Reuse of greywastewater in multi-story buildings: a sustainable solution to save water

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Abstract

Gray water makes up 60-70% of a home's water requirement and thus can be an alternative source of water for flushing toilets. However, although it is intended to be quite "clean", it can be contaminated and thus pose potential health and aesthetic risks. This article describes the quantity and quality of different sources of domestic gray water and their relative contribution with respect to reuse for toilet flushing. The dishwasher was found to be a major source of organic matter and nutrients, while baths and showers were identified as major sources of fecal coliforms. Six different scenarios were studied, in each of which a different greywater source was xcluded from the 'mainstream' greywater stream and the impact on the quality and quantity of the raw 'mainstream' was examined. The potential for water savings in the domestic sector was then assessed, with Israel serving as a case study, representing a semi-arid country suffering from water shortages. Reusing greywater for toilet flushing in the domestic sector will increase the sustainable use of water in the urban environment.

Key words: greywater reuse, water conservation, alternative water resources, sustainable water use, urban water reuse

1 Introduction

Water storage, typical for Georgia, is the main reason for the introduction of a national desalination scheme in the country with a capacity of hundreds of millions of cubic meters per year (MCM/y) in 2008. However, this "non-traditional" water source entails high production costs as well as negative environmental impacts such as increased emissions (CO_2 and other pollutants), environmental degradation, etc. Therefore, in parallel with the development of desalination capacities, a review of domestic water consumption is required in order to reduce the overall demand and thus minimize the use in desalination. The total specific urban water demand is about 300 liters per capita per day (l/c/d), while domestic demand (excluding horticulture and other external uses) is 100-150 l/c/d, which in total amounts to 240-360 million cubic meters per year worldwide - the second largest water consuming sector after agriculture. Except for small amounts, most domestic water consumption is converted into domestic wastewater, which can be divided into two main categories:

1. Gray water: generated from all household "water-generating" appliances, with the exception of toilets, and accounts for 60–70% of domestic water consumption.
2. Black water: formed from toilets, and accounts for 30-40% of domestic water consumption.

Since the quantity of greywater is substantially higher than that of blackwater, direct in-house reuse of greywater for toilet flushing is possible. This would result in a potential saving of around 40 l/h/d (15 m^3/h/year) of specific domestic water demand - a significant reduction in urban water demand if significant implementation were to be achieved. The concept of in-house greywater reuse has been explored in recent years, particularly in the EU and Japan, where conservation of natural resources is a major motivation for this initiative. However, since it is a relatively new concept, full-scale systems are not common (UK Environment Agency, 2000). Most studies to date have focused on the single-house scale, with little coverage of the high-rise/neighbourhood scale.

- There is no uniform approach to greywater reuse in the EU, for example in Denmark internal greywater recycling is not permitted, in Austria, Germany and Sweden it is permitted, while in the UK there is no legislation or clear guidelines. In Austria and Germany pilot systems have been installed in housing estates. In 2000 the UK Environment Agency (2000) completed a two-year trial in 10 single-family homes.
- The United States has long experimented with greywater reuse, primarily because about 60% of homes in the country are not connected to sewer systems and rely on on-site treatment. Despite this, on-site greywater recycling has not been well established. In 1989, Santa Barbara County in the United States became the first region to legalize greywater reuse. In 1992, Los Angeles completed a pilot project to reuse greywater for gardening (toilet flushing was not an option due to health concerns). Although drought-prone western states reuse greywater for irrigation, there is little evidence of household recycling of non-potable greywater.
- Water reuse in Japan is strongly focused on urban reuse, unlike other countries where water reuse is mainly used for agricultural irrigation. Greywater treatment and reuse systems in Japan range from simple ones in residential areas to advanced recycling systems in high-rise areas. For example, in Tokyo, greywater recycling is mandatory for all new buildings over 3,000–5,000 m^2 (Ogoshi et al., 2001).

Greywater, although considered to be fairly unpolluted, can be highly polluted and thus pose a potential health risk and aesthetic nuisance (Almeida et al., 1999; Diaper et al., 2001; Dixon et al., 1999; Rose et al., 1991 and others). Greywater also exhibits internal variability which is reflected in high variations in discharge volumes and pollutant loads, for example: shower discharge volumes range from 2 to 120 L/use and its COD loads range from 8000 to 36000 mg/use (Friedler and Butler, 1996). As a result of the above, direct indoor reuse requires highly efficient and reliable transport, storage and treatment systems to prevent the use of water that may pose a health risk and have negative aesthetic effects such as odour and colour.

Various treatment processes are proposed in the literature. However, because domestic gray water recycling is in its infancy, only a few off-the-shelf systems are available for commercial use, and even fewer have been tested at full scale over extended periods of time (UK Environment Agency, 2000; Diaper et al., 2001). Initially, preference was given to physical processes. Today, a combination of physical, biological and chemical treatment processes are reported. These are usually followed by a disinfection plant. Due to space limitations, processes with a small footprint have been selected. The main ones are listed below (Hills et al., 2001; Jefferson et al., 2001; Ogoshi et al., 2001; Shin et al., 1998):

- Physical: filtration, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) & reverse osmosis (RO);
- Biological: membrane bioreactors (MBR), biological aerated filters (BAF) and SBR bioreactor;
- Disinfection: chlorination, ozonation & UV irradiation;

A study was conducted to investigate the feasibility of greywater reuse in an urban setting. The conditions differ from those in most countries where indoor greywater reuse has been investigated, as higher ambient temperatures may increase the rate of organic matter decomposition and enhance pathogen regrowth. This may result in higher health risks and negative aesthetic effects, and thus require more stringent treatment. The study is divided into four phases: characterization of different sources of indoor greywater; assessment of realistic water savings potential on a national scale; a pilot study of treatment and reuse; and a feasibility study.

This article describes the results of a sampling campaign conducted to characterize greywater produced by different water-generating devices, compares the results with literature data, and discusses the implications of the results for treatment and reuse options. The final part of this article analyzes the potential for water savings in the domestic sector, serving as a case study representing a semi-arid country suffering from water resource depletion.

2 Methods and materials

A sampling campaign was performed in order to characterise the quantity and quality of greywater generated from individual household appliances. Details about samples distribution is presented in Table 1. Each time a sample was taken the discharge volume of the event was measured. 20 parameters were analysed in the laboratory in accordance with the methods of Standard Methods (APHA et al., 1998): pH, electrical conductivity (EC), chlorides, sodium, boron, ammonia, phosphate, total solids, volatile total solids, suspended solids (total & volatile), COD (total & dissolved), BOD (total & dissolved), TOC (total & dissolved), total oil, MBAS and faecal coliforms (FC).

Table 1. Greywater samples distribution

All information was stored in a database containing over 2,000 data records. We can see the average values obtained for each parameter-device combination. They show that the kitchen sink and the first two stages of the washing machine and dishwasher cycle are the main sources of contamination, as described below:

Appliance	**No. of samples**
Wash basin (WB)	33
Shower (SH)	19
Bath (BT)	10
Kitchen sink (KS)	19
Dishwasher (DW)	(6*4)24
Washing machine (WM)	(7*5)35
TOTAL	**140**

- Boron – The highest concentrations and loads were found in stage 2 of the dishwasher: 7.5 mg/L and 58 mg/use, respectively. Unlike other countries, washing machine wastewater in Israel does not contain high concentrations of boron, since all washing powders in Israel are required to have a low boron
- pH – Generally in the range of 7 to 8, except for the last stages of dishwashers (~8.5).
- Organics – The highest COD and BOD values were found in greywater from the first stages of washing machine and dishwashers, while the highest load was found in greywater from the first stage of washing machine operation: over 70 and 20 g/use COD and BOD respectively.
- Phosphates – The highest concentrations were found in greywater from dishwashers (second stage): concentration close to 1300 mg/L and load 10 g/use. Washing machine produces 524 mg/L and about 9 g/use.
- Ammonia - The most important source was the washing machine with concentrations of 7.0-13 mg/L and 137-222 mg/L in the first two cycles. The dishwasher contributed 10 and 7.9 mg/L in the first two cycles, but the load was much smaller. · Sodium - The highest concentrations were found in the first cycles: 1205 mg/L with an average load of over 20 g/use. In the second cycle, the dishwasher greywater contained 1108 mg/L and a load of 8.5 g/use.
- Chloride – The highest concentrations were found in the first two stages of the dishwasher: 777 and 1261 mg/L. The highest chloride load was found in stage 4 of the washing machine (over 12 g). Relatively high chloride loads were found in the greywater generated in the shower, bathtub and all other stages of the washing machine and dishwasher.
  content (Israel Ministry of the Environment, 1999).

3 Research object

As a preliminary step in developing an appropriate greywater treatment and reuse scheme, all municipal greywater sources should be assessed in terms of their daily discharge volume and pollutant load. The product of the average pollutant concentration and the average daily use volume of the relevant device yields the specific daily load (load/hour/day) of each pollutant-device combination. The overall specific daily load of a municipal greywater with a discharge volume of 104 l/hour/day, a TSS load of 27 g/hour/day and a BOD load of 36 g/hour/day, the last two representing 50-60% of the "typical" specific load of a municipal wastewater. The relative contribution of each device has been calculated and the variability between devices is very high. For example:

- The dishwasher and washing machine were identified as the major contributors to most pollutants, with 24% and 16% of the daily discharge volume, 49% and 12% of TSS, 36% and 25% of CODt, 49% and 22% of BODt, 51% and 19% of total oil, respectively.
- The sink, on the other hand, was found to be the least polluting appliance, contributing less than 10% of the total pollutant load.

Since the daily water consumption used to flush household toilets is significantly less than greywater consumption (about 50% or less), it is possible to avoid treating and recycling all greywater streams, and instead select those streams that are less polluted and therefore require less treatment and have fewer potential negative health and aesthetic impacts.

This approach is particularly strengthened by the results presented in Figure 1. To examine the potential effects of such measures, six baseline scenarios were studied, each with one greywater generating device excluded, and the total daily discharge and pollutant loads were recalculated. The results are presented as a residual percentage of the baseline (all devices included). As expected, the most significant improvement occurred when the dishwasher discharge stream was excluded, reducing the load of most pollutants to 50-60% of their baseline levels, with a milder impact on the total daily flow (a reduction of only about 25%). Thus, eliminating this stream from the greywater to be treated and reused will reduce the size of the treatment device. This is true for organic matter and nutrients, however, when it comes to pathogens (as indicated by faecal coliforms), the dishwasher is a minor contributor, while the bath and shower are major contributors, with reductions of up to 65% of the original FC concentration when either is removed from the total greywater stream. This creates a dilemma, as high concentrations of organic matter and nutrients can lead to negative aesthetic effects and a greater potential for pathogen regrowth on the one hand, while potentially high concentrations of pathogens (as indicated by high FC concentrations) pose a higher health risk on the other. A slightly different treatment setup may be required to combat each of the two types of contaminants mentioned above.

4 Results and analysis

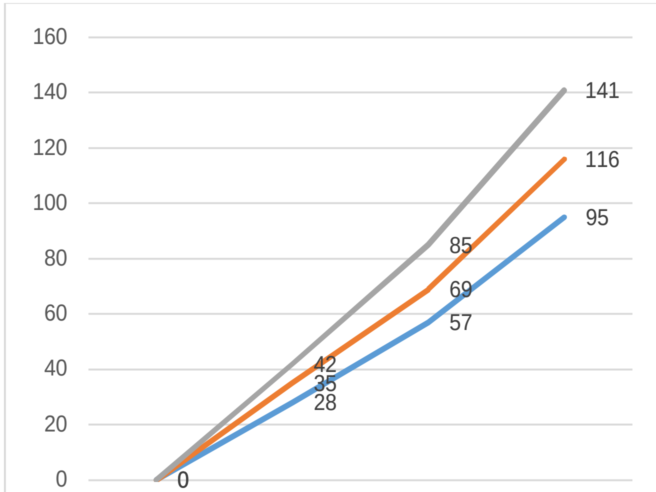
The discussion so far has focused on the quantitative and qualitative characteristics of the different greywater sources and their impact on treatment and reuse. As stated in the introduction, most greywater reuse schemes to date have focused on single-household to small-scale systems, which have their own merits but do not have an impact on the regional/national water budget. This section analyses the water saving potential of large-scale implementation of greywater reuse schemes in the urban sector and their impact on the water budget of urban centres. An effect that could lead to a more intelligent approach to greywater use that takes into account not only human needs but also broader environmental aspects, thus improving the sustainable use of water in the urban environment.

To assess the likelihood of achieving the penetration rate and, consequently, the water saving potential in the urban sector in Israel, the following assumptions were made:

- The lower limit for installing a greywater recycling system is a 3-story building with 12 apartments. This is the smallest building that can finance the operation and maintenance of a greywater recycling system by a professional, certified firm. Over the past 20 years, about 55% of new apartments have been built in buildings at least 3 stories high. It was assumed that this ratio would continue in the future.
- The average "core" family size is 3.36 people. It was assumed that each

apartment is occupied by one "core" family, and the size of the "core" family would not change in the future.

A realistic penetration rate was estimated using two independent methods: the design life of buildings and data on new residential buildings in Israel. The penetration rate for 2021, estimated using the results of the above analyses, was between 20% and 35%, corresponding to water savings of 25-50 million m3/year on a national scale.



5 Conclusions

Domestic greywater, although considered fairly 'clean', can be highly contaminated and thus pose a potential health risk and aesthetic nuisance. It also exhibits high variability between appliances. This led to the investigation of 6 different scenarios, in each of which a single greywater generating appliance was removed from the 'main stream' for treatment and reuse, and the effects on the quality and quantity of the 'main stream' were examined. This analysis revealed that the dishwasher was the main source of organic matter and nutrients, while the bath and shower were identified as the main sources of faecal coliforms. This creates a dilemma where treatment and reuse are seen as high concentrations of organic matter and nutrients, which may lead to negative aesthetic effects and a greater potential for pathogen regrowth, on the one hand, while on the other hand, potentially high concentrations of pathogens (as indicated by high FC concentrations) pose a higher health risk. Slightly different treatment conditions may be required to combat each of the two abovementioned types of contaminants.

Reusing greywater for toilet flushing in the domestic sector can save significant amounts of freshwater. Around 25-50 million m3/year of freshwater could easily be saved in the domestic sector alone over 20 years (nationally). Reusing greywater for toilet flushing in the domestic sector will lead to a smarter approach to household water use that takes into account not only human needs but also broader environmental aspects, thereby increasing the sustainable use of water in the urban environment.

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