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Long-term changes in spatial variation of soil electrical conductivity and exchangeable sodium percentage in irrigated mesic ustifluvents

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ABSTRACT

Soil salinity and sodicity obscure growth of many field and horticultural crops. Spatial and temporal variations of these attributes should be known to avoid their impacts on plant growth. We studied long-term changes in spatial variation in soil electrical conductivity (EC) and soil exchangeable sodium percentage (ESP) in 8186 ha Bafra plain, located in Middle Black Sea region of Turkey. Data collected in 1966 and 2008 were evaluated and compared by geostatistical and GIS techniques. Semivariograms for EC and ESP were calculated and graphed for 0–30, 30–60, and 60–90 cm depths for both sampling times and complementary kriging prediction maps were built. Both EC and ESP decreased from 1966 to 2008 in acreage and severity in all three studied depths. The EC values ranged from 0.32 to 22.61 dS m^{-1} in 1966 and from 0.51 to 7.38 dS m^{-1} in 2008, and ESP values ranged from 12.8 to 76.0 in 1966 and from 9.77 to 40.71 in 2008. In both sampling times, increasingly greater values of EC and ESP occurred by depth. In 1966, 3181 ha of study area had a severe salinity and sodicity problem, while this acreage decreased to 548 for salinity and 2128 ha for sodicity by 2008. Soil EC above threshold level (4 dS m^{-1}) decreased considerably from 1966 to 2008, and this decrease was attributed to that irrigation and complementary drainage removed excess salts away from the soils. Soil ESP decreased to below threshold value of 15 almost in entire area for 0–30 soil depth while it remained over threshold value in 30–60 and 60–90 cm soil depths in eastern part of the study area. A multivariate analysis along with geostatistical analysis can aid to evaluate impact of soil management and land use change on soil EC/ESP as well as soil variables having correlations with EC and ESP.

1. Introduction

Soil salinity and sodicity are two principal factors limiting plant production in flat irrigated agricultural lands. Stalinization is the accumulation of water-soluble salts in the soil profile to a level that limits crop production. Soil salinity becomes important when salt concentration in soil solutions exceed crop tolerance level. Excessive amounts of salt accumulations occur in poorly drained soils subjected to high evapotranspiration (Wang et al., 2008). Of the current 230 million ha of irrigated land worldwide, 45 million ha (20%) are salt affected (FAO, 2008). Soil sodicity becomes effective when exchangeable sodium percentage (ESP) exceeds 15%. Degraded soil structure, decreased soil hydraulic conductivity, soil aeration, and infiltration rate, and increased soil pH to 8.5 or higher are the main causes of the soil sodicity for decreased crop production (Richards, 1954). Soil salinity may be controlled by many means such as drainage, irrigation, and cropping pattern (Cetin and Kirda, 2003).

Studies have been conducted to evaluate spatial and temporal variation of soil salinity. Herrero and Pérez-Coveta (2005) studied 24-year change in soil salinity in Flumen irrigation area of Spain. They compared soil salinity for 1975, 1985, 1986, and 1999, and they found that the median EC of non-saline soils changed only slightly in non-saline portion, while in the saline areas, the median EC for studied soil depths averaged over a 1-m was 5.9 dS m^{-1} in 1975, 3.1 dS m^{-1} in 1985 and 1986, and 1.9 dS m^{-1} in 1999.

Geostatistics and Geographical Information System (GIS) are extensively used in assessing spatial and temporal variation of soil and water properties (Cemek et al., 2007; Delgado et al., 2010; Eldeiry and Garcia, 2012; Guagliardi et al., 2012; Miao et al., 2006; Mousavifard et al., 2013; Safari et al., 2012; Shouse et al., 2010; Zhou et al., 2010). Arslan (2012) evaluated changes in groundwater salinity from 2004 to 2010 by Ordinary Kriging (OK) and Indicator Kriging (IK). Kai-Li et al. (2011) analyzed spatial and temporal changes in soil salinity by OK in China between 1981 and 2008 and they found that salinity of topsoil gradually decreased

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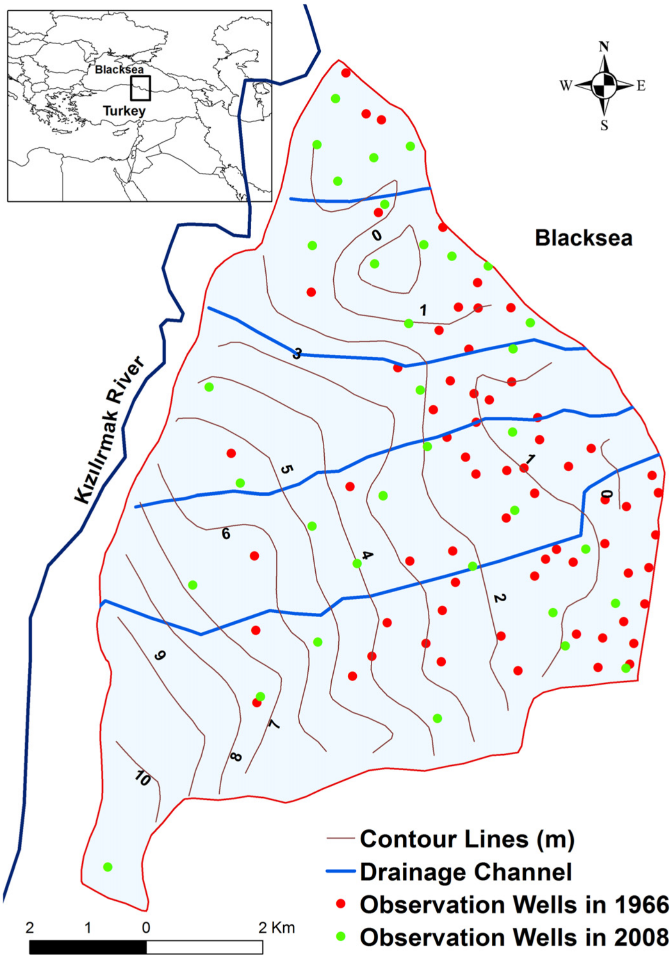

Fig. 1. Location of study area and soil sampling sites.

during the study time. Wang et al. (2008) studied changes in salinity, groundwater depth, and soil management practices from 1983 to 2005 using classical statistics, geostatistics, and GIS. Ibrakhimov et al. (2007) investigated changes in groundwater level and salinity by GIS in Uzbekistan. Ahmadi and Sedghamiz (2007) measured groundwater level in 39 wells in Iran and analyzed spatial and temporal changes in groundwater level by geostatistical techniques.

In this study, changes of spatial variation in EC and ESP of Bafra plain soils between 1966 and 2008 were evaluated by geostatistical and GIS techniques, and effect of irrigation and drainage on soil salinity and sodicity was assessed. The results showed that soil EC and ESP had spatial variation structures at all three studied soil depths in both 1966 and 2008 and that irrigation and drainage resulted in substantial decreases in soil salinity and sodicity in the plain.

2. Material and methods

2.1. Study area

The study area, Bafra plain, locates in the Middle Black Sea coastal region in northern Turkey, within latitudes of 41°10′ and 41°45′ North and longitudes of 35°30′ and 36°15′ East (Fig. 1). The plain has a semi-humid climate with mean temperatures ranging from 6.9 °C in January to 22.2 °C in July (annual mean temperature is 13.9 °C). The Bafra plain's soils are mainly deep, formed on alluvial delta and colluvial terrace-alluvial fans. These are young soils extremely variable in texture, ranging from sandy loam to heavy clay. Soil profiles are uniform up to one to three meters depth at some places while they are highly stratified with readily noticeable horizons in other places. Saturated water conductivity (K_s) ranges from 2.47 cm h^{-1} in silty clay topsoil to 0.03–0.05 cm h^{-1} in heavy clay soils.

Table 1
Cropping acreages (%) in the study area in 1966 and 2008.

Crops	1966	2008
Rice	5.3	36.0
Tobacco	16.3	–
Vegetables	1.4	14.0
Sugar beets	–	2.0
Wheat	16.0	20.0
Grassland	8.0	6.0
Water melon–melon	–	12.0
Corn	9.0	10.0
Not used area	35.0	–
Other uses area	9.0	–

Construction of irrigation and drainage infrastructures were completed by 1990, and 300 km of irrigation and 200 km of drainage channels were constructed by 2008. The irrigation water is delivered by open canals from nearby Kızılırmak River and furrow and surface irrigation techniques are principally applied in the plain. Sprinkler irrigation is rare, and drip irrigation is not practical in Bafra plain. Approximately 75% of the area is irrigated with surface water and the remaining 25% with groundwater (Arslan, 2013). Wheat, tomatoes, peppers, watermelons, sugarbeets, cabbages, corn, and rice are extensively grown in the area.

In 1966, groundwater was the only source of irrigation. Groundwater depth in the plain changes seasonally as well as spatially. The region has a mean annual precipitation of 802.6 mm, most of which falls between September and April. Open drainage systems are applied mainly in the plain, and pumping drainage is applied at some localities where open drainage does not work. Applied irrigation water amount varies depending on crop type and crop water need.

The land use and crop pattern in the plain changed considerably from 1966 to 2008 (Table 1). The most drastic changes occurred in tobacco and rise production acreages. Rice had been grown in 5.3% percent of the soils in 1966 while this ratio increased to 36% in 2008, and 13.8% of the plains soils were used for tobacco production in 1966 while no tobacco was grown in 2008. In 1966, approximately 35% of the plain's soils were not used due to serious salinity and alkalinity problems caused by high water table. These soils have been used for agriculture since irrigation and drainage constructions were completed. While very limited acreage was used for vegetables (1.4%) in 1966, 10% of the soils were used for vegetables in 2008. In addition, 2% of the soils were used for sugarbeets in 2008 while no sugar beets had been grown in 1966. The wheat production acreage remained relatively unchanged. In 1966, 16% of the soils were used for wheat production and this portion increased to 18% in 2008. Also, acreage of grasslands decreased from %8 in 1966 to 6% in 2008. In 1966, well water had been used for irrigating rice, tobacco, corn, and vegetables. However, diverged water from nearby river Kızılırmak (red river) has been used for irrigation since irrigation facilities have been in use.

2.2. Soil sampling and laboratory analyses

Soil salinity study was conducted first time in Bafra Plain by General Directorate of State Water affairs (DSI) in 1966. In this first study, 65 soil samples had been taken from 0 to 30 cm soil depth, 55 from 30 to 60 and, 39 from 60 to 90 cm between June and September. Basic soil properties including electrical conductivity (EC) and exchangeable sodium percentage (ESP) were measured