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Epidemiological study for the assessment of health risks associated with graywater reuse for irrigation in arid regions

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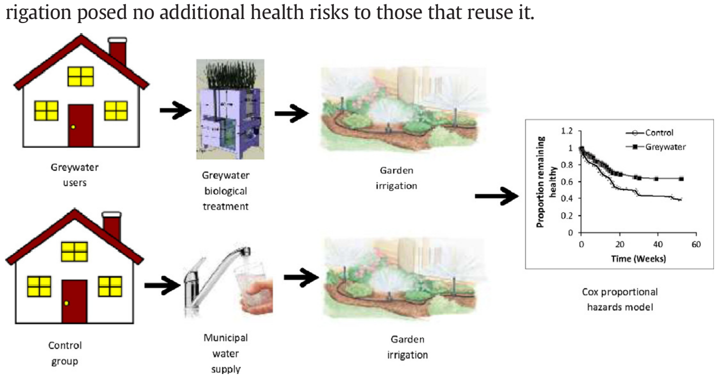
HIGHLIGHTS

- No additional burden of disease was found among graywater users in this study.
- Rate of illnesses found was less than the Israeli national rate for gastroenteritis.
- No specific exposures could be distinguished as a cause of illness.

GRAPHICAL ABSTRACT

Schematic representation of experimental design and main results suggesting that greywater use for garden irrigation posed no additional health risks to those that reuse it.



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ABSTRACT

Graywater reuse is rapidly gaining popularity as a viable source of reclaimed water, mainly for garden irrigation and toilet flushing. The purpose of this study was to determine, by epidemiological survey, the risk for gastroenteritis symptoms associated with graywater reuse. The study comprised a weekly health questionnaire answered by both graywater users and non-graywater users (control group) regarding their health status over a period of 1 year, and periodic sampling for graywater quality. Participants were also asked to respond to a one-time lifestyle questionnaire to assess their level of exposure to graywater or potable water used in garden irrigation. Graywater quality was typical and comparable to previous studies, with average fecal coliform concentration of 10^3 CFU 100 ml^{-1}. A Cox Proportional Hazards model indicated a somewhat higher health risk for the control group ($P < 0.05$), suggesting that there was practically no difference in the prevalence of water-related diseases between users of graywater and potable water. Since the concentration of pathogens in the current study was higher than that suggested by quantitative microbial risk assessment (QMRA), yet there was no difference in the prevalence of water-related diseases between control and graywater users, it was postulated that QMRA is conservative and can safely be used toward the establishment of regulations governing graywater reuse.

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1. Introduction

Recently, there has been growing interest in the separation and reuse of graywater as a water-saving strategy, particularly in water-scarce regions. Approximately 60% of domestic effluent is graywater, including effluents from washing, bathing and laundry, but excluding toilet water (Gilboa and Friedler, 2008). Graywater is typically used to irrigate gardens and flush toilets and can save up to 50% of household freshwater demand (Maimon et al., 2010; Ottoson and Stenström, 2003). Furthermore, graywater reuse can be economically feasible on both a national and household scale (Gross et al., 2015).

Alongside its potential water-saving benefits, graywater must be handled responsibly to eliminate potential environmental and health risks (Gross et al., 2015). Graywater is often found to be contaminated with various pathogens associated with fecal contamination, as well as opportunistic pathogens (Table 1).

Fecal contamination of graywater is usually the result of activities such as washing fecally contaminated laundry (e.g. diapers and underwear) and showering and washing hands after contact with potentially contaminated surfaces and objects (Ottoson and Stenström, 2003). Fecal contamination, which is commonly estimated by fecal coliform concentration, exhibits high variability, ranging from non-detectable to as many as 10^6–10^7 CFU 100 ml^{-1}. The skin and mucus pathogens *Pseudomonas aeruginosa* and *Staphylococcus aureus* have been found in graywater at concentrations of 10^2 and 10^5 CFU 100 ml^{-1}, respectively (Gilboa and Friedler, 2008). Occasionally gastrointestinal bacteria, such as *Salmonella enterica* and *Campylobacter*, can be introduced by food-handling in the kitchen (Ottoson and Stenström, 2003; Gilboa and Friedler, 2008). On-site treatment systems and the subsequent localized discharge of treated effluent can lead to public health and environmental concerns through direct contact with the effluent and contamination of groundwater resources (Levett et al., 2010). Given the prevalence of fecal related bacteria found in graywater, the health concerns often associated with graywater reuse are mild to moderate gastrointestinal diseases brought on by the possible ingestion of minute to significant amounts of graywater via various exposure pathways (O'Toole et al., 2012; Maimon et al., 2010).

Epidemiology is an essential part of risk assessment. However, it may be limited by the sensitivity of the study, and seeking to associate very small risks to the background can prove to be challenging (O'Toole et al., 2012). Nevertheless, despite their limitations and difficulties, epidemiological studies can provide valuable information on the possible scale of water-related hazards, which complement the predictions obtained from quantitative microbial risk assessments (QMRAs). In addition, epidemiological studies are generally more readily understood and accepted by the public than theoretical models designed to predict disease risks (Sinclair et al., 2010). Interestingly, despite the increasing use of graywater worldwide, only a handful of studies have attempted to evaluate the health risks associated with graywater reuse by epidemiological methods (O'Toole et al., 2012; Sinclair et al., 2010). These studies were all performed in temperate regions where exposures are expected to differ from those in arid regions. Moreover, they were short-term, retrospective studies which were unable to account for seasonality and long-term effects.

In the study by O'Toole et al. (2012), members of an exposed (graywater-using) population in Australia were asked to respond to a questionnaire corresponding to the 2 weeks following graywater sampling in order to assess any link between the pathogens found in the graywater and cases of gastrointestinal illness within the household. Sinclair et al. (2010) performed an epidemiological study on a neighborhood in Australia with a dual reticulation system, where highly treated recycled wastewater was used for toilet flushing and other non-potable uses. The study compared the health status of residents from the dual reticulation area with that of residents of a nearby neighborhood with conventional water supply. Health-status determination was based on the reasons why the residents consulted local general physicians. There were no differences between the exposed group and the control group in either study.

The objectives of this study were, first, to determine whether long-term reuse of graywater for garden irrigation in an arid region leads to a higher incidence of gastrointestinal illnesses compared to a control group, and second, to compare the results of the epidemiological study to published results of health risks determined by QMRA, a common tool used by policy-makers to define risks.

Table 1
Concentrations of pathogens and indicator bacteria found in raw, biologically treated and disinfected graywater by different studies and various enumeration techniques (Numbers in brackets are typical mean orders of magnitude).

Bacteria	Units	Raw graywater	Biologically treated graywater	Disinfected graywater
Total coliforms[a]	Log CFU 100 ml^{-1}	5–7 (5)	2–7 (<2)	n.d.–2 (<1)
Fecal coliforms[a]	Log CFU 100 ml^{-1}	1–7 (4)	1–5 (2)	0–5 (<0)
Pseudomonas aerigunosas[a]	Log CFU 100 ml^{-1}	3–5 (3)	n.d.–4 (2)	n.d.–4 (<1)
Staphylococcus aureus[a]	Log CFU 100 ml^{-1}	4–6 (4)	n.d.–3 (1)	n.d.–3 (<1)
Shigella spp.[b,e]	Log gene copies 100 ml^{-1}	n.d.[b,c]	n.d.–4 (n.d.)[e]	n.d.
Salmonella enterica[d,e]	Log gene copies 100 ml^{-1}	n.d.[d]	n.d.–3 (n.d.)[e]	n.d.

n.d. — non-detectable.
[a] Gilboa and Friedler, 2008; Winward et al., 2008; Boyjoo et al., 2013.
[b] Jefferson et al., 2004.
[c] No mention of methodology or units.
[d] Birks and Hills, 2007.
[e] Benami et al., 2013.

2. Materials and methods

2.1. Study population and climate

Exposed (graywater-using) and control (non-graywater-using) populations from the Ramat Negev regional council, Central Negev, Israel were asked about their health status on a weekly basis for a period of 1 year from December 2013 until December 2014. In Israel, graywater reuse is not prevalent due to legal issues. No official registry of graywater users exists, limiting the sample size in this study. The exposed group consisted of all known families recycling graywater in the region, i.e., 20 families totaling 75 individuals, and a matched control group consisting of 17 families with a total of 73 individuals. The control group was matched based on region and age. The ages of the study participants ranged from several months to a maximum 62 years at the start of the study (Fig. C.1 in Appendix C). The age distribution was similar for both groups ($\chi^2 = 7.525$, DF $= 5$, $P = 0.184$).

The climate in the Central Negev, Israel is arid desert with an average yearly precipitation of < 100 mm over a period of 41 days per year, mostly during the winter months (December to March) with only few rain events in fall and spring and no rainfall at all during the summer months. During the hot summer months (May through September), the average temperature is 32 °C and during the colder winter months, the average temperature is 18 °C (data represent trends from 1970–2000) (Israel Meteorological Service, 2015).

2.2. Graywater quality

Graywater samples from participating houses were sampled at least five times during the study and analyzed for fecal coliforms, total suspended solids (TSS) and biological oxygen demand (BOD) to identify the quality spectrum of the graywater used. Samples were taken back to the laboratory and analyzed for fecal coliforms by membrane-filtration