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Research paper

A review of untreated household greywater quality to inform the water saving–risk trade-off in South Africa

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Interest in greywater reuse is increasing in South Africa, because of the potential to supplement scarce freshwater resources in the face of increasing demand and aridity. This paper aims to inform the water saving–risk trade-off associated with residential untreated greywater use, through a statistical analysis of greywater quality results as sourced from prior South African studies. Greywater sources included in this review were the bathroom, kitchen, laundry, mixed and general residential sources. Variability in terms of each of the reported physical, chemical and microbiological constituents by source and between result sets was noted. Statistically significant differences were evident between the pH, conductivity and phosphorus values of certain sources. A risk assessment undertaken for each of the constituents revealed further variability. The constituent with the highest number of high-risk samples was total dissolved solids. The relatively high risk and negative consequences in greywater practices in terms of public health, the environment, and infrastructure, given this variability, provide insight into the trade-off with potential water savings. It is recommended that a more nuanced view of the potential potable savings associated with greywater reuse and also improved risk management is required by the user.

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INTRODUCTION

Globally, water reuse is encouraged because of its potential to (i) supplement freshwater resources; (ii) provide reliable water services in remote or environmentally sensitive locations; (iii) mitigate the rising costs of meeting drinking water treatment and wastewater discharge standards; and (iv) reduce sewage discharges to water bodies. In South Africa, interest in greywater reuse is increasing because of its potential to supplement scarce freshwater resources in the face of increasing demand and aridity (Ilemobade et al., 2013).

Greywater is normally defined as untreated wastewater from all domestic activities other than toilet flushing (Rodda et al., 2010), although some definitions also exclude kitchen wastewater. The informal use of untreated greywater in poorly serviced areas is common (Carden et al., 2007). Untreated greywater is also reused at households in fully serviced urban areas (Nel and Jacobs, 2019). Greywater reuse practices, especially untreated reuse, can negatively impact public health (WHO, 2006; Carden et al., 2018; Oteng Peprah et al., 2018), the environment (Friedler and Gross, 2019), household and agricultural fittings (DWAF, 1996) and water services infrastructure (Penn et al., 2012). The inevitable increased uptake of supplementary water sources, particularly untreated greywater, in South Africa (Nel and Jacobs 2019; Friedler and Gross, 2019) therefore requires better understanding.

Various technologies exist for the treatment of greywater and the reduction of notable risks associated with handling untreated greywater (Sadr et al., 2015; Sadr et al., 2016). However, ignorance, expense, complexity, or lack of risk-testing procedures (Toifl et al., 2019) may pose barriers to entry. Where such technologies are used, understanding of safe application may be lacking for the reasons stated above. Additionally, in situations where greywater is used to supplement formal supply such as in emergency drought situations, risk often falls on the user rather than the local authority. Here, the user may decide to ignore risks associated with untreated greywater reuse when faced with costs of alternative supply options, compared to the perceived benefits of the related water savings.

Based on the findings of a user survey and online forum, as undertaken by Nel and Jacobs, (2019), the practice of untreated household greywater reuse for non-potable purposes in South Africa provides the focus of this study. In light of the trade-off between the risks associated with untreated greywater reuse and the water savings achieved (i.e., the water saving–risk nexus), particularly in water-scarce conditions, a risk-based analysis of residential greywater irrigation is a knowledge gap that this study will be addressing.

The assessment of greywater reuse volumes (i.e., water savings) undertaken by Nel et al. (2021) was the initial component identified to inform the water saving–risk trade-off. An investigation into potential risks (including to public health, the environment, and infrastructure) associated with untreated greywater reuse practices in a fully serviced home, is the second component towards exploring the trade-off and forms the focus of this study.

Aim and objectives

This paper informs the water saving–risk trade-off associated with serviced residential untreated greywater use. The first objective was to identify reported major hazards, risks, and consequences associated with untreated greywater reuse at the household level, through a comprehensive knowledge review including international studies. The second objective was to identify greywater constituents of interest and accordingly relevant South African water quality guidelines. The third objective was to report characteristics (including relevant water quality parameters and source) of greywater samples from prior South African studies. Data collection was limited to South African studies, given ethical and budget constraints and the use of relevant regional water quality guidelines. Untreated greywater reuse was found to be common in Cape Town, South Africa, during a severe drought (Nel and Jacobs, 2019) and, thus, sufficient untreated greywater quality data was available for analysis. The characteristics of the reported greywater samples were compared through a statistical analysis of each parameter, to determine the significance of differences by source and between samples. A risk assessment was presented for each parameter for each reported greywater sample with a view to exploring the trade-off between the identified risks associated with untreated greywater reuse and the water savings achieved.

Limitation

Some reported greywater parameters employed in this study were based on average values, or values obtained from single samples. This limits the extent of the variability of greywater quality reported in earlier studies. Insufficiently reported measurements for certain greywater quality parameters were a further limitation and meant that data analysis could not be undertaken for all parameters and all samples.

Greywater water-saving potential

Nel et al. (2021) estimated the water-saving potential of untreated greywater reuse in formal, serviced residential areas, using a stochastic end-use water consumption model based on reported ad-hoc water-use practices. Greywater could represent up to ~50% (Ilemobade et al., 2012), 60–70% (Friedler and Gross), or even ~85% (Jamrah et al. 2008) of the domestic wastewater stream. The maximum portion of greywater reused, after treatment – and therefore the net potable savings – is generally considered to be <50%. When the focus is shifted to untreated household greywater and typical DIY-practices, reuse was found to reduce water consumption in a single-person suburban household by between 1% and 9% (Nel et al., 2021).

Greywater: hazard, risk, and consequence

Under emergency conditions, consumers are faced with a trade-off between the risks and consequences of reusing versus not reusing greywater. A correct understanding of the distinction between hazard, risk, and consequence is critical for the determination of the possible impact of untreated greywater reuse on the health and well-being of the user, the environment and water services infrastructure.

Greywater hazards

A hazard is broadly defined as an agent (such as contaminated greywater) that has the potential to cause harm (Bernstein, 2018). Reported greywater characterisation studies have illustrated the varying physical, chemical, and microbial characteristics of greywater (see Christova-Boal et al., 1996; Eriksson et al., 2002). Variation in the composition of greywater is heavily dependent on service levels, the lifestyle of household occupants, products used in the home, age of the occupants, prevailing health conditions, hygiene practices, the source of the water, the quality of the water supply, and the extent of leaching from piping and processes in the biofilm on the piping walls (Carden et al., 2018; Eriksson et al., 2002; Oteng-Peprah et al., 2018). Three hazard categories of greywater could be identified:

- Physical hazards: These include constituents such as pH, conductivity, and suspended material amongst others (Toifl et al., 2019).
- Chemical hazards: Residential greywater consists of a complex mix of chemicals originating from various household products used for cooking, cleaning, and personal hygiene and well being. Untreated greywater invariably contains different substances, including fragrances, flavours, preservatives, surfactants and solvents, dyes, sunscreen agents, oil, UV blockers, paints and enzymes (Christova-Boal et al., 1996; Eriksson et al., 2002; Roesner et al., 2006).
- Microbiological hazards: Greywater typically contains microorganisms such as bacteria, protozoa, viruses, and helminths mainly emanating from personal hygiene activities and food handling (Oteng-Peprah et al., 2018). For instance, pathogens associated with faecal matter can be introduced to greywater from showers and baths, as well as via washing machines with faecally contaminated laundry.

Greywater reuse risks

Risk is a measure of the likelihood of harm from the hazard – it is a product of probability and consequence (Swartz et al., 2018). Given the potential presence of physical, chemical, and microbial hazards in untreated greywater, the risk of causing harm is further dependent on a complex interplay of various factors. These factors include hazard type and concentration, exposure, vulnerability, and scale of use. Risks to public health, the environment, the household, the agricultural sector and water services infrastructure are linked to untreated greywater reuse.

Greywater reuse consequences

A consequence is a measure of the severity of the negative impact of an event. The distinction between risk and consequence allows for the evaluation of the payoff for taking a certain risk for improved risk management. Consequences can range from small/moderate to high/severe. Measuring the severity of the impact of a greywater reuse practice allows for this evaluation and an understanding of various scenarios ranging from low risk/low consequence to high-risk/high consequence; with the latter being of greater concern.

METHODOLOGY

Data collection

National and international literature sources were reviewed to gain an overview of the hazards, risks, and consequences of untreated greywater reuse at household level. Greywater constituents of greatest relevance in the South African context, in terms of human health, plant growth/yield and soil health and infrastructure, as well as water quality criteria, as presented in Rodda et al. (2010) (see Table 1), were included. A compilation of reported greywater samples including the measured greywater constituents and the relevant greywater source was prepared through a comprehensive knowledge review of South African studies.

Data analysis

Statistical analysis

A statistical analysis of the raw data, as derived from literature, was undertaken to determine the significance of differences in the quality of greywater for each reported parameter, by source and between samples. Comparisons of different areas were done using one-way ANOVA with Fisher least significant difference (LSD) post-hoc testing. Normality was assessed by inspecting normal probability plots, which were in all cases found to be acceptable. Levene's test was done to test for homogeneity-of-variance assumption and in cases where this was strongly rejected ($p < 0.01$), Games-Howell post-hoc testing was reported.

Risk assessment

A risk assessment was undertaken to inform the exploration of the water saving–/risk trade-off. The methodological approach presented by Nel et al. (2013) and Swartz et al. (2018) was adapted to perform a risk assessment of each reported constituent, per greywater sample, as per the risk matrix shown in Fig. 1. The risk matrix is a visualisation of the product of the likelihood (probability) of a hazard and the consequence of the hazard (David and Wilkinson, 2009; Swartz et al. 2018). This framework indicates whether the risk is 'unacceptable, 'acceptable' or two tiers (low and high) of 'as low as reasonably practicable' (ALARP).

Figure 1 shows the consequence and probability levels used in this study to inform the *x*- and *y*- axes of the risk assessment, as adapted from Swartz et al. (2018). The levels of probability were assigned by greywater source based on the findings of Nel and Jacobs (2019) reporting on a small-scale survey in 2018 in Cape Town, South Africa, to assess the extent of greywater reuse under drought conditions. The levels of probability are based on the majority of survey respondents in the study.

The levels of consequences were assigned as per the approach outlined by Swartz et al. (2018), of comparing concentrations to a relevant safety reference value. Each reported greywater parameter was evaluated for compliance with the water quality guidelines by Rodda et al. (2010). This was considered reasonable since greywater guidelines for reuse of untreated greywater at other end-use points were not available for South Africa at the time of publication. Potable drinking water guidelines would not be applicable. Once a risk assessment was performed for each recorded parameter, a risk distribution for the physical, chemical, and microbiological constituents was generated.

Greywater constituents and water quality guidelines

Rodda et al. (2010) provide a consolidated list of greywater constituents that were found to be consistently in excess of water quality guidelines in various South African studies, and were considered of greatest relevance to use for irrigation in terms of

Table 1. Water-quality guidance for use of greywater for small-scale irrigation in South Africa, as presented in Rodda et al. (2010)

Greywater hazard	Target water quality range (suitable for unrestricted use with minimal risk to human health, plants, or soil)	Maximum water quality range (increasing risk to human health, plants, or soil)	Water quality suitable only for short term use on a site-specific basis (significant risk to human health, plants, or soil; tolerable for short-term use only)	Water quality not recommended for irrigation use (excessive risk to human health, plants, or soil)
Electrical conductivity (mS/m)	<40	40–200	200–540	>540
Oil and grease (mg/L)	<2.5	2.5–10	10–20	>20
+pH	6.5–8.4	6–9	6–9	<6 and >9
Suspended solids (mg/L)	<50	50–100	>100	>100
Boron (mg/L)	<0.5	0.5–4.0	4.0–6.0	>6.0
Chemical oxygen demand (COD, mg/L)	<400	400–5 000	>5 000	>5 000
Sodium adsorption ratio (SAR)	<2.0	2.0–5.0	5.0–15.0	>15.0
Total inorganic nitrogen (mg/L)	<10	10–20	20–60	>60
Total phosphorus (mg/L)	<10	10–15	15–50	>50
E. coli (colony-forming units, CFU/100 mL)	<1	1–103 (1–1 000)	103–105 (1 000–100 000) Note: Only with appropriate exposure restrictions	>107 (> 10 000 000)

			Probability (Nel and Jacobs, 2019)				
			Rare (less than once per week)	Unlikely (at least once a week)	Moderate (between 2 and 4 times a week)	Likely (at least once a day)	Almost certain (more than once a day)
Consequence			1	2	3	4	5
Insignificant	Target water quality range (Table 1)	1	1	2	3	4	5
Minor	Maximum water quality range (Table 1)	2	2	4	6	8	10
Major	Water quality suitable only for short term use on site - specific basis (Table 1)	3	3	6	9	12	15
Significant	Water quality not recommended for irrigation use (Table 1)	4	4	8	12	16	20

Key:
Acceptable risk; ALARP (low); ALARP (high); Unacceptable risk

Figure 1. Risk assessment matrix for reported greywater constituents

human health, plant growth, crop yield and soil fertility. A graded series of quality ranges was derived by the authors, based on the South African Water Quality Guidelines for irrigation (DWAF, 1996) and other relevant literature where constituents were not available. Table 1 provides the quality criteria against which the reported greywater constituents in the subsequent section were compared, in order to determine the associated risks.

RESULTS AND DISCUSSION

Results from a total of 49 raw domestic greywater quality samples were captured from the following South African studies: Christen (2019), Jackson et al. (2006), Bakare et al. (2018), Engelbrecht and Murphy (2006), Madubela (2020), and Isidama (2018). The comprehensive dataset is provided as supplementary material. The measurements for each of the constituents listed in Table 1 were recorded where possible. Greywater sources included the bathroom, the kitchen, the laundry and mixed (kitchen and bathroom) and general household sources.

In terms of the reported physical constituents, 40 of the samples collected in this manner included conductivity measurements, 40 included pH and 15 included TSS. Of the chemical constituents, 33 samples included values for COD and 30 samples included phosphorus values. In terms of microbiology, *E. coli* was recorded in 24 of the 49 raw greywater samples. Four constituents, namely, total nitrogen, oil and grease, boron and SAR, did not have sufficient measurements to perform the data analysis and were thus excluded from the analysis. Boron and SAR are both critical parameters in view of irrigation use and their exclusion due to lack of data is acknowledged as a limitation. The statistical analysis of each parameter by source and between samples is presented below (Figs 2–8).

Physical, chemical, and microbiological constituents varied by source and between greywater samples, which is also an indication of the variation of risk involved with untreated greywater reuse. The chemistry of a particular sample of untreated residential greywater, for example, could have serious implications for soil quality and the ability of various plants to grow, but may not directly impact on public health. The microbiology, on the other hand, may have a direct, immediate, and often notable impact on public health through various transmission routes due to the presence and survival rate of pathogens in greywater (e.g., Christova Boal et al., 1996), but the plant growth may not be impacted. The physical, chemical, and microbiological constituent findings are discussed separately below.

Physical constituents

The mean reported electrical conductivity (EC) of the greywater samples was 49.33 mS/m, 230.09 mS/m, 245.06 mS/m, and 35.43 mS/m for mixed, kitchen, laundry, and bathroom greywater sources, respectively (Fig. 3). Application of the Games Howell post-hoc test indicated a significant difference ($p < 0.05$) between mixed and laundry greywater sources as well as the bathroom and laundry sources. The mean value for EC for the bathroom greywater is the only paramater and source that falls within the target water quality range as per Table 1. The highest EC values were from the kitchen and laundry, which is in alignment with a study by Bakare et al. (2018). According to the irrigation water quality guidelines (Table 1) the water would be suitable only for short-term use on a site-specific basis. While these higher EC values could cause a reduction in plant productivity and changes in soil properties (DWAF, 1996), the risk assessment indicated that the majority of the recorded samples were of acceptable risk and the first tier of ALARP (Fig. 3).

The mean pH value for all the greywater sources was found to be 7.81. The mean pH values per source were found to be 7.43, 7.32, 6.98, and 8.81 for mixed sources, the bathroom, kitchen, and laundry, respectively (Fig. 4). Greywater from laundry, in particular, had pH values at an unacceptable level (Table 1). Application of the Games Howell post-hoc test further indicated a significant difference ($p < 0.05$) between the pH values of laundry greywater sources compared to the pH values of bathroom and mixed sources. Alkaline greywater is prevalent with powdered detergent use, and is a contributing factor towards aggressive soil degradation (Hardie et al., 2021) and hard setting of the soil surface. Unacceptable pH levels could also cause corrosion of equipment, damage to plants, and changes in biochemical processes (Eriksson et al., 2002). The majority of samples were of acceptable risk with an even spread among the two tiers of ALARP and unacceptable risk (Fig. 4).

Level	Probability	Consequence
5	Almost certain (more than once a day)	-
4	Likely (at least once a day)	Significant
3	Moderate (between 2 and 4 times a week)	Major
2	Unlikely (at least once a week)	Minor
1	Rare (less than once per week)	Insignificant

Assignment of levels of probability	
Greywater source	**Probability (Nel and Jacobs, 2019)**
Bath	Less than once per week
Shower	At least once a day
Hand basin	More than once a day
Mixed bathroom sources	At least once a day
Washing machine	Between 2 and 4 times weekly
Laundry trough (or similar)	Less than once per week
Dishwashing machine	Less than once per week
Kitchen basin	At least once a day

Consequence	Water quality range (see Table 1)
Significant	Parameter in water quality range not recommended for irrigation use
Major	Parameter in water quality range suitable only for short term use on a site-specific basis
Minor	Parameter in maximum water quality range
Insignificant	Parameter in target water quality range

Figure 2. Consequence and probability levels used for risk assessment (adapted from Swartz et al., 2018)

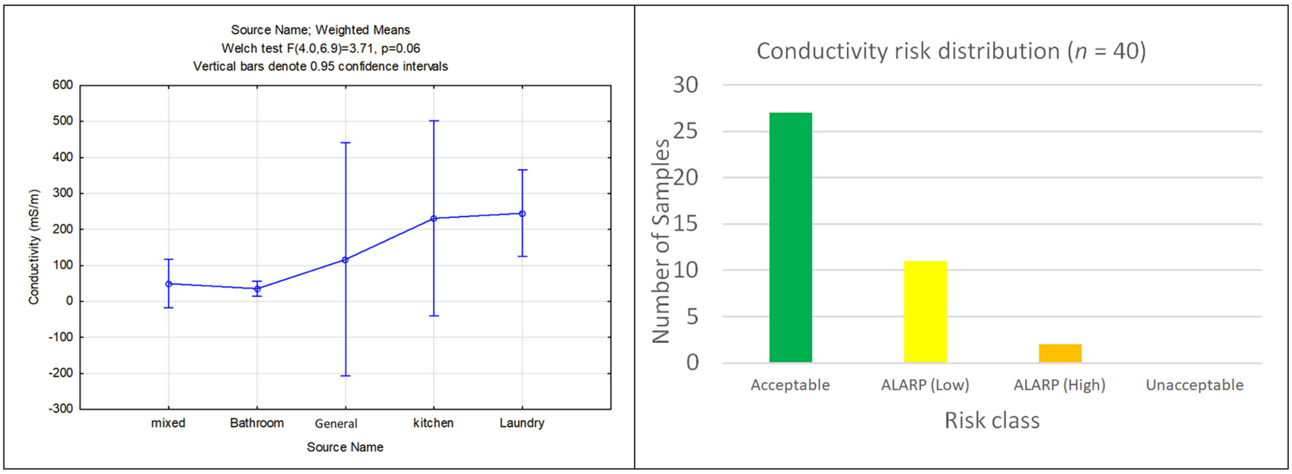

Figure 3. Electrical conductivity analysis (statistical analysis and risk assessment)

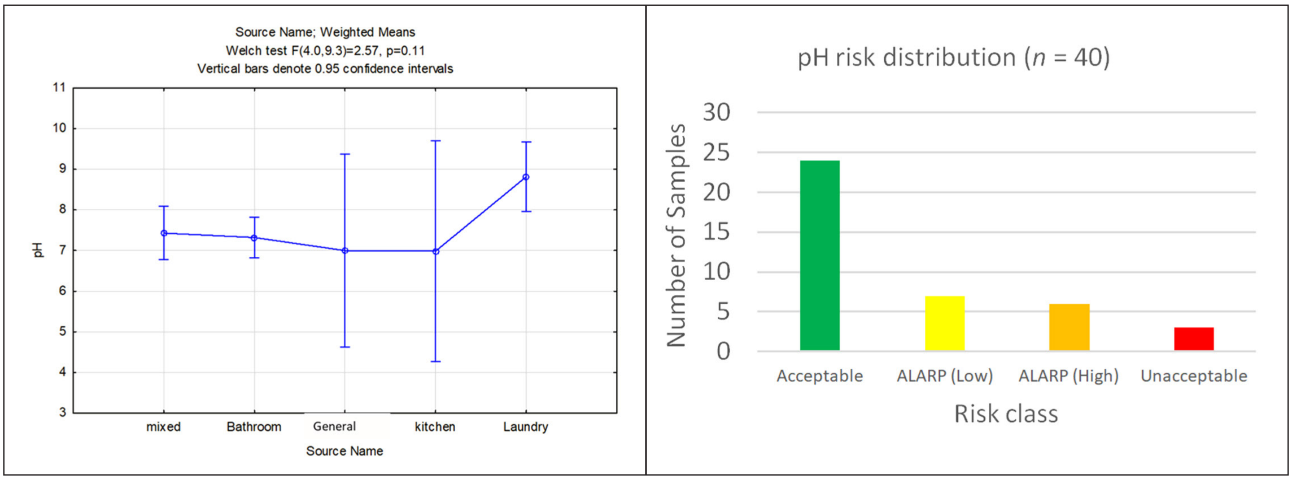

Figure 4. pH analysis (statistical analysis and risk assessment)

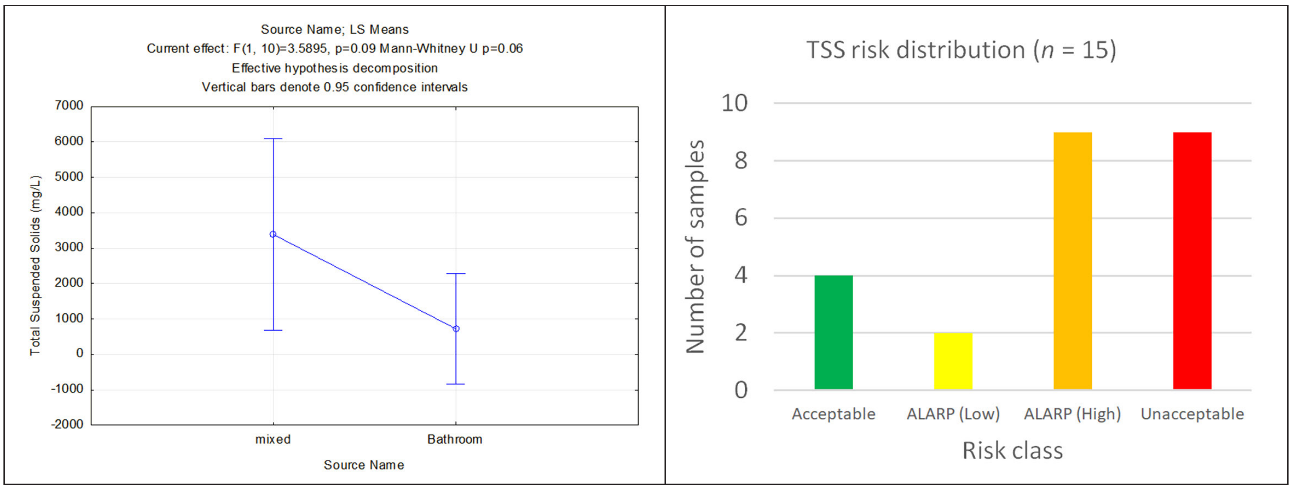

Figure 5. TSS analysis (statistical analysis and risk assessment)

Values for TSS were reported from mixed sources and the bathroom, with mean values at 3 338 mg/L and 723.6 mg/L respectively (Fig. 5). Both mean values are in the water quality range where use of the water is not recommended, even for irrigation (see Table 1). High values of suspended solids were also reported by Oteng-Peprah et al. (2018), from kitchen and bathroom washing and rinsing activities, who state that high TSS values are common, which, in turn, increases the turbidity. The risk assessment in this study indicated that the majority of samples (for the two sources) are high risk or second tier ALARP (Fig. 5) where high levels of TSS, when using greywater for irrigation, can cause clogging of irrigation emitters and the formation of a soil surface crust which inhibits water infiltration, seedling emergence and soil aeration (DWAF, 1996).

Chemical constituents

The mean values for COD were measured at 2 739 mg/L for mixed sources, 1 164.7 mg/L for bathroom greywater, 2 572.83 mg/L for kitchen greywater, and 1 281.17 mg/L for laundry greywater (Fig 6.); therefore, no mean values fall within the target water quality range for irrigation (see Table 1). In alignment with this, Friedler and Gross (2019) state that COD in greywater can range from about 7 mg/L to more than 2 500 mg/L. Application of the Games Howell post-hoc test indicated no significant differences between the COD values for the four sources. COD measures the amount of oxygen required to oxidise organic material and is an indication of the polluting strength. The greywater from mixed sources showed the highest level of organic compounds. Further to this, the risk assessment indicates that the majority of samples have a medium risk to pollute, with some exhibiting an acceptable risk and some an unacceptable risk (Fig. 6).

The mean phosphorus values for the domestic raw greywater samples were 6.08 mg/L for mixed sources, 3.53 mg/L for bathroom sources, and 2.84 mg/L for laundry sources (Fig 7.), and therefore all were within the target water quality range (see Table 1). While excess phosphorus concentrations can induce clogging of irrigation equipment (DWAF, 1996), the risk assessment indicates that the risk is relatively low (Fig. 7). Application of the least significant difference (LSD) post-hoc test also indicated a significant difference ($p < 0.05$) between the phosphorus values of mixed, bathroom, and laundry greywater sources.

Microbiological constituents

Mean reported values for *E. coli* were 1 024.8 counts per 100 mL for mixed sources and 1 429 counts per 100 mL for laundry greywater (Fig. 8). Both these mean values fall within the water quality range that is suitable only for short-term use on a site-specific basis (see Table 1). Although the risk assessment indicated an acceptable risk for the majority of samples, with some samples an ALARP risk (low and high) in terms of causing infection in humans and animals (Fig. 8), this does not include an assessment of pathogen types within the microbes. Further research into the specific microbial risk is warranted and the results should be considered with caution, given the high dependency of *E. coli* counts on sampling times, length of storage, etc. This outcome indicates a possible shortcoming in the risk analysis method, indicating that future research into providing more nuanced additions to cater for more detailed risk analysis should be undertaken as for WHO (2015).

The interaction between the type of constituent present and the physical hazards, such as temperature, could influence the hazard concentration because the toxicity and dose level needed for potential infection and the survival rate in the environment are relevant. The storage of greywater further influences the concentration of microbial hazards. Natural processes can create anaerobic conditions within hours, resulting in offensive odours, a breeding ground for mosquitoes, and perfect conditions for the proliferation of microorganisms (WHO, 2006). Another key consideration is the quantity of potable water employed in the

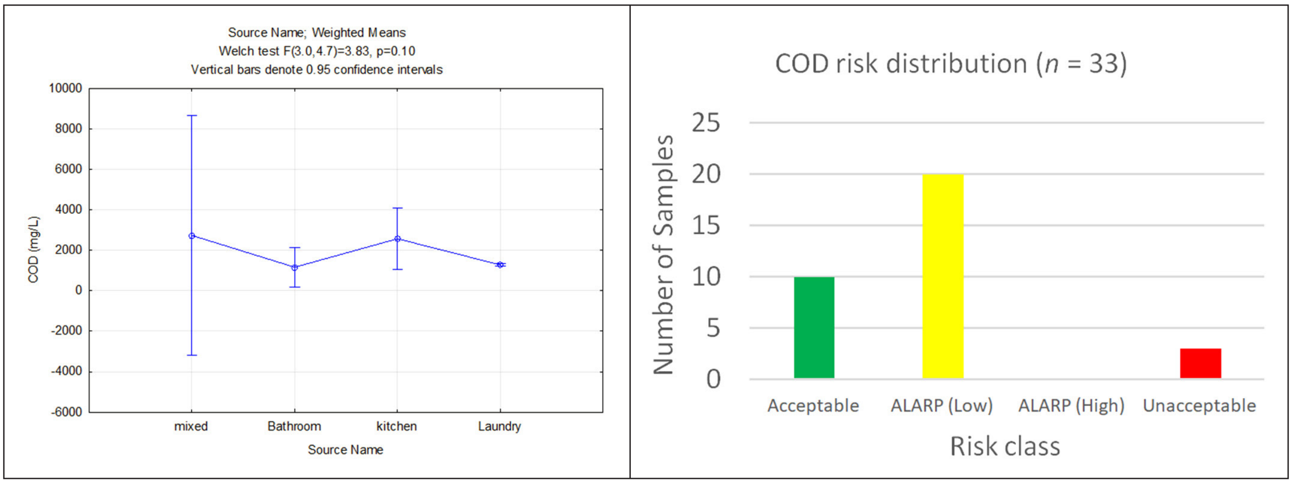

Figure 6. COD analysis (statistical analysis and risk assessment)

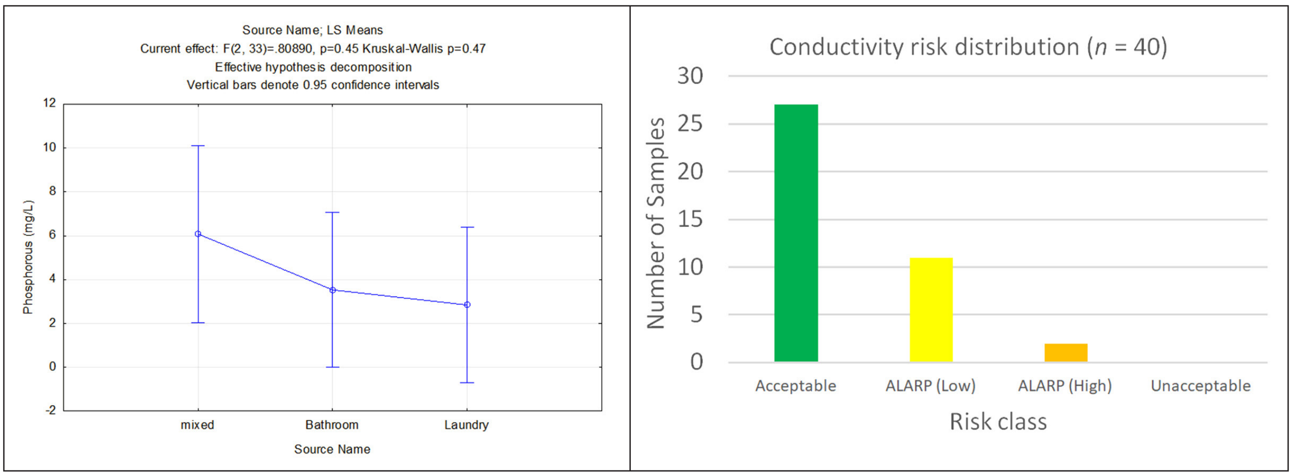

Figure 7. Conductivity analysis (statistical analysis and risk assessment)

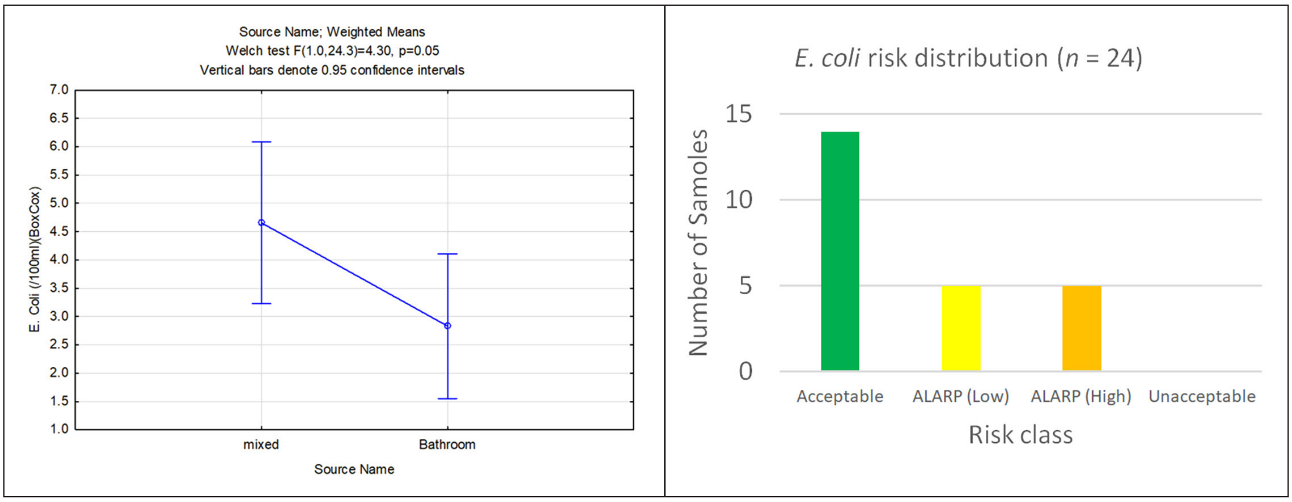

Figure 8. *E. coli* analysis (statistical analysis and risk assessment)

household that will impact the dilution of the greywater produced. For instance, increased water conservation efforts in a home could decrease the quantity used and thus increase the concentration of pollutants in the greywater produced, thereby increasing the risk.

Risk

The risk assessment undertaken in this study has confirmed that the likelihood of a batch of untreated greywater causing harm is complex. Contributing factors to greywater risk include exposure, vulnerability, and scale of reuse, as it relates to humans, the environment, and infrastructure.

Public health risk: exposure and vulnerability

Pathogens present in greywater have the potential to cause disease, so the exposure of humans to these pathogens, as well as the vulnerability of the individual, influences the health risk. Exposure can occur through the consumption of edible crops that have been irrigated with greywater (Carden et al., 2018); splash-up of contaminated greywater while irrigating; aerosols as a result of irrigation with greywater; aerosols when filling up a toilet cistern, or when the toilet is flushed (Christova-Boal et al., 1996); coming into contact with ponded greywater (Roesner et al., 2006); handling greywater-contaminated plants/crops; and handling a pet that frequents areas of the garden where greywater is utilised. Accidental cross-connection of greywater and potable water pipes, or drinking water from a garden hose used for greywater irrigation, also generates the risk of consumption of greywater.

The public health risk associated with greywater reuse is further increased according to the age and health of the recipient population, with the more vulnerable sectors of society more likely to fall ill when in contact with harmful pathogens (Carden et al., 2018). Ilemobade et al. (2013) employed the Disability Adjusted Life Year (DALY) index to estimate the health risk per annum (using the DALY number and unit cost) due to diarrhoea caused by greywater reuse for toilet flushing at two universities.

Environmental risk: exposure

Certain applications of greywater, such as plant bed irrigation (Roesner et al., 2006), can create transmission routes for exposure of the environment to greywater hazards. While the health risks of reusing household greywater due to exposure to potential pathogens are well documented, there is less information on the effects of greywater on soil microorganisms and downstream urban ecosystems; possibly because these impacts may be difficult to predict due to the variability of greywater (Roesner et al., 2006). In terms of greywater chemistry, given its unpredictability, the impacts of greywater irrigation on soil chemistry and aquatic ecosystems are also complex, with authors such as Rodda et al. (2010) attempting to address the complexity.

Literature on the long-term effects of greywater irrigation on ornamental plants is also scant. Roesner et al. (2006) recommend relatively saline-tolerant plant species when irrigating with greywater. Dissolved salts can be absorbed up through the plant by the roots and result in scorched leaves. WHO (2006) suggests that plants that can thrive under high alkaline conditions are key to plant health under greywater irrigation conditions.

Nel et al. (2013) state that greywater ponding and runoff into the stormwater system (e.g., when irrigating with untreated greywater) poses considerable dangers to the environment (e.g., polluting rivers and wetlands) and public health. Greywater reuse for garden irrigation may result in pollution of the downstream aquatic environment when rain falls on the urban space and stormwater carries the contaminants (originally deposited with the untreated greywater) further downstream (Nel et al., 2013). This risk is poorly researched, is hard to quantify and is not appreciated by uninformed home owners who may use untreated greywater with the best intentions.

Infrastructure risk: scale of use

In serviced urban areas, the reuse of greywater is likely to alter the quality and quantity of (i) wastewater exiting a particular home and entering the sewage system, and (ii) runoff from the plot and entering the stormwater system. Sewers and stormwater pipes are designed according to certain criteria, to ensure that the minimum flow velocity is exceeded, as specified, and pipes are regularly scoured to remove settled solids. A notable reduction in flow rate, i.e., as a result of greywater reuse, would also reduce the flow velocity. The cumulative effect of altered wastewater from many households could impact the sewer network (where further research into the potential clogging of pipes is required), the wastewater treatment works (Penn et al., 2012) and the stormwater system.

Consequences

Public health consequences

The varying hazards and the varying risks associated with untreated greywater, also give rise to variable consequences. The public health impact of greywater reuse could range from a small impact on health or discomfort (e.g., odours and mosquitoes), to death or a permanent reduction in health depending on the risk factors as previously discussed. Contracting a disease could in turn have severe financial consequences due to the required medical care and compromised economic opportunities of an ill individual (Ilemobade et al., 2013).

Environmental consequences

The environmental consequences of greywater reuse include changes in soil chemistry (Hardie et al., 2021) and contamination of both groundwater and downstream aquatic ecosystems. Greywater use potentially pollutes the stormwater system and ultimately rivers and wetlands further downstream (Nel et al., 2013). This consequence could be severe due to the diverse and important ecological, aesthetic and recreational functions that waterways fulfil in serviced urban areas. In the same vein, contaminated runoff is likely to cross property boundaries and put others at risk, with legal consequences for both homeowners and water service providers. Despite the notable health risks as previously discussed, studies on the effect of greywater on crop yield have also been undertaken (e.g., Jackson et al., 2006) and indicate varied but mostly non-detrimental impacts (i.e., low consequence).

Environmental degradation (through a decrease in soil health, groundwater contamination, and polluted stormwater) and its direct cost are well documented in the literature (e.g., Ilemobade et. al., 2013). The natural environment fulfils diverse, social, cultural, and economic functions that are all interdependent, and undermining these functions comes at a socio-economic cost.

Infrastructure consequences

Increased greywater reuse (coupled with other water conservation efforts in suburban homes) and lower wastewater flows could result in higher incidents of sewer blockages (Penn et al., 2012). The consequential infrastructure damage and maintenance requirements could financially impact both water services providers and consumers. Should a pipe burst, or an overflow occur, it may, in turn, cause substantial pollution of the surrounding stormwater system and pose a health risk to those living nearby. The capacity and functioning of stormwater infrastructure may also be compromised with the shift of wastewater flows from the sewer to the stormwater system as a result of outdoor greywater practices, e.g., garden irrigation and hard surface cleaning (Jacobs and Nel, 2019).

At a household level, when using untreated greywater for toilet flushing, hair, various other organic materials, sand, lint, fats and other undesirable materials present in the greywater could cause clogging of the operating components in the toilet cistern, such as the inlet valve (Christova-Boal et al., 1996). Valve clogging results in water leakage into the toilet bowl. Untreated greywater use for toilet flushing could thus negate the intended water savings. Greywater use may lead to clogging of irrigation equipment, particularly drip irrigation and micro-jets (DWAF, 1996). Cross-connections of greywater that is supplied under pressure into any household plumbing system could contaminate the water network via feed into the water distribution pipes, although such connections are normally prohibited by law (City of Cape Town, 2021).

CONCLUSION

Greywater sources included in this study were the bathroom, kitchen, laundry, and mixed sources. Variability in terms of each of the reported physical, chemical, and microbiological constituents by source and between result sets was noted. These variations concur with studies such as Oteng-Peprah et al. (2018) that identified notable variations in greywater constituents across both place and time. Statistically significant differences were evident between the pH values of laundry greywater sources and the pH values of the bathroom and mixed sources, as well as the electrical conductivity levels of laundry greywater sources compared to mixed and bathroom sources. Statistically significant differences were also found between the phosphorus levels in the mixed, bathroom and laundry greywater samples. These variations also extend to the risk assessment which was undertaken for each of the constituents. Based on the data in this study (with TSS samples from mixed sources and the bathroom), it was found that the constituent with the highest number of high-risk samples was TSS.

The greywater source is often used to classify greywater as a way of determining the potential levels of contamination and thereby the risk (e.g., Carden et al., 2018). The variability of greywater by source as shown in this study, however, is an indication that the popular classifications of greywater use by source as a surrogate indicator of its contents and concentration is inappropriate and can be misleading. While greywater originating from a particular source in one household could differ from another household, so too greywater composition from a specific source in one household may vary temporally throughout the day, from day to day and seasonally.

Nel et al. (2021) showed that the reuse of untreated greywater through manual collection methods contributed <10% to total water savings in a suburban household for various lifestyle levels. While this value is relatively low, the authors recognise that any reduction in water consumption, particularly in water-scarce conditions, is noteworthy and that larger scale use would mean more significant water savings. By contrast, the relatively high risk and high level of negative consequences for greywater practices in terms of public health, the environment, and infrastructure, given the variability and unpredictability of untreated greywater quality as noted in this study, provide insight into the trade-off involved in these potential water savings.

The various facets of risk, as discussed previously, are also escalated as the reuse of greywater becomes more widespread. Household greywater risk management could be improved through pre-emptive action, either through removing the hazard (e.g., Hardie et al. (2021) recommending against the use of powdered laundry detergent greywater), removing exposure, or minimising the consequence. Alternatively, the greywater could be treated and disinfected to the desired water quality before application.

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