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A Procedure for Salinization and Waterlogging Susceptibility Zonation Using Conditional Analysis Method and GIS Techniques in Central Iran

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ABSTRACT

The objective of this research was to develop a GIS-based model of salinity hazard for the Southeast of Esfahan in the centre of Iran and to determine the impacts of natural and manmade land attributes on salinity and waterlogging. GIS techniques were elaborated and the databank of the area was constructed using available spatial data like ground water depth, claypan depth, irrigation canals and drainage network. Probability conditional techniques were used and several regression models were developed, which explain the relationship between soil salinity or waterlogging and each criterion. The regression models explain the sensitivity of each part of a factor to soil salinity. For each attributed factor a hazard map was delineated and the final hazard model prepared by multiplication of all single hazard maps. Comparing the final hazard model and the indicator map of severe saline soils shows that 81% of severe saline soils are located in severe hazardous areas. The resulted hazard map indicates the efficiency of the method for inventory of the susceptible zones to salinity and could be a valuable document for decision makers and engineers.

Key Words: Soil salinity; Waterlogging; Conditional analysis; GIS

INTRODUCTION

Hazard is a probability of occurrence feature in a certain time and place and the major purpose of hazard mapping is forecasting the event in the future (Varenes, 1984). Elisabeth (1997) delineated the salinization hazard of Queensland using climate, geology, land-use and soil depth factors. He defined salinity hazard as potential of suffering from salinity. Principally salinization develops in lowlands, where groundwater table (GWT), geomorphologic and hydrologic conditions are provided. There is not a certain methodological approach for hazard mapping but confirmation is that past and present of an event are keys for the future. Among all suggestions direct and indirect approaches are common. In direct method the factors, which looked involve in hazard are sorted and weighted according to their importance (Hansen & Franks, 1991; Hansen, 1994). Statistical method is an indirect approach in which the role of each factor is determined according to hazard distribution. The simplest statistical approach is probability conditional analysis, which is based on Bayasian theory (Morgan, 1968; Clerici *et al*., 2002). According to the method probability of hazard is calculated by using the magnitude of hazardous areas. Many researchers used probability conditional analysis for exploring minerals and oil (Dowds, 1961) and prediction the risk of landslides (Chung & Fabbri, 2002, 03 & 2004; Clerici *et al*., 2002; Gokeceglu *et al.*, 2005; Chung, 2006).

We elaborated probability conditional analysis to study the spatial influence of soil attributed physiographic and hydrologic factors on salinization and waterlogging and to find susceptible zones to salinity and waterloggings in the southeast of Esfahan.

MATERIALS AND METHODS

Study site. Study area was situated between 32° 20' to 32° 34' N and 52° to 52° 43' E. It covers an area about 44,000 ha in the southeast of Esfahan Metropolitan area in the centre of Iran. As there were new plans for agricultural extension of the area forecasting the influences of artificial drainage and irrigation networks on soil salinity and waterlogging was very important. Furthermore there were existed a considerable published researches regarding the spatial characteristics of soils, groundwater, land use and irrigation and drainage canals of the area, which were required for execution of the model. The Zayanderod River (as a source of freshwater in the centre of Iran) crosses the area and pours into Gavkhoni Playa in the east. According to Alizadeh (1990) who calculated De Martonne index for climatologically data of Varzane station, the climate of the area is Arid. Maximum and minimum temperatures are

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37°C and 5.6°C and occur in July and December, respectively. The mean annual precipitation for the study area was less than 150 mm (Ganji, 1955). Krinsley (1970) studied the Esfahan-Sirjan watershed and reported that Esfahan region is the moistest part of this watershed. The major factors, which influence land degradation of the area are topography, lithology and stratification of sediments.

Databank construction. Databank of the study area was constructed using available reports and spatial data. Severe saline soils of the area were mapped by Naderi (1998) using Landsat TM data. The map indicates soils, which are suffered by capillary movement of brackish water and are in waterlogging condition or are covered by saltcrust. Severe saline soils, which are waterlogged or covered by saltcrust comprise 5,224 ha of the area. Landsat TM data were used and the drainage and irrigation networks of the area were extracted manually.

The groundwater table (GWT) map (1:50,000) of the area was also prepared by Zayandab Eng. Con. Co. (1990) with isoline intervals of 1 m. The shallowest depth is 60 cm and the maximum depth is 473 cm. The isolines of map were digitized and interpolated.

A thick claypan was developed in the area, which impedes natural drainage of soils and seems has important impacts on salinity and waterlogging development. The map of claypan (1:50,000) was prepared by the Zayandab Eng. Con. Co. (1990) in three sheets and isoline intervals of 50 cm. The map indicates that the maximum depth to the claypan is 605 cm and the minimum depth is zero, where the pan is exposed at the soil surface. The isolines were digitized, interpolated and digital elevation model (DEM) of claypan was calculated.

Probability conditional analysis. All thematic factors were sliced into different classes and each class was considered as a unique condition unit (UCU). According to Bayesian theorem (Morgan, 1968) ratio of surface area of severe saline soils (SSA) in each UCU to the surface area of UCU is considered as severe salinity frequency (SSF) or conditional probability of severe salinity for that unit:

SSF= SSA/UCU (Eq. 1)

Relative frequency of each UCU (FUCU) is calculated by dividing surface area of each UCU to the surface area of total study site (TSS):

FUCU= UCU/TSS (Eq. 2)

The ratio of SSF to FUCU equals R and represents the importance of each UCU for salinization and waterlogging or hazard indicator of each unit:

R= SSF/FUCU (Eq. 3)

R values greater than 1 indicate that UCU have positive influences on salinity and waterlogging conditions otherwise the impacts are not sensible. A regression model was elaborated between UCU values and attributed R values. By using the regression model a hazard map was calculated for each factor. The final hazard map was calculated by multiplication of all four factor maps.

RESULTS AND DISCUSSION

Thematic Hazard Maps

Drainage canals. The distance map to the main drainage canals was calculated and was sliced into 16 unique condition units (Fig. 1). For each UCU attribute values of SSF, FUCU and the corresponding R values were calculated (Table I). The R values indicate that drainage canals lead to salinity and waterlogging of soils to a distance of 1000 m in the either side of canals but the soils to a distance of 1000 to 3000 m from canals are drained by drainage canals. It seems that the impacts of the main drainage canals disappear beyond 3000 m from the main drainage canals, because R values once more increases at this distance. A second order regression equation explains the relation between R values and the distance to the drainage canals (Table II).

Irrigation canals. The relationship between R values and distances to irrigation canals is very complex. Khan *et al.* (2005) reported from Pakistan that seepage and percolation from large irrigation systems gave rise to water table and thus gradually and substantially contributed to the out burst of waterlogging and salinization. The relationship of R values and distances to irrigation canals shows that there are three different trends in the area, which could be related to the magnitude of the canals therefore, the distance to the irrigation canals was divided into 3 sections and for each section a regression model was calculated (Table II). All

Table I. Classification of the distance to drainage canals map and attributed values of unique condition units

UCU No.	Distance (m)	SSF^Z	UCU/EA^Y	Ratio
1	0-250	0.29	0.08	3.6
2	250-500	0.18	0.07	2.6
3	500-750	0.16	0.07	2.3
4	750-1000	0.10	0.09	1.1
5	1000-1500	0.08	0.14	0.6
6	1500-2000	0.08	0.13	0.6
7	2000-2500	0.08	0.12	0.7
8	2500-3000	0.05	0.08	0.6
9	3000-3500	0.06	0.05	1.2
10	3500-4000	0.08	0.05	1.6
11	4000-4500	0.08	0.04	2.0
12	4500-5000	0.07	0.30	2.3
13	5000-5500	0.02	0.02	1.0
14	5500-6000	0.02	0.01	2.0
15	6000-6500	0.13	0.007	18
16	6500<	0.30	0.004	75

^{Z} and ^{Y} denote Severe Saline Frequency and Entire Area respectively.

Table II. Regression models between R values and distance or depth factors (X)

Factor	Model	R^2
Distance to drainage canals	$R=8E\text{-}07X^2+0.0042X+5.1071$	0.55
Depth to groundwater table	$R= 2E\text{-}11X^{4.5487}$	0.77
Depth to clay pan	$R= .0491X^3+09702X^2-4.1619X+5.5733$	0.96
Distance to irrigation canals (from 0 to 650m)	R= 0.0055X-0.3380	0.99
Distance to irrigation canals (from 650 to 2500 m)	R= 0.0041X-2.2895	0.97
Distance to irrigation canals (from 2500 to 5500m)	R= 0.0034X-6.1157	0.95

Fig. 1. The drainage network and slices of the buffer zones around the drainage canals of study area

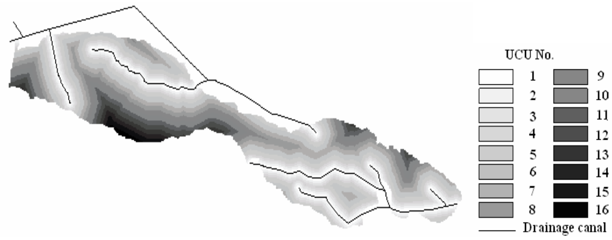


Fig. 2. Frequency of severe salinity and unique condition units for distance map from the drainage canals

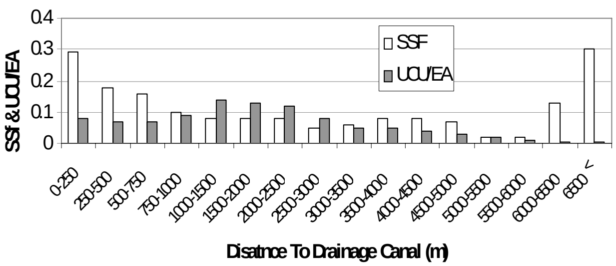
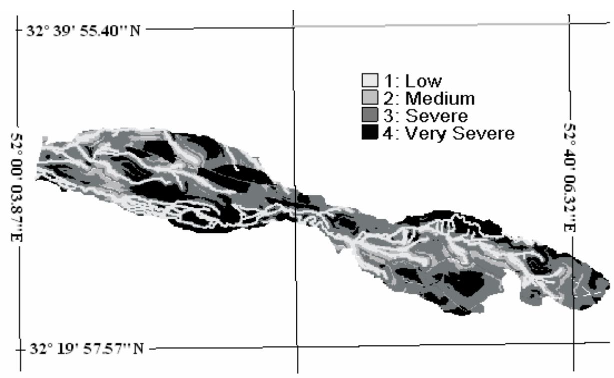


Fig. 3. The hazard map of the area which is classified into 4 hazard classes



three models are linear, which indicate that by increasing the distance from canals soil salinity increases.

Groundwater table. Groundwater table (GWT) depth varies between 60 and 473 cm. The probability of salinization and waterlogging is very high for areas with GWT depth less than 120 cm (Fig. 3). By increasing the depth of GWT from 120 to 200 cm the risk of soil salinity decreases and for areas with GWT depth more than 200 cm again the risk of land degradation increases. An exponential regression equation describes the relations between R values and the corresponded depth to GWT (Table II). The importance of shallow groundwater table for soil salinization is reported from other similar areas by Bonham-Carter and Wright (1990) and Zhao *et al*. (2004).

Claypan. The probability of salinization and waterlogging is considerably high for soils overlying claypan depth less than 1.5 m (Fig. 3). Kitchen *et al*. (2005) also demonstrated that productivity zones on claypan soil fields is related to ECa and that possible mapping of productivity zones by using ECa and elevation on such soils. It seems that the shallow perch GWT leads to high capillary movement of water in such areas and increases the risk of salinization. By increasing the depth to claypan between 1.5 to 3.5 m the hazard of soil salinity decreases, which could be due to natural draining of soils. The hazard of soil salinity increases by increasing the claypan depth beyond 3.5 m, which could be due to the depressions of the claypan. A third order regression equation explains the relation of R values and attributed depths to claypan (Table II).

Hazard maps. In the previous sections for each factor a regression model was calculated. For each factor a hazard map was delineated by using the attributed regression model. The final hazard map was calculated by multiplying all four hazard maps, which shows the spatial variations of salinity hazard over the study area. To estimate the reliability of the hazard map it was classified into four arbitrary hazard classes of low (<1), moderate (1-3), severe (3-20) and very severe (20<). The hazard model was compared with the indicator map of severe saline soils of the area, which was prepared by Naderi (1998). The comparison indicates that 81.37% of severe saline soils are located in the severe and very severe hazardous areas, while 18.63% of severe saline soils are located in the low and medium hazardous areas.

There are many reasons for 18.63% discrepancies of the hazard model and the salinity maps. One reason could be that saltcrusts are inherited from previous conditions, while at the moment the agents of soil salinity are removed or the model needs more factors for a better prediction of salinity hazard. The limits for classification of continuous hazard map are deterministic so changing the limits may provide a more precise hazard map. However the results are reasonable and indicate the possibility of mapping susceptible sites to salinity by integration of conditional analysis and GIS techniques.

The classified hazard model (Fig. 3) also shows prominent influences of irrigation canals on soil salinization of the area. A buffer zone around the irrigation canals is indicated as low hazardous area. Microtopography and elevation of lands around the irrigation canals, feasibility aspect of irrigation, high quality of water and cultivation of lands could be the main reasons of low salinization hazard of these soils. Distant areas from irrigation canals and soils in the vicinity of the main drainage canals are prone to salinity and waterlogging.

A high risk of salinization for the soils with shallow GWT (less than 100 cm) seems logic. Elisabeth (1997) also reported that high and medium salinity hazard occurs, where GWT is shallow. The risk of salinization is low for soils with GWT depth between 100 and 200 cm, which could be due to increasing the distance from the GWT. Also drainage of soil profile encourages farmers to cultivate such soils and indirectly aids leaching of excessive salts from root zones. Increasing the risk of salinization for soils with GWT depth more than 200 cm could be due to the geomorphology of the claypan. The spatial map of depth to claypan shows that there are several depressions on the claypan, which are filled by younger alluviums therefore accumulation of brackish water inside the depressions may leads to salinity hazard of overlying soils.

CONCLUSION

The conditional analysis and GIS techniques have great potential for mapping salinity hazard. Using more land attributes in the model like detailed digital elevation model (DEM), microtopography and soil permeability maps may improve the results. The depressions on the claypan may induce severe salinization and waterlogging in some parts of the area. Conditional analysis reveals that the drainage canals impact salinization and waterlogging of soils, which are located at a distance of less than 1000 m by charging the attributed GWT and the efficiency of the drainage canals eliminates at a distance of 3000 m. The soils, which are located at a distance of 240 m and more from irrigation canals are also prone to salinity. The study also indicated that soils with GWT depth less than 100 cm, GWT depth more than 200 cm, claypan depth less than 150 cm and claypan depth more than 400 cm are more vulnerable to salinity and waterlogging. Geomorphology of claypan plays a great role on soil salinity and waterlogging of the area. The hazard model could aid decision makers and engineers for agricultural planning and proper designing of irrigation and drainage networks.

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