DIRECT ON-SITE GREY WATER REUSE – AN ILLICIT OR ILLUSTRIOUS OPTION?

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Abstract

Grey water – wastewater from the bath, shower and washing machine – is available to all residential water users as a personal, on-site water resource (POSWAR). Despite contradicting reports on the value versus danger of on-site reuse, grey water constitutes a significant fraction (± 50%) of wastewater flow from a typical suburban home, where pharmaceuticals and personal care products (PPCPs) enter the water stream as soluble substances at grey-water producing points in a home. The work focuses on the impact of prolonged grey water reuse on soil chemistry and vegetation growth. An internet survey of 19 respondents suggests that garden watering is the predominant application for untreated, private on-site grey water reused in South African urban areas. As part of this research 15 different soil samples were collected from grey water use points and control points on 6 properties in the Western Cape, South Africa. The test results for acidity (pH), sodium (Na), phosphorous (P), electrical conductivity (EC) and nitrogen (N), show only Na to be consistently higher (on average by ±150%) in soil irrigated with grey water, compared to controls. However, grey water use does not appear to impact negatively on the vegetation growth in any of the sites inspected, despite one site reusing grey water for 20 years. All respondents to the survey reported that plants thrive when irrigated with grey water and could note no visible change in the soil, even after prolonged use. The same was confirmed during the six site visits. Extended research in the field is crucial to ensure the effective application of available water sources, including grey water, without compromising the health and safety of the urban environment.

INTRODUCTION

Three “grey water questions”

Personal, on-site water resources (POSWAR) are available to all residential water users. The three common POSWAR are grey water, rainwater and groundwater. Grey water is probably the most contentious of the three. It is always available given that water is used in the home, but should it be reused on-site? Grey water has been reused worldwide to reduce costs and even more importantly to save water supplied from other resources via potable distribution systems. Some of the grey water reuse systems are designed with filters or treatment processes. In contrast, this study focuses on grey water reuse without any treatment prior to application. It was noted during the study that filtering is often employed in cases where grey water is pumped via piped irrigations systems. Filtering is not considered to be a form of treatment since it does not alter the water chemistry.

Few would argue that, from the viewpoint of a thirsty plant, some grey water is better than no water at all! The plant population would say, "Yes – give us grey water". Lush plant growth is confirmed by numerous respondents who reuse grey water and were involved in this study. From this viewpoint, grey water should be reused.

This leaves (at least) two questions unanswered:

1. How does continuous grey water application, say over many years, impact the soil? For a short duration of grey water use, say maybe a few days, such use is clearly preferable (compared to insufficient or no water from other sources). Yet, even from the viewpoint of a thirsty plant, the soil quality should not be compromised or become degraded over time beyond a point where death of the plant is inevitable, despite sufficient water being supplied. The soil quality is as important as water for plant survival. Degradation of the soil beyond such a point would not only result in the plant dying, but also in failure of other plants growing in its place to beautify the earth for future generations.
2. We are humans, not plants – and consider ourselves superior beings. Does it harm our race to allow the plants to make use of grey water in order to thrive, or survive? The slightest hint at such harm would probably result in the death of grey water reuse and possibly also of many plants during water restrictions (but at least the human race would survive the "grey water era").

This research is an attempt at providing some answers about soil degradation and its impact on plant growth with prolonged application of grey water – the first of the two questions. The second question will remain unanswered in this text.

<u>Definitions</u>

Direct, personal on-site grey water reuse, for the purpose of this investigation, is defined as follows:

- "direct" – the grey water is reused directly without treatment prior to application
- "personal" – the system is brought in place by a private home owner living in a serviced urban community
- "on-site" – the grey water is reused on the same residential property where it is generated (i.e. the point where the potable water becomes polluted)
- "grey water" – relatively unpolluted wastewater from the bath, shower, washing machine and possibly the hand basin, containing soap, detergents, washing powder, bleach and other PPCP's[(1)].
- "reuse" – water is redirected away from the piped sewerage system by modifying the plumbing in order to apply the water to water demand points elsewhere on the property; the water is thus reused to meet a secondary need on the same property than its primary point of application.

<u>Contradicting news: an illicit or illustrious option?</u>

During the summer of 2004/2005 water users in Cape Town were subjected to relatively severe water restrictions[(2)]. Consider the following two contradicting reports on grey water reuse spread to laymen via the general media during that period:

- the illicit option: "Die Tygerburger", a community newspaper with a circulation of about 150 000 in the Northern suburbs of Cape Town[(3)] cautioned its readership about reusing grey water on 23 February and again on 9 March 2005 under the titles, “Grey water hazard” and “Eye out for grey water”. The warning centred around the possible degradation of soil and reduced plant health. Subsequent to publication, 57 telephonic queries were received by the author of those publications[4].

- the illustrious option: a month later the “Cape Argus” newspaper, with a circulation of about 75 000 [3], encouraged its readership on April 21, 2005 to make use of grey water in gardens as one of various water saving tips, “*Re-use water from baths, sinks and basins on the garden or in the toilet cistern. Don't forget to do the same with water collected in buckets as you shower*”. Based on this information, grey water promised a greener future to residential home owners faced by dry, dull gardens and demanding water bills.

In 2008 laymen remain confused, with good reason. Research on the topic is also divided on whether grey water reuse should be viewed as illicit or illustrious. Some researchers suggest that grey water is generally unfit for use, except under controlled conditions and could lead to reduced crop yields and crop quality[5,6]; the latter study focuses on grey water disposal in non-sewered, high-density communities, not to be compared directly with low-density, serviced urban areas forming the focus of this text. Others report increased crop yields and improved quality[7,8].

This study reinforces the latter opinion that grey water used for garden irrigation leads to lush vegetation growth, although sodium levels in soil are noted to increase in all test samples.

<u>System description</u>

Figure 1 is a schematical presentation of a typical private, on-site grey water reuse system as it is viewed for the purpose of this research. The diagram shows garden watering as the only application point, as is commonly the case.

For untreated grey water, no filtering or other treatment system is installed. Thus effluent from the washing machine or bathroom is directly diverted into the garden. This occurs via a connection of pipes between the plumbing inside the house and the garden. No further pumps are used, rather water moves inside the pipes due to the existence of a natural gradient and the head provided by the washing machine outlet pump. In some cases water is stored and then pumped to garden irrigation points via existing irrigation systems (filters are required to prevent clogging). The use of automatic irrigation systems without filtering is impractical, because hair, soap, skin and other organic materials accumulate at connections and sprinklers and thus cause blockages. Untreated systems are also the most cost efficient grey water reuse systems.

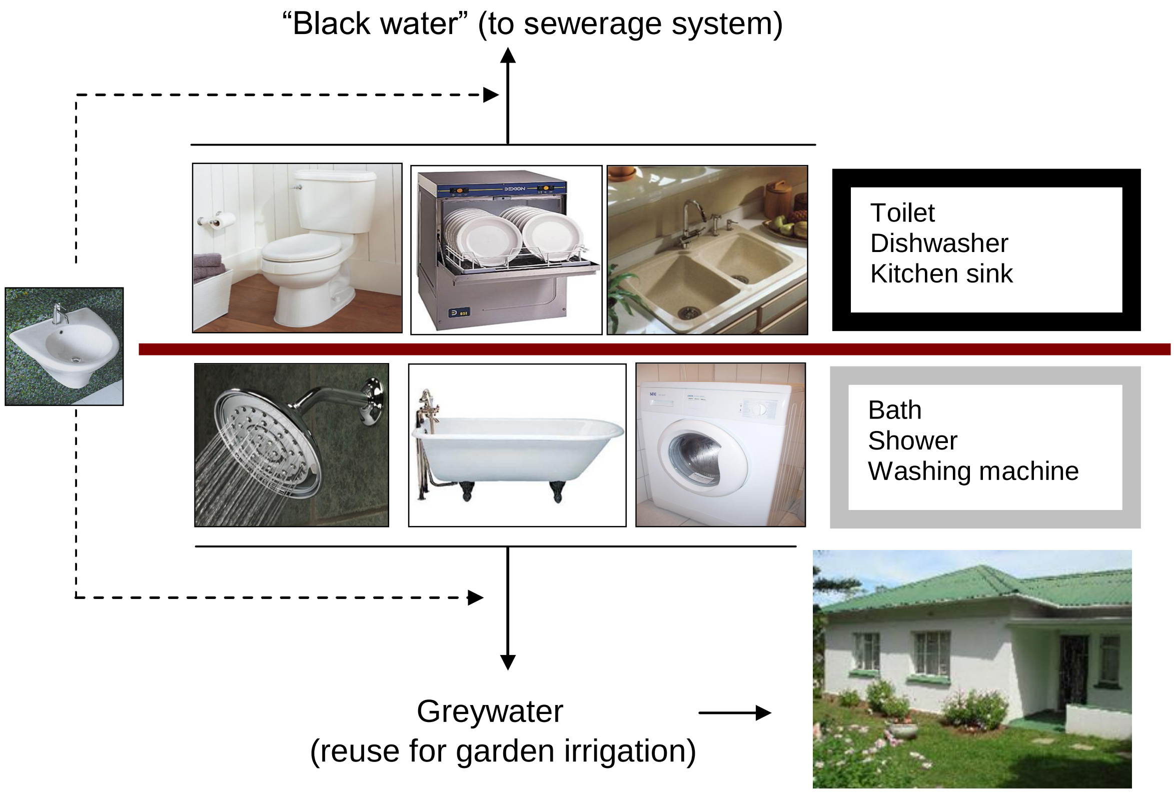

Figure 1: Schematic presentation of a grey water reuse system.

One of the survey respondents also reuses swimming pool backwash water to irrigate the lawn. This method of lawn irrigation has been practiced on the property for about 7 years with no detrimental effects – in contrast, the lawn was reported to be very green in this area. However, swimming pool backwash water is not considered as part of the grey water stream in this study due to its use being uncommon.

SCOPE OF THIS STUDY

The following three aspects of grey water reuse are addressed in this study:

- impact of grey water reuse on soil (experimental analyses of 15 soil samples from six properties in the Western Cape)
- a survey of home owners who use grey water to establish typical application methods, sources of grey water and reported effects of prolonged use (19 responses were received)
- a focus on vegetation growth when irrigated with grey water (literature review, survey responses and visual inspections of the former six properties where soil samples were collected).

LIMITATIONS OF THIS STUDY

<u>Community health</u>

Health concerns were not addressed as part of this study. Some prior publications provide valuable information for further reading. Researchers have recently reported on potentially toxic compounds used in households[9], the presence of waterborne bacteria, viruses, parasites and chemical compounds in grey water[10] and a methodology to assess the pathogen risk of wastewater reuse[11]. As part of another study researchers made use of site surveys in 39 low-income non-sewered settlements and reported that significant risk is involved in the disposal of grey water in high-density urban communities[5,6]. However, the same authors conclude that the quality of grey water in non-sewered areas differs significantly from grey water that is generated in higher-income, sewered areas. No report could be traced during the literature review of on-site grey water reuse for garden watering in low-density residential areas being a health risk.

<u>Groundwater contamination</u>

Investigating the impact of grey water reuse for garden watering on groundwater recharge is beyond the scope of this investigation. Grey water application in excess of plant needs obviously percolates into the natural store of water in the ground. However, water can still be taken up by trees or shrubs that have deep root systems. When the water table is close to the surface, the water absorption ability of soil is restricted and the potential for groundwater pollution is increased[5,6]. A rule of thumb is that up to 5% of the water that seeps into the ground after a rainy season, recharges groundwater.

The relative small volume of grey water available at a residential property is typical less than the requirement for garden irrigation, suggesting that aquifer recharge is unlikely. The treatment capacity of the topsoil layer is enormous, with 90% of plant roots and many micro-organisms present in the top metre of soil[12,13].

LITERATURE REVIEW: SOME CASE STUDIES IN SOUTH AFRICA

<u>eThekweni Municipality</u>

The eThekweni Municipality investigated ways of using domestic grey water as a resource rather than treating it as waste[7]. The reason behind the project was the high HIV positive rate in Kwa-Zulu-Natal, leaving many households without a breadwinner. The aim was to improve the nutritional status of the households, by using grey water for irrigation of vegetables. The preliminary trial was done in 2003, where grey water was used to irrigate 4 different types of vegetables. Vegetables were internally and externally examined for coli forms like *E.coli*, *Enterococcus* and *Staphylococcus*, as these are potential viral indicators. The tests were carried out at the University of Kwa-Zulu-Natal with three different irrigation systems and commercial vegetables from a local supermarket as control measures.

The experiment was then expanded to eight different crops that were grown in plastic bags filled with sterile, low nutrient Berea red sand and drip-irrigated through plastic bottles with either municipal tap water, grey water or a hydroponics solution. The vegetables were watered daily with 500mℓ of the relevant solution and harvested at maturity, thus approximately after three to four months. The results show substantially better growth by grey water-irrigated vegetables than those irrigated with potable water. Long-time concerns noted during the study include possible soil salinisation and eutrophication of the water. Coliforms were also noted to be markedly higher in the grey water. Additional investigations and experiments are being performed as the project progresses.

Nietvoorbij Research Project

A research project, which was conducted in 2005 in the Western Cape at ARC Infruitec-Nietvoorbij, focused on the effects of grey water irrigation on the quality and yield of tomatoes and beans[8]. Furthermore, the infiltration tempo, permeability and element content of three different soil types, namely sand, loam and clay, were examined. Unfiltered grey water from the washing machine, bathroom sink, hand basin and kitchen sink was applied to potted crops. Both water and soil samples were taken during the experiment.

No negative effect on infiltration due to grey water application was observed. An increase in sodium and phosphorous levels was recorded during the chemical analysis, while the level of macro-nutrients in plants growing in sandy soil was low compared to the level in plants growing in the other soil types. The results also showed that plant growth and productivity were higher with grey water application than with potable water. However, long-term effects on soil were not studied.

University of Stellenbosch Department Soil Science Research

Three sets of 12 water samples in different suburbs in the Western Cape were taken and analyzed by the University of Stellenbosch (US).[4,14] The first set of samples contained water from the bath, shower and hand-basin, while water from the washing machine was analyzed separately as a second set. Tap water was taken as a control measure. The quality of grey water was compared with the irrigation water quality criteria set by the Department of Water Affairs and Forestry and the UN's Food and Agricultural Organization. Grey water collected from the bath, hand-basin, shower and the rinse cycle of the washing machine complies with the criteria. Water from the wash cycle of the washing machine and dishwashing water does not comply with the standards for irrigation water quality.

Grey water in non-sewed areas of South Africa and related health considerations

A study to estimate the scope of grey water reuse in highly dense areas[5,6] was initiated due to the poor level of sanitation in high-density (mainly informal) settlements throughout South-Africa. Grey water is often disposed of above the ground on the soil surface outside dwellings, resulting in pollution and environmental problems. On-site disposal of grey water under such circumstances can easily cause pounding, where pathogenic organisms are effortlessly transferred. The findings are not necessarily directly transferable to low density high income suburban areas forming the focus of this study.

GREY WATER GENERATION RATE

Literature reports

Grey water generation rate was not measured as part of this study. Nevertheless, an understanding of the grey water generation rate is essential, justifying measurement of the volume at one property as well as a brief review of values reported elsewhere. According to general sources grey water comprises approximately 50 to 80% of residential wastewater[13].

A more precise estimate of the grey water volume from the particular end-uses where grey water is generated is possible by means of end-use modelling. The results of such an end-use modelling exercise are presented by Jacobs and Haarhoff[15,16], who estimated the water demand and sewer flow from each end-use at a residence. The published results were reworked during this study to estimate the contribution of grey water-generating end-uses in a “typical” suburban home. The results show that the bath-shower and washing machine contribute respectively 116 and 102 ℓ/stand·d to the indoor demand of 559 ℓ/stand·d in that case. Presuming for the moment that the water supplied to each end-use point is reused 100% effectively, the total grey water volume available for use is thus 218 ℓ/stand·d, representing 39% of the total indoor demand (garden water demand is highly variable and thus the indoor use only is considered here).

Eriksson et al.[9] cite others to state that grey water contributes up to 75% of the total wastewater flow to domestic sewers. Literature also suggests that grey water generating end-uses contribute a significant fraction to the indoor water demand in a typical suburban home. In urban Australia the combined grey water from the bath, shower and basin is reported to contribute 26% to total household consumption and the washing machine an additional 15%, resulting in a grey water contribution of 41% to total demand, including outdoor use.[17] The total average water consumption of the dwelling in consideration was 250 kℓ/a, thus suggesting a grey water volume of 280 ℓ/stand·d.

Another perspective is gained by considering area-wide use. Given a property size of about 1000 m^2 and a coverage of 75% (private residential properties as percent of the total land area in a particular suburb), the grey water generated per land area by properties similar to those in this study could reach a maximum of about 2000 ℓ/ha·d – if all properties in a specific area were to reuse all available grey water. These estimates of grey water volume place such residential communities in the bracket with a grey water generation rate of between 500 and 2500 ℓ/ha·d, where on-site disposal and reuse “could be considered” from a health-perspective.[5,6]

Measurement of generation volume at one property

The grey water volume from one survey responded could be measured as part of this study. On the particular property the grey water is stored in a 1 000 ℓ drum and is subsequently irrigated onto the garden by a level-control pump and piped irrigation system when the drum is full. It was thus relatively simple to determine the frequency of irrigation events by simply counting each event, which corresponds to 1000 ℓ of grey water per event. It was found that an average of ± 333 ℓ/stand·d of grey water was irrigated on-site by the home owner during summer, with about 10 applications of 1 000 ℓ/event each month. Based on end-use model estimates for the grey water generation rate on the particular property (Cape Town; 4 people per household), the theoretical grey water yield for the property based on end-use modelling is 346 ℓ/stand·d, or 87 ℓ/c·d.

GREY WATER DEMAND POINTS

Demand could be viewed as the combined water use at end-uses (“usage points”) for grey water on the property. Application points are limited largely by the poor quality of the water compared to the potable water supply. Based on the literature review and survey responses, garden irrigation appears to be the most common application. Some reports also mention grey water use for toilet flushing (e.g. Argus newspaper article, April 21, 2005). This is reinforced by some survey respondents in this study who intend to use grey water for toilet flushing in future. However, plumbing complexities regarding the toilet as end-use application point appear to hamper practical application in most South African homes.

Garden water demand is influenced by factors such as vegetation type, climatological and environmental factors such as evapotranspiration, rainfall, runoff, infiltration, root zone storage and soil type[15,16]. Of course, human habits (e.g. over and under-irrigation) also play a significant role in the actual volume irrigated in relation to theory. Analysis of the outdoor water demand is beyond the scope of this study. This is not a concern, since the garden water demand in low-density areas normally exceeds the available grey water generation rate, particularly in dry seasons. In most cases evaluated during this study, all the grey water generated inside the home was used in the garden (some survey respondents in the Western Cape reported that grey water was redirected to the sewerage system during the wet winter period to prevent waterlogged soil).

CHARACTERISING GREY WATER

Grey water generally contains soap, shampoo, toothpaste and washing powder but could also contain disinfectants, shaving cream, bleach and other household chemicals. These are often referred to as pharmaceuticals and personal care products (PPCP's). No attempt was made in this study to characterise the grey water in order to assess its quality. Reports in literature suggest that grey water quality is highly variable, depending on the products added to the water stream at water use points in the home. In general grey water is found to contain lower levels of organic matter and nutrients than ordinary wastewater, but the levels of heavy metals are in the same range[9].

The amount of chemicals contained in wastewater is dependent upon the type and amount of laundry detergents and soap used in the relevant household. The chemical ratios (N:P:K) of the nutrients in most grey water fail to meet plant's requirements, whereas their chemical load nearly always exceeds the demand by plants and organisms and might thus cause harm to the soil.

THE THEORY BEHIND GREY WATER AND SOIL INTERACTION

Salinity is a measure of the amount of all salts in water, bar sodium, while sodicity is a measure of the amount of sodium specifically in the water stream[18]. An increased salinity may seriously degrade the soil and may cause loss of vegetation, while sodicity has a negative impact on the plant's function. Together, salinity and sodicity change the soil's pH value and have the ability to reduce the soil's hydraulic conductivity[19]. How do soil properties change due to the impact of the various chemicals in grey water?

Laundry detergents are rich in phosphorus, sodium and nitrogen[19]. Sodium salts are used in laundry powder as a manufacturing agent, or simply as filler, which reduces the hardness of water. Van der Graaff and Patterson[18] measured sodicity as sodium held in exchangeable form in the soil, which is in equilibrium with the subjected water. Exchangeable sodium percentage (ESP) is the amount of sodium held in exchangeable form on the soils cation exchange complex. This is expressed as a percentage of the total cation exchange capacity (CEC) which is the amount of positively charged cations the soil can hold.

Different soil textures (i.e. sand, silt or clay) have different CEC's. For example, clay has the highest CEC, as clay minerals have a deficiency of positive electric charge, that is, they have a permanent negative charge. To make up the deficiency they attract positively charged ions (cation) like Na^+ from the surrounding soil water. Clay particles do not have a strong preference for certain cation types during this compensation process. Therefore, if the main absorbed cation was Ca^{2+} prior to grey water reuse, but the soil was continuously irrigated with water rich in Na^+ ions, the Ca^{2+} will gradually be replaced by absorbed Na^+. When this happens, the ESP and hence the sodicity, increases. Soils have a preference for cations with more than one positive charge, so it is easier to replace Na^+ with Ca^{2+} or Al^{3+} on the exchange complex than vice versa.

The salinity of the soil is measured by making slurry from water and soil and measuring the electrical conductivity (EC) of the slurry. The higher the salt contents in the soil, the higher the electric conductivity. Highly saline soil is very permeable, but leaching out the salts by using low salinity water causes the clay to flocculate and the soil to close up. Therefore, when saline soils are regenerated, gypsum is used. It is based on calcium instead of sodium and thus salinity is kept high, while the sodium is gradually replaced by calcium. Sodium lowers salinity but increases the ESP and sodicity, which reduces porosity and therefore increases the risk of poor movement of water through the soil.

Furthermore, if clays are of a high CEC type, the soil's permeability might be reduced in the long run. However, if raw grey water is used for direct irrigation, the clogging layer that develops at the wetted surface might reduce the transmission rate to a certain extent. Nevertheless, the permeability of the surrounding soil is still adequate to let the water flow through. If the clay particles are strongly bound together by other cementing substances the soil will not be damaged(18).

Laundry powders and liquid detergents in Australia were found to exceed the allowable maximum value of 20 mg P/l of phosphorous set by the Australian government.(12) The phosphorous content in grey water per full wash was measured to be 50 *mg /l*. This gives an indication of the amount of phosphorous that finally reaches the garden. The desired ratio of N:P is 17:1, while it is about 3:1 if grey water were to be used. Thus, for grey water use, more nitrogen has to be added to the soil to cancel out the effect of the excessive amounts of phosphorous. A 50 percent reduction of phosphorous in grey water would have significant overall benefits in balancing nutrient loading. Some soils have a natural mechanism to immobilize the phosphorous and thus minimise its availability to plants. High phosphorous levels enhance the risk of eutrophication of any water body into which the grey water might seep, unless the nitrogen present is utilised(7).

Theory suggests a significant increase in the pH level of wash water, caused by the high pH value of detergents needed to successfully remove stains from fabric. Soil and grease are more easily removed with high pH washing powders. The negative impact could be considered to be more significant for cloth life than the environment. The cloth deteriorates quicker when washing in liquids with high pH values.

PLANT GROWTH

Grey water contains nutrients and minerals such as potassium, sulphur, calcium, magnesium, iron, zinc and many more that are all essential to plant life. Plant growth is stimulated by the availability and uptake of water, minerals and nutrients. Although grey water contains various nutrients and some minerals, the relevant nutrient ratios are insufficient and could be harmful to plants, therefore it cannot be used as a substitute for fertilizers.

A mismatch between the nutrient applied by on-site grey water disposal and the nutrients required for plant growth exists. Different plants obviously need different ratios, but Patterson (1999) found a typical N: P: K: S: Na ratio for mixed pasture, namely 17:2:14:1:1. From this ratio, it can be seen that N: P should be 17:2, compared to grey water's ratio of 3.5:1. The grey water thus contains far less N than is required by plants. Similarly, the ideal ratio of K: Na in mixed pasture is 14:1 while grey water's is 1:2.

Grey water enables a landscape to flourish, because water would otherwise not be available. As a result, trees, flowers and shrubs remain green between rainy seasons. In addition to this somewhat obvious statement, other studies have reported a higher production of vegetables with the application of grey water than with potable water from municipal supply – even if the same volume of water were used (i.e. plant growth when irrigated with grey water outperforms plants irrigated with a similar volume of potable tap water). The presence of nutrients in grey water explains this observation. However, some plant genotypes may die, due to the inability of the roots to take water with a higher pH.

A common characteristic of all salts is that they dissociate into positively charged cations and negatively charged anions. Grey water contains a high level of sodium but since none is needed by the plant, this constitutes a problem. Excess sodium in the soil causes the so-called perceived drought effect inside a plant. The plant shows "burnt edges" and will eventually die. This is explained by a phenomenon known as osmosis. Osmosis is the process of water moving from a high water potential towards a low water potential. Here, the high water potential is inside a plant's cell, while the lower water potential is in the ground surrounding the root system. This will, according to theory, eventually cause reduction in plant quality and productivity.

Boron, found in soaps and detergents, is an important macronutrient for plants, essential for the development and growth of new cells, proper production, fruit set and synthesis of proteins. Different plant species require different levels for optimum growth and in some plants, the margin between deficiency and toxicity is very narrow(5,6). This means that, when reusing grey water, high levels of boron can kill plants, but lower levels will act as fertilizers.

That said, 9 of the 19 respondents in this study reported improved vegetation growth when using grey water compared to tap water. The other 10 reported no notable change.

SOIL ANALYSIS AND RESULTS

Experimental procedure

As part of this study soil samples were collected for analysis. As a first step the team had to identify suitable grey water users – those (a) in close proximity to Stellenbosch or research team members' homes in view of site-visits and subsequent travel expenses, (b) people who have been reusing grey water continuously on a property for at least a year, (c) those who were prepared to take part in the research and were able to provide a soil sample from the garden at the point of grey water application, without financial compensation. Six users were identified, located in Somerset West, Boston, Stellenbosch and one in Namibia (close proximity to student's home).

During each of the six site visits the researchers collected various soil samples. One sample was collected at the grey water discharge point. A control sample of similar soil was taken elsewhere on the same property – at a location where no grey water had ever been used. In three of the six cases the system comprised two separate grey water use points on opposite sides of the house – one for the bathroom and another for the washing machine. In these cases three soil samples were collected (two grey water samples and one control sample). This also enabled results to be obtained for the washing machine separately from the bath/shower.

Each home owner also took part in a detailed survey, results of which are presented in this paper.

Laboratory tests and results

Standard soil analyses were performed on each sample, testing for acidity (pH), sodium (Na), Phosphorous (P), electrical conductivity (EC) and nitrogen (N). The analytical results for normal water- and grey water-irrigated samples are given in Table 1, giving the results of each sample tested and also the percentage that a particular parameter value is higher in the grey water sample than in the control sample. Table 2 shows the results for the three properties with separate grey water application points (i.e. the washing machine and bathroom).

Only sodium is consistently higher in the grey water samples than the control samples, reinforcing the literature reports and the concern that the soil might become "too saline" with prolonged use. For agricultural purposes a Na-value of lower than 70 mg/kg is recommended(4). The highest value measured in this study is 367 mg/kg, with only one of the six samples having Na < 70 mg/kg. It is not clear at this stage why garden plants and lawns flourish on Na values in excess of what is recommended for agricultural purposes.

Survey questionnaires and results

Questionnaires regarding grey water use and customer habits were distributed by electronic media (e-mail) to identify additional grey water users in South Africa. In addition to the six grey water users who took part in the soil analyses, 13 more survey responses were received. The responses were limited to those who are reusing grey water.

Table 1: Standard soil analyses of all control (C) versus grey water (GW) samples

Results for each parameter tested and each soil sample										
No.	pH		Na (mg/kg)		P (mg/kg)		EC (mS/m)		N (%)	
	Control	GW	Control	GW	Control	GW	Control	GW	Control	GW
1 [A]	6.9	6.5	17	31	683	312	36	60	0.15	0.14
2	7.0	7.3	63	175	1 064	257	22	13	0.27	0.15
3	7.3	7.1	167	246	460	651	28	32	0.15	0.22
4 [A]	7.3	7.3	28	131	208	397	30	43	0.14	0.13
5	6.3	7.1	41	97	100	335	10	18	0.10	0.19
6 [A]	7.7	7.9	32	92	414	620	22	39	0.17	0.25

Percentage increase in each parameter value (decrease shown as negative)							
	pH	Na (mg/kg)	P (mg/kg)	EC (mS/m)	N (%)	Time (Yrs) [B]	Comment
1	**-6.5**	**79.4**	**-54.4**	**65.3**	**-10.0**	5	Fertilizer used prior to collecting control
2	**4.3**	**177.8**	**-75.8**	**-40.9**	**-44.4**	2	sample; might have resulted in high P
3	**-2.7**	**47.3**	**41.5**	**14.3**	**46.7**	4	
4	**-0.7**	**367.9**	**90.6**	**41.7**	**-7.1**	2	Sandy soil with high permeability
5	**12.7**	**136.6**	**235.0**	**80.0**	**90.0**	2	
6	**2.6**	**187.5**	**49.6**	**77.3**	**47.1**	20	Grey water mainly from bathroom basin

Notes:
A) Two samples tested; values weighed by water volume (say 50% bathroom, 50% washing machine)
B) Time elapsed since startig to use grey water on a regular basis

Table 2: Results for properties with more than one GW application point

Results for each parameter and each soil (control values from Table 1 repeated here)										
No.	pH		Na (mg/kg)		P (mg/kg)		EC (mS/m)		N (%)	
	Control	GW	Control	GW	Control	GW	Control	GW	Control	GW
Washing machine wastewater (all cycles)										
1	6.9	**6.2**	17	**12.0**	683	**285.0**	36	**59.0**	0.15	**0.1**
4	7.3	**6.9**	28	**233.0**	208	**608.0**	30	**67.0**	0.14	**0.2**
6	7.7	**8.0**	32	**104.0**	414	**801.0**	22	**45.0**	0.17	**0.2**
Bathroom wastewater (sample 1 = bath & shower, sample 2 bath only; sample 6 basin only)										
1	6.9	**6.7**	17	**49.0**	683	**338.0**	36	**60.0**	0.15	**0.1**
4	7.3	**7.6**	28	**29.0**	208	**185.0**	30	**18.0**	0.14	**0.1**
6	7.7	**7.8**	32	**80.0**	414	**438.0**	22	**33.0**	0.17	**0.3**

In total 19 survey responses were obtained and analysed. In designing the questions, the researchers attempted to learn more about the particular grey water reuse system, its operation as well as customer satisfaction with regards to soil and vegetation growth. A summary of the survey responses are presented in Table 3. The survey questions centred around the headings of the table.

From the survey responses the following is noted:

- all respondents use grey water only for garden irrigation (two indicated that they plan to extend the system for toilet flushing, but that it had not been done due to plumbing complexities)
- all respondents were satisfied with vegetation growth, with 9 of the 19 reporting improved growth with grey water application
- the average time elapsed in years since starting to reuse grey water was 5.7 years, with the maximum 20 years and most systems being in use for 3 years

- those systems that have been in use for three years in Cape Town were probably implemented during the severe water restrictions of 2004-2005 reported on elsewhere.(2)
- those who use pump and pipe systems to irrigate the water, also make use of drums or tanks to store the water prior to irrigation. These users all make use of level switches and most make use of filters. Some of these respondents indicated that irrigation of stored water had to be done at a high frequency – say daily – since storage of grey water for more than 2 to 3 days resulted in a stench.
- Most of the responses were from the Western Cape, probably due to the location of the University of Stellenbosch in this province (the electronic distribution of the survey was initiated here).

Table 3: Summary of grey water users' survey responses

No.	Location	Yrs [A]	Treatment	Storage	Application	Distribution method	Comments [B]
1	Somerset West (WC)	3	None	In drum	Garden irrigation	Pump & pipe system	Grass growth improved
2	Somerset West (WC)	3	None	None	Garden irrigation	Gravity, surface flow	No change
3	Durbanville (WC)	3	None	1 kl drum	Garden irrigation	Pump & pipe system	No change
4	Stellenbosch (WC)	5	None	No	Garden irrigation	Gravity, surface flow	No change
5	Bellville (WC)	5	None	No	Garden irrigation	Gravity, surface flow	No change
6	Durbanville (WC)	3	Filter	1 kl tank	Garden irrigation	Pump & pipe system	Plants and lawn greener
7	Vredendal (NC)	15	None	1 kl tank	Garden irrigation	Pump & pipe system	No change
8	Johannesburg (GP)	3	None	Wetland	Garden irrigation	Gravity, surface flow	Improved vegetation growth
9	Somerset West (WC)	2	Filter	200ℓ drum	Garden irrigation	Pump & pipe system	Lawn growth more vigorous
10	Phillipi (WC)	3	None	In drum	Garden irrigation	Pump & pipe system	Improved lawn growth
11	Worcester (WC)	3	None	No	Garden irrigation	Gravity, surface flow	No change
12	Hermanus (WC)	14	None	No	Garden irrigation	Gravity, surface flow	No change
13	Giyani (NP)	7	None	No	Garden irrigation	Gravity, surface flow	No change
14	Somerset West (WC)	2	None	No	Garden irrigation	Gravity, surface flow	Improved vegetation growth
15	Bellville (WC)	5	None	No	Garden irrigation	Gravity, surface flow	Improved vegetation growth
16	Otjiwarongo (Namibia)	20	None	No	Garden irrigation	Gravity, surface flow	Geraniums do better
17	Bellville (WC)	5	None	No	Garden irrigation	Gravity, surface flow	Improved lawn growth
18	Somerset West (WC)	4	None	No	Garden irrigation	Pump & pipe system	No change
19	Somerset West (WC)	3	None	No	Garden irrigation	Pump & pipe system	No change

Notes:
A) Years elapsed since starting to reuse grey water on the particular property; most report reuse only during dry season
B) Compared to growth prior to reusing grey water.

The survey did not gain information regarding cost, but some respondents provided such information as well. Many of the systems had negligible installation cost (e.g. one 90˚ bend for a wastewater plumbing pipe to divert it to a garden bed instead of the sewerage catch pit), making grey water reuse a financially viable alternative to using potable tap water for garden irrigation. Also, all the respondents reported a good technical understanding of their own grey water reuse system.

DISCUSSION

Grey water as illustrious option

No consistent pH increase was recorded on the six properties taking part in the soil analyses tests, contrary to expectations. The pH for three samples showed an increase, two a decrease and one no change. Only sodium increased in all cases, as predicted by theory.

None of the 19 survey respondents reported a negative impact on vegetation growth, even after prolonged reuse, nor did the soil display visual signs of degradation (e.g. the formation of a crust, white deposits or reduced porosity). In contrast, vegetation growth with grey water application was vigorous. The soil was biologically active with, for example, the presence of earth worms. These findings were consistent even at properties where grey water had been reused for many years.

In the three cases where soil from separate washing machine and bath/shower discharge points were tested on the same property no substantial conclusion could be drawn. Of all parameters tested it was noted that only EC increased at all three properties where the washing machine water was used (sodium increased at two of the three washing machine discharge points). Only sodium increased at all three bathroom use points.

Possible future applications

Apart from garden watering, toilet flushing seems to be the only potential alternative application for direct grey water reuse. Using grey water for toilet flushing has three distinct disadvantages over application outdoors: (i) it is not exposed to the ultra-violet rays of the sun when stored in the toilet cistern thus reducing the die-off rate of pathogens, (ii) storage of the grey water in a toilet cistern may lead to unwanted odours in the bathroom and (iii) plumbing complexities complicate the transfer of grey water from generation points to toilet cisterns.

FUTURE RESEARCH NEEDS

An acute lack of knowledge regarding the use of POSWAR as additional water resource to potable Municipal supply exists in South Africa. The Water Research Commission has realised the need for further research in this field by driving various projects to gain knowledge about grey water reuse. The nature and extent of POSWAR-application by individual water users, particularly in residential areas, impacts on all infrastructure elements of the water supply and waste cycle. POSWAR-application creates an apparent load reduction on all piped reticulation systems, treatment works and on the water supply resources. Unfortunately these "insignificant" resources are entirely neglected during urban and resources planning exercises.

Future research should focus on all POSWAR options, including both rainwater and groundwater abstraction by means of well points or boreholes in addition to on-site grey water reuse. This study was limited to untreated (direct) reuse of grey water, but grey water reuse systems with various forms of treatment and disinfection are available from commercial suppliers. Future research should establish the status quo of POSWAR and provide a conceptual end-use model incorporating POSWAR to assess its impact theoretically. The work regarding grey water reuse could also be extended to include swimming pool backwash water as grey water generation point.

CONCLUSION

On-site application of grey water on residential properties is clearly still a grey area. Grey water should not necessarily be viewed as water of a “poor quality”. Although this might be true for potable water users, it is untrue for plants. Previous research on plant growth and crop production clearly suggests that the nutrients in grey water enhance plant growth when compared to irrigation of a similar volume with potable water. Other studies focused on vegetables grown under crontrolled conditions, but the finding seems to be transferable to garden vegetation and lawn grass in particular, based on 19 survey responses from residential home owners who reuse grey water in this study. The average sustained grey water reuse period of the respondents was almost 6 years, with the longest being 20 years.

Soil samples from six households reusing grey water were analysed during this study. Standard soil analyses were conducted on 15 soil samples from grey water use points and control samples on each property. The only finding that was consistent throughout all the samples was that grey water reuse results in an increased sodium level – to a point substantially higher than that generally recommended for agricultural purposes, namely 70 mg/kg. However, garden vegetation and lawn grass seems to thrive when irrigated with grey water, despite the higher-than-recommended sodium content in the soil.

The verdict? Based on the limited scope of this study, greywater is considered to be suitable for on-site garden irrigation. However, possible health concerns regarding its long-term or wide-spread reuse in any particular area has to be resolved urgently. Also, future research could advise on a recommended value for the soil sodium content suitable for garden vegetation. The authors would not advise local authorities to specifically ban or promote grey water reuse, thus leaving home owners room to reuse grey water, or refuse to do so, based on personal preference. The main avantage of this approach is that information for future research would thus be available in years to come.

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