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A Prediction Model for Soil Salinity Using its Indicators: A Case Study in Southern Iran

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ABSTRACT

South of the Zagros belt, the entire land of Southern Iran faces problems arising out of various types of land degradation of which soil salinity forms a major type. The Mond river basin, located centrally to this zone, has been selected as a test area to develop a statistical model for predicting the salinity of soil using different indicators of soil salinity. The soil salinity data were taken at 49 different samples in the study area. The data as indicators of soil salinity have been gathered from the records and reports published by the different departments of the Ministries of Agriculture, Defence and Energy of Iran. The GIS analysis of various indicators and salinity of soil samples considered proved useful for understanding their relationship in a statistical software. In the present study, the relations between the soil salinity and the indicators of soil salinity have been found statistically in the software of SPSS. To find a regression equation for soil salinity, max EC in 1 m depth of soil has been considered as dependent variable while the indicators of soil salinity including soil texture, water table, dry index, slope, index of efficacy of surface geology (ESG) and groundwater quality are considered as independent variables. For this purpose, the regression equations for two methods of 'enter' and 'stepwise' in software of SPSS have been established. The linear regression equations define the variations of the soil salinity depending on the indicators and also give an idea about the levels of relations. The results obtained show that the relations between the soil salinity and the indicators especially groundwater data do exist.

INTRODUCTION

The soils containing soluble salts in the root zone in quantities large enough to adversely affect plant growth are called salt affected. Commonly, they are devoid of good natural vegetation cover. The term saline refers to more than just the content of sodium or chloride. Other ions as magnesium, calcium, carbonate, bicarbonate, and sulphate also contribute to the soil salinity. If, however, the predominant ion is sodium, the soil is said to be sodic.

Soil salinization is a natural process that has been continuously operating over a length of time, and its intensity is influenced by climatic conditions, geomorphology and the drainage through the geological formations. It is sometimes contributed to, as in the present case, by surface water or groundwater draining evaporite formations and salt domes, from higher altitudes or mountainous areas into a low dry land; the dissolved salts precipitate and get concentrated into the upper layers of the soil. Also, the arid and semiarid climate subjects the moisture in the upper soil to intense evaporation which in turn promotes capillary action whereby salts get transported upwards by the brackish groundwater. Apart from these natural factors that have been degrading the soil ever since the landscape came into existence, the human activity towards agricultural and horticultural improvement has also contributed to the soil salinity. Of greater concern is the salinization caused by brackish water for agricultural purposes, as is the case in many areas of Iran (Siadat et al. 1997) which enhances the soil salinity.

Lying within the arid and semi arid climatic belt, in which the land degradation processes are known to progress more speedily and pervasively, the present status of land degradation in Iran is particularly alarming, compared to other countries in the Middle East. According to the FAO (1994) report, about 94% of arable lands and permanent pastures in Iran are threatened of land degradation, and about 27% of the land has already been affected by soil salinization. Thus, evolving a model, such as the present one, for assessing the soil salinity will prove extremely important for regional planners and policy makers in adopting agricultural and environmental strategies.

The paper presents a statistical model that is able to predict amount of soil salinity. This is based on linear regression technique. Linear regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable which is soil salinity. For this purpose a large statistical and graphical software package (SPSS, Software Package of Social Sciences, V. 10), that is one of the best known statistical packages has been used (Kinnear 2002).

THE STUDY AREA

The Mond basin is bounded between Lat. 27°20' and 29º55' N and Long. 51°09' and 54°45' E. It lies in the Bushehr and Fars provinces of southern Iran. The basin covers an area of nearly 47,835 sq. km of which about 14,709 sq. km form the plains. The main river of the basin is the Mond river which flows down the Zagros to the Persian Gulf (Fig. 1). The elevation varies between see level to

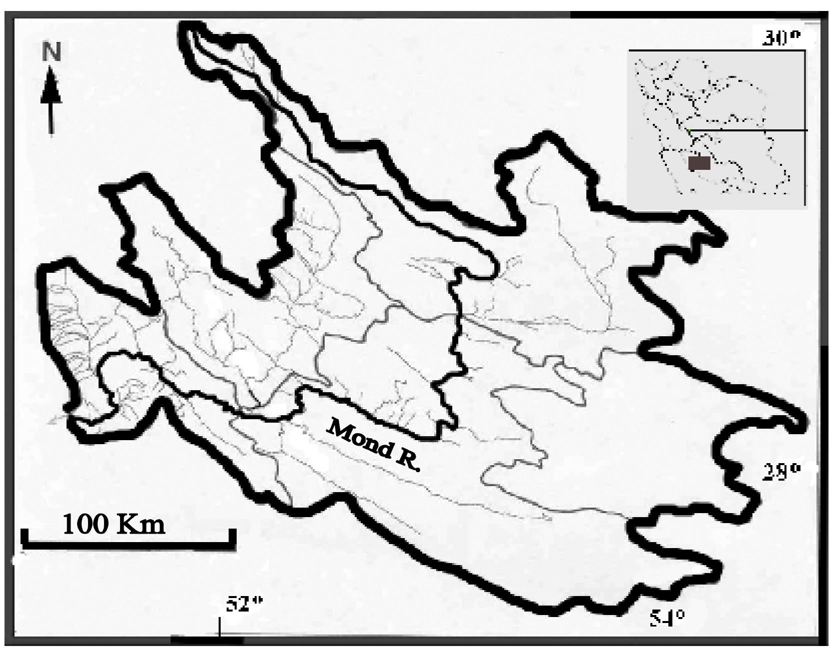

Fig 1. Mond basin in the Southern Iran.

3185m in Kharman Kuh mountain. About 66% of the area is mountainous and hilly. The landscape units are mountains, hills, piedmont and plains. The climate is arid and semiarid in most parts of the area with a mean annual rainfall range of 150-700 mm but most parts of basin have mean annual rainfall of < 350mm. The main period of precipitation is during winter (60% of total rainfall). The mean annual temperature measured at the Qantareh station is 26.1°C, at Fasa 19.4°C, and at Band Bahman 14.4°C. Various soil types with varying depth normally show a great variability. According to Iranian classification seven main classes of soils are present in the basin: lithosols, colluvial soil, alluvial soil, brown soil, solonchaks, gypsiferous marl and regosol.

MATERIALS AND METHODS

The present paper examines to find a model for estimating the salinity of soil for the studied area using GIS and software of SPSS. Some soil samples were used to find a quantitative relationship between their salinity and different indicators of soil salinization. The data obtained as indicators of soil salinity were of two types, 1) numerical data, and 2) thematic maps, but mainly in the map format, deployed for the GIS analysis using ARC VIEW 3.2 software. All such relevant data were obtained from the local and main offices and institutes of the Ministries of Agriculture and Energy of Iran and processed thoroughly, using the GIS technique.

In the present paper six indicators as the causes of soil salinity have been used. These are: soil texture, water table, dry index, slope, index of efficacy of surface geology (ESG) and groundwater quality. The thematic maps of indicators were digitized and processed in the GIS. The recommendations appearing in the FAO publications (FAO/UNEP 1984) and other literatures as well as the statistically suitable parameters for local conditions in the basin have also been taken into consideration while fixing the thresholds of severity classes of some indicators, namely, soil texture, water table, slope and groundwater quality (Table 1). To understand and evaluate the ESG as an indicator the abundance of salty units in the geological formations has been calculated in the GIS by finding the ratio of the area occupied by the evaporite formations to the total area of other formations, all derived from the geology map. Deploying the GIS, for each hydrological unit which form small sub basins of Mond basin, the ESG has been calculated as (Masoudi et al. 2005) below.

ESG = [(2 × salt dome area) + (area of evaporite formations) + (0.5 × area of formations with less evaporate material)] / area of other geological formations

Table 1: The indicators used in the model of assessment of soil salinization.

Indicators	Class limits and their ratings score				
	None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
1. Depth of water table, m. (Ref: FAO/UNEP 1984, Feiznia et al. 2001)	> 5	3-5	1-3	0.5-1	< 0.5
2. Soil texture	Coarse soils of mountains and hills	Coarse to medium and medium	Moderately fine	Fine	Very fine (clay texture)
3. Slope, %	30+	15-29	5-14	1-4	< 1
4. Groundwater quality					
EC (μmhos/cm)	< 250	250-749	750-2249	2250-4999	5000+
SAR (Ref:FAO/UNEP 1984, Das 1996)	< 10	10-17	18-25	26-29	30+

After that all the maps of indicators have been overlaid in the GIS and soil samples were located on the recent map to further find different attributes of indicators against soil salinity of each soil sample (Table 2). In the next step, maximum amount of electrical conductivity (EC) in 1m depth of soil, which represents the soil salinity, has been considered as dependent variable for statistical analysis in SPSS software while data of indicators have been selected as independent variables. The relationship between the dependent variable and each independent variable should be linear, and all observations should be independent. The significant values in output are based on fitting a single model.

Some options are available in this software; these options apply when the 'enter', 'forward', 'backward', or 'stepwise' variable selection method has been specified. Method selection allows you to specify how independent variables are entered into the analysis. Using different methods, you can construct a variety of regression models from the same set of variables. The model for predicting soil salinity was determined by using two multiple regression modelling procedures of 'enter method' and 'stepwise method'. In 'enter method' all independent variables selected are added to a single regression model. In 'stepwise', which is better, all variables can be entered or removed from the model depending on the significance. Therefore, only those variables, which have more influence on dependent variable, are observed in a regression model. In the present work, soil sample no. 44 was deleted as 'casewise diagnostic' from the analysis of stepwise method.

RESULTS AND DISCUSSION

According to above explanation, Table 3 shows the relationships between soil salinity and indicators of soil salinity. For example, the concentration of soil salinity depends on soil texture, water table, dry index, slope class and groundwater quality. Correlation coefficients, significant at the 0.05 level, are identified with a single asterisk (significant), those significant at the 0.01 level with two asterisks (highly significant), and those significant at 0.001 level are identified with three asterisks.

Table of analysis of variance (Table 4) shows, both regressions of 'enter' and 'stepwise' methods, which are highly significant indicating a significant relation between the different variables. In Table 5, the coefficients of salinity model and regression lines for, both enter and stepwise methods, are presented. Regression coefficients, standard errors, standardized coefficient beta, 't' values, and two-tailed significance level of 't' have been shown in the Tables.

The linear regression equations show that the soil salinity depends on the indicators and also give an idea about the levels of relations. The linear model equations after using 'enter method' and 'stepwise method' are:

Max EC in 1 m depth of soil using 'enter method' = –26.07 + (2.48) soil texture class + (21.11) water table class + (–18.46) dry index + (0.44) slope class + (–2.82) index of ESG + (1.58) groundwater quality class
R = 0.79 (significant at 0.001).

Max EC in 1 m depth of soil using 'stepwise method' and deleting sample no. 44 = –26.22 + (16.85) water table class + (3.96) groundwater quality class
R= 0.74 (significant at 0.001).

The values and significance of R (multiple correlation coefficient) in both the equations show capability of them in predicting soil salinity. The value of R^2 in first equation is 0.63 showing different indicators used can calculate almost 63% variability of soil salinity. On the other hand, although

Table 2: Soil samples with different attributes of their indicators.

Soil sample	Max EC in1m (mmhos/cm)	Class of soil texture	Class of water table	Dry index	Class of slope	Index of ESG	Class of ground water quality
1	0.8	3	1	0.17	4	0.09	2
2	0.6	2	1	0.17	3	0.41	2
3	1.2	2	1	0.17	4	0.41	2
4	0.9	2	1	0.17	4	0.41	3
5	1.3	3	1	0.17	4	0.41	3
6	1.0	2	1	0.17	2	0.86	3
7	0.7	2	1	0.14	4	0.86	3
8	1.1	3	1	0.14	4	0.86	4
9	0.6	2	1	0.17	4	0.41	3
10	0.6	1	1	0.17	3	0.41	2
11	1.0	2	1	0.17	4	0.41	3
12	0.6	2	1	0.17	4	0.41	3
13	0.9	2	1	0.16	3	0.41	3
14	4.4	3	1	0.17	4	0.41	3
15	3.1	2	1	0.17	4	0.41	2
16	1.5	2	1	0.21	3	0.37	3
17	0.8	2	1	0.35	4	0.19	3
18	0.9	1	1	0.19	4	0.37	3
19	1.0	1	1	0.19	3	0.37	3
20	0.6	2	1	0.26	3	0.29	3
21	0.7	2	1	0.30	4	0.19	3
22	1.0	3	1	0.35	4	0.19	3
23	0.9	3	1	0.21	4	0.15	3
24	0.9	2	1	0.21	3	0.15	2
25	1.5	2	1	0.16	4	0.15	3
26	1.1	2	1	0.21	4	0.15	3
27	8.0	3	1	0.21	4	0.15	4
28	1.1	2	1	0.16	4	0.15	3
29	8.2	2	1	0.13	4	0.33	4
30	1.1	2	1	0.14	4	0.86	4
31	2.6	2	1	0.16	4	0.33	4
32	8.5	3	1	0.16	3	0.33	4
33	1.3	2	1	0.16	4	0.33	4
34	8.2	3	1	0.21	4	0.33	3
35	0.9	2	1	0.19	4	0.37	3
36	1.2	2	1	0.21	4	0.33	3
37	1.5	2	1	0.21	3	0.33	2
38	54.2	4	2	0.11	5	0.68	5
39	12.2	3	1	0.11	5	0.68	5
40	9.8	3	1	0.11	4	0.68	4
41	23.2	4	2	0.11	5	0.68	5
42	2.4	4	1	0.11	5	0.68	4
43	12.0	4	2	0.12	5	0.37	4
44	54.3	4	2	0.12	5	0.37	4
45	4.6	4	1	0.12	4	0.90	4
46	9.9	4	1	0.10	5	0.68	5
47	4.4	4	1	0.11	5	0.68	4
48	15.8	4	2	0.11	5	0.68	5
49	30.8	4	1	0.12	5	0.68	4
Mean	6.24	2.57	1.10	0.17	3.97	0.44	3.35
Std. Deviation	11.71	0.88	0.31	0.05	0.69	0.22	0.85

Table 3: Correlation coefficients between dependent variable (max EC) and different independent variables (indicators of soil salinity).

		Max EC	Class of soil texture	Class of water table	Dry index	Class of slope	Index of ESG	Class of ground water quality
Pearson Correlation	Max EC	1.000	0.604***	0.746***	–0.406**	0.533***	0.242*	0.551***
Sig.(1-tailed)	Max EC		0.000	0.000	0.002	0.000	0.047	0.000
N		49	49	49	49	49	49	49

Table 4: Tables of analysis of variance for both regressions of 'enter' (a) and 'stepwise' (b) methods.

	Analysis of variance (a)				
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	4117.268	6	686.211	11.687***	0.000
Residual	2466.092	42	58.716		
Total	6583.360	48			

Predictors: (Constant), soil texture, water table, dry index, slope, index of efficacy of surface geology (ESG) and ground water quality. Dependent variable: Max EC

Analysis of variance (b)

Regression	2341.79	2	1170.89	27.96***	0.000
Residual	1883.96	45	41.87		
Total	4225.76	47			

Predictors: (Constant), water table and ground water quality. Dependent variable: Max EC

Table 5: Coefficients of soil salinity model and regression lines for both 'ente'r (a) and 'stepwis'e (b) methods.

Model	Coefficients (a) Unstandardized Coefficient		Standardized Coeff.		
	B	Std. Error	Beta	t	Sig.
(Constant)	-26.057	11.458		-2.274	0.028
Class of soil texture	2.482	1.972	0.189	1.259	0.215
Class of water table	21.108	4.538	0.551	4.651***	0.000
Dry index	-18.464	27.691	-0.088	-0.667	0.509
Class of slope	0.444	2.464	0.026	0.180	0.858
Index of ESG	-2.824	6.917	-0.054	-0.408	0.685
Class of groundwater quality	1.579	2.063	0.115	0.766	0.448

Coefficients (b)

(Constant)	-26.219	4.327		-6.060	0.000
Class of water table	16.849	3.909	0.496	4.311***	0.000
Class of groundwater quality	3.962	1.271	0.359	3.117**	0.003

Dependent variable: Max EC

R in enter method is higher (0.79) compared to stepwise method (0.74), the difference is low (0.04). Therefore, second equation based on stepwise method can be used to predict soil salinity in the study area instead of using first equation which needs more data. On the other hand, the low difference between the two R values indicates that the excluded variables in second equation have less effect on measuring the soil salinity in the study area. Also, the second equation shows importance of groundwater data for predicting soil salinity in the study area. If water table belongs to first class as it is observed in most parts of the study area, the second model will be applicable if groundwater quality belongs to third or higher class of quality.

Beta in Table 5 shows those independent variables (indicator) which have more effect on dependent variable (soil salinity). The beta in Table 5 shows a highly significant effect of water table class compared to other indicators for measuring the soil salinity. Soil salinity data in Table 2 shows wherever water table is under class 2 (< 5m) the soil salinity is > 12 mmhos/cm. A relationship is observed between beta data and data showing Pearson Correlation (Table 3), indicating variables with higher beta coefficients have higher correlation with soil salinity also.

Parameter Sig (P-value) from Table 5 shows amount of relation between soil salinity and indicators of soil salinity. For example, Table 5a shows dry index has lower effect than soil texture on soil salinity. From the above it can be concluded that the relations between the soil salinity and other indicators of soil salinity except groundwater data are existing but they are not very strong, in general.

CONCLUSION

Preparation of a regression model to predict soil salinity can be helpful for environmental and agricultural planning. For the entire southern Iran, highly threatened by soil salinity, it is the need of the day. The present equations derived by two methods of 'enter' and 'stepwise' in software of SPSS are the first attempt of their kind in southern Iran for defining the amount of soil salinity and may be applicable for other areas with same conditions of the study area. The main results of the present study are:

1. The hazard maps of different indicators processed in the GIS give a far better opportunity to evaluate relationship between them and the amount of soil salinity.
2. Stepwise method has given the better results for identifying the main indicators which have more effect on soil salinity of the study area.
3. Although all the indicators used in this assessment show correlation with amount of salinity of soil samples but only groundwater data including water table and groundwater quality show strong significant effect on the soil salinity. Results show when water table comes up near the ground surface, soil salinity is increased. With increasing salinity of groundwater, the soil salinity is also increased.

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