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Seasonal changes of spatial variation of some groundwater quality variables in a large irrigated coastal Mediterranean region of Turkey

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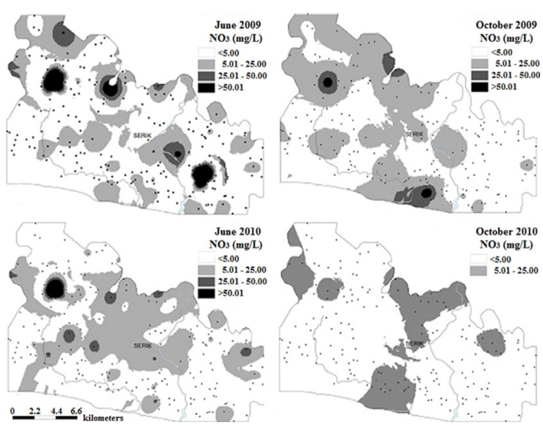
HIGHLIGHTS

- In this study, we investigated spatial variation of groundwater data.
- The data were analyzed using GIS and geostatistical methods.
- All variables were strongly spatially dependent for all samplings.
- Spatial pattern of groundwater EC changed drastically from June 2009 to October 2009.
- Spatial structure of NO_3 highly varied across the sampling campaigns.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil and groundwater degradations have taken considerable attention, recently. We studied spatial and temporal variations of groundwater table depth and contours, and groundwater pH, electrical conductivity (EC), and nitrate (NO_3) content in a large irrigated area in Western Mediterranean region of Turkey. These variables were monitored during 2009 and 2010 in previously constructed 220 monitoring wells. We analyzed the data by geostatistical techniques and GIS. Spatial variation of groundwater table depth (GTD) and groundwater table contours (GTC) remained similar across the four sampling campaigns. The values for groundwater NO_3 content, EC, and pH values ranged from 0.01 to 454.1 g L^{-1}, 0.06 to 46.0 dS m^{-1} and 6.53–9.91, respectively. Greatest geostatistical range (16,964 m) occurred for GTC and minimum (960 m) for groundwater EC. Groundwater NO_3 concentrations varied both spatially and temporally. Temporal changes in spatial pattern of NO_3 indicated that land use and farming practices influenced spatial and temporal variation of groundwater NO_3. Several hot spots occurred for groundwater NO_3 content and EC. These localities should be monitored more frequently and land management practices should be adjusted to avoid soil and groundwater degradation. The results may have important implications for areas with similar soil, land use, and climate conditions across the Mediterranean region.

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1. Introduction

Groundwater is a dynamic system. In general, the upper boundary of the saturated zone in soil profile, commonly referred as water table, shows fluctuation depending on seasonal changes in evapotranspiration rates as well as in response to precipitation events (Daniels and Buol, 1992). Seasonal fluctuation in groundwater table depends on several factors including soil characteristic, drainage and climatic conditions, management practices etc. Khan and Fenton (1994) observed 10-year water table-depth-ranges from 1.0 to 3.2 m for well drained, 0.4 to 2.8 m for somewhat poorly drained, and 0.2–1.2 m for poorly and very poorly drained fields that were tile-drained. Rise of groundwater table due to heavy rains, excessive irrigation, seepage from canals and riverbeds, and artesianic pressure of groundwater can cause disruption of air/water balance in the root zone in irrigated agricultural areas. Fluctuation of shallow groundwater table depth are important at the plot-, field- and watershed-scale since its proximity to the surface impacts crop development, farm machine trafficability, agricultural chemical transport, soil salinity, and drainage. In addition, salts transported from groundwater table by capillarity can cause salinity and alkalinity in plant rooting zone in irrigated areas. Groundwater table depth and its composition should be monitored periodically to avoid its likely hazards on soils.

Groundwater monitoring can provide fundamental information to sustainable water resource management. The goals of groundwater monitoring can be ambient resource condition, compliance, risk detection, and research monitoring, or a combination of these (Gangopadhyay et al., 2001). Land and water management practices should be developed according to results of continuous monitoring of water table depth and groundwater qualities (Foglia et al., 2007). In irrigated areas, monitoring wells commonly used to evaluate spatial and temporal changes in water table level and groundwater quality (Kaman et al., 2011). In Turkey, General Directorate of State Water Affairs (GDSHW) monitors water tables periodically in irrigated areas.

The United States Environmental Protection Agency's maximum contaminant level for nitrate (NO_3) is 10 mg L^{-1}. Nitrate concentrations >10 mg L^{-1} in drinking water pose health risks of methemoglobinemia (blue baby syndrome) in infants (Fan and Steinberg, 1996) and stomach cancer in adults (Mason, 2002). Nitrate is a widespread contaminant in shallow groundwater systems in the areas with high agricultural activities (Freeze and Cherry, 1979). Atmospheric deposition, discharge from septic tanks and leaking sewers, use of sewage sludge, improper use of fertilizers in agriculture, and seepage from the landfills may also contribute to the NO_3 loads in shallow groundwater systems (Pasten-Zapata et al., 2014). During the last two decades, groundwater contaminations from extensive fertilizer applications have been reported by many researchers (Frind et al., 1990; Hu et al., 2005; Jalali, 2005; Kurunc et al., 2011; Sonmez et al., 2007). Hu et al. (2005) reported that ground water pollution by NO_3 leaching occurred in the county site areas in the North China plain due to the use of wastewater for irrigation and excessive fertilization. Jalali (2005) stressed that NO_3 levels exceeded EU standard of 50 mg L^{-1} NO_3 in 37% of 311 wells in Hamadan, Iran, where ground water is used for drinking. He further stated that NO_3 content of all well water in the region can reach or pass the critical limit if NO_3 leaching from agricultural lands continues.

Nitrate contamination of groundwater has been reported in many places of Turkey. For example, in Demre, Antalya, one of the important greenhouse production regions in Turkey, the NO_3 level in 45% of the wells exceeded the EU standard of 50 mg NO_3 L^{-1} for drinking water that is also applied in Turkey (MFWA, 2012), and frequent and excessive use of fertilizers in the Serik plain resulted in a significant NO_3 pollution in shallow groundwater systems (Kurunc et al., 2011).

Spatial variations can be random or systematic. A systematic variation has a consistent spatial pattern which allows predicting value of a particular property at a given location. Geostatistical analysis has been widely used to analyze the systematic variation of soil and water variables in space and time (Ersahin, 2003; Ersahin and Brohi, 2006; Isaaks and Srivastava, 1989; Kurunc et al., 2011; Vieira et al., 1981; Yates and Warrick, 1987). Geostatistical application includes three stages in evaluating process: descriptive statistics (univariate statistics), analyzing spatial structure by semivariograms, and predicting the corresponding variable at the unvisited locations by various forms of kriging procedure (Isaaks and Srivastava, 1989).

Characterization of spatial relationship between groundwater properties, and soil and management attributes is important for a sustainable soil and water management planning. Water table monitoring studies have been conducted with new technologies and related maps were built by Geographic Information Systems (GIS) (Demir et al., 2009). GIS has the ability to work with large data. However, GIS modeling requires a complete dataset at every site where simulation to be performed (Corwin et al., 1997), and it is impossible to sample all the locations where modeling will be performed. Geostatistical techniques (i.e. kriging) can be used when the data are sufficient for making spatial interpolation (Corwin et al., 1997). Geostatistics module included in GIS packages can be used to evaluate spatial interrelations among the variables in decision making studies (Wylie et al., 1994).

Although the Serik plain is one of the most active irrigated agricultural areas in Southern Turkey, only limited information is available on anthropogenic effect on shallow groundwater systems in this region. Therefore, tracking the spatial and temporal changes in groundwater composition as related to irrigation and fertilization and highlighting seasonal variations in impacted areas were the main purposes of this study. Apart from these aims, this study was conducted to evaluate spatial and temporal variations in groundwater monitoring data of water table depth, pH, electrical conductivity (EC) and nitrate (NO_3) concentrations, measured in 211 groundwater monitoring wells, located in an irrigation area of Antalya Köprüçay right and left banks, by GIS and geostatistical techniques. Greater attention was given to groundwater NO_3 concentrations as NO_3 pollution of groundwater is one of the most important research topics worldwide (Anayah and Almasri, 2009; Flipo et al., 2007).

2. Material and methods

2.1. Study area

Study area (Köprüçay Irrigation District) is located in the east of the Antalya basin in Southern Anatolia (30° 49′ 63″ and 31° 16′ 62″ east longitudes, and 36° 49′ 75″ and 37° 01′ 97″ north latitudes (Fig. 1)). The study area covers approximately 36,000 ha (a 30 km by 15 km rectangular area) of which 24,420 ha is used for agriculture.

The Taurus Mountains surround the study area from the North. The soils derived from crystalline schist, dolomite, flysch, radiolarites, serpentines, diorites, and andesites (GDSHW, 1964) and are classified in three groups by topography (GDSHW, 1981). The base land (talf) consist of alluvial soils with 0–2% slope in north-south direction constitutes most of the plain, while hillsides (rises) with a 4–8% slope are mainly located on the west of the plain, and high lands are found in the north and middle of the plain. Soil on rises derived from in-place deposits (mainly residuum) and high soils derived from mass movement deposits (mainly colluvium). The soils are rich in $CaCO_3$ (10–20%) because of calcareous and many parent materials (GDSHW, 1981). The main aquifers of the high land area are the Mesozoic carbonate unit and the travertine deposits whereas sand, gravel and conglomeratic levels of alluvial deposits show aquifer characteristics in the base land (GDSHW, 1964). The study area is in West Coast Mediterranean climate zone in Dry Summer Subtropical Humid Coastal Mediterranean climate is (Iyigun et al., 2013). Monthly mean temperature ranges from 13 °C in January to 34 °C in July, the average annual rainfall and evapotranspiration are 1150 and 1330 mm, respectively (TUMAS, 2011).