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Identification of nitrate leaching hot spots in a large area with contrasting soil texture and management

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ABSTRACT

Identification of nitrate (NO_3) leaching hot spots is important in mitigating environmental effect of NO_3. Once identified, the hot spots can be further analyzed in detail for evaluating appropriate alternative management techniques to reduce impact of nitrate on groundwater. This study was conducted to identify NO_3 leaching hot spots in an approximately 36,000 ha area in Serik plain, which is used intensively for agriculture in the Antalya region of Southern Turkey. Geo-referenced water samples were taken from 161 wells and from the representative soils around the wells during the period from late May to early June of 2009. The data were analyzed by classical statistics and geostatistics. Both soil and groundwater NO_3-N concentrations demonstrated a considerably high variation, with a mean of 10.2 mg kg^{-1} and 2.1 mg L^{-1} NO_3-N for soil and groundwater, respectively. The NO_3-N concentrations ranged from 0.01 to 102.5 mg L^{-1} in well waters and from 1.89 to 106.4 mg kg^{-1} in soils. Nitrate leaching was spatially dependent in the study area. Six hot spots were identified in the plain, and in general, the hot spots coincided with high water table, high sand content, and irrigated wheat and cotton. The adverse effects of NO_3 can be mitigated by switching the surface and furrow irrigation methods to sprinkler irrigation, which results in a more efficient N and water use. Computer models such as NLEAP can be used to analyze alternative management practices together with soil, aquifer, and climate characteristics to determine a set of management alternatives to mitigate NO_3 effect in these hot spot areas.

1. Introduction

Over-fertilization to obtain greater crop yield has triggered excessive nutrient loads in soil, groundwater, and surface water of agricultural regions (Volk et al., 2009; Kundu et al., 2009). Agricultural activities, involving the application of excessive inorganic nitrogen fertilizers, lead to groundwater pollution by nitrate (NO_3) leaching from agricultural lands. As NO_3 is a water soluble and negatively charged ion, under aerobic conditions, surplus NO_3 is readily transported by percolating water through the soil profile and accumulates in aquifers (EPA, 1987; van Duijvenboden and Loch, 1983).

The fate of NO_3-N in soil is affected by the position of a water table and an aquifer, rainfall and irrigation, organic matter content, and other chemical soil properties (van Duijvenboden and Loch, 1983). Water flow and NO_3 leaching from root zone to aquifer are also controlled by soil physical characteristics, such as soil hydraulic conductivity, water holding capacity, texture, thickness, soil structure, and characteristics of soil pores. In general, soil water moves downward more rapidly in sandy soils than in clayey soils, resulting in NO_3 movement to greater depths. Nitrate leaches less likely in soils with greater water holding capacity (Knox and Moody, 1991; Lægreid et al., 1999).

High NO_3-N in groundwater causes toxicity in human and animals. The EU and the World Health Organization considers 50 mg L^{-1} NO_3 (11.3 mg L^{-1} NO3-N) to be the critical value for drinking water (EC, 1998; WHO, 2006). The Environmental Protection Agency of the USA set this value to 10 mg L^{-1} NO_3-N (EPA, 2009). Nitrate levels exceeding 50 mg L^{-1} in drinking water may cause a disease known as methaemoglobinaemia with symptoms of cyanosis and asphyxia, especially in bottle-fed infants (WHO, 2007).

Pollution of groundwater by nitrate leaching is a common problem worldwide (Flipo et al., 2007; Anayah and Almasri, 2009). The WHO (2007) reported that the percentage of the population exposed to NO_3 levels above 50 mg L^{-1} in drinking water ranges from 0.5 to 10%, corresponding to nearly 10 million people in Europe. Hu et al. (2005) reported that groundwater pollution by

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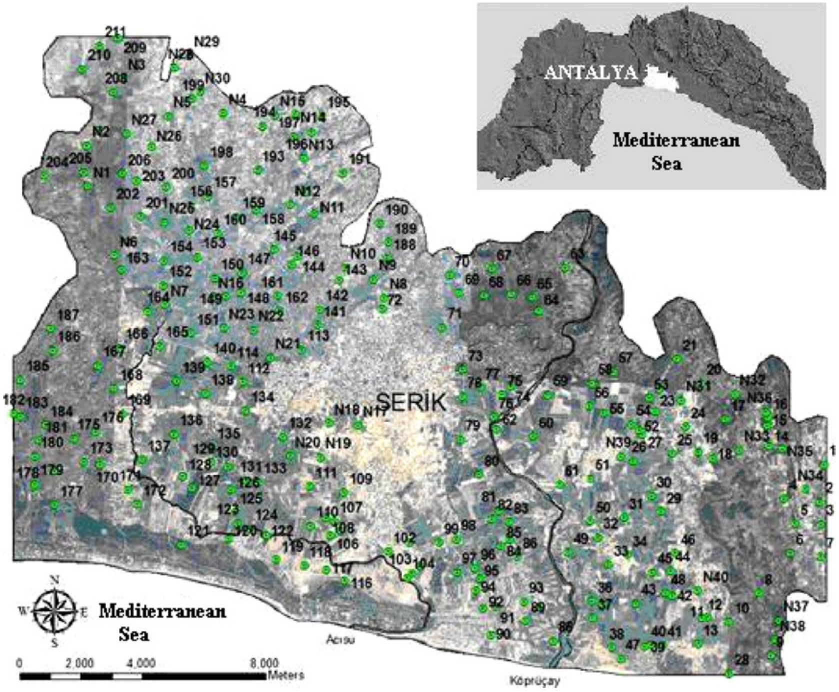

Fig. 1. Map, produced from IKONOS image, showing location of study area and soil sampling points in the study area.

NO_3 leaching occurred in the County Site areas in North China plain due to the use of wastewater for irrigation and excessive fertilization. Jalali (2005) reported that nitrate levels exceeded 50 mg L^{-1} NO3 in 37% of 311 wells in Hamadan, Iran, where groundwater is used for drinking. He suggested that, if NO_3 leaching from agricultural lands continues, NO_3 content of all well waters in the region will reach or pass the critical limit. In Demre, Antalya, one of the important greenhouse production regions in Turkey, the NO_3-N level in 45% of the wells exceeded the acceptable threshold value and the average topsoil NO_3-N content was found to be 108 mg L^{-1} (Sönmez et al., 2007).

Once NO_3 pollutes the aquifers, they will remain polluted for decades, even when satisfactory measures are taken to reduce NO_3 leaching (WHO, 2007). As stated by the EU Water Framework Directive, necessary measures must be taken to reduce NO_3 leaching through the soil profile and to prevent NO_3 pollution in aquifers (O'Shea and Wade, 2009). Identification of regions under the risk of NO_3 contamination is an important step in deciding on appropriate alternative management practices to protect aquifers (Masetti et al., 2008).

Geostatistics is used to determine the hot spots where nitrate concentrations exceed the predetermined threshold value in groundwater. Kriging, an interpolating technique, can be used for this purpose. Kriging technique can provide a map of spatial distribution of a variable across a study area by taking spatial structure into account. This spatial structure, explained by a semivariogram, shows how the variability of a variable increases with the distance (Flipo et al., 2007).

Since NO_3 is a mobile ion and is affected by several factors, the distribution of NO_3 content is expected to be heterogeneous and less spatially dependent. However, its spatial dependency may indicate considerably important implications on the causes and effects of NO_3 leaching in a landscape, and since NO_3 has an economical and ecological importance, many researchers have focused on the determination of its spatial variability (Stenger et al., 2002).

This study was conducted to identify NO_3 leaching hot spots in an approximately 36,000 ha area in Serik Plain, mainly used for irrigated agriculture in Antalya of Southern Turkey.

2. Materials and methods

2.1. Study area

The study area, Serik Plain, is located in between the $30^\circ 49'63''$ and $31^\circ 16'62''$ East longitudes, and $36^\circ 49'75''$ and $37^\circ 01'97''$ North latitudes, in the east of the Antalya basin, Southern Anatolia (Fig. 1). Serik Plain covers an area of approximately 30 km long and 15 km wide, totaling nearly 36,000 ha, and 24,420 ha of this plain is used for agriculture. The area is surrounded by the Taurus Mountains, formed from crystalline schist, fossiliferous paleozoic, dolomite, mesozoic calcareous with schisthy part, flysch, radiolarites, serpentines, diorites, and andesites. The soils in the plain are divided into three groups based on topography. The base land with 0–2% slope in north–south direction constitutes most of the plain. Hillsides are mainly located on the west of the plain and have a 4–8% slope. High lands are found in the north and middle of the plain. Base lands consist of alluvial soils, and hillside and high soils are formed in residual formations and collouvial deposits. The plain soils are rich in $CaCO_3$ (10–20%) due to the effect of calcareous and marn parent materials (DSI, 1981). The main water sources of study area are Creeks of Koprucay and Acisu (DSI, 1964). The town of Serik is located in the middle of the plain. This area has a typical Mediterranean climate of hot, dry summers and warm, wet winters. Average annual total rainfall in the region is 1150 mm and the monthly mean temperature ranges from 13 °C in January to 24 °C in July.

2.2. Methods

2.2.1. Sampling design and well water and soil sampling

Water and soil samples were collected in the period from late May to early June, 2009. Water samples were collected from 161 out of 210 groundwater observation wells installed by DSI (State Water Works of Turkey). The remaining 49 wells were out of service during the time of the sampling. Observation wells were georeferenced by a portable hand Magellan Explorist 500 GPS. A 1-m resolution pan-sharpened IKONOS color image was used to show