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Effects of long-term greywater disposal on soil: A case study

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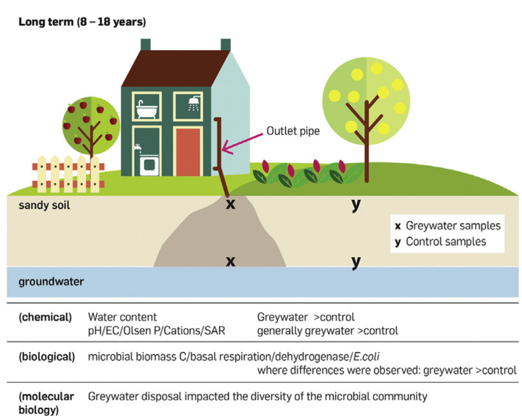
HIGHLIGHTS

- Long term greywater disposal impacted the soil environment.
- Results included increased pH, SAR, EC and dehydrogenase activity.
- The soil microbial community was affected by greywater disposal.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the environmental health risks to soil and potential risks to groundwater associated with long term (8–18 years) greywater disposal practices. Land application of greywater is likely to have environmental impacts, which may be positive or negative. Greywater can contain plant macronutrients that may benefit plant growth. Conversely, high levels of surfactants, oils, grease, sodium and potentially pathogenic organisms may negatively impact environmental and human health. In this study, land disposal of untreated greywater was practiced at five coastal domestic properties. At each property, soil samples were collected at two depths from areas used for greywater disposal and from control areas that were not exposed to greywater. Soils were analysed for chemical and biological responses to greywater exposure. Generally, greywater irrigated soils had higher pH, Olsen P, base saturation, and increased soil microbial activity (as measured by biomass carbon, basal respiration and dehydrogenase activity). A pH of >9 was recorded for some greywater treated soil samples. *Escherichia coli* (*E. coli*) were detected at up to 10^3 MPN/g in the greywater exposed surface soils at some sites. Terminal Restriction Fragment Length Polymorphism (TRFLP) analysis revealed that greywater affected the soil microbial community structure, which may have implications for soil health and fertility. Overall, this study shows that the long-term application of greywater at the investigated sites had a moderate impact on the soil environment. This may have been due to the sandy soils and high rainfall that would flush the soil. Increases in microbial biomass and dehydrogenase indicate that greywater application may be beneficial for plant growth. However, high levels of *E. coli* in some soils may be a risk to human health and sub-surface irrigation should be the recommended application method.

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1. Introduction

Greywater is domestic wastewater originating from laundry, bathroom sinks, baths and showers (Nolde, 2000) and in some cases, kitchen sink and dishwasher waste (Maimon et al., 2014). Greywater is typically combined with blackwater (toilet, bidet or urinal waste) and discharged to a reticulated or on-site wastewater treatment system. However, there is growing interest in the benefits of separating domestic greywater and blackwater streams.

Countries that experience water shortages may reuse greywater for irrigation or toilet flushing. This can reduce potable water requirements within a household by up to 50% (DHWA, 2002; Friedler, 2004; Jefferson et al., 2004; Jeppesen, 1996; Maimon et al., 2014). In water rich countries, greywater is not typically reused for irrigation purposes. However, greywater may be separated from domestic wastewater for other reasons, such as improving the efficiency of a poorly functioning septic tank system (Beal et al., 2005). Greywater diversion reduces the volume of wastewater entering an overloaded septic tank, thereby decreasing the hydraulic retention time and theoretically improving the treatment capability of the system (Siggins et al., 2013). Greywater diversion may also decrease the burden on reticulated sewage networks and treatment systems, reducing the need for costly upgrades (Maimon et al., 2010). It is increasingly apparent that many older homes do not have sufficient plumbing to cater for the increased use of water-intensive appliances. In these circumstances, it is not uncommon for homeowners to discharge laundry wastewater directly onto land rather than bear the expense of plumbing a waste pipe to a reticulated or on-site wastewater treatment system, and the greywater is unlikely to undergo any form of treatment prior to on-site land disposal. This is particularly applicable to rural properties with seasonal occupancy (e.g. holiday homes). Such practices potentially pose a high risk to the receiving environment, and have very different considerations than land application for irrigation. For example, greywater for irrigation is more likely to undergo a treatment process, which may be as basic as a coarse filter to remove lint and fibres, or as sophisticated as a customised treatment system (Gunady et al., 2015). Furthermore, an irrigation system will disperse the greywater evenly over a larger surface, with some consideration given to the nature of the receiving environment, including soil type and groundwater depth. Disposal methods tend to result in the application of greywater at a high rate to a small area, with risks such as surface ponding or leaching to groundwater (Beal et al., 2005).

Any land application of greywater is likely to have environmental impacts, which may be positive and/or negative (Muanda and Lagardien, 2008). Greywater may contain plant macronutrients, particularly nitrogen and phosphorus. If these nutrients are present in the right quantities, greywater may act in the same manner as a fertiliser and benefit plant growth (Rodda et al., 2011). In the context of greywater disposal, these benefits do not typically apply, as the application rate is too high and the nutrients are condensed in one small area. Conversely, high levels of surfactants, oils, grease and sodium have been reported to cause soil hydrophobicity or otherwise negatively impact the soil structure and the ability of that soil to support plant growth (Gross et al., 2005; Rodda et al., 2011; Travis et al., 2010; Wiel-Shafran et al., 2006). This is of particular concern with long term exposure to greywater due to the accumulation of salinity in the soil (Al-Hamaiedeh and Bino, 2010). This decline in soil structure over time may also exacerbate the potential for groundwater contamination by greywater, particularly in areas with a shallow water table and soils that are prone to leaching (Stevens et al., 2011).

This study aimed to investigate the environmental health risks to soil and potential risks to groundwater associated with long term (8–18 years) greywater disposal practices. Five coastal properties, each practicing greywater disposal, were included in this study. Soil was sampled from areas of significant greywater exposure at two depths, one at the soil surface and one above the water table. Corresponding control soil samples were also collected at each property from areas that were not used for greywater disposal at any point, to the best of the homeowner's knowledge. Analyses of chemical and biological indicators of soil health were used to compare soils that were exposed to greywater with those that were only exposed to rainwater. *Escherichia coli* was enumerated as an indicator of potential human health risks.

2. Materials and methods

2.1. Site selection

Five properties were selected from a coastal community of approximately 400 homes on the west coast of New Zealand's North Island. A community survey (Lowe Environmental Impact, data not shown), identified that ca. 50% of the community were using some form of greywater disposal, typically over long periods of time. Properties were selected based on the criteria that: there were two or more occupants; occupants were preferably permanent residents; greywater originating from the property was disposed of on-site; the greywater was not treated prior to disposal.

These criteria identified 35 potential sampling sites, which were narrowed to ten based on accessibility to the site and specifically areas for soil sampling. Homeowners of five of these suitable sites gave consent for sampling to occur on their properties. Details of these five sites are presented in Table 1.

2.2. Site sampling

The sampled soils were flattened, uniformly graded, dune sands (96%), with 2% silt and 2% clay. Soil samples were collected within a specified radius of the greywater outlet point (Table 1). Corresponding control samples were collected from a nearby location within the property that did not receive greywater. At each sampling location, triplicate composite samples were collected using a hand tube auger. Surface samples were collected from the top 150 mm of soil from all five properties. For three of the five properties (sites 1, 2, 3), 150 mm deep samples were also taken above the water table (from approximately 1 m depth) to assess potential risks to groundwater as a result of leaching. This resulted in a total of 24 greywater exposed soil samples and 24 corresponding control samples. Approximately 350 g soil was collected for each replicate sample and transported on ice to the laboratory, where debris was removed and soil was homogenised by sieving to 2 mm. All samples were stored at 4 °C for a maximum of 48 h prior to analysis.

2.3. Analytical methods

2.3.1. Chemical analysis

Chemical analysis of the soil samples was conducted using the methods described at www.landcareresearch.co.nz/resources/laboratories/environmental-chemistry-laboratory/services/soil-testing. The parameters investigated were pH, electrical conductivity (EC), organic C, hot water extractable organic and inorganic C, Olsen P, base saturation, cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), Cation Exchange Capacity (CEC), Sodium Adsorption Ratio (SAR).

2.3.2. Biological analysis

Biological analysis of the soil samples was conducted using the methods described at www.landcareresearch.co.nz/resources/laboratories/environmental-chemistry-laboratory/services/soil-testing. The parameters investigated were microbial biomass C and basal respiration.

Dehydrogenase enzyme activities were measured as reported by Prosser et al. (2011).

The method for enumerating *E. coli* in soil samples was a five-tube “most probable number” (MPN) method according to APHA 21st