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Soil Salinity and Alkalinity Map Preparation Based on Spatial Analysis of GIS (Case Study: Tabriz Plain)

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Abstract

Better management of agricultural fields is related to valuable information which can derived from soil salinity and alkalinity maps. These maps are considered as one of the most important factors which restrict plant growth as well as decline crops yield. The objective of this research was preparing of soil salinity and alkalinity maps in Tabriz plain over 50,000 hectares based on different techniques of spatial analysis in GIS software. For this mean, study area was divided in 1500 × 1500 m^2 grid cells. Then, geographical coordinate of each grid recorded in UTM system. So, they were transferred into GPS for navigating to the exact excavation location. After soil sampling and transferring to the lab, their EC and PH were measured in saturation extract of soil samples. So, spatial distribution of soil sampling points was prepared in form of point map by GIS software. Generalization of point information to surface was performed using different interpolation algorithms and based on standards of Soil and Water Research Institute. Accuracy of interpolated maps was evaluated due to the MAE and MBE values. The results showed that the lowest observed error is related to the Spline method and therefore, this method was used for spatial modeling of salinity and alkalinity maps in the intended area. The research findings demonstrated that from total of 50,000 hectares, only 3066 hectares were without salinity and alkalinity limitation (6.1%), 9066 hectares had low salinity and alkalinity (18.1%); 17,772 hectares had average limitation for salinity and alkalinity (35.6%) and the remaining 20,096 hectares had high and very high limitation for salinity and alkalinity.

Keywords

GIS, Interpolation Techniques, Salinity and Alkalinity Map, Tabriz Plain

1. Introduction

Saline soils are covered wide area of Iran. These soils were scattered in small and large scales at different parts of country, which due to salinity spread from these soils, adjacent lands are threatened. Although in recent decades, excavation of deep and semi-deep wells has been solved the problem of water scarcity in many parts of this country, uncontrolled exploitation of groundwater resources was caused reduction in groundwater levels and intrusion of saltwater into freshwater aquifers in many plains [1]. Soil salinity has two main reasons: salinity related to nature, soil texture and geological formations of area in different times and tectonic effects which refer to initial salinity. The second type is known as secondary salinity which caused by irrigation with saline water or swamp and rising groundwater levels [2]. Salinity and alkalinity of area soil and salinization of its adjacent lands are one of the most important problems in this country that can reduce soil fertility and make them barren gradually. This process is inhibited only with scientific prudence and correct management. The first step in better management of salt-affected soils is monitoring and evaluation of salt areas and map preparation of salinity and alkalinity soil to determine which areas have the salinity problem and spatially distribution of salted area and how much is the rate of its expansion [3]. It is certain that sampling from soils in large-scale at different times is necessary for detection and monitoring of spatial variability of salinity and alkalinity soil. One of the main problems in this aspect is long leading time to sampling process as well as high cost of laboratory and accuracy of those analyses. In Hungary based on soil protection legislation which was approved in parliament 1994; maps of soil salinity and soil alkalinity were prepared on scale of 1:25,000. For this mean, soil samples were collected from each 5 hectares. These studies showed that about 13% of the country's soil had salinity problems. Then it was decided that sampling is done per 12 hectares for monitoring of changes in salinity and alkalinity in ten-year' time periods. Maps comparison in GIS environment showed that this problem is spreading due to secondary salinity of soils and the main factor of soil salinization is because of irrigation with saline water and unethical management of land [4]. In conventional methods in Iran; the information was obtained from profiles in form of spot and there was no information up to adjacent sampling. Therefore, it is essential that the obtained data from sampling is extended to surface. So that based on available profiles data; status and characteristics of adjacent areas soils are to be reconstructed [5]. The process of data estimation for locations where there is no information for them based on information of sample areas, called spatial interpolation [6]. Different algorithms for spatial interpolation are available in GIS software which has been used in different studies. Different interpolation methods such as: Inverse Distance Weighted (IDW), Spline, ordinary Kriging and universal Kriging are used to convert point data to surface information based on different models of semi-variograms [7]. Geostatistics is used to investigate spatial distribution of variables and interpolates. This science enters into the science field from mid-twentieth century and creates possibility of data development and description of spatial data. Geostatistics is included all statistical methods (classical statistics and spatial statistics) which are used in earth sciences. [8] prepared maps of salinity and alkalinity for 14 states in India at the GIS environment. These maps showed about 6.7 million hectares of India's lands located in arid and semi-arid areas and they are influenced by various salts, which has been affected their fertility severely. First, these soils were classified in 15 groups, but for applying of corrective actions management; these soils were classified in three groups: saline soils, saline and alkali soils and alkaline soils. [9] prepared soil salinity zonation maps using GIS and geostatistics. [10] used interpolation method consists of Moving average, inverse distance squared, triangular, Laplace and ordinary kriging for estimation of surface soil acidity. The results of these researchers showed that the accuracy of Kriging method in estimation of soil acidity was higher than other methods. According to the research by [11] in the field of soil salinity and soil alkalinity, kriging method has been more accurate than other methods. [12] were the first researchers who suggested application of geostatistics to estimate the spatial structure of soil properties and development of precision agriculture. In recent decades in Iran, many studies have been done about use of geographic information system in map preparation with soil subject. [13] in Qazvin ziaran plain used kriging, cokriging and IDW methods for preparation of salinity map and Sodium Absorption ratio. They reported that kriging and cokriging methods are more accurate than IDW method. [14] estimated some models of Geostatistics for assessment and zoning of spatial variability in soil salinity, they concluded that IDW method with power of three is more accurate for zoning of saline soils. [15] used kriging and cokriging methods for estimation of salinity spatial variability and preparation of soil salinity map. The results of this study showed that Kriging method with correlation coefficient of 0.97 has high accuracy for estimating salinity values in points without information. [16] prepared map of soil salinity and soil alkalinity in Marand Harzandat plain using GIS and reported that from total of 16,867 hectares, 11,437 hectares were without limitations of salinity and alkalinity, 1809 hectares had low alkalinity and without limitation of salinity, 2940 hectares had some limitations of salinity and alkalinity, 269 hectares had relatively high limitation of salinity and 421 hectares had relatively high limitation of salinity and low alkalinity. [17] prepared zoning map of salinity hazard for Southeast of Isfahan by using GIS and multi-criteria evaluation and reported that depth of groundwater and depth of impenetrable layer play major role in salinity of these lands. [18] evaluated salinity and alkalinity of Isfahan soils and prepared zoning map of salinity and alkalinity for study area soils by using the ILWIS 3.8.1 software. Reduction in water level of Uremia Lake and its drying in recent years are caused increase of saline and alkali saline lands around the lake. Increment of electrical conductivity amounts in soil solution raises its osmotic pressure therefore plants cannot absorb required water from soil. While alkalinity augmentation is destroyed soil structure due to sodium ion-specific effect and these lands are prone to wind erosion which have been made them source of salty micro dust ultimately. This subject has been caused to environmental concerns in recent years [19]. Restoration committee of Urmia Lake was described effect of the Urmia Lake drying on agriculture and residents of this area, in his third report as follows: 1) development of salty micro dust due to increment of dust production center and desertification 2) fertility decline, resonance of soil salinity and loss of agricultural lands, orchards and pastures due to salt dispersal by wind 3) entrance of toxic compounds to food chain and creation of incurable diseases in the region 4) augmentation of immigration specially villages evacuation around the lake 5) ecosystem alteration and intensification of climate change and drought [20]. With regards to large area of saline soils in this region and intensification of soil salinity due to the lake drying, it is necessary to determine salinity and alkalinity of area soils and define its future changes by continuous sampling and periodic trends and with application of necessary management prevent from expansion of saline lands and intensification of soil salinity. In this regard, the study was carried with purpose of zoning maps preparation for salinity and alkalinity of Tabriz plain soils at level of 50 thousand hectares, using various techniques of spatial analysis in GIS 12.3.2 software.

2. Materials and Methods

Location of the studied area

Tabriz plain with more than 100 thousand hectares is located in the east part of Uremia Lake. This area is on two physiographic units of floodplains and lowlands. Generally, slope of these lands is less than 2% without lateral slope and topography; in some parts have minor roughness. Water sources of Tabriz plain are Aji Chai River, Sinikh Chai River, Sofiyan Chai River, Lighvan Chai River, semi-deep and deep wells with salty water and brackish water. Aji chai is the largest river of Tabriz. Water of this river is fresh in upper parts and headwaters but it dissolves various solutes due to going across from marl formations in its path and turn into salts, so that it is unusable in case of water shortage and in summer and autumn months due to high salinity. Aji Chai River in time of flooding which soil salinity has been intensified with drying of Urmia Lake and irrigation with saline water of wells. Diversity of native plants is high relatively which are mostly in form of small bushes of halophytes plants. Crop plants are involved: wheat, barley, alfalfa, sugar beet and onion [8]. Soft deposits of Uremia Lake are mainly as result of sediments from lake deposits of Maragheh formation, shales and sandstones of Cretaceous and Neogene, limestone of Qom formation and masses of granite. Material of lake deposits is often clay, silt, fine sand and very low situ chemical sediments. In its detrital deposits; quartz, calcite and mica are more abundant than other minerals. Clay-minerals in these detrital deposits are mainly illite, kaolinite and chlorite also situ deposits have the highest values of aragonite. Generally, amount of organic matters in the sediments of Urmia Lake are low, but this value increase in wetlands and salt marshes of the Lake [21]. Location of studied area has been presented in Figure 1.

Figure 1. Location of studied area.

Research Methodology

Sampling was done based on of 1500 × 1500 m^2 grids and in the case of drastic changes; sampling was also conducted in shorter distances (Figure 2). Then, geographical center coordinate of each reticule in form of UTM was transferred to GPS for determination of the exact sampling locations. After departure to the region; excavation of profile and sampling of different layers were carried out. Soil samples were transferred to the soil and water laboratory in Research Center of Agriculture and Natural Resources in East Azerbaijan. After preparing the soil samples; electrical conductivity and pH were measured in saturation extract of soil samples using Ec meter and pH meter (8). All amounts of salinity and alkalinity were measured in each profile and their thicknesses were classified in three depths of 50 - 0, 100 - 50 and 150 - 100 cm. According to the amounts of these variables in the above thicknesses, salinity and alkalinity class of profiles were determined in Table 1 and Table 2 [22]. Until this step, salinity and alkalinity of study area soils were identified in form of point and in locations of profile excavation. In next step; different interpolation methods such as: Inverse Distance Weighted (IDW), Spline, ordinary Kriging and universal Kriging are used to convert point data to surface information based on different models of semi-variograms. Selection of the most suitable interpolation method was done using

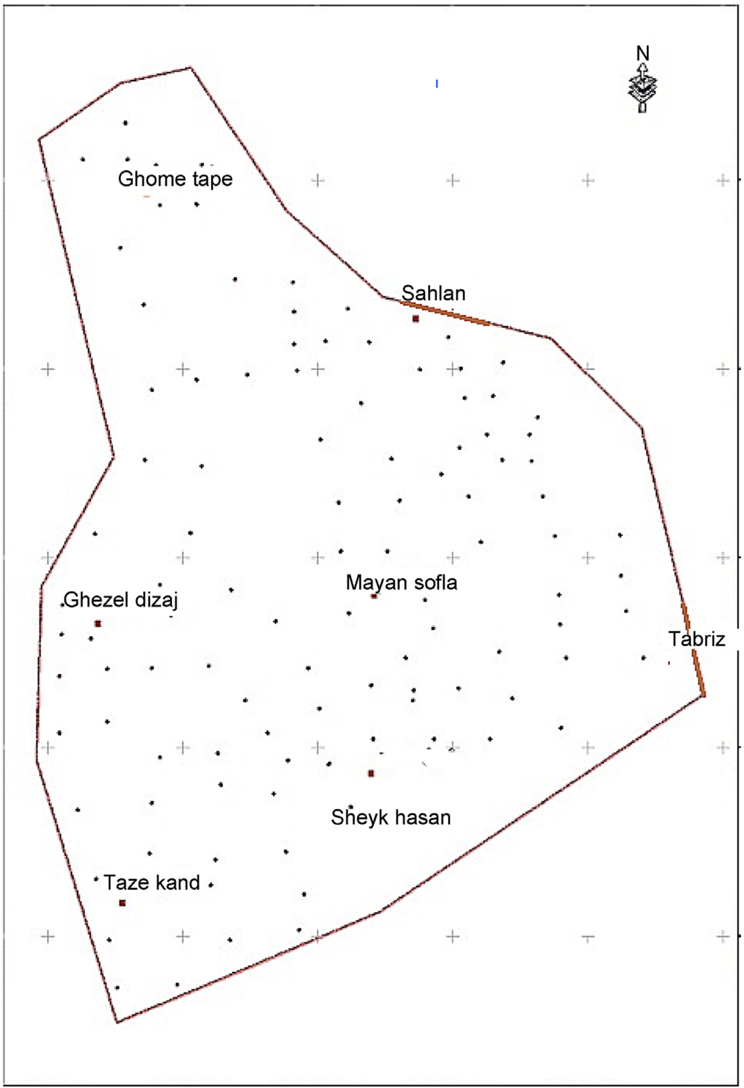

Figure 2. grids map and position of sampling points.

Table 1. Classification standard of lands in terms of salinity (4).

Description	Electrical conductivity (dS/m)	Sign
Without salinity limitation	<4	S_o
Low salinity limitation	4 - 8	S_1
Relatively high salinity limitation	8 - 16	S_2
High salinity limitation	16 - 32	S_3
Very high salinity limitation	>32	S_4

Table 2. Classification standard of land in terms of alkalinity (4).

Description	pH amount	Sign
Without alkalinity limitation	<8	A_o
Low alkalinity limitation	8 - 8.5	A_1
Relatively high alkalinity limitation	8.5 - 9	A_2
High alkalinity limitation	9 - 9.5	A_3
Very high alkalinity limitation	>9.5	A_4

cross-validation and based on criteria of MAE and MBE. This means that in each interpolation method, the observed values were removed from total data temporarily and interpolation process was run again with others samples and the new value was estimated for that point. Finally, validation of different interpolation methods was carried out by comparing observational amounts with its corresponding estimated values and if the numerical values of mentioned criteria was zero or close to zero, it was indicated that this method is proper and whatever distance from zero was higher, it was indicated deviation from desirability of interpolation or otherwise deviation from the actual values and shouldn't be used that method for preparation of surface maps. After determination of the most suitable interpolation method, surface maps of soils salinity and alkalinity were prepared by selected interpolation method. Homogeneous zones in terms of salinity and alkalinity were done in GIS software based on standards which were presented by the Institute of Soil and Water Research (Table 1 and Table 2) and using Re-classify method. Surface maps were prepared in order to estimate alteration of EC and pH in the studied area and then one map as salinity and alkalinity map was prepared with combining two maps for ease of use in management application and suggestion of improvement programs.

3. Results

According to the research method and based on different algorithms of interpolation in GIS software and using ILWIS software in each interpolation method, the observed values were removed from total data temporarily and interpolation process was run again with others samples and the new value was estimated for that point and a table was formed with observed and estimated values for each mentioned interpolation algorithms. In the next phase, the results of different interpolation methods in preparation of considered maps was assessed through statistical comparison of observed values with its corresponding estimated values which have been presented in Table 3. According to this information, the least amount of error was belonged to spline interpolation method and ordinary Kriging method was after that.

Therefore, surface maps of salinity and alkalinity for soils of Tabriz plain were prepared based on spline method. At this stage, referred maps were classified to different groups based on classification values which were presented in Table 1 and Table 2; final combination map was provided for the studied area by combining maps of salinity and alkalinity classes.

Table 3. Results of different spatial interpolation methods.

Row	Method	MBE	MAE
1	Spline	0.5	185.5
2	IDW	0.7	275
3	Universal kriging	0.88	58
4	Ordinary Kriging	0.6	288.5

4. Discussion and Conclusion

The results of interpolation and surface map preparation of salinity and alkalinity for Tabriz plain are given in Table 4 which showed amounts of salinity and alkalinity increased in close parts to Urmia Lake so that from total of 50,000 hectares, only 3066 hectares (6.1%) were without salinity and alkalinity limitation. 9066 hectares (18.1%) had low salinity and alkalinity; it means salinity is below 4 - 8 dS and pH is 8 - 8.5. In case of supplying proper water, cultivation pattern should be reformed in these lands and salt-tolerant crops such as saffron, safflower, canola and pistachio should be cultivated instead of crops with high water demand such as alfalfa, onion and sugar beet. Naturally, development of greenhouses especially for vegetables and also modified irrigation from basin to drip systems in orchards is recommended in this part of the plain. In 17,772 hectares (35.6%) of these lands, salinity is 8 - 16 dS and pH is 8.5 - 9. These lands are barren now, but remnant of old plots show that cultivation has been existed at these lands in not too distant days. Therefore, in these lands, salinity tolerant crops such as barley and pistachio can be cultivated by supplying proper water, drainage and specific management. Existence of multiple waterways assembles possibility of drains construction and depletion of canals area and performance downfall in these lands will also be evident absolutely.

These results are conformed with studies in recent 20 years, anomaly exploitation of water and soil resources, unauthorized digging wells and uncontrolled exploitation of groundwater which were caused groundwater salinization and eventually were led to soil salinity in marginal east lands of Lake Urmia or Tabriz plain where until a few years ago agriculture was booming in there [23]. As it is clear in the maps, amount of salinity and alkalinity in soil have the converse relationship with distance from the lake and with approaching to the lake, salinity and alkalinity increase in soils due to augmentation of influence possibility of salt water from the lake into groundwater and irrigation with saline water have been caused further increase of salinity and alkalinity in these lands. These results correspond with the results of Wang *et al.*; they reported that soil salinity in the Yellow River delta in China increased by reducing the distance from Bo Sea which had salty water [24].

About 12,000 hectares (12%) of study area have high salinity and alkalinity; from past times, farmers used these lands as pasture. These lands are lowlands mainly in which cultivation is not possible due to clay soil texture and increment

Table 4. Various classes area of salinity and alkalinity in Tabriz Plain.

Class	Area (ha)	Class	Area (ha)
S_0A_0	3066	S_3A_1	207.5
S_0A_1	80.5	S_3A_2	6432.5
S_1A_0	475	S_3A_3	5741.5
S_1A_1	9066.5	S_4A_3	2819
S_2A_1	9813.5	S_4A_4	4279.25
S_2A_2	7958.75	**sum total**	50,000

of sodium surface adsorption ratio in these soils and on the other hand, reduction of soil permeability as well as poor drainage. It is necessary to amplify these lands with management application and with abatement of uncontrolled grazing; because by losing vegetation and with approaching to dry bed of the lake, it can be focuses of dust. The remaining 8000 hectares are the western part of the studied area which has high salinity and alkalinity and years away, were parts of Uremia Lake but these parts have come out of water with retrogression of the lake and are now bare and without of any vegetation. High water level in saline groundwater is certain in some seasons of the year in this part of the region so that in constructed profiles, temporary wetlands symptoms are clear which include brick and black pigments that represent restored iron and manganese, respectively. In summer, these lands become as focuses of salty micro dust, due to destruction of soil structure caused by sodium ion-specific effect in severe winds. Soil salinity and alkalinity are a continuous quantity, as the maps show; these factors increased from south and east-south to west gradually until lands become with high salinity and alkalinity which from this area to the next, a leap forward occurs in values so that, Ec reaches to more than 100 dS/m and pH reaches to more than 10. In this area, these factors will lose their continuity, and in the past, these lands were part of the lake bed and had come out of the water over time with drying of the lake. In recent years, the lake lost miry status due to surface water drop and became source of salty micro dust in the dry seasons. Retrogression of Uremia Lake is as a result of imbalanced development and dominance of individual profits over regional and national profits in which one of its implications is intensification of salinity and alkalinity in the region soils. Therefore, it is essential to evaluate changes of these two factors in short, medium and long-term and it should be prevented from salinity development and specially focuses of salty micro dust with creation of information bank and management application by updated information.

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