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MAPPING BORON POLLUTION USING GIS FOR BORON-AFFECTED SOILS IN WESTERN TURKEY

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Abstract: This study was aimed to assess status of boron pollution, identification of agricultural soils at risk in Seydisuyu Watershed of Western Turkey, which has rich B deposits. The maps of borom pollution for the soils were produced using GIS. Boron concentrations in the irrigated soils varied widely, from 0.08 to 3.40 mg kg^{-1} depending on the sampled fields and soil depths. The highest boron concentration was found in the top layer of soil (0–30 cm) for all sampled fields. This revealed that the top layer of soil was most affected by accumulation of boron. However, there is no excessive boron pollution especially in terms of crops. Thus, decision makers, irrigators and farmers could be used these boron pollution maps for appropriate irrigation and soil management.

Key words: boron, soil, pollution, GIS, mapping, Turkey

1. INTRODUCTION

The use of geographical information systems (GIS) for agricultural resources management is gaining interest among researchers. It is one of the tools that can be used in their bid to use their soil resources sustainably. It makes soil management less tedious and costly, by collecting a wider spectrum of data in a much shorter span of time.

GIS have, thus, become essential tools for the practical deployment of watershed assessment projects and ultimately for providing support for water quality protection and conservation (Diluzio et al., 2004). The GIS can also be used to prepare maps showing the vulnerability of areas to exceed selected standards of chemical movement. Within these frameworks digital soil information and data sets play a key role in defining the spatial distribution of soil pollution and unaffected soil pollutants. Soil mapping or soil surveying is, thus, a process in which the spatial distribution of physical, chemical and descriptive soil properties are evaluated and presented in a form that can be understood and interpreted by various users (Beckett, 1976; Dent & Young, 1981).

The long history of agriculture and settlement, the intensive mining of minerals and lignite, and the widespread (mis) management of soils have caused a complex pattern of soil degradation and pollution all over the world (Batjes, 2000). On the other hand, decision-making is becoming increasingly complex as dwindling natural resources and more demanding economic priorities diminish the change of today's decision being right now. Furthermore, environmental awareness is ever increasing (Bernhardsen, 1992). The pressing global challenges are now: uncontrolled desertification, erosion, pollution of rivers, lakes, soils and oceans, and reduced ozone layer etc.

Digital mapping of regional soils affected by boron is essential when monitoring the dynamics of soil boron and planning land development and reclematation schemes. Soil mapping or soil surveying is a process in which the spatial distribution of physical, chemical and descriptive soil properties are evaluated and presented in a form that can be understood and interpreted by various users (Sheng et al., 2009).

Soils are critical environments where rock, air and water interface. Consequently, they are subjected to a number of pollutants due to different anthropic activities (industrial, agricultural, transport, etc.). Soils can also be a source of pollution to surface and ground waters, living organisms, sediments, and oceans (Facchinelli et al., 2001).

Boron (B) contamination in the agricultural lands is an important problem for Western Turkey, which has rich boron deposits. One of the biggest borax mining in Turkey is in the Seydisuyu Watershed in Eskisehir Province of the Western Turkey. In the preliminary study in this area, boron concentrations in the water of Catoren Dam and Kunduzlar Dam, which are main water resources for irrigation in the study area, were 4.6 and 1.8 mg L^{-1}, respectively. In addition, boron concentration in the water of deep wells situated in the plain in the downstream of the catchment area ranged from 1.2 to 4.2 mg L^{-1}. Water contamination has erupted in irrigation water in Seydisuyu Watershed. Since both these water which were upstream of the watershed and the plain are found contaminated, farmers and decision makers fear adverse effects on their lands. To establish reliable and realistic guidelines, thus, it is necessary not only to have a good knowledge of the mean content and the variability in space of boron content in soils, but also to apportion anthropogenic and lithogenic inputs. Therefore, preparing maps on boron-affected soils and/or the soils under the boron pollution risk will be necessary for farmers, irrigators, and irrigation scheme and decision makers.

The study was aimed to assess status of pollution as accumulated boron, identification of areas at risk. The polluted soils or risk areas with boron were, thus, determined using GIS.

2. MATERIAL AND METHODS

2.1. Study area

The watershed area in the study region covers approximately 180 km^2 between 30°16′–31°07′ E and 38°85′–39°36′N in Seydisuyu Watershed in Eskisehir of Western Turkey. Irrigated area in the watershed was totally 15,500 ha. This area is located in the terminal of Seydisuyu River. The area has a typical continental temperate climate with a mean annual precipitation of 369mm, a mean annual evaporation of 922mm, and an average annual air temperature of 10.0°C. Elevation is 945 m (DSI, 1983). Furthermore, the soil formation process in the study area is rather weak due to the arid climate and sparse vegetation (Anonymous, 2004).

The terrain of the study area is relatively sloppy except the banks of Seydisuyu Creek and lowers the plain. There are different types of soil parent materials within the area, limestone, marn, old clayey and Neogen deposits. Calcium content of soils is high (Onocak, 1990). There is no other surface water available in the study area. The groundwater table is greater than 10m deep.

2.2. Soil sampling and analysis

Number of positions from where the samples were taken was 256. In selection of the sampling fields, different land characteristics such as topography, soil depth, soil texture, and irrigation water sources (surface water or ground water) were taken into account. The interval between each two points from sampling ranged approximately from 250 m to 1000 m, and each sample represent approximately area of 0.52 km^2. Thus, the method of "guided soil sampling" was used for soil sampling. The soil samples were collected by means of an auger every 30 cm to a depth of 120 cm as long as soil profile was available. The samples of 3 through 5 were collected from each site and each depth depending on the size of the field, in an effort to represent the entire field. The soil samples from same depths in the same field were mixed; thus, one soil sample at each soil depth from each field was obtained. Soil samples were obtained from the 0–30, 30–60, 60–90 and 90-120 cm depth intervals. Thus, every point contains four samples from the four depths. However, the numbers of samples were less than 4 if soil depth is limited. Soil sampling points were positioned using Global Positioning System (GPS).

The soils brought into the laboratory were air dried, ground, and sieved for preparing laboratory analysis. The soils were analyzed using the Karmen method in determining boron content of the soils (Richards, 1954).

2.3. Data analysis methods

The map sections in the scale of 1/100 000 pertaining the catchment area were scanned and placed in the map coordinates and Modular GIS Environment (MGE)). The catchment data required were digitized from these map sections. That the places of sampling points were determined the coordinates by means of GPS were marked on the digitized maps. The distribution of boron-affected soils was computed using geostatistical analysis (GS, 5.0). Thus, normal distributions for soil data were checked using Kolmogorov-Smirnev test (SPSS, 11.0). The semivariograms were realized for the spatial determination.

The experimental semivariogram was computed for 4 direction of North-south (0^0), Northern-east-Southern-west (45^0), east-west (90^0) and Southern-Northern-west (135^0).

2.4. Generation of soil pollution map

The softwares of ARC/INFO 7.2.1, ArcView 3.1, SURFER-6.01, geostatistical analysis (GS, 5.0), semivariogram, Kriging interpolation were used to analysis and map the levels of boron-affected soils. Interpolation was used to estimate the values in the areas in which there is no data from the collected data in the study area. Kriging is a method which is used to generate a surface from the series of Z points sporadically distributed in the area. It determines the domain variations from the points of Z. These values of Z might be soil variabilities (Webster & Oliver, 1990).

The centered log-ratio transformation (CLR) was used for the semivariogram models and corresponding parameters of B levels. Firstly, the Kriging interpolations were performed on B levels by CLR to generate a map of their spatial distribution, back-transformation were done to recover original variables map using the Raster Calculator Tools program in the ArcGIS software.

Mapping pollution for boron affected soils were based on the boron ranges for slightly B: <0.7 ppm; moderate B: 0.7-1.5 ppm, high B: 1.5-3.75 ppm and very high B: >3.75 (Ozgul, 1974). All the maps were produced considering these boron ranges.

3. RESULTS AND DISCUSSIONS

3.1. Elevation and boron pollution map of the catchment area

The elevation map of the whole catchment area was produced (Fig. 1). The highest altitude was more than 1700 m and the minimum altitude was 860 m. The sloppy of the area is from South through north direction. The elevation of the irrigated lands is mainly between 860 and 1050 m. The downstream of the catchment area are slightly flat. However, the lands in the area are, in general, curly sloppy except near the bank of the Seydisuyu Creek. The soils had fertility, deep profile and flat are located near the each banks of the creek. The other lands mainly are more or less sloppy and curly.

On the other hand, boron pollution of the whole catchment area was produced (Fig. 2). B levels in the catchment area are mainly slight and/or moderate levels. The highest level is in the very small area which is in the upstream of the catchment and near the boron enterprise. This could be from geological formation.

3.2. The map of boron pollution risk for the irrigated area

Database was used to monitor soil pollution in the Seydisuyu Watershed. Thus, boron pollution risk map of the irrigated area, totally 15 000 ha, were generated according to the different soil depths. The results of boron pollution maps are shown in figures 3, 4 and 5.

Boron concentrations in the irrigated soils varied widely, from 0.08 to 3.40 mg kg^{-1} depending on the sampled field, soil depth. The highest boron concentration was found in the top layer of soil (0–30 cm) for all sampled fields. This revealed that the top layer of soil was most affected by accumulation of boron.

According to the pre-study carried out by the authors, the amount of boron in irrigation water ranged from 0.87 mg L^{-1} to 3.38 mg L^{-1} depending on the stage of the irrigation season, the source of the irrigation water, and the study year. The levels of boron concentration in irrigation water were obviously higher than 1 mg L^{-1}; thus, it appeared that the water was seriously polluted with boron. One reason was that the study area was located in the same catchment area as the largest borax mining operation in Turkey, upstream of the study area.

The largest area in the study area is moderate boron soil in terms of boron level. There was no any area had very high boron soil in the irrigated area (Figs. 3, 4 and 5). Considering crop growth in the irrigated area, it could be considered that there was no significant danger in terms of boron pollution. However, it is clear that there is a risk for the soils and crops. Thus, the digital soil mapping is better suited to this area which is small, has a relatively flat relief and only a single type of vegetation, and base the credible interpolating method to be used in conjunction with GIS tools (Sheng et al., 2009).

As seen in figure 3, 4 and 5, there are some differences in boron concentration in the distinct area of the irrigated soils. The reasons of this could be soil texture, the topography of the lands and resource of the irrigation water i.e. deep well water or surface water from the dams. The soils in the study area are irrigated by both weep well water and surface water. Because, the concentration levels of boron were different depending on the water resource. In addition, the areas which have boron concentration are, in general, near the Seydisuyu Creek and those are flat area. These features could cause the higher boron concentration in the flat and near lands of Seydisuyu Creek. In addition, boron concentrations in the inclined and fluctuated lands were less than those in the flat lands. That is, there was no accumulation of boron in the soil.

On the other hand, the soils in the study area had, in general, high clay content and lime. Because soil texture can influence how soils and irrigation water are managed, maps which delineate soil texture will be useful in designing management strategies.

These soil characteristics enable them to tolerate the negative impacts of boron.

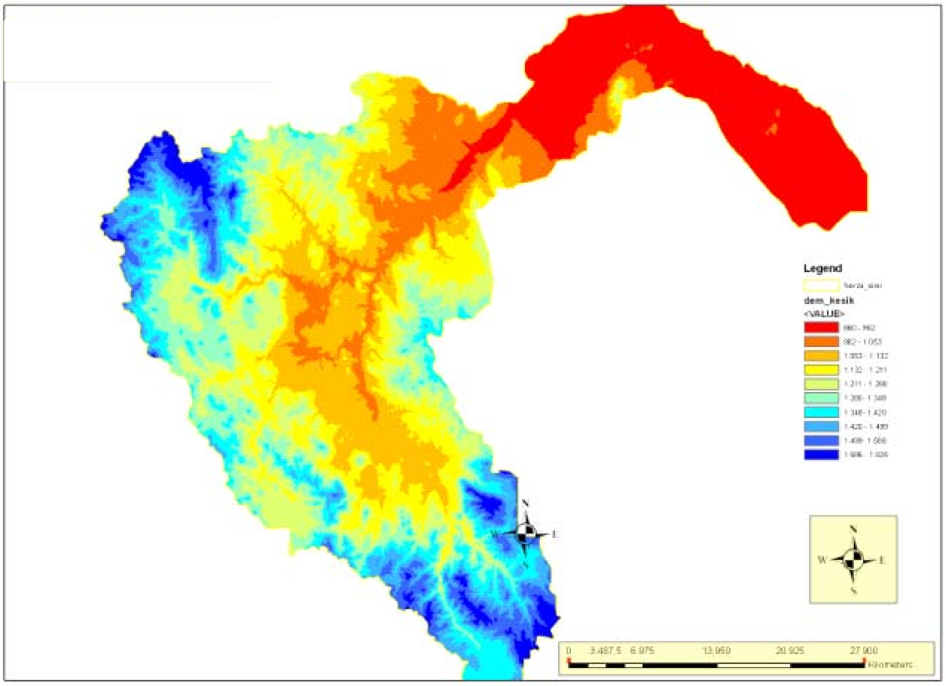

Figure 1. The elevation map of the Seydisuyu Watershed

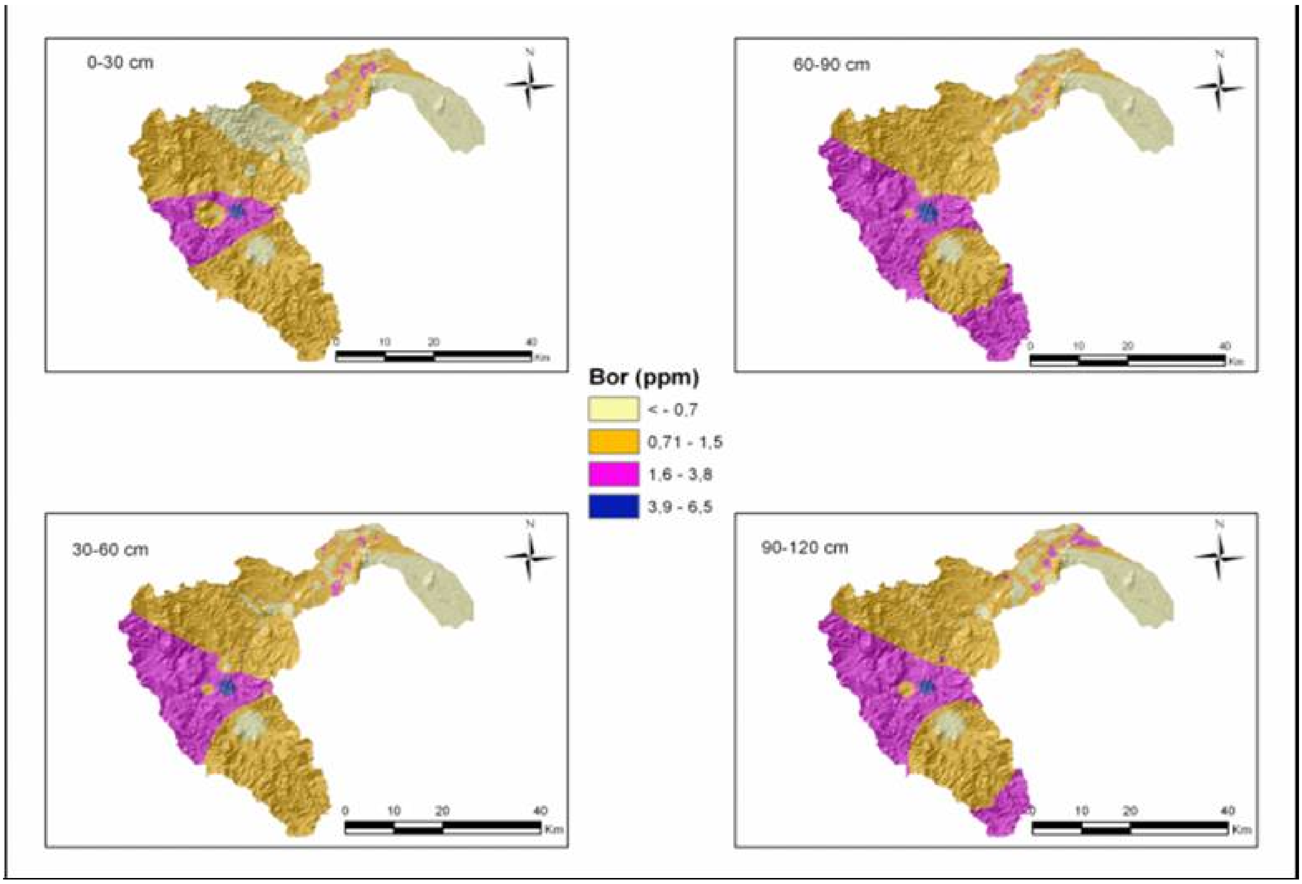

Figure 2. Classification of boron pollution for the whole catchment area according to the different soil depths.

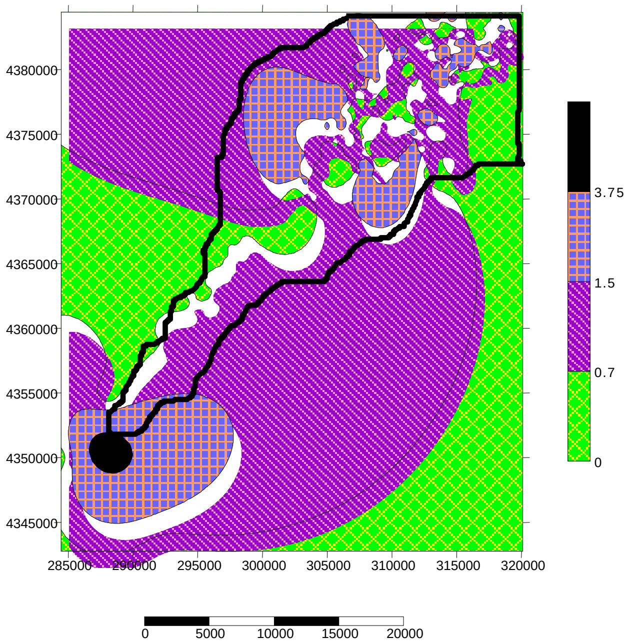

Figure 3. The distribution of boron pollution in the irrigated soils (the soil depth of 0-30 cm)
(The black lines in the graph show the irrigated land)

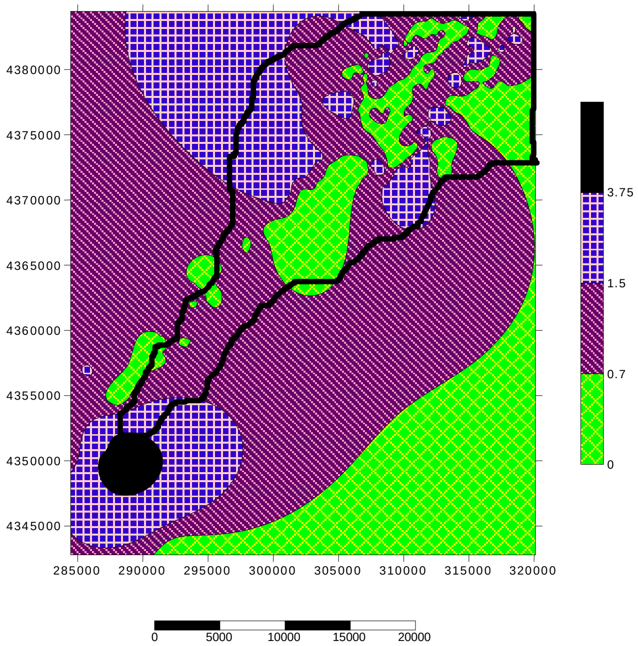

Figure 4. The distribution of boron pollution in the irrigated soils (the soil depth of 30-60 cm)
(The black lines in the graph show the irrigated land)

The soil matrix adsorbs a fraction of boron, and the remaining portion is held in the soil solution. If use of irrigation water containing boron continues, the boron concentration in the soil solution may eventually equal that in irrigation water (Anonymous, 2003).

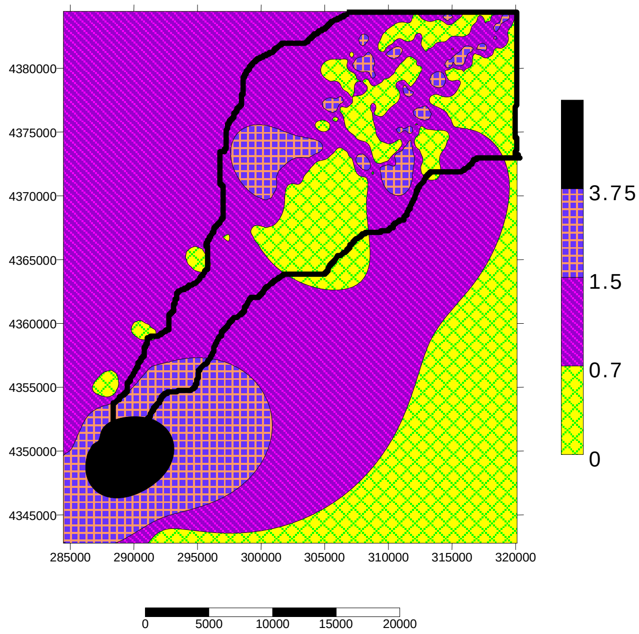

Figure 5. The distribution of boron pollution in the irrigated soils (the soil depth of 60-90 cm)
(The black lines in the graph show the irrigated land)

According to the data in the literature, optimum levels of boron in soil are 0.5–1.0, 0.9–1.5, and 1.1–2.0 mg kg^{-1} for sands, loamy sands; sandy loams, loams, silt-loams, silts; clays and muck, and peats, respectively. Similarly, if a boron soil test indicates 0.0–0.9 mg kg^{-1}, alfalfa and vegetables need to be fertilized with boron fertilizers (Kelling, 1999). However, 1.0–5.0 mg kg^{-1} of boron in soil might be considered adequate for crops. If the concentration of boron in soil is greater than 5.0 mg kg^{-1}, it is excessive for crops (Rehm et al., 1993). Considering the levels of boron in the soil for the study area, it could be stated that there is no excessive boron pollution especially in terms of crops.

As it was stated by Nable et al. (1997), sorption capacity of soil is crucial for determining the amount of boron in solution. A soil with high adsorption capacity would be expected to maintain lower soil solution boron over a longer period of time than a soil with low adsorption capacity when both soils are irrigated with the same boron laden water. Thus, the extent of boron adsorption depends on the pH of water and concentration of boron in solution. Boron is adsorbed onto soil particles, with the degree of adsorption depending on the type of soil, pH, salinity, organic matter content, iron and aluminum oxide content, iron and aluminum-hydroxyl content, and clay content. Boron adsorption can vary from being fully reversible to irreversible, depending on the soil type and condition (Anonymous, 1998).

In addition, spatial analysis for digital maps showed that boron-affected irrigation water used from surface and well water has slightly affected soil pollution came from water that contains boron these element accumulate within arable lands nearby river as a result of flooding irrigation.

4. CONCLUSIONS

The use of GIS-based maps was selected according to their capability to visualise spatial relationships between environmental data and other land features. In particular, GIS is a valuable tool for interpreting spatial variability and evidencing some chemical such as boron contamination. The most significant results essentially concern the superficial horizon (Facchinelli et al., 2001).

From a methodological point of view, multivariate statistics were found to be powerful tools for the identification of factors controlling the variability of geochemical data and for the interpretation of results, while GIS software, evidencing spatial relationships, proved very useful in the confirmation and refinement of geochemical interpretations of the statistical output.

In general, the results confirm the contribution of both parent rock and non-point-source pollution to the chemical properties of soils. Consequently, background values, together with realistic mandatory guidelines, are impossible to fix without an extensive data collection and, most important, without a correct geochemical interpretation of the data.

GIS is a valuable tool for interpreting spatial variability and evidencing boron contamination. Soil data can be easily updated and new maps easily reproduced, saving time and money with quality assurance. Thus, decision makers, irrigators and farmers could be used these boron pollution maps for appropriate irrigation and soil management.

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