Environmental impact and health risks associated with greywater irrigation: a case study

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Abstract There is an increasing trend to use greywater for irrigation in households. This is partly due to the notion that greywater is of better quality than wastewater and therefore does not need extensive treatment beyond addressing public health issues. The aim of the study was to evaluate the environmental impact and health risks associated with the use of greywater for irrigation on a small private farm. Over a three-year period, each of three plots on a farm was irrigated with either freshwater, fertilized water, or greywater. Irrigation water and soil from the plots were analyzed for a wide range of chemical and microbial variables. Results suggest that greywater may be of similar quality to wastewater in several parameters such as BOD and faecal coliforms. For some other variables such as boron and surfactants, greywater may even be of worse quality than wastewater. Long-term irrigation of arid loess soil with greywater may result in accumulation of salts, surfactants and boron in the soil, causing changes in soil properties and toxicity to plants. Faecal coliforms did not survive in the soil. Treating greywater before using it for irrigation is recommended, even in places where this is not a requirement.

Keywords Greywater; environmental harm; nitrification; surfactants; faecal coliforms

Introduction

A modern lifestyle requires large quantities of potable water and generates large amounts of wastewater. Domestic wastewater is composed of blackwater, which is effluent from toilets, and greywater (GW), which is the remaining wastewater comprising washing, bathing, and kitchen effluents. Some regulatory agencies separate kitchen effluents from the rest of the GW. In recent years, there has been an increase in the use of GW for landscape irrigation, particularly in households. It is commonly thought that GW is of relatively good quality, and consequently only minor treatment is needed before its use. This concept is evident in several state regulations such as those in California, USA, in which the use of GW is allowed for flood irrigation with no treatment, as long as certain barriers are implemented to minimize the possibility of human contact with the water (California Graywater Standards, 1995). However, using GW for landscape irrigation (in particular for household gardening) poses two major hazards that have not been studied thoroughly. One hazard is the harmful environmental effects and pollution caused by elevated levels of salinity, boron and surfactants that can alter the soil properties, damage plants and contaminate ground water (Garland et al., 2000; Abu-Zreig et al., 2003). The other hazard is related to potential health risks associated with the spread of pathogenic...
organisms (Dixon et al., 1999). The current study aims were to evaluate the environmental impact and health risks associated with the use of greywater for irrigation.

**Materials and methods**

**Study area and management**

The area of the study (Carmey Avdat Farm), constructed next to the bank of a small dry streambed, is located in the Israeli Negev desert approximately 50 km south of Beer Sheva. The location of the plots is depicted in Figure 1. The climate is arid with an average annual precipitation of 80 to 100 mm and an average of 300 dew nights that contribute annual deposits of 30 mm (Shachak, 1976; Bowman et al., 1986). The average summer and winter temperatures are 24.5 and 13°C respectively, and the potential evapotranspiration is 240 to 260 cm yr⁻¹ (Israeli meteorological services, Bowman et al., 1986). The soil is native loess and rocky colluvium situated on a limestone rock formation. (Bowman et al., 1986). The four plots used in the study covered 500 m² and were subjected to different irrigation regimes for 3 years before the study. These were: (a) no irrigation (control), (b) irrigation with freshwater, (c) subsurface irrigation with raw GW and (d) freshwater irrigation with the addition of fertilizers (fertigation). The GW was collected from a six-person family house with an extended kitchen and laundry facility that supports nearby guesthouses. The amount of GW used was recorded with a water meter and averaged 8.2 m³ per week. Upon use, the GW flowed to a perforated barrel that was attached to a 30 cm deep perforated pipe that passed through the middle of the plot. The plots receiving freshwater and fertigation were irrigated for 30 weeks a year (between March to October) at an approximate rate of 50 L per tree per week, controlled by an irrigation computer. The liquid fertilizer used was Gopher 6:6:6 (ICL Fertilizers Ltd.), containing 4.2% (NH₄)₂SO₄–N; 1.8% KNO₃–N, HPO₃ and micro-elements (Fe, Mn, Zn, Cu, Mo). The fertilizer was applied with the irrigation system at an annual rate of 375 g N, 164 g P, and 311 g K per tree.

![Figure 1](https://iwaponline.com/wst/article-pdf/52/8/161/434449/161.pdf)

**Figure 1** Schematic map of Carmey Avdat Farm with the locations of the irrigated plots. (A-D) guesthouses. At the time of the study there was only one active guesthouse (F) family house from which the GW was supplied. (1) control plot, (2) fertilized plot, (3) greywater plot, and (4) freshwater plot.
Water analyses

Freshwater and GW samples that were used for irrigation were collected biweekly from April to December 2001. Unless stated otherwise, samples were analyzed by standard procedures (Standard Methods for the Examination of Water and Wastewater, 1998) for: total suspended solids (TSS) gravimetrically; soluble reactive phosphorus (SRP) by filtration on GF filter followed by the vanadomolybdate method; total phosphorus (TP) and total nitrogen (TN) by persulfate digestion followed by a vanadomolybdate finish and UV method respectively; total ammonia nitrogen (TAN) by the sodium salicylate method (Krom, 1980); nitrite nitrogen (NO₂⁻N) with diazo salts; nitrate nitrogen (NO₃⁻N) by the sodium salicylate method (Yang et al., 1998); electrical conductivity (EC) and pH with a WTW oxi340-meter; anionic surfactants by the methylene blue active substances (MBAS) method; 5-day biochemical oxygen demand (BOD₅); chemical oxygen demand (COD) by dichromat digestion; boron (B) by inductively coupled plasma (ICP) and faecal coliforms (FC) by the pore plate method using TBX agar (Merck, 2000). Because GW is expected to contain contamination originating from peoples’ bodies (mainly skin) rather than high faecal contamination, it was tested for the pathogens Staphylococcus aureus and Pseudomonas aeruginosa, which are related to skin flora. Analyses followed standard methods (Merck, 2000). The load of N, P, K and trace elements in the water used for fertigation were calculated based on the composition of the fertilizer and the volumes used.

Soil analyses

Five soil samples from each plot were collected twice, in August and November 2001, and were analyzed for pH, EC, organic carbon, and total Kjeldahl nitrogen (TKN) (Soil and Plant Analysis Council, 1999). Minerals and metals (Ca, Mg, Na, K, Fe, Mn, Cu, Al, Zn) from the soils were extracted using 0.05N HCl and 0.025 N H₂SO₄ as described in the double acid extraction method (Jackson, 1958) following analysis by ICP (IRIS/AP, Jarrell Ash) and AA (Perkin-Elmer 1100B). Anionic surfactants in the soils were determined by extraction with 0.2 N NaCl and acetone followed by the MBAS procedure (Kornecki et al., 1997).

The impact of soil surfactants on the capillary rise of water in the soil was used to demonstrate the possible impact of surfactant accumulation on soil hydrological properties. Sieved (1.4mm mesh), oven-dried loess soil from the farm that was never irrigated, was mixed with laundry detergent solution of known concentration to give 10% soil moisture content (w/w). Concentrations of surfactants in the soil ranged from 0 to 100 mg kg⁻¹. The soil was placed in a 25 cm column (2.5 cm diameter) and covered with a fine mesh at one end. The column was attached to a balance and its base was located on the water surface of an open reservoir containing freshwater. The weight change due to the capillary rise in the column was recorded every second (McGinnis, 2001). Each surfactant concentration was replicated five times. Faecal coliform (FC) count was determined in five undisturbed cores (~6 g wet weight from depths of 5 cm) of each treatment that were transferred into sterile tubes. Pyrophosphate buffer (10 mL) was added and the samples were shaked for an hour. The supernatant was used for FC count on TBX agar plates (Merck, 2000). Bacterial counts were calculated on a dry weight base. Soil nitrification was evaluated by introducing sub-samples of 2 g of soil from each plot into Erlenmeyer flasks containing sterile free N buffer solution (pH 8.0) enriched with 28 mg L⁻¹ of NH₄Cl–N (Gross et al., 2003). One millilitre samples were withdrawn at prescribed times from the flasks and analyzed for ammonia nitrite and nitrate as described above. Samples from these Erlenmeyer flasks were also used to characterize the microbial population. Total DNA was extracted using a commercial kit (UltraClean Soil DNA Isolation Kit, MO BIO Lab. Inc., Solana Beach, CA). A DNA fragment (323 base pairs (bp)) from
the 16S rDNA gene was PCR-amplified using two primers specific to the domain Bacteria (Jackson et al., 2001). The DNA band was carefully excised under UV from agarose gel, extracted from the gel slices using the NucleoSpin Extract kit (Macherey-Nagel, Duren, Germany) and cloned in plasmid pTZ57R using the InsT/ATM PCR Product Cloning Kit (MBI Fermentas, Hanover, MD). After transformation, random clones were selected for DNA sequencing. Sequencing was performed with an ABI Prism 377 DNA sequencer (Perkin Elmer). Sequences were analyzed using the BLAST (www.ncbi.nlm.nih.gov/blast) similarity search program in order to find the most similar available database sequences.

Statistical analysis
The differences in water quality and soil parameters were compared by analysis of variance (ANOVA) with \( p < 0.05 \) for significance, using the Sigma Stat 2.0 package (SPSS, 1997).

Results and discussion
Characterization of water sources
A summary of the irrigation water quality is presented in Table 1. Since fertilized water is composed of fertilizer with known composition and freshwater, and since it was applied over a relatively short period during the irrigation, which makes interpretation of results difficult, we did not characterize the water but calculated its expected contribution in terms of nutrients and elements.

Faecal coliforms are used as an indication of faecal contamination and reflect the risk of encountering pathogens in the water. The FC count in the GW averaged 106 CFU 100 mL\(^{-1}\), and did not meet current standards for unlimited irrigation, which range between 0 to 200 CFU 100 mL\(^{-1}\) in most western countries, (ANZECC, 1992; Halperin and Aloni, 2003). As expected, FC were not found in the freshwater. Staphylococcus aureus and Pseudomonas aeruginosa were not detected in any of the samples from any treatments. The TSS and BOD\(_5\) averaged 138 mg L\(^{-1}\) and 270 mg L\(^{-1}\) respectively, which is similar in magnitude to domestic wastewater. The high positive correlation and the value of 1.7 for the slope of the curve suggest that a significant fraction of the TSS was organic (Figure 2) and degradable. The high BOD\(_5\) is attributed to the extended kitchen and laundry effluents that support the guesthouses.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Freshwater</th>
<th>Greywater</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>Not detected</td>
<td>138 ± 21</td>
<td>&lt;10</td>
</tr>
<tr>
<td>BOD(_5)</td>
<td>0.5 ± 0.1</td>
<td>270 ± 60</td>
<td>10</td>
</tr>
<tr>
<td>COD</td>
<td>Not detected</td>
<td>686 ± 255</td>
<td></td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>0.08 ± 0.00</td>
<td>17.7 ± 5.1</td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>5.7 ± 1.5</td>
<td>14.0 ± 2.0</td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>0.1 ± 0.0</td>
<td>0.6 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>Anionic surfactants</td>
<td>Not detected</td>
<td>40 ± 4</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.6 ± 0.3</td>
<td>6.7 ± 0.1</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>EC (dS m(^{-1}))</td>
<td>1.2 ± 0.1</td>
<td>1.4 ± 0.0</td>
<td></td>
</tr>
<tr>
<td>(^2)Average SAR</td>
<td>3.1</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Faecal coliforms (CFU 100 mL(^{-1}))</td>
<td>&lt;1</td>
<td>(10^6 ± 10^5)</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

\(^1\)Standard applies to the Israeli guidelines for effluent quality for use in cities (Halperin and Aloni, 2003).

\(^2\)SAR: sodium adsorption ratio (calculated).
The electrical conductivity that is correlated to salinity, ranged between 1.3 to 1.5 dS m\(^{-1}\) for the GW. This was only slightly higher than that of freshwater (Table 1) suggesting that the GW would not show negative effects due to salinity. Nitrogen and phosphorus are essential nutrients for plants but excess amounts can alter the microbial population in the soil as described below. In the current study the measured concentration of P and N in the raw GW did not exceed concentrations normally found in fertilized water (Table 1) and we could not observe negative effects of these nutrients. Detergents and soaps are the main sources of boron (B) and surfactants found in domestic effluents and they are more concentrated in GW because the toilet stream is excluded. As expected, levels of B and anionic surfactants were low in the freshwater and highest in the GW (Table 1). Boron is an essential micronutrient for plants but excessive amounts are toxic. The recommended value for irrigation water varies between 0.3 and 1.0 mg L\(^{-1}\) for non-tolerant plants (ANZECC, 1992). The average concentration in the GW was 0.6 and ranged between 0.1 to 1.6 mg L\(^{-1}\), suggesting the possible occurrence of negative effects to a variety of ornamental plants. Surfactant concentrations ranged between 29–60 mg L\(^{-1}\) with an average of 40 mg L\(^{-1}\). Surfactants can alter soil properties and be toxic to plants at these concentrations (Bubenheim et al., 1997; Abu-Zreig et al., 2003). The average concentration of the metals in all water treatments was similar and low except for slightly higher calculated concentrations in the fertilized water (data not shown). The sodium adsorption ratio (SAR) of the GW ranged between 2.8 and 6.0 and averaged 4.8 (Table 1). A sodium adsorption ratio of 8 was suggested as the higher limit for irrigation of non-tolerant plants (ANZECC, 1992). However, long-term irrigation using water with a SAR higher than 4 can negatively alter the soil properties (i.e. a high Na concentration leads to soil dispersion). The natural salinity and SAR of desert soils are often high, suggesting that the moderately elevated SAR and salinity of the GW would not be detrimental in such areas.

The impact of the irrigation regime on the soil

Comparisons were conducted between native soil properties (not irrigated) and nearby plots that were irrigated for 3 years with freshwater, GW, and fertilized water (Table 2). Faecal coliforms did not survive well in the soil despite the fact that the GW contained \(10^6\) CFU 100 mL\(^{-1}\). The nature of GW includes a high concentration of organic matter, some of which is poorly degraded such as some surfactants and oils. Significant accumulation of nitrogen was found in the fertilized plot but not in the GW-irrigated plot. The addition of nitrogen in fertigation is greater by at one or two orders of magnitude than in fresh or GW respectively. As expected, the soil salinity (as measured by electrical conductivity) was lowest in the plot irrigated with freshwater.
Although accumulation of salts was found in the GW plot, this was not greater than the salinization that occurred in the fertilized plot used for agriculture purposes, and even after three years, salinity did not reach levels that can affect most plants. Salinity does not therefore seem to pose a major problem for the farm. It is important, however, to take the source of salinity into account; for example the results indicated that there was some accumulation of boron in the soil due to irrigation by GW (Table 2). High boron concentrations exert negative effects on the soil properties and are toxic to plants (Nable et al., 1997). Use of low B detergents would remedy such problems. Recently, new environmental regulations in Israel have limited the amount of B permissible in detergents, and B levels in cleaning agents are expected to decrease gradually. The average SAR in the GW-irrigated plot was 1.01, followed by the dry (non-irrigated) plot (0.84), fertilized (0.72) and freshwater (0.60) plots (Table 2). As discussed above, the increase in SAR may negatively affect the soil properties and limit the species of plants that can be grown. The native soil in the farm and the relatively high natural concentration of Ca in the farm soil reduces the SAR and minimizes potential negative harm to the plants. The concentration of metals in the soil varied between samples and between plots, but its concentrations were within ranges found naturally (data not shown). The pH of the soils ranged from 7.86 to 8.16 with no significant differences among plots (Table 2). The fertilized plot had slightly lower pH, presumably due to the acidity produced by higher nitrification (Figure 3).

In the soil, ammonia is oxidized by bacteria to nitrite that can be toxic to plants, and to nitrate, which is not toxic, in a process called nitrification (Hooper, 1989). The biological conversion of ammonia to nitrite is carried out by ammonia-oxidizing bacteria (AOB) and the subsequent oxidation of nitrite to nitrate by nitrite-oxidizing bacteria (NOB). Both bacterial groups, obligate autotrophs, grow slowly (Hooper, 1989) and have different sensitivities to environmental constraints such as salinity, light intensity and pH (Focht and Verstraete, 1977). This may lead to imbalanced nitrification and an accumulation of toxic ammonia or nitrite. Nitrification potential of the soil, which is an important microbial process, and the soil microbial population were used as indicators of possible differences between the plots. The ammonia fertilized plots had the highest nitrifying potential, followed by the GW and freshwater plots, respectively (Figure 3). It is reasonable to assume that there was a developed nitrifying bacterial population in the fertilized plots, as they had been irrigated with ammonia for over 3 years before sampling.

### Table 2

Mean ± standard error values of soils (n = 10) from three irrigated plots (freshwater, fertilized water and greywater), and a dry plot (not irrigated) in Carmey Avdat farm. Soil samples were taken in August and November 2001. Plots were irrigated similarly for three years before sampling.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Freshwater</th>
<th>Fertilized water</th>
<th>Greywater</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.1 ± 0.1</td>
<td>7.9 ± 0.1</td>
<td>8.2 ± 0.1</td>
<td>8.1 ± 0.1</td>
</tr>
<tr>
<td>EC (dS m⁻¹)</td>
<td>0.7 ± 0.1b</td>
<td>2.2 ± 0.4a</td>
<td>2.5 ± 0.8a</td>
<td>1.6 ± 0.7a</td>
</tr>
<tr>
<td>Mean SARC</td>
<td>0.6</td>
<td>0.7</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>²FC (CFU g⁻¹)</td>
<td>1ND</td>
<td>1 ± 1</td>
<td>3 ± 2</td>
<td>ND</td>
</tr>
<tr>
<td>TN (mg kg⁻¹)</td>
<td>330 ± 40a</td>
<td>1,700 ± 500b</td>
<td>400 ± 100a</td>
<td>300 ± 20a</td>
</tr>
<tr>
<td>Anionic surfactants (mg kg⁻¹)</td>
<td>4.3 ± 1.8a</td>
<td>5.3 ± 2.4a</td>
<td>23 ± 4.5b</td>
<td>4.5 ± 1.9a</td>
</tr>
<tr>
<td>Boron (mg kg⁻¹)</td>
<td>0.4 ± 0.1a</td>
<td>1.1 ± 0.2ab</td>
<td>2.5 ± 1.2b</td>
<td>0.9 ± 0.5ab</td>
</tr>
<tr>
<td>³OM (%)</td>
<td>0.6 ± 0.04</td>
<td>0.5 ± 0.1</td>
<td>0.9 ± 0.06</td>
<td>0.5 ± 0.03</td>
</tr>
</tbody>
</table>

¹ND, not detected
²FC, faecal coliforms
³SAR, sodium adsorption ratio
⁴OM, organic matter; a, b indicate statistical significance (p < 0.05).
Interestingly, it seems that there was unbalanced nitrification in the freshwater plot that led to the accumulation of nitrite. Accumulation of nitrite was also found in the GW treatment but an increase in nitrate was also noticed from the eighth day. Unfortunately, we did not identify the nitrifying bacterial population in any of the plots. Nitrifying bacteria do not tend to appear in high numbers in nature, particularly when organic matter is abundant, as they are out-competed by heterotrophic bacteria. We could not identify differences between the microbial groups in the plots. The main groups found were: uncultured delta proteobacterium, *Rhizobium* sp., *Treponema* sp., *Flexibacter tractuosus*, *Pseudomonas* sp. and *Microscilla sericea*. Accumulation of surfactants in soils irrigated with GW was demonstrated (Table 2). The low surfactant concentration in the native and freshwater irrigated soils is probably due to the presence of some native organic substances rather than an external source. The potential effects of surfactants on the capillary rise in loess suggest that GW irrigated soils might become more hydrophobic (Figure 4). Hydrophobic soils are not suitable for healthy plant growth. This could explain the...
observations of retarded growth in a few plants in this plot. Surfactants have also toxic effects on many plants (Bubenheim et al., 1997), but their toxicity to grown plants was not investigated in the current study.

Conclusions
Greywater does not meet current guidelines for unlimited irrigation, yet these guidelines involve mainly health issues and neglect potential environmental risks such as elevated B and surfactants. We demonstrated that using raw GW for irrigation might cause environmental harm in addition to public health risks. We conclude that treating GW before its use for irrigation is recommended, even when this is not a legal requirement.

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References


