The use and disposal of greywater in the non-sewered areas of South Africa: Part 1 – Quantifying the greywater generated and assessing its quality

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Abstract

The potentially negative impacts from greywater disposal are felt most strongly in those areas where water supply services and on-site sanitation have been implemented, but little or no consideration has been given to the planning for and management of greywater. The main aim of this research was to quantify the greywater problem in these areas and develop options for the management thereof, both in terms of reducing health and environmental risks by eliminating inappropriate disposal of greywater, as well as providing benefits to some through controlled reuse. The determination of typical volumes of greywater generated in the non-sewered areas of South Africa and the likely impacts of changes in service levels with respect to water supply has been calculated by using average water consumption data determined from on-site surveys and settlement data from Census 2001 and its updates. The results of greywater quality sampling from site surveys indicate high levels of pollution emanating particularly from the more densely populated informal settlements, and suggest that greywater from non-sewered areas is generally unfit for use except under controlled conditions.

Keywords: greywater quantities, greywater generation, greywater quality, non-sewered areas

Introduction

There is currently a strong drive from the South African government to attain a basic water and sanitation service throughout the country. The targets for the provision of basic water services are set out in the 'Strategic Framework for Water Services' (DWAF, 2003) which outlines Government's commitment to eliminating the backlogs and to progressively improving the levels of service over time. In the short term, the government is hoping that everyone will at least have access to a basic water supply – defined as 25 ℓ of potable water *per capita* per day (ℓ/cap·d) within a 200 m cartage distance – by 2008, and basic sanitation – defined as on-site dry latrines (VIPs or similar) – by 2010. To meet these requirements, the connection of low-income settlements to municipal water sources has subsequently occurred on a massive scale, frequently without giving adequate attention to greywater management in those areas that are non-sewered.

Recent estimates show that there are approximately 20 m. people in South Africa without access to on-site waterborne sanitation (Statistics South Africa, 2005). In the absence of suitable conveyance systems, greywater – here defined as wastewater that is produced from household processes (e.g. washing dishes, laundry and bathing) without input from latrines (Ludwig, 1997) – is generally disposed of onto the ground outside the dwellings. The resulting total pollution load, particularly from the more densely populated informal settlements, has the potential to create a host of environmental and health impacts.

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The association between poor sanitation and ill health is well-known; for example the World Health Organisation (WHO, 1996) estimates that diarrhoeal diseases are responsible for over a quarter of the deaths of children in the world, and that 80% of these deaths are as a result of a lack of adequate water and sanitation (Esrey, 1998). In South Africa, recent research has shown that 43 000 people, mainly children under the age of five years, die from diarrhoeal diseases each year (Mara, 2001). If water services are improved without addressing the management of greywater, environmental and health impacts are likely to increase disproportionately.

In response to this, the Water Research Commission of South Africa (WRC) invited the University of Cape Town to conduct a two-year investigation into the use and disposal of greywater in the non-sewered areas of South Africa. Non-sewered areas were accepted as those areas without on-site waterborne sanitation, whilst waterborne sanitation was taken to include all methods of sewage treatment from flush toilets, including septic tanks. Settlements with dysfunctional or inadequate sewerage systems (particularly communal toilet facilities) were also included in the definition of non-sewered areas. The main aim of this research was to quantify the greywater problem and develop options for the management thereof, both in terms of reducing health and environmental risks by eliminating inappropriate disposal of greywater, as well as providing benefits to some settlements through controlled reuse. This paper, the first in a series of two on the subject, seeks to shed some light on the quantity and quality of greywater generated in the non-sewered areas of South Africa.

Methodology

On-site surveys of selected settlements in six of the nine provinces of South Africa (39 sites in total) were conducted over a period of approximately one year through the use of standardised questionnaires. These questionnaires were piloted at two survey sites in the Western Cape before being used for the remainder of the survey, and included specific questions on:

- General household information – e.g. house type, income, occupation, number of people in household.
- Available services, water use habits – sanitation type, distance to water source, water use, detergent use, etc.
- Greywater management – disposal methods, opinions on greywater use, etc.
- General site characteristics – e.g. existing greywater management systems, soil type, topography, environmental concerns.

Cultural practices pertinent to water use and management were documented to determine whether they hindered or promoted the adoption of greywater recycling and how they impacted on greywater management as a whole. The volumes of greywater generated were calculated from the amount of water consumed per household. In the absence of any formal metering, the figures for water consumption were based on estimates given by the occupants themselves (usually determined by the number of buckets of water collected during each day). General observations were also made of the physical surroundings and climate as well as any other environmental considerations related to the settlement.

Limited water quality sampling of typical greywater and the associated source water was undertaken so as to get a general understanding of the overall quality of greywater emanating from non-sewered areas, particularly in respect of its nutrient loading and oxygen demand. In each settlement, from one to five greywater samples and one to two potable water samples (typically from the most-used tap-stands in the vicinity of the greywater samples, failing which, local boreholes, stored water or river water) were tested – mainly through the use of field test kits. The field-test kits were used to measure pH, electrical conductivity (EC), total phosphorus (as P), dissolved oxygen (DO) and ammonia nitrogen (NH_3). Control samples were also collected at most sites for more accurate analysis in a registered laboratory, and in some instances, to test for selected parameters that could not be analysed in the field, such as chemical oxygen demand (COD), oil and grease, sodium (Na), boron (B) and *E. coli*. These variables are all commonly used as water quality indicators (Sanders et al., 1987; DWAF, 1998), with the possible exception of boron. Boron, found in soaps and detergents, is an essential macronutrient for plants, but different species require different levels for optimum growth, and in some plants there is only a narrow margin between deficiency and toxicity (Murphy, 2006). Levels of boron as low as 0.3 mg/ℓ can be toxic to sensitive plants such as citrus, fruit trees and grapes (DWAF, 1996).

It was critically important that the settlements surveyed in this project were representative of the different types of settlements to be found in the non-sewered areas of South Africa. What made this particularly difficult to achieve was the fact that there are a large number of these settlements spread over a vast geographical area, and there were only resources to survey a limited number of them. Site selection started in the Western Cape Province and was an evolutionary process that developed over time, culminating in a procedure for site selection that was used for the remainder of the country. A combination of four different approaches was used to select suitable settlements for the study:

- Census 2001 data (Statistics South Africa, 2001) was used to draw up lists of the non-sewered settlements as at the time of the census, categorised by province, district, race and type of water supply. This was used as a guide to potential representative settlements.
- 1:50 000 topographical maps from the Chief Directorate: Surveys and Mapping (Department of Land Affairs) were used to identify settlements in areas where there were specific environmental concerns, whilst the Department of Water Affairs and Forestry (DWAF) geohydrological maps depicting groundwater conditions on a regional basis (1:500 000 scale) were used to highlight areas with known aquifers. It was not possible to pinpoint specific groundwater information to the survey sites that were selected, but any use of groundwater as a supply source was noted during the interview process.
- Discussions were held wherever possible with the relevant local authorities (usually the housing or planning departments) to determine the suitability of the various settlements within their area of jurisdiction, including the current status of the water supply and sanitation services.
- Informal discussions with local residents (at taxi-ranks for instance) were used in some instances to guide the final choice of settlement and obtain first-hand knowledge of living conditions within them.

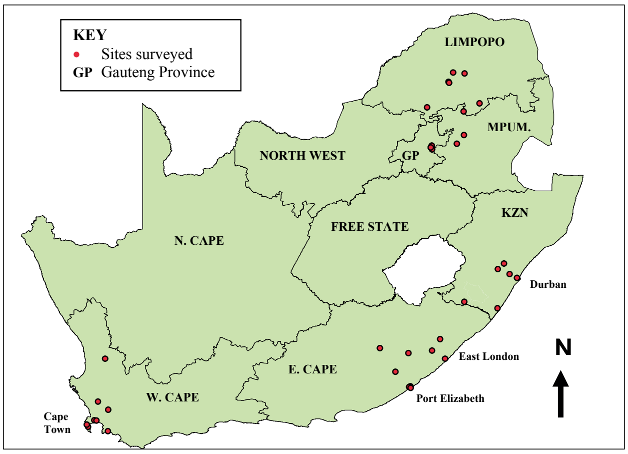

Figure 1
Location of settlements chosen for on-site surveys

In the end, the research team visited 39 settlements in 6 of the 9 provinces of South Africa, which collectively represented the range of problems associated with greywater disposal in different types of non-sewered settlements (Fig. 1).

Quantity of greywater generated in the non-sewered areas of South Africa

One of the principal objectives of this study was to quantify the greywater generated in the non-sewered areas of South Africa. The generation of greywater is directly related to the consumption of water in a household and is dependent on a number of factors including the level of service provision, tolerance of residents to pollution and an awareness of health and environmental risks. It is assumed that greywater accounts for virtually all water use in non-sewered areas except for that which is used for drinking purposes, that which is used consumptively in cooking, and water that remains on surfaces of washed articles.

The estimated household water use determined in the site surveys throughout South Africa was found to vary from 20 to

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200 litres per dwelling unit per day (ℓ/du·d), with an average daily consumption of 104 ℓ/du·d. This, however, does not reflect the total water delivered to the settlements as leaks and under-reporting are not included. Only 6 of the 39 settlements visited had piped water in the yards (on-site water) and from these sites it appeared that there was very little difference between the average household water consumption in houses with on-site supply (117 ℓ/du·d) compared with those who had to walk to fetch water, i.e. off-site supply (102 ℓ/du·d). The water consumption figures from the site surveys indicated a large range of values however, and the sample size was not really large enough to be able to get a real understanding of the differences in consumption between on- and off-site water. The literature suggests that the consumption in low-income households with an on-site water supply could be at least twice that of those with off-site water (Graham, 2003). This would amount to some 200 ℓ/d, roughly equivalent to the current free basic water rate of 6 kℓ per household per month. One of the most extensive areas currently being serviced with on-site water supply and dry sanitation is to be found in the peri-urban areas of eThekwini Municipality (KwaZulu-Natal). Here many low-income households are being supplied with water by way of 200 ℓ on-site tanks that are filled on a daily basis – effectively limiting the consumption to 200 ℓ/du·d. Thus, for the purpose of estimating the total quantity of greywater generated in the non-sewered areas of South Africa, the decision was made to adopt the rounded figures of 200 ℓ/du·d and 100 ℓ/du·d for the average water consumption from on- and off-site supplies respectively.

It was not possible during this research to accurately measure the volumes of greywater being produced in the settlements visited owing to the fact that the time spent conducting surveys at particular settlements was usually limited to one day or less. In the absence of actual measurements of greywater production, the only feasible way for the researchers to determine volumes of greywater in non-sewered areas was to apply a return factor to the amount of water consumed per household. The range of figures for greywater return factors varies widely in the literature, with figures ranging between 65% and 87%. In the absence of definitive measurements of greywater generation, the decision was taken in this study to adopt an average greywater return factor of 75%. This figure was then applied to the estimated average water consumption figures in each settlement to give estimated quantities of greywater produced there. In order to quantify the total amounts of greywater generated throughout South Africa, modified population estimates from Census 2001, with provincial splits for on- and off-site use, were combined with the assumed average water consumption figures for both water use categories.

The average water consumption figures and greywater return factors adopted compare well with the figures available in literature. In a previous study on greywater by Alcock (2002) it was noted that water consumption in low-income households without waterborne sanitation is markedly less than in Western-style households and is primarily dependent on the availability of a tap-stand to the house. Water consumption for people in households with a tap-stand in the yard was reported as being of the order of 30 to 80 ℓ/cap·d with multiple tap households using substantially more water than those with access to only one tap. Where water has to be carried from an external source (greater than 250 m to the source), a mean consumption of 9 to 50 ℓ/cap·d could be expected. These figures correspond with Graham's (2003) observations that locating a water supply point on the property, i.e. in-house or yard tap could increase consumption by as much as two to three times compared to having to walk to fetch water.

Alcock (2002) estimated that the available greywater generated per person on site could be of the order of 25 to 75 ℓ/d. Elmitwalli et al. (2003) suggested that greywater represents 65 to 75% of domestic wastewater, and Eriksson et al. (2002) estimated that the total greywater fraction accounts for approximately 75%. One of the few SA studies to have conducted actual measurements of greywater production in low-income settlements was the work done by Stephenson et al. (2006) in Kwamathukuza, KwaZulu-Natal. Seven households were provided with 200 ℓ drums for the disposal of their greywater so that daily volumes of greywater produced could be measured. The average water consumption from communal tap-stands in Kwamathukuza was found to be 153 ℓ/du·d (29 ℓ/cap·d), with greywater comprising about 87% of this, or 133 ℓ/cap·d (25 ℓ/cap·d).

Table 1 (next page) summarises the figures obtained for water consumption during the on-site surveys throughout SA and also provides estimates for the volumes of greywater produced in these settlements, based on the adopted greywater return factor of 75%.

Determination of total quantities of greywater

Census 2001 data were used to calculate the total quantities of greywater being generated by settlements without on-site waterborne sanitation in SA, but had to be modified to take into account the changes in service status, population numbers and names of settlements that have occurred, particularly in the major urban areas, since 2001. In order to do this, certain categories in Census 2001 were compared with later studies; the Non-Financial Census of Municipalities, 2002; 2003; 2004 (Statistics SA, 2002; 2003; 2004) and the General Household Survey, GHS 2004 (Statistics SA, 2005) and the percentage differences in numbers of non-sewered households in each province were then applied to the Census 2001 data.

Table 2 shows that the overall total number of households without on-site waterborne sanitation in SA has decreased by 3% between Census 2001 and the latest census updates released in the Non-Financial Census 2004 (Statistics SA, 2004) and the 2004 General Household Survey (Statistics SA, 2005). These reports estimate that approximately 20 m. people in SA live in non-sewered households, i.e. no sanitation or basic sanitation facilities. The latest Department of Water Affairs and Forestry Annual Report, 2004/2005 (DWAF, 2005) reports that a further 1.3 m. people were served with basic sanitation facilities during the year under review, so that the reported percentage access to some form of sanitation services has increased to 67% of the population.

The reduction of 3% cannot be applied across all provinces, however, as there have been large differences in the numbers of people moving between provinces, as well as the levels of service provision in the different provinces. This can be seen in Table 3 which shows the 2004 General Household Survey (Statistics SA, 2005) figures for non-sewered households in each province (with the percentage differences) and the corresponding calculated greywater volumes.

The large decrease in numbers of non-sewered households in the Western Cape and Gauteng Provinces is indicative of the strong drive towards providing waterborne sanitation for as many households as possible, even though there have been large influxes of people into these two provinces. KwaZulu-Natal on the other hand, has experienced an increase in the numbers of non-sewered households owing to the fact that whilst they have also experienced positive net migration into the province, dry sanitation options such as urine diversion toilets are being

TABLE 1 Water consumption and greywater generation figures from on-site surveys					
Name of settlement	**Province[1]**	**On- or off-site water**	**Average per capita water use (ℓ/c·d)**	**Average house-hold water use (ℓ/du·d)**	**Average house-hold greywater produced[2] (ℓ/du·d)**
Clanwilliam	WP	Off	25	65	50
Redhill	WP	Off	18	75	60
Fairyland	WP	Off	13	75	55
Kleinmond	WP	Off	19	105	80
Sweet Home Farm	WP	Off	13	70	55
Masiphumelele	WP	Off	18	100	75
Khayelitsha RR	WP	Off	15	55	40
Lingelethu	WP	Off	11	55	40
Silvertown	EC	Off	22	70	55
Bongweni	EC	Off	26	160	120
Orange Grove	EC	Off	27	60	45
Phakamisa Park	EC	Off	13	80	60
New Payne	EC	On	17	80	60
Mputhi	EC	Off	11	75	55
Mthento	EC	Off	11	150	115
Mpathi	EC	Off	25	100	75
Emahobeni	EC	Off	12	45	35
Zolani	KZN	Off	27	85	65
Boboyi	KZN	Off	15	110	85
KwaShange	KZN	On	16	95	75
Emambedwini	KZN	On	11	80	60
Emaqedini	KZN	On	17	100	75
Cato Manor	KZN	Off	28	95	70
Leeufontein	LIM	Off	38	150	115
Manapyane	LIM	Off	20	150	115
Jane Furse	LIM	On	24	180	135
Doornkraal	LIM	Off	54	135	100
Mothlakaneng	LIM	Off	41	140	105
Seshego Zone 5	LIM	Off	27	115	85
New Pietersburg	LIM	Off	63	130	100
Mahwelereng	LIM	Off	34	145	110
Mashati	LIM	On	30	165	125
Winnie Park	LIM	Off	27	140	105
Tlhalampye	LIM	Off	27	130	100
Masakhane	MP	Off	24	115	85
Doornkop	MP	Off	22	120	90
Mayfield Ext.	GP	Off	21	95	70
Freedom Square	GP	Off	42	110	80
Barcelona	GP	Off	20	95	70
Average for sites assessed			23	104	80
Average for off-site water			24	102	78
Average for on-site water			**19**	**117**	**88**

Notes: 1. WC – Western Cape, MP – Mpumalanga, LIM – Limpopo, EC – Eastern Cape, KZN – KwaZulu-Natal, GP - Gauteng
2. Based on the assumption that an average of 75% of the water consumed ends up as greywater

widely used in preference to water-borne sewage systems.

The estimates for total volumes of greywater should be considered with caution, however, as they may not include areas that have been nominally provided with services (and are therefore considered to be sewered in the census data) but where the services are dysfunctional. This was found to be the case in many of the areas visited during the on-site surveys and these settlements were therefore included in the study as they function essentially as non-sewered. The figures also assume from Census 2001 data that approximately 25% of the total non-sewered areas in South Africa have access to an on-site water supply and that they consume approximately twice the average amount of water than those that use off-site water, i.e. 200 ℓ/du·d. Finally, anecdotal evidence suggests the data could be considerably in error in some provinces, e.g. the Western Cape.

With all of the various assumptions described above, the total volume of greywater that is generated on a daily basis in the non-sewered areas of South Africa (based on an average 75% return factor) is estimated at just under 490 000 m^3/d. This amounts to approximately 180 x 10^6 m^3/yr – equivalent in volume to a medium-sized impoundment such as Voëlvlei Dam near Cape Town, or approximately 50% of the current water demand of that city. The estimated greywater return figure of 75% has little bearing on this outcome. The corresponding figures for total greywater volumes in non-sewered areas using the upper (87%) and lower (65%) limits for the return factor, as per the literature, would be approximately 570 000 m^3/d and 430 000 m^3/d respectively, which are not significantly different from the initial estimate. This illustrates the relatively limited potential for the use of greywater from non-sewered areas as an alternative water resource at a country-wide scale, and suggests that potential benefits from greywater use would only be from irrigation at the household level to supplement nutritional requirements. On the other hand, these figures also highlight the fact that greywater disposal in densely-settled non-sewered areas is likely to result in significant health and environmental impacts, particularly in urban environments where large volumes of greywater are generated.

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TABLE 2 Comparison of South African Census data						
Criteria	**SA Census 2001**	**Non-financial Census 2002**	**Non-financial Census 2003**	**Non-financial Census 2004**	**GHS 2004**	**Difference 2001 / 2004 (%)**
Population	44 800 000	-	-	-	46 500 000	+3.7
No. of households	11 205 711	11 237 275	12 018 221	12 200 000	12 196 000	+8.1
Households with water-borne sanitation	5 812 998	5 417 000	6 097 717	6 989 571	6 968 000	+16.6
Non-sewered households	5 392 690	5 820 275	5 920 504	5 210 429	5 237 000	-3.0
% non-sewered	48.1%	51.8%	49.3%	42.7%	42.9%	-5.4

Notes: 1. 2005 population figures estimated at 46 900 000; i.e. population growth rate approx. 1% per annum since 2001
2. Total no. households in 2004 was 12 196 000, average household size is 3.8 persons
3. Areas of largest % non-sewered include Limpopo, KZN and Eastern Cape
4. Internal migration patterns show a shift to three main areas: Gauteng, W. Cape and KZN have positive net migration; E. Cape and Limpopo have largest negative net migration

TABLE 3 Total quantities of greywater in the non-sewered areas of South Africa							
Province	**Total no. households Census 2001**	**Non-sewered households Census 2001**	**Non-sewered households GHS 2004**	**Difference 2001 / 2004 (%)**	**On-site water use[1] (m^3/day)**	**Off-site water use[2] (m^3/day)**	**Estimated greywater volumes[3] (m^3/day)**
W. Cape	1 173 303	162 473	85 000	-48	4 250	6 375	7 969
E. Cape	1 512 664	1 016 668	1 151 000	+13	23 020	103 590	94 958
N. Cape	206 844	69 819	64 000	-8	5 760	3 520	6 960
Free State	733 302	393 850	324 000	-18	29 160	17 820	35 235
KwaZulu-Natal	2 086 251	1 219 474	1 303 000	+7	52 120	104 240	117 270
North West	929 000	603 438	545 000	-10	32 700	38 150	53 138
Gauteng	2 651 247	484 533	298 000	-38	17 880	20 860	29 055
Mpumalanga	733 135	452 866	418 000	-8	29 260	27 170	42 323
Limpopo	1 179 965	989 569	1 049 000	+6	62 940	73 430	102 278
SA total	**11 205 711**	**5 392 690**	**5 237 000**	**-3**	**257 090**	**395 155**	**489 184**

Notes: 1. Using provincial splits for on-site water from Census 2001 and assumed water consumption of 200 ℓ/du·d
2. Using provincial splits for off-site water from Census 2001 and assumed water consumption of 100 ℓ/du·d
3. Estimated by applying factor of 75% to total water consumption

Quality of greywater in non-sewered areas

As previously mentioned, limited greywater quality sampling was undertaken so as to quantify any potential risks to human and environmental health associated with greywater use and disposal. The average values for greywater qualities for the settlements surveyed in each province; Western Cape (WC), Mpumalanga (MP), Limpopo (LIM), Eastern Cape (EC), KwaZulu-Natal (KZN) and Gauteng (GP) are summarised in Table 4. Samples were taken of greywater from a variety of washing activities taking place in different settlements as well as from the closest water source (tap-stand, borehole, river) so that water quality could be compared to that of the greywater samples being tested.

In general the results indicate high levels of pollution emanating from the use of household chemicals and detergents and suggest that greywater is generally unfit for use except under controlled conditions. Of interest are the ranges of values obtained for COD and oil and grease which highlight the extent of risks that could arise from the use of this type of greywater, particularly in respect of the resultant impacts on soils and plants. Levels of phosphorus and sodium were also particularly high in certain cases. Whilst the links between greywater use and the polluting effects of detergents were not specifically addressed in this study, it is well known that high levels of sodium (derived from the soluble salts in detergents) in greywater that is used for irrigation can cause reduced crop yields and quality due to sodium uptake through the roots and leaves of sodium-sensitive plants, impaired soil physical conditions (reduced soil permeability) and an increased tendency for hard setting (DWAF, 1996). Further investigation is therefore required into the effect of detergent use on the quality of greywater and how this impacts on the use of the greywater as a resource.

Only limited microbiological sampling was conducted (samples were tested using the membrane filtration method, South African Bureau of Standards, Standard Method, SABS SM221) and accurate counting was not done (organisms were only counted up to 1 800 organisms/100 mℓ). However, the samples generally showed levels of faecal contamination in the greywater samples of above 1 800 organisms/100 mℓ, indicating the potential presence of pathogenic organisms and the fact that, without treatment, the greywater is likely to be a health hazard. Boron analyses were only undertaken on the greywater samples from two of the study sites (KwaShange and Redhill), and one of these samples (Redhill) produced a measurable amount of boron (1.9 mg/ℓ). More sampling needs to be conducted in order to fully understand the impacts of boron in greywater where it is to be used as irrigation water.

The water quality figures are compared to the ranges of values quoted in the available South African literature on low-

TABLE 4
Greywater quality at survey sites

Name of settlement	n	Prov#	Average values for greywater samples							
			COD (mg/ℓ)	DO (mg/ℓ)	pH	NH_3 (mg/ℓ)	TKN (mg/ℓ)	Tot P (mg/ℓ)	Oil & Grease (mg/ℓ)	Cond (mS/m)
Clanwilliam	0	WC	-	-	-	-	-	-	-	-
Redhill	100	WC	1 470	-	7.6	-	20	27	176	155
Lingelethu	4	WC	6 190	-	-	-	-	-	-	-
Fairyland	3	WC	2 320	-	-	-	60	88	30	-
Kleinmond	2	WC	3 510	-	-	-	110	146	29	-
Masiphumelele	3	WC	7 850	-	-	-	130	98	242	-
Khayelitsha RR	5	WC	3 580	3.7	-	-	-	-	-	-
Sweet Home Farm	3	WC	8 490	-	-	-	172	144	307	-
Masakhane*	5	MP	-	-	7.3	3+	-	5+	-	1 040
Doornkop*	3	MP	-	-	9.6	3+	-	5+	-	126
Mashati*	2	LIM	-	-	10.4	3+	-	5+	-	289
Manapyane*	1	LIM	-	-	9.3	3.0	-	5	-	112
Tlhalampye*	2	LIM	-	-	9.3	3+	-	5+	-	461
Leeufontein*	1	LIM	-	-	10.9	-	-	-	-	770
Jane Furse*	1	LIM	-	-	10.3	2.9	-	1.6	-	389
Winnie Park*	1	LIM	-	-	10.1	3+	-	5+	-	234
Seshego Zone 5*	3	LIM	-	-	8.6	3+	-	5+	-	140
Mahwelereng*	2	LIM	-	-	9.1	0.5	-	5+	-	90
Doornkraal*	1	LIM	-	-	9.7	3+	-	5+	-	489
New Pietersburg*	1	LIM	-	-	8.9	3+	-	5+	-	1 530
Mothlakaneng*	2	LIM	-	-	9.4	3+	-	5+	-	196
Mpathi	0	EC	-	-	-	-	-	-	-	-
Mthento	0	EC	-	-	-	-	-	-	-	-
Emahobeni*	2	EC	-	-	7.8	3+	-	2.9	-	381
Mputhi*	2	EC	-	0.2	8.9	2.0	-	1.3	-	783
Phakamisa Park*	2	EC	-	-	8.8	3+	-	1.9	-	514
Bongweni*	1	EC	-	-	7.8	3.0	-	3.5	-	916
New Payne*	1	EC	-	-	7.7	2.6	-	4.5	-	113
Silvertown*	1	EC	-	-	8.0	3+	-	5+	-	189
Orange Grove*	1	EC	-	-	7.6	2.2	-	5+	-	764
KwaShange	8	KZN	-	0.1	9.1	12.5	56	57.4	730	59
Emambedwini	8	KZN	-	0.6	9.9	8.5	39	112.4	1 365	567
Emaqedini	5	KZN	-	0.6	8.7	5.7	7	115.6	397	70
Boboyi	100	KZN	-	0.6	9.5	3.0	20	34.4	1 948	128
Zolani	9	KZN	-	1.2	8.8	3+	45	37.6	1 947	199
Cato Manor	3	KZN	-	0.6	8.8	7.6	164	7.5	108	54
Barcelona	0	GP	-	-	-	-	-	-	-	-
Mayfield Ext.	1	GP	-	0.6	9.8	21.8	43	240.0	1 484	653
Freedom Square	0	GP	-	-	-	-	-	-	-	-
Average			**4 770**	**0.9**	**8.8**	**-**	**72**	**-**	**730**	**366**

Notes: 1. ** indicates sites where analyses were conducted with field test kits only*
2. *+ indicates extent of measurement range for field instrument*
3. *# WC – Western Cape, MP – Mpumalanga, LIM – Limpopo, EC – Eastern Cape, KZN – KwaZulu-Natal, GP – Gauteng*

income settlements as well as in the international literature for greywater from mixed sources in developed countries in Table 5 (Eriksson et al., 2002). The results from this study indicate a large variability and highlight differences in the ranges of quality for certain variables in the greywater from sewered areas in developed countries.

One observation from the site surveys that could explain the high levels of chemicals was that, in the absence of hot water, residents of low-income settlements tended to leave the ubiquitous green detergent bar (example 'Sunlight Soap') in the laundry water for several hours, resulting in large amounts of detergent dissolving in the water. A comparison of the lower and

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TABLE 5
Comparison of greywater quality results

Variable	This study (2006)	Eriksson, et al. (2002)	Källerfelt and Nordberg (2004)	Pollution Research Group (2005)	Stephenson et al. (2006)
pH	3.3 - 10.9	5.0 - 8.7	6.1 - 7.0	5.8 - 6.3	-
Conductivity (mS/m)	28 - 1 763	32 - 2 000	83 - 132	144 - 148	-
PO_4-P	0.7 - 769	0.6 - 68	14.8 - 56.2	11	0.3 - 18.9
COD	32 - 11 451	13 - 549	530 - 3 520	1 135	999 - 1 625
Suspended solids	-	6.4 - 330	69.0 - 1 420	-	265.2 - 1 261
Oil & Grease	8 - 4 650	3.1 - 12	-	-	-
TKN	0.6 - 488.0	2.1 - 31.5	-	24 - 30	-
Ammonia nitrogen	0.2 - 44.7	0.03 - 25.4	-	20	-
Sodium	96 - 1 700	29 - 230	-	-	-

Note: Values are quoted in mg/ℓ if not stated otherwise.

TABLE 6
A comparison of averages for water use and water quality between lower quartile and upper quartile ranges with reference to settlement density

Value	Density (du/ha)	Average water use (ℓ/du·d)	Greywater generation (ℓ/du·d)	NH_3 (mg/ℓ)	TKN (mg/ℓ)	Tot P (mg/ℓ))
Lower quartile: Low settlement density						
Min. value	3	80	225	3	7	2
Max. value	5	180	675	13	56	112
Mean	4	130	412	5	31	27
Upper quartile: High settlement density						
Min. value	25	55	1196	2	43	5
Max. value	162	140	13365	22	172	240
Mean	45	88	3029	9	113	92

upper quartiles for greywater quality from non-sewered settlements sorted by density in dwelling units per hectare (du/ha), indicates that the concentration of sodium and phosphorus is highest in more densely populated settlements (Table 6). It is assumed that this concentration is high because the daily water use in dense settlements is lower on average compared to less dense settlements. The study did not determine why dense settlement dwellers reported a lower volume of water use. One possible explanation is that there are very often long queues at the tap stands and water supply is not always guaranteed throughout the day, resulting in a restriction in the amount of water that people can collect. The high concentrations of pollutants, combined with the increased volumes of greywater being generated in dense settlements result in these areas posing considerable risks to human health and the receiving environment.

No attempt was made to try and calculate total pollution loads with the water quality data owing to the fact that neither the greywater volumes nor the water quality analyses were considered to be accurate enough for these calculations. Instead, the water quality sampling results merely serve to provide a general understanding of the overall quality of greywater emanating from non-sewered areas, particularly in respect of its nutrient loading and oxygen demand.

Conclusions

This study has attempted to quantify and characterise the greywater generated in the non-sewered areas of South Africa with a view to developing strategies and management options to limit potentially negative impacts from its use and disposal, particularly in the more densely-populated informal settlements of SA. The following conclusions have been reached:

- The figures for household water consumption, and therefore the volumes of greywater generated in non-sewered areas, vary considerably. This may be due to the fact that many of these areas are informal settlements which are by definition areas in flux, where there is considerable variation with respect to population numbers and available services. The average water consumption measured in the study was just over 100 ℓ/du·d, whilst a greywater return factor of 75% was assumed. Future studies should include a greater focus on the amount of water consumed and the associated greywater return factor.
- The water quality data from the on-site surveys suggest that the greywater is generally unfit for use except under controlled conditions. This is confirmed by the reluctance of people living in non-sewered settlements to use greywater for irrigation purposes as it is considered harmful to certain species of plants. Should the use of using certain classes of greywater, such as first-wash or rinse water, be considered for irrigation purposes, methods of reducing levels of sodium and phosphorus in greywater, such as discouraging the use of high phosphate detergents, need to be investigated. Furthermore, the high levels of *E. coli* suggest that there is a serious health risk associated with the indiscriminate use of the greywater, particularly in an environment where many residents may have compromised immune systems. Care must be taken to ensure that pathogenic organisms are not passed through any produce that may have been grown with the assistance of greywater. There is also significant risk

involved with on-site disposal of greywater owing to possible ponding and / or contamination of the groundwater.

- The quality of greywater in non-sewered areas differs significantly from that which is generated in higher-income, sewered areas in that it is generally much more polluted and in many instances should be considered hazardous.
- The quantity of greywater generated in the non-sewered areas of South Africa is closely related to household water supply. Although increasing the water supply to settlements will generally bring about benefits to these areas, it will also have the effect of increasing the amount of greywater to be managed. Failure to implement effective management systems for greywater could undermine the benefits of the improved water supply if it results in a decrease in community health.

The quantification of greywater generated in the non-sewered areas of South Africa has highlighted the fact that greywater disposal in densely-settled non-sewered areas is likely to result in significant health and environmental impacts. The greywater generated in the typical high-density informal settlements that are mushrooming around the main cities in South Africa is particularly hazardous from a pathogenic and salinity point of view (i.e. it is 'dark' greywater!) and should be managed as a sanitation issue rather than a drainage one. These negative impacts are likely to worsen in the event that the current levels of service with respect to water provision are increased. It is essential therefore that that there is systematic management of greywater in non-sewered settlements. Whilst it is important that residents are educated and empowered with respect to greywater management, it is the responsibility of the local authority concerned to ensure that working systems are in place.

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