

Analysis of grey-water used for irrigating vegetables and possible effects on soils in the vicinity of Umtata Dam, Eastern Cape

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ABSTRACT

In the search for alternative and reliable water sources to irrigate vegetables for backyard gardens, an experimental field was set up in the vicinity of the Umtata Dam, north-west of the town of Umtata, to test grey-water quality and its effects on soil nutrient content following 4 successive growing seasons. Samples of grey-water that were generated from informal housing adjacent to the Umtata Dam were collected from kitchen and bath tubs/washing basins. These samples were analysed before being used for irrigating vegetable crops. The results showed that grey-water quality was 'fit for purpose' for irrigating edible vegetable plants. Although the average Na^+ (16 mg/l) and Cl^- (15 mg/l) ions were significantly higher ($p = 0.05$) for grey-water than other treatments, both were below the limit of 100 mg/l set in the South African Water Quality Guidelines. The concentrations of nutrients and heavy metals found in the grey-water samples were significantly lower compared to the World Health Organization guidelines for the safe use of grey-water and within the target water quality range (TWQR) prescribed by South African guidelines for irrigation water. However, the study strongly recommends that grey-water be diluted in order to lower the salt content and to improve the irrigation water quality. Results from an analysis of soil samples showed no significant differences in pH as a result of applying grey-water throughout the soil profile of up to 90 cm depth. Na content of the soil irrigated with grey-water was not significantly different than that of plots where diluted grey-water and potable water were used. Therefore, the grey-water used in this study does not appear to cause an accumulation of salts and heavy metals in soil, in the short term.

Keywords: grey-water, vegetables, soil, heavy metals, pH

INTRODUCTION

The use of untreated domestic grey-water for irrigating crops in small home gardens has several advantages (Holtzhausen, 2005; Al-Zu'bi and Al-Mohamadi, 2008). One obvious advantage is that it saves on the use of scarce freshwater resources. Studies show that supplementing irrigation sources can lead to a reduction of household potable water consumption by about 30% (Jeppesen, 1996). Further advantages, as shown in several studies, are that grey-water irrigation increases plant growth (Day et al., 1981; Rusan et al., 2007) and crop yield (Salukazana et al., 2005; Misra et al., 2009) without any effect on the quality of the crop (Day et al., 1981; Zavadil, 2009).

Environmental effects of grey-water on soils are positive and negative depending on how it is managed. For instance, in rural areas grey-water is disposed of directly on the ground near to dwelling places and often results in various health and environmental hazards such as pollution of wetlands, contamination of underground water supply and infiltration of salts, oils and grease into the soil (Van Vuuren, 2007). However, the organic matter contained in grey-water could contribute to the total loading of organic matter in the soil over time and therefore support crop production (Rusan et al., 2007). A search of the academic research literature fails to identify any studies that have determined the negative impact on soils due to irrigation of edible crops with grey-water, barring a few in which researchers discovered that irrigating with untreated wastewater elevated

the pH level by 2 to 3 units and resulted in the accumulation of heavy metals in soils to levels that were above the maximum permissible limits (MPL) according to Irish standards (Qishlaqi et al., 2008). Also, Pinto et al. (2010) discovered that electrical conductivity (EC) and soil pH were significantly elevated due to grey-water irrigation compared to potable and diluted grey-water (1:1) treatments. However, in the study by Rusan et al. (2007), although the accumulation of pollutants was due to grey-water irrigation, soil pH was not affected. Despite these reports on the accumulation of heavy metals and elevation of pH and EC, some findings suggest that it does not pose any risks to the health of soils (Faruqui and Al-Jayyousi, 2002; Pinto et al., 2010). Whereas, Sharville and co-workers (2012) investigated the effect of grey-water irrigation over the long term (more than 5 years) on landscapes, and observed accumulation of salts in soils which posed a risk to leach down to the water table. However, Sharville and co-workers suggested that with a sound grey-water management system, the contamination of the water table could be minimised.

For these reasons, samples of household grey-water, diluted grey-water (1:1 ratio), and potable water from a tap stand were tested. Analyses were also conducted on soils irrigated with these water treatments to determine the concentration of nutrients and heavy metals in order to establish if the use of such irrigation water might result in the accumulation of impurities in the soil.

METHODOLOGY

Experimental site

The Umtata Dam Research Station (31°30'04"S 28°42'24.5"E) north-west of the town Umtata, Eastern Cape Province, was

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Figure 1
Location of the experimental site
(Source: Google earth)

chosen as the study site (Fig. 1). This site receives between 800 and 950 mm/a of rainfall, which falls mainly in the summer months, between October and March (Prinsloo and Schoonbee, 1984). The site is ideal for conducting a field experiment of this nature because it is managed by the Eastern Cape Provincial Department of Rural Development and Agrarian Reform, and offers a secure environment in which to conduct the experiment. In addition, low wage earners employed by the Department, being unable to afford rentals in Umtata, were allowed to build shack dwellings immediately outside the yard of the premises. Together these houses resemble a small informal settlement reflecting conditions typical of underserviced informal housing conditions in South Africa. Two tap-water stands support these 12 shack dwellings, and there are no toilet facilities. In this instance, the grey-water from this small settlement is generated mainly from the washing of clothes and bodies, and from the washing of crockery and cutlery. Waste material is collected and burnt occasionally, while for most wastewater is disposed of on the ground close to the dwellings, again typical of many informal settlements in South Africa. At the outset soil tests conducted on the soil profile classified the soils as Hutton deep red soils that are well drained and had developed from basic doleritic parent material (Soil Classification Working Group, 1991).

The study used a completely randomised design (CRD) in the layout of 3 field plots, with each of the fields receiving separate treatments, namely, potable water from a municipal tap stand, grey-water diluted with potable water (1:1), and undiluted grey-water collected from the informally constructed houses.

Grey-water collection

Grey-water samples were collected from the shack dwellings for 3 consecutive days before trial initiation. These samples were analysed for pH and EC using a calibrated HANNA Combo pH and EC, (model HI 98129) portable meter. These tests were

conducted to provide an indication of the quality of grey-water as well as the volume required for daily irrigation. The mean values for pH and EC, although these were inconsistent, were below 7 pH and ≤ 25 mS/m, respectively, but at an acceptable level for irrigation purposes (Bauder et al., 2014).

A total of number of 24 water samples per treatment (6 samples per season) were taken from the collection containers situated amongst the informal dwellings. In each plot a combination of a root and leafy crops were planted in each season (4 seasons in total) in the following order: cabbage and onion, spinach and beetroot, lettuce and beetroot, cabbage and onions. Data on yield and aesthetic value, chemical content and bacteria content (*Enterococcus*, *Streptococcus* and *E. coli*) of these vegetable crops were recorded but did not form part of the scope of the investigation reported on here.

Soil sampling

After each season, a soil auger was used to collect soil samples directly from the plots that were irrigated with potable water, diluted grey-water (grey-water diluted with potable water on 1:1 ratio) and grey-water with no dilution. A total of 32 soil samples per treatment (8 samples per season) were taken at different soil depths within each plot, namely 0–10 cm, 10–30 cm, 30–60 cm and 60–90 cm.

Afterwards, both water and soil samples were analysed in a laboratory for presence of Na, Fe, K, Mn, Cu, Zn, Ca, P, Mg, Cd, Pb, Ni, Cr, EC and pH (KCl). Samples were analysed at the Döhne Laboratory in Stutterheim. Döhne Laboratory is a member of AgriLasa (Agricultural Laboratory Association of Southern Africa) and used the following techniques: (i) flame atomic absorption spectrometry to determine cations (Ca, Mg, K, Na, Cu, Mn, Fe and Zn) and (ii) graphite furnace, for analysis of heavy metals (Cd, Pb, Cr and Ni) (Thomas 1982). The differences in water and soil parameters were compared by single-factor analysis of variance (ANOVA) with $p = 0.05$ and using GenStat 12th edition (Payne et al., 2009).

TABLE 1 Physical properties of the soil before planting, a collective sample from all plots						
Soil properties	Physical properties					
	Classification	Texture (%)				
		Sand	Clay	Silt	Infiltration rate (mm/h)	
Collective sample	Sandy loam	76.6	14.4	9	7	

TABLE 2 Chemical analysis of water samples taken over the period of a year, (n = 24)								
Treatments	pH	EC (mS/m)	CaCO ₃	Cl ⁻	HCO ₃ ⁻	Mg ⁺	Na ⁺	SAR
			(mg/l)					
PW*	6.2 a ^x	6.0 c	39.5a	14.0 ab	43.0 c	2.0 a	1.0 b	0.0 c
DGW*	6.4 a	33.0 b	1.0 bc	7.0 b	140.0 b	1.0 a	9.5 ab	1.8 ab
GW*	6.5 a	50.0 a	2.5 b	16.0 a	223.0 a	1.5 a	15.0 a	2.5 a
LSD (0.05)	NS	3.513	12.30	7.026	27.88	NS	13.72	1.45
								36.04

^xNumbers in columns with different letters are significantly different (p≤0.05, LSD).

* PW – potable water; DGW – diluted grey-water; GW – grey-water.

RESULTS AND DISCUSSION

Water quality analysis

There were no observed differences in pH and Mg in each of the treatments for potable and grey-water (Table 2). However, there were significantly higher values for Cl⁻, EC, HCO₃⁻, Na⁺, sodium adsorption ratio (SAR) and total dissolved solids (TDS) when grey-water was used in the experiment (p>0.05), and significantly higher CaCO₃ hardness of the potable water. As expected, all concentrations were lower when diluted grey-water was tested compared to the concentrated grey-water solution.

From these observations, grey-water contained elevated concentrations of Na⁺ (15 mg/l) and Cl⁻ (16 mg/l) ions although this was below the limit of 100 mg/l given in the South African Water Quality Guidelines (Fatoki et al., 2002). Grey-water at pH 6.7 falls within an accepted range of pH (6.5–8.4) indicating the likelihood that this water is suitable for irrigation (Bauder et al., 2014). However, the elevated EC levels could increase the risk to human health, plants or soil as the observed EC was within a range of 40 to 200 mS/m (Rodda et al., 2011). An average of 50 mS/m EC was observed when grey-water was used and was recorded in the upper quartile of 70 mS/m at least once for the six samples tested.

It was surprising that although grey-water caused significantly higher bicarbonate (HCO₃⁻) concentrations, which in turn could have caused a rise in pH, there were no significant differences in grey-water relative to other treatments with respect to the observed pH. HCO₃⁻ raises the pH by causing Ca⁺ and Mg⁺ ions to form insoluble minerals leaving Na⁺ ion uncompetitive in the solution (Bauder et al., 2014). The presence of high-acid food, for example, tomatoes and cooking oil, in grey-water could be the cause of lower average pH of 6.7 (Al-Jayyousi, 2004). Tomatoes contain about 9% citric acid, 4% malic acid and 2% dicarboxylic acid (Petro-Turza, 1987), and cooking oil contains fatty acids (Noureddini et al., 1992).

It is interesting to note that Ca⁺ in potable water was significantly higher and Mg⁺ was not significantly different than in the other water treatments, which, in combination with Na⁺, was useful in calculating the SAR (sodium absorption ratio). Grey-water had a significantly higher SAR value of 2.5, but,

TABLE 3 Average heavy metal content within water samples						
Treatments	Cd	Cr	Cu	Ni	Pb	Zn
	(mg/l)					
PW	0.283 a ^x	2.2 a	8.2 a	6.6 a	1.0 a	0.085 a
DGW	0.046 bc	25.2 a	16.0 a	25.6 a	16.0 a	0.000 a
GW	0.062 b	42.2 a	18.8 a	16.4 a	46.0 a	0.000 a
LSD	0.078	N.S	N.S	N.S	N.S	N.S

^xNumbers in columns with different letters are significantly different (p≤0.05, LSD).

according to Gross et al. (2005), this appears not to be destructive to the environment and soil properties in the long term. Salinity of diluted grey-water in this study was lower than that of grey-water. Al-Jayyousi (2004) discovered that diluting grey-water with rainwater reduces salinity caused by salts contained in food particles in grey-water. Therefore dilution of grey-water with potable water in this study helped to minimise the salinity content.

There were no significant differences in heavy metals in the water samples except in the case of Cd (Table 3). Heavy metals were much lower in concentration than that found by Surendran and Wheately (1998) in grey-water generated from bath/shower activities. However, Pb, Cd, Cu and Zn were not detected in the aforementioned study from washbasin water. Since the houses where the grey-water was collected were unserviced, most grey-water was generated from the use of washbasins and kitchens, and hence Zn was also not detected in the current study. Water from washbasins was the least polluted compared to dishwasher and washing machine water (Friedler, 2004). Zn (0.085 mg/l) levels in potable water were lower than the target water quality range (TWQR) of 1 mg/l permitted by South African guidelines for irrigation (DWAF, 1996). However, Pb (46 mg/l) and Cu (18.8 mg/l) observed in the grey-water used in this study exceeded the permitted TWQR of 0.2 mg/l (DWAF, 1996).

The overall quality of grey-water used in this study is comparable with that of the tap water used by Jackson et al. (2006) in eThekwin Municipality in the KwaZulu-Natal Province and even better than that of a tap stand in Nkonkobe Municipality in the Eastern Cape Province (Lehloesa and Muyima, 2000).

TABLE 4
Chemical analysis of soils exposed to three different treatments: PW – potable water; DGW – diluted grey-water; GW – grey-water; LSD – least significant difference (n = 32).

Treatments	pH	Al	P	K	Mg	Na	Ca	Total cations
	(mg/kg)							
0–10 cm								
PW	5.20 a ^x	0.167 a	81 a	348.3 a	2265 a	72.6 a	365a	21.5 a
DGW	5.20 a	0.217 a	68 a	255.7 b	1283 bc	95.9 a	195 c	12.4 bc
GW	5.73 a	0.183 a	47 a	236.7 bc	1434 b	212.2 a	248 bc	13.8 b
LSD	N.S	N.S	N.S	58.04	744.1	N.S	123.9	6.50
10–30 cm								
PW	5.33 a	0.217 a	34c	202.7 a	1256 b	73.4 a	268 a	12.4 a
DGW	5.10 a	0.183 a	81a	243.7 a	1608 a	118.4 a	239 a	15.2 a
GW	5.67 a	0.20 a0	49b	205.7 a	1577 ab	328.2 a	270 a	15.0 a
LSD	N.S	N.S	1.15	N.S	250.4	N.S	N.S	N.S
30–60 cm								
PW	5.17 a	0.150 a	43.0 a	155.0 a	1925 a	66.3 a	371 a	18.2 a
DGW	5.77 a	0.183 a	19.7 a	91.0 a	1241 a	125.7 a	180 a	11.5 a
GW	5.80 a	0.150 a	23.3 a	121.3 a	1521 a	245.2 a	261 a	14.3 a
LSD	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S
60–90 cm								
PW	5.53 a	0.12 a	35.0 b	98 a	2396 a	68.3 a	455 a	22.3 a
DGW	5.33 a	0.12 a	47.7 a	150 a	1794 b	128.5 a	350 b	17.0 b
GW	5.70 a	0.17 a	13.7 c	78 a	1428 bc	174.9 a	223 bc	13.2 bc
LSD	N.S	N.S	12.44	N.S	423.2	N.S	167.2	3.98

^xNumbers in columns with different letters are significantly different (p≤0.05, LSD).

In some cases, water from a tap stand in a rural area might not be fit to irrigate food crops due to salinity and high EC (Lehloesa and Muyima, 2000; Fatoki et al., 2003). For this reason, dilution of grey-water (with high total soluble salts) with potable water at a 1:1 ratio, as in the study by Day et al. (1981), lowered the salt content and improved water quality for irrigation purposes.

Soil chemistry

At a soil depth of 0 to 10 cm, there was no significant difference in pH, Al and P between treatments, whereas K, Mg, Ca and total cations were significantly higher in the case of the plots irrigated with potable water (Table 4). At 10 to 30 cm soil depth, only P and Mg were significantly higher due to diluted grey-water irrigation whereas at depths between 30 and 60 cm there was no significant difference between treatments for all elements. At soil depths of 60 to 90 cm, P once again was significantly higher as a result of the diluted grey-water treatment, and Mg, Ca, and total cations were significantly elevated as a result of potable water treatment. There appeared to be no leaching of any of the measured elements from the topsoil to the lower subsoil during experiments. This was confirmed from measurement of similar pH values and chemical concentrations being contained within a similar range throughout the profile and across treatments.

Due to slight acidity of the grey-water used in the study, there were no significant differences observed in pH throughout the soil profile of 0 to 90 cm, whereas in some other studies an increase of 1 to 2 units has been observed (Qishlaqi et al., 2008). Weil-Shafran and co-workers (2006) discovered that the pH of soils irrigated with grey-water was significantly lower than that of soils irrigated with potable water, and suggested

that this change was probably due to enhanced bacterial activities such as respiration.

Although Na showed no significant differences between various levels within the soil profile, it was found to be almost 3 times higher for grey-water compared to soils irrigated with potable water. High Na content in the soil had the effect of disturbing the soil structure through swelling and dispersion phenomena (Halliwell et al., 2001). Bauder et al. (2014) explained this phenomenon by suggesting that Ca flocculate and Na disperses soil particles resulting in soil crusting which in turn adversely affects infiltration and permeability of water. However, in this study, soil structure after the experiment was not determined.

There was no significant difference in all heavy metal concentrations between treatments and from 0 to 90 cm soil depth, with the exception of Cu at 30 to 60 cm and Pb at 60 to 90 cm soil depth (Table 5). In a similar study by Al-Zu'bi and Al-Mohamandi (2008) there was no accumulation of heavy metals in the soil due to grey-water irrigation. However, Cr, although the difference was not statistically significant, was slightly elevated in the soil irrigated with grey-water, with values ranging from 28.34 to 31.66 mg/kg. Kabata-Pendias and Pendias (1992) found that the range for Cr in soil irrigated with grey-water was between 75 and 100 mg/kg, while the prescribed threshold for soil Cr in South Africa is 150 mg/kg (Herselman and Steyn, 2001). The highest Cd content obtained from diluted grey-water irrigated soils was 0.06 mg/kg, far less than 3–8 mg/kg which is the Cd critical soil total concentration (Kabata-Pendias and Pendias, 1992). However, the Dutch guidelines for Cd range from 0.5 to 10 mg/kg (Mc Laughlin et al., 2000), whereas in South Africa the threshold is 2 mg/kg (Herselman and Steyn, 2001). In the current study, it was observed that the Ni level was 22.6 mg/kg in soils irrigated with grey-water,

TABLE 5
The effect of irrigation water on soil heavy metal status (n=32): PW – potable water; DGW – diluted grey-water; GW – grey-water; LSD – least significant difference.

Treatments	Zn	Cu	Cd	Pb	Ni	Cr
(mg/kg)						
0–10 cm						
PW	0.767 ax	22.83 a	0.051 a	5.56 a	10.16 a	30.98 a
DGW	0.933 a	21.84 a	0.032 a	5.28 a	4.91 a	28.34 a
GW	1.133 a	22.25 a	0.028 a	5.67 a	14.01 a	31.34 a
LSD	N.S	N.S	N.S	N.S	N.S	N.S
10–30 cm						
PW	0.63	23.09 a	0.047 a	5.50 a	7.53 a	31.66 a
DGW	1.03	21.99 a	0.034 a	5.62 a	8.90 a	29.76 a
GW	1.23	22.31 a	0.034 a	5.59 a	13.46 a	29.70 a
LSD	N.S	N.S	N.S	N.S	N.S	N.S
30–60 cm						
PW	0.77 a	23.11 a	0.053 a	5.87 a	14.95 a	30.34 a
DGW	1.07 a	21.04 c	0.066 a	6.09 a	4.03 a	28.90 a
GW	0.57 a	22.43 ab	0.006 a	5.58 a	22.34 a	31.41 a
LSD	N.S	1.199	N.S	N.S	N.S	N.S
60–90 cm						
PW	0.100 a	21.91 a	0.010 a	5.82 a	9.61 a	29.12 a
DGW	0.267 a	21.63 a	0.037 a	5.05 bc	5.43 a	28.54 a
GW	0.133 a	21.41 a	0.008 a	5.09 b	11.98 a	28.38 a
LSD	N.S	N.S	N.S	0.277	N.S	N.S

xNumbers in columns with different letters are significantly different ($p \leq 0.05$, LSD).

which was the highest concentration obtained amongst the treatments. Compared to other elements, Ni content was far less than the South African threshold of 80 mg/kg (Herselman and Steyn, 2001).

As much as grey-water might contribute to soil pollution by adding pollutants such as heavy metals, some impurities can also be added to the soil through application of inorganic fertilisers (Schroeder and Ballassa, 1963; Carnelo et al., 1997), agrochemicals such as pesticides, fungicides and herbicides (Gimeno-Garcia et al., 1996; Nicholson et al., 2003) and corrosion of metal objects such as water pipes, taps and roof materials (Boller, 1997; Sörme and Lagerkvist, 2002).

The analysis of soil profiles suggests that grey-water irrigation contributes minimally to heavy metal concentration build-up in the soil and therefore grey-water does not solely pollute the soil or pose an environmental risk to the soil within the time frame of a year.

CONCLUSIONS

The study concludes that the concentrations of nutrients and heavy metals found in the grey-water samples were significantly lower compared to the World Health Organization health guidelines for the safe use of grey-water (WHO, 2006) and were within the target water quality range (TWQR) permitted by South African guidelines for irrigation (DWAF, 1996). However, it is strongly recommended that grey-water must be diluted in order to lower the salt content and to improve the irrigation water quality so as to avoid long-term risks to the soil and the environment. Furthermore, it is recommended that grey-water and potable water dilution rates should be studied further. This study did not aim to determine optimal dilution rates other than the 1:1 ratio used.

In this study, which was conducted over a relatively short-term period, there was no accumulation of toxins or pollutants that could contaminate the underground water since pH values and all other chemical elements were consistent throughout the soil profiles. Besides the foregoing, pollutants in the soil were found to be within the acceptable thresholds for South African soils (Herselman and Steyn, 2001). The study findings conclude that the use of grey-water for irrigation probably does not pose any environmental risk to soils in the short term.

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