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Novel approach for quantitatively estimating element retention and material balances in soil profiles of recharge basins used for wastewater reclamation

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HIGHLIGHTS

- Sc proved as a reliable tracer for reconstructing the initial soil elemental contents.
- Mass-balance for 18 elements resulting from 19 years of SAT operation is presented.
- After 19 years of operation Cr, Ni, and P inputs may not reach the groundwater.
- The inputs of other 15 elements may reach the groundwater.
- 58, 60, 30% of initial soil content of Mn, Ca, Co res. leached from the upper 2-m.

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ABSTRACT

We investigated changes in element content and distribution in soil profiles in a study designed to monitor the geochemical changes accruing in soil due to long-term secondary effluent recharge, and its impact on the sustainability of the Soil Aquifer Treatment (SAT) system. Since the initial elemental contents of the soils at the studied site were not available, we reconstructed them using scandium (Sc) as a conservative tracer. By using this approach, we were able to produce a mass-balance for 18 elements and evaluate the geochemical changes resulting from 19 years of effluent recharge. This approach also provides a better understanding of the role of soils as an adsorption filter for the heavy metals contained in the effluent. The soil mass balance suggests 19 years of effluent recharge cause for a significant enrichment in Cu, Cr, Ni, Zn, Mg, K, Na, S and P contents in the upper 4 m of the soil profile. Combining the elements lode record during the 19 years suggest that Cr, Ni, and P inputs may not reach the groundwater (20 m deep), whereas the other elements may. Conversely, we found that 58, 60, and 30% of the initial content of Mn, Ca and Co respectively leached from the upper 2-m of the soil profile. These high percentages of Mn and Ca depletion from the basin soils may reduce the soil's ability to buffer decreases in redox potential pe and pH, respectively, which could initiate a reduction in the soil's holding capacity for heavy metals.

1. Introduction

The Soil Aquifer Treatment (SAT) system has been used worldwide in order to recover depleted aquifers and/or to manage treated effluent used for irrigation. The SAT system was found to improve the recovered water quality such as suspended matter, microorganisms and viruses, organic and inorganic constitutes. Most studies on the SAT system relied on comparative analyses of the effluent and the recovered water to evaluate metal removal, essentially treating the soil and the aquifer solid-matrix as a "black box" (Lin et al., 2008). Despite the importance of heavy metal removal for the sustainable reclamation operation, only limited direct and quantitative information is available on metal retention processes in the soil compartment of SAT and their potential effect on the long-term sustainability of the SAT.

We conducted a comprehensive research project to study the effect of effluent recharge on the accumulation or leaching of chemical elements in the soils of the recharge basins during the reclamation of municipal wastewater in an operating wastewater treatment plant (WWTP) (Banin et al., 2002). Our approach was to measure the total 18 elements contents by digesting the soils samples. The common methods for soils digestion are expensive and highly time consuming.

Abbreviations: SAT, Soil Aquifer Treatment; HF, Hydrofluoric Acid; NA, Nitric Acid; 4A, 4 Acids; TEL, Total Elements Loaded; ER, Element Retained.

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Most methods include 2 to 3 steps and/or require the use of hydrofluoric acid (HF), which is the most aggressive inorganic acid (Smith and Arsenault, 1996). Moreover, solutions containing HF attack the quartz and the Pyrex spray chamber of the ICP. Han and Banin (1995) suggested the use of 4 N nitric acid (NA) combined with microwave energy for minerals soil digestion which was demonstrated to be reliable, fast and less expensive.

To quantify the changes in elements content of basin's soil profile, the initial concentration profiles were needed. Since a similar survey had not been performed prior to the onset of effluent recharge, and we had no data to rely on, we attempted to reconstruct the needed information. We sampled and analyzed similar soil profiles adjacent to and outside the recharge basins and used the data as a reference database for reconstructing the pristine profiles of the basin soils prior to the initiation of recharge. Since the soil profiles were relatively heterogeneous, reconstruction of the pristine profiles required specific and individual calculation for each profile, which correctly takes into account its initial composition.

To reconstruct the initial concentration profiles, a conservative component was required. We hypothesized that Sc could be used as a proxy tool to calculate the initial elemental concentrations in a soil that has undergone geochemical changes during effluent recharge. In this paper we will present our approach and its quantitative validation and application for two representative elements.

The cornet study has 4 objectives: (1) to identify the geochemical changes which have taken place over the years in the soil; (2) to quantify the material balances and penetration depths of heavy metals, other trace elements, and biogenic elements added with the effluent; and the additional two objectives are: (3) to test the reliability of the 4 N nitric acid (NA) combined with microwave energy for the minerals soil digestion method; (4) to develop an approach for reconstructing an initial elemental profile for soils that have undergone intensive geochemical changes due to an anthropogenic activity, by using Sc as a conservative element.

2. Methods and materials

2.1. The study site

The study was held in Basin 103/4–5 (Fig. 1) of the Soreq site of a large scale WWTP (SHAFDAN), employing the SAT approach since 1977, located south of Tel-Aviv, Israel (31°57′38.92″N; 34°′46'4.35″E) (Kanarek and Michail, 1996). In the SAFDAN, the TWW is recharged to the Coastal Plain Aquifer at infiltration sites consisting of a number of spreading basins. The overlying coastal sand dunes are primarily loose or partly consolidated deposits, rich in quartz and containing small amounts of carbonate and accessory aluminosilicate minerals. Buried lenses and horizons of more clayey paleosols are typically present in the vadose zone. The Coastal Plain Aquifer consists of clastic sediments, mainly calcareous sandstones of Pleistocene age (Isar, 1968).

The basin we studied was originally split into two basins, 103/4 and 103/5; between 1987 and 1989, intensive work was done in those basins, when the upper 0.5 to 1 m of the basin soils were removed and placed on the earthen dams around the basins. In July 1996, the earthen dam separating basins 103/4 and 103/5 was removed and spread over the basin surface and the other earthen dams. At the time of sampling (January 1997), the basin had received a cumulative hydraulic load of about of 1150 m of effluent.

2.2. Soil sampling and analysis

Grid of six profiles was hand-augered to a depth of 4 m: three profiles (P1, P2, and P3) were sampled in basin 103–4 in a northwest to southeast transact, and additional three profiles (P4, P5, and P6) in basin 103–5, also in a northwest to southeast transact. Samples were taken from 10 horizons (0–15, 15–30, 30–60, 60–90, 90–150, 150–200, 200–250, 250, 300, 300–350, 350–400 cm) for a total population of 59 samples (designated M_{in}). We also sampled soils adjacent but

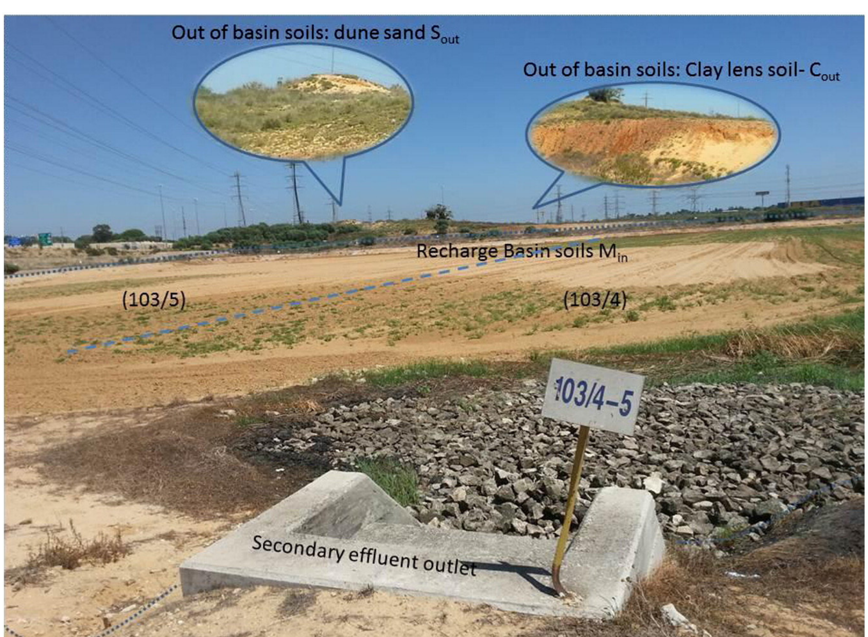

Fig. 1. An overview of the studied site that demonstrates the location of soil sampling in &out the basin.