the study area's soils which prevents soils from becoming more alkaline (Aydemir and Sonmez, 2008). The existences of gypsum were also shown with spectroscopy studies (Bilgili, 2011) performed on the soils of the study area.

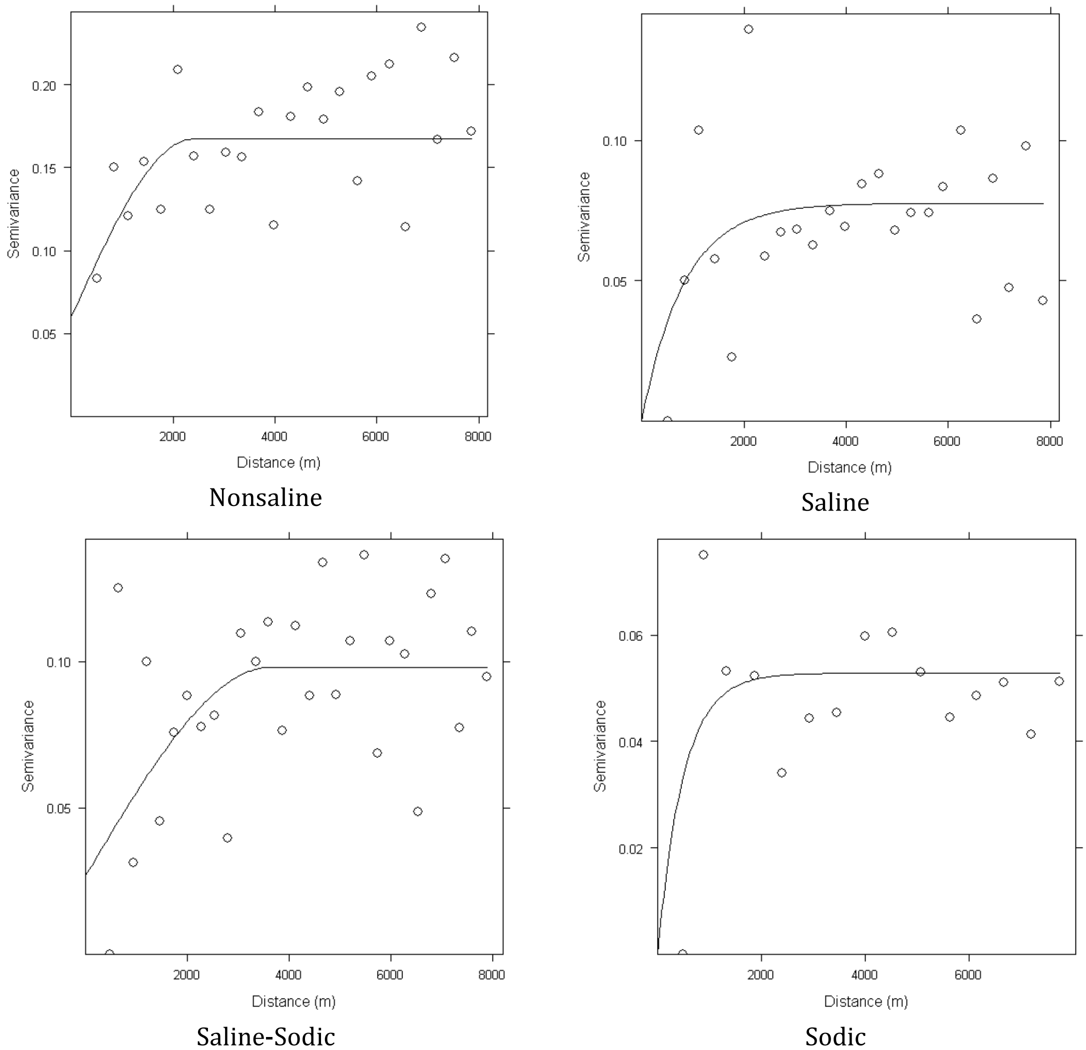


Fig.3. Fitted indicator variograms for different soil salinity groups

Although salt affected areas of the study area has been determined using the combination of ordinary kriging and traditional methods, IK in the current study succesfully delineated spatial distribution of different soil salinity groups, each of which require different management strategies. In addition, variables such as soil salinity may show high skewed distribution as in the case of the current study (Figure 1). This negativelly affects the accuracy of estimations using methods such as linear kriging and thus nonlinear enterpolation methods such as IK can be more succesfull in dealing with such data. IK has also been used succesfully by different workers (Hu et al., 2005; Demir et al., 2009; Dash et al., 2010) with other contaminants for the delineation of risky zones. Recently in the study area, drainage studies have been initiated by the government in salt affected locations. However, for more efficient and faster management of these degraded areas by salinity and alkalinity, the drainage studies have been accompanied by other remediation methods such as growing crops as animal feed as well as improving the irrigation efficiency.

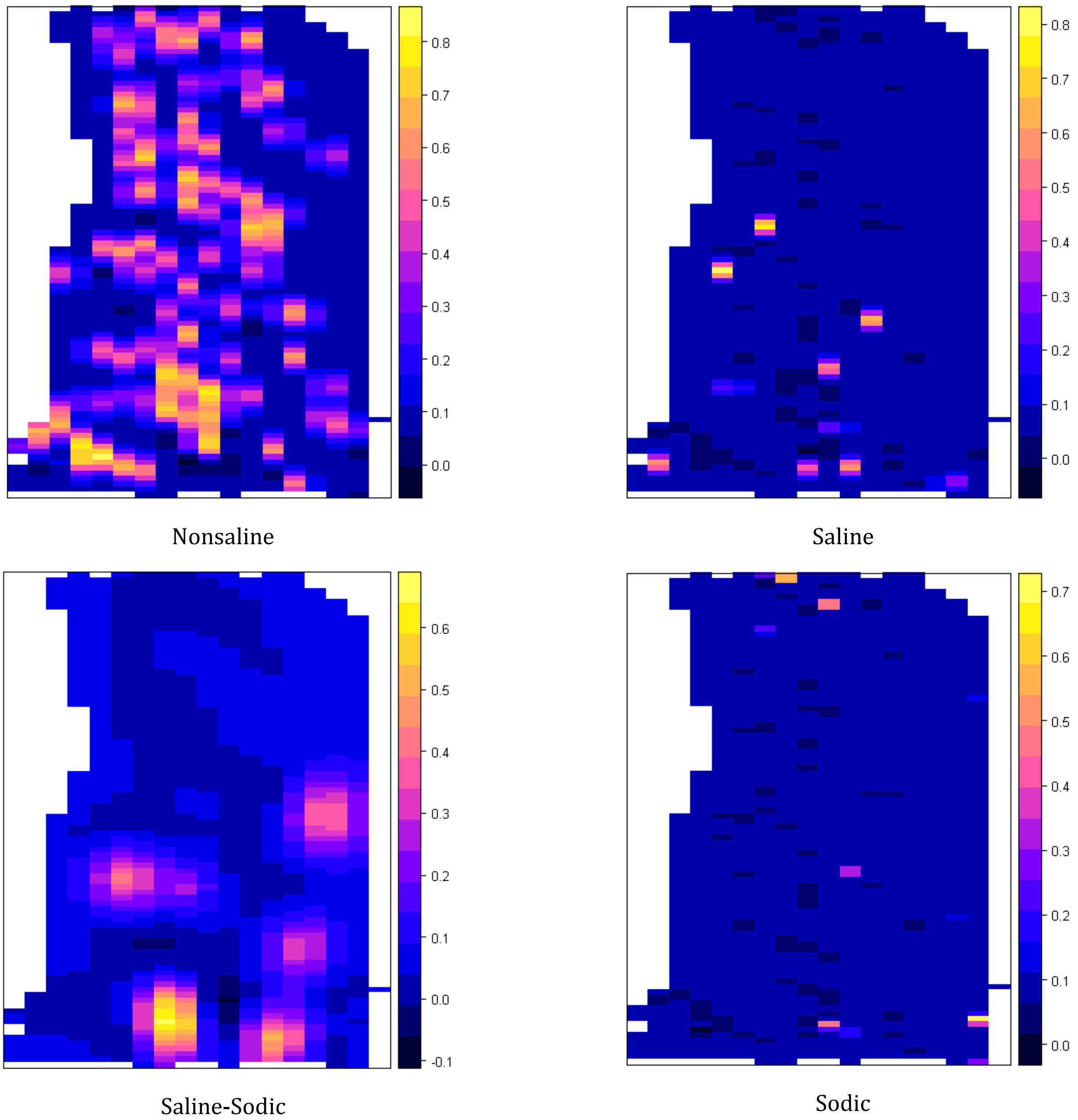


Figure 4. Probability maps of different soil salinity classes obtained using indicator kriging

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