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Long-term nitrogen behavior under treated wastewater infiltration basins in a soil-aquifer treatment (SAT) system

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A B S T R A C T

The long term behavior of total nitrogen and its components was investigated in a soil aquifer treatment system of the Dan Region Reclamation Project (Shafdan), Tel-Aviv, Israel. Use is made of the previous 40 years' secondary data for the main nitrogen components (ammonium, nitrate and organic nitrogen) in recharged effluent and observation wells located inside an infiltration basin. The wells were drilled to 106 and 67 m, both in a similar position within the basin. The transport characteristics of each nitrogen component were evaluated based on chloride travel-time, calculated by a cross-correlation between its concentration in the recharge effluent and the observation wells. Changes in the source of recharge effluent, wastewater treatment technology and recharge regime were found to be the main factors affecting turnover in total nitrogen and its components. During aerobic operation of the infiltration basins, most organic nitrogen and ammonium will be converted to nitrate. Total nitrogen removal in the upper part of the aquifer was found to be 47–63% by denitrification and absorption, and overall removal, including the lower part of the aquifer, was 49–83%. To maintain the aerobic operation of the infiltration fields, the total nitrogen load should remain below 10 mg/L. Above this limit, ammonium and organic nitrogen will be displaced into the aquifer.

1. Introduction

Some wastewater treatment plants (WWTP) consist of facilities for secondary and tertiary treatments purposes. Ground-water recharge of secondary treated wastewater (TWW) may serve as a tertiary treatment known as Soil Aquifer Treatment (SAT). In the Dan Region Wastewater Reclamation Project (Shafdan), Tel-Aviv, Israel, the initial stage of the SAT process is based on flooding and drying cycles within infiltration basins leading to subsequent flow through the vadose zone into the underlying aquifer. The first SAT system in Israel was set up in 1977 at the Soreq infiltration basin (Fig. 1). The infiltration basins are used to further clean municipal TWW for reuse in agricultural irrigation. The TWW source is sewage from the Dan region, the most populated area in Israel.

The SAT system efficiently removes contaminants such as microorganisms, suspended solids, ammonium, and reduces chemical oxygen demand, biological oxygen demand and phosphates. In addition, the SAT system removes potentially toxic inorganic constituents, such as heavy metals and trace oxyanions (Idelovitch and Michail, 1984; Bouwer, 1991; Pescod, 1992; Kanarek and Michail, 1996; Fox et al., 2001; Idelovitch et al., 2003; Lin et al., 2008; Lin and Banin, 2006; Amy and Drewes, 2007).

Only a few studies have studied nitrogen balance under SAT systems. Idelovitch et al. (2003) analyzed long-term SAT performance. The overall nitrogen removal was calculated from the difference between inflowing TWW and outflow at an observation well (OW). The drawback with this comparison (also done by Icekson-Tal et al., 2013) is that each nitrogen component behaves and moves differently in the soil, and has a different retardation time on its way through the aquifer. Environmental or operative conditions, such as flooding regime, determine which nitrogen component will be dominant in the soil water; in other words, before analyzing nitrogen removal by SAT, one must identify the relevant nitrogen component. The only report on the Soreq infiltration basins that considered ion retention time was carried out by Lin and Banin (2006) in their research on phosphorus. However, their study has not addressed or analyzed issues regarding nitrogen.

Quantification of nitrogen balances in large-scale wastewater-

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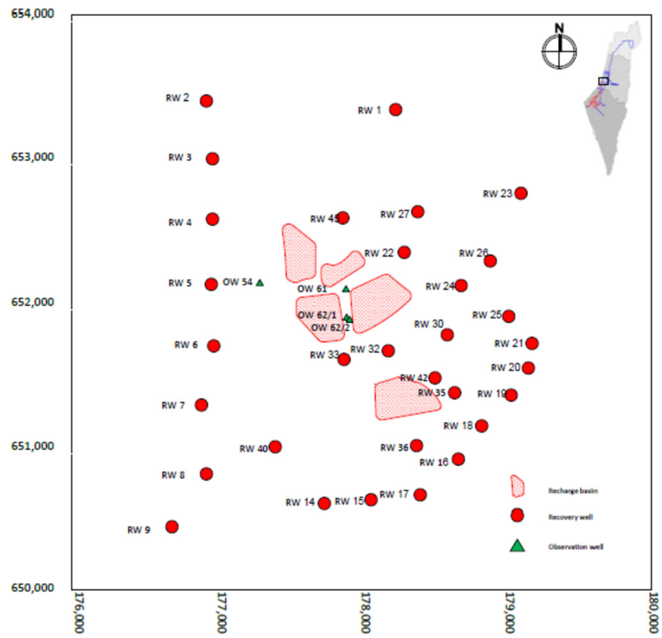

Fig. 1. Soreq infiltration fields, site location, observation wells and recovery wells.

treatment processes employing soils, such as SAT systems, is important in terms of both recovered water quality and potential contamination of the aquifer by nitrogen or secondary contaminations (Oren et al., 2007). A better understanding of the nitrogen cycle can help prevent poor water quality events.

The soil nitrogen cycle in SAT systems can be governed by physical and/or biological processes, depending on environmental conditions and hydraulic and nitrogen loads. The main nitrogen components in TWW are ammonium (NH_4^+) and organic nitrogen. Outlet of nitrogen from the SAT system occurs through two main processes: (i) with nitrogen-containing water pumped from the aquifer and (ii) by denitrification. The latter is the process by which nitrate (NO_3^-) or nitrite (NO_2^-) is reduced to nitrous oxide (N_2O) and nitrogen gas (N_2) by denitrifying bacteria under anaerobic conditions. When TWW is applied to the infiltration basin's soil surface, the concurrent environmental conditions will dictate the course of the nitrogen cycle. Nitrogen can decrease in the system via mobilization and movement to the aquifer, or it can be immobilized through both biotic and abiotic processes (Balesdent and Balabane, 1996). Ammonium is efficiently immobilized by clay minerals and organic matter (OM) in sediments (Boatman and Murray, 1982; Lau et al., 1995; Van Raaphorst and Malschaert, 1996; Liu et al., 2002). However, other studies have indicated that OM adsorbed onto clay surfaces blocks ammonium-exchange sites and results in decreased ammonium-adsorption capacity (Swift, 1980; Hedges and Keil, 1995; Alongi, 1996; Holmboe and Kristensen, 2002). Accumulation of OM is expected to occur in the top 30 cm of the infiltration basin (Lin et al., 2008). Another process of immobilization is through assimilation by plants and microorganisms when exchangeable or fixed forms of ammonium or nitrate are available to them. Addition of substrates with a high carbon-to-nitrogen ratio will bring about rapid microbial assimilation of ammonium (Mengel, 1996). Physical immobilization by ion exchange of nitrogen generally occurs for positively charge nitrogen ions (i.e. NH_4^+) and biological immobilization when the ions are either NH_4^+ or NO_3^-. Any immobilization, physical or biological, will increase the retardation time for nitrogen reaching the aquifer.

In this study, use is made of the previous 40 years' secondary data, to evaluate the long-term behavior of nitrogen in the SAT system. Processes concerning the main nitrogen fractions (ammonium, nitrate and organic nitrogen), their long-term behavior in the SAT system and their retardation in the vadose zone, and assess threshold limits for nitrogen loads are the focus.

2. Materials and methods

2.1. Site description

The SAT infiltration basins are located above the costal aquifer of Israel, 10 km south of the city of Tel Aviv. The infiltration basins consist of four spreading basins (Fig. 1) surrounded by recovery wells (RWs) and OWs. The depth to the groundwater table at Soreq is about 20–30 m, depending on topography and seasonal water level (Vengosh and Keren, 1996). The bottom of the aquifer is the Saqiya layer located approximately 180 m below the soil surface. The soil profile contains mainly quartz-rich dune sand, primarily loose or partly consolidated deposits of calcareous Pleistocene sandstones and some small amounts of sandy clay lenses, located throughout the soil profile (Issar, 1968; Lin et al., 2008). The topsoil layer contains soil OM originating from long-term recharge with TWW. The percentage of OM decreases from 0.6 to 0.11 between 0 and 0.30 m soil depth (Lin et al., 2008).

2.2. Operation regime

The operation of the infiltration basin includes a routine recharge regime of flooding and drying cycles. The recharge cycle employed there since its establishment in 1977 consists of 1–2 days of flooding followed by 5–7 days of drainage and drying. From 1977 to the end of 2015, a total of 730 million cubic meters of TWW were recharged to the aquifer through the Soreq recharge basins. Infiltration basin maintenance includes ploughing of the upper soil layer (0–30 cm) every 2 weeks.

A set of RWs and OWs are supplementary to the infiltration fields. RWs collect the treated water, mixed with groundwater, at a distance of approximately 1–2 km from the centers of the recharge sites (Lin and Banin, 2006). A set of OWs are located between the infiltration site and the RWs. OWs 62/1 and 62/2 (Fig. 2) are located inside the infiltration basin, on a dike between two pools, in the same position (Fig. 1). OW 62/1, drilled to 106 m, screens depths of 86–102 m. OW 62/2, drilled to 67 m, screens depths of 31–63 m (Fig. 2). The aquifer is naturally divided into four horizons, separated from each other by a layer of sandy clay. Horizon A is open to

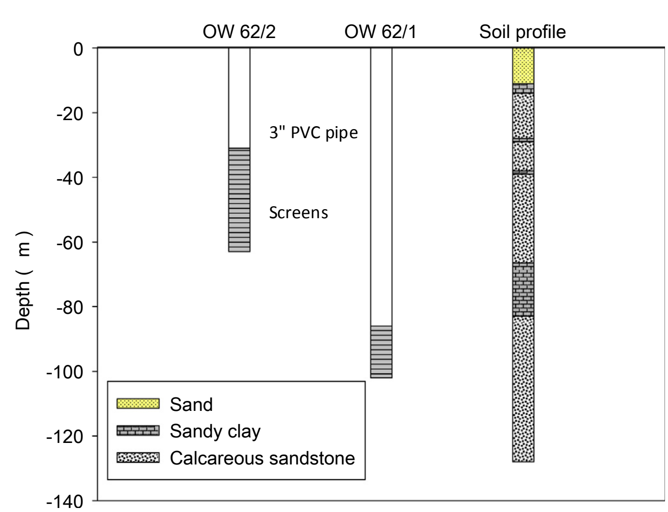

Fig. 2. Soil profile of observation wells 62/1 and 62/2.