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Current greywater disposal practice in Waruku low-income area

Urban agriculture practiced using untreated greywater in Waruku

Impacts of long-term greywater disposal on soil properties and reuse in urban agriculture in an informal settlement – A Case Study of Waruku, Nairobi

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MSc Thesis MWI- 2008/10
April 2008

UNESCO-IHE
Institute for Water Education

Impacts of long-term greywater disposal on soil properties and reuse in urban agriculture in an informal settlement – A Case Study of Waruku, Nairobi

Master of Science Thesis
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This research is done for the partial fulfilment of requirements for the Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, The Netherlands

Delft
April 2008

Dedication

This work is dedicated to any person who strives to share acquired knowledge to improve life of the poor and the disadvantaged for the glory of the almighty God.

Abstract

With increasing urban population exerting pressure on the fast dwindling fresh water resources, wastewater reuse is gaining popularity in many parts of the world. Greywater, which is household wastewater without input from toilet waste, has attracted special attention for possibilities of reuse, particularly in urban agriculture, because it has low pathogen content and can therefore be treated easily for reuse.

The trend towards reuse of treated greywater in urban agriculture is driven by the need to maximise limited water resources and to benefit from the nutrients such as phosphorus available in the greywater. However, the sustainable reuse of greywater in urban agriculture is likely to be hampered by the high dissolved solids in greywater, that include soluble sodium that impinges on soil properties, which cannot be removed by the conventional biological wastewater treatment systems. Only, energy-intensive size exclusion systems such as reverse osmosis and membrane technologies can remove greywater dissolved solids but these systems are beyond the reach of developing countries. Thus, there is a need to study the impacts of greywater on soil properties in order to gain insights into its long-term potential reuse in urban agriculture.

Soil sampling was carried out in a site that had been drained with greywater for over 20 years in Waruku urban informal settlements, Nairobi. The greywater from the study area had sodium adsorption ratio (SAR) of 8.0 and electrical conductivity (EC) of 1.1 dS/m. The results of the study indicated that soils (sampled to 150 mm depth) from the greywater disposal site were statistically different in terms of soil exchangeable sodium, with $p < 0.001$ for significance compared with non-greywater irrigated site located within the study area (taken as the control). The greywater disposal site exhibited 2.1 units of higher pH and 326% higher soil sodium adsorption ratio (SAR). It had high soil salt accumulation (soil ECe), increasing to 4.1 dS/m, which was 569% higher than the control site, indicating potential yield reduction of salt sensitive crops such as cabbage due to unplanned greywater disposal.

Regular monitoring of site-specific greywater and soil, and appropriate management practices such as periodic leaching, are needed to mitigate the negative impacts of greywater reuse in urban agriculture due to high soil sodium accumulation and salinity build up. Despite these challenges, the study also revealed opportunities exist in greywater reuse in urban agriculture. It is a powerful means for water conservation and nutrients recycling thereby reducing demands for freshwater and mitigating pollution of aquatic systems.

Keywords: Greywater, reuse, sodium, ecosan, urban agriculture

Acknowledgements

This research study was a culmination of invaluable support and assistance that I received from many people and institutions, but due to limited space, unfortunately, only a few are hereby acknowledged.

I acknowledge the Dutch government, which through NFP funded my MSc. Programme in Sanitary Engineering, and Eawag-Sandec of Switzerland for funding the research phase of my study at UNESCO-IHE, Institute for Water Education. I also thank my employer; Nyeri Water & Sewerage Company (Nyewasco), for being granted study leave to follow this programme. In particular, I thank the former Nyeri Municipal Town Clerk, Mr. Gikuhi and the MD, Nyewasco, Eng. Nguiguti for the trust and confidence they demonstrated in my ability to pursue this noble purpose.

I register my deep appreciation to my supervisor, Prof. Dr. Gary Amy for his guidance in this work. It was a great pleasure to learn from this expert. Your insights enabled me to shape and improve this work. I especially appreciated your quick response to my many requests, some of which were made at short notice.

I express my sincere gratitude to my two mentors; Dr. Elisabeth von Münch from UNESCO-IHE and Dr. Christoph Lüthi from Eawag-Sandec for the invaluable support you accorded me during the entire period of the research phase. I was greatly encouraged by your sustained interest in this work and extremely motivated for giving me a large degree of freedom to define and carry out the research.

I would like to acknowledge the support and cooperation that I received from Maji na Ufanisi during the fieldwork in Waruku, Nairobi. I was provided with competent and committed household survey assistants that enabled me to collect good quality socio-economic survey data. I also appreciate the survey assistants for their excellent work.

I am greatly indebted to the seven households in Waruku informal settlements that willingly participated in the greywater quantification and characterisation exercise. Allowing me to participate in your struggle for life, your deep commitment and in going a long way to collect the greywater in what you joyfully used to call "the researcher's drum'', you gave me a great opportunity to discover the greywater characteristics. It is my greatest hope that the findings of this research work will contribute to betterment of your life and to offer hope to millions in similar localities.

No research findings would have been possible without greywater and soil samples analysis. In this respect, I acknowledge great support I received in all laboratories that I worked. I particularly acknowledge assistance I received from Mr. Tangus and Mr. Wambua from Mines and Geology Laboratory, Mr. Muasya and Mr. Kingori from Central Testing Laboratory and Mr. Kimathi from KARI Soil Survey Laboratory.

I extend my thanks to all my family members and to everyone who prayed for my success and my apologies to those I have failed to mention. Omissions are unintentional.

Finally, my special thanks to my dear wife, Lillian and children (Faith and David) for your love, patience and endurance. May the almighty God abundantly bless you.

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List of Abbreviations

ANZECC	Australian and New Zealand Environment and Conservation Council
ASTM	American Society for Testing Materials Designation
BOD	Biological oxygen demand
CBO	Community Based Organisations
CEC	Cation exchange capacity
CFU	Colony forming units
COD	Chemical oxygen demand
DNR	Department of Natural Resources
DOC	Dissolved organic carbon
EAWAG	Swiss Federal Institute of Environmental Science and Technology
EC	Electrical conductivity
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organisation
GR	Gypsum required
GW	Greywater
HCES	Household Centered Environmental Sanitation
KARI	Kenya Agricultural Research Institute
Ksh.	Kenya shillings
LF	Leaching fraction
MnU	Maji na Ufanisi
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organisations
NOM	Natural organic matter
OC	Organic carbon
SANDEC	Department of water and SANitation in DEveloping Countries, Switzerland
SAR	Sodium adsorption ratio
TDS	Total dissolved solids
TP	Total phosphorus
TSS	Total suspended solids
UNESCO	United Nations Education Scientific and Cultural Organization
USDA	United States Department of Agriculture
USSL	United States Salinity Laboratory Staff
WHO	World Health Organisation

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1. Introduction

1.1. Background

Water shortage, poor water quality and water-related disasters have been identified as major global concerns related to current and future water resources (UNESCO, 2003). Increasing scarcity of freshwater resources and growing environmental awareness are important drivers to adopt reuse of wastewater as an additional source of water supply. In addition, with rapid population growth, which further exerts pressure on the fast-decreasing water resources, reuse of wastewater attracts attention as a viable alternative of freshwater supply in developing countries (WHO, 2006).

While planned (treated) wastewater reuse is being practiced in many developed countries, mostly for landscape irrigation, unplanned (untreated) wastewater reuse is still common in many low-and middle income countries. Many examples have been cited where untreated wastewater reuse is being practiced in urban areas of the developing countries (Rutkowski *et al.*, 2007);(Keraita *et al.*, 2002). Greywater, which is household wastewater without toilet waste input, is gaining popularity in many developing countries as it can be treated and reused more easily than mixed domestic wastewater. Greywater reuse in urban agriculture and for other domestic uses has a potential of significantly reducing pressure on fresh water resources.

Although the benefits of greywater reuse in urban agriculture are undoubtedly many, there are two areas of concern with the practice. One is the potential threat to human health and the other, is its potential long-term impacts on environment with particular interest to soil properties and plants. A lot of research has been undertaken to address the concern of microbiological health impacts, which have led to development of myriad wastewater treatment technologies.

However, the conventional wastewater treatment technologies available, with exception of energy-intensive reverse osmosis, which are uncommon in the developing countries, cannot remove soluble sodium in the wastewater streams. Sodium causes soil sodicity problems that have potential of not only degrading agricultural land, where wastewater reuse in land application is practised, but can also reduce crop productivity. Despite these real implications, research work on this concern is limited, although it is the key to understanding the impacts of greywater quality on soil properties and plants for attainment of sustainable greywater reuse in urban agriculture. Thus, there is a need for a research study to investigate the impacts of greywater on soil properties to gain insights on its long-term potential reuse in urban agriculture.

Although research on greywater reuse in developed countries exists, there is limited scientific data and information relevant to the developing countries. Few research studies have been carried out in low-income high-density areas of the developing countries with respect to greywater disposal and reuse. In a detailed research on greywater management in non-sewered areas of South Africa, (Carden *et al.*, 2007a) observed that there is still scant information on greywater impacts on soil characteristics. In recognition of the possibility of the greywater reuse in the urban agriculture in non-sewered areas, the authors recommended further research on greywater impacts on soil properties.

This research study, which was carried out in a non-sewered urban informal settlement in a developing country (Kenya), contributes to filling certain knowledge gaps in this important area. It provides insights into the impacts of long-term greywater disposal on soil properties that offers an opportunity to understand the long-term effects of greywater reuse in urban agriculture.

1.1.1. Household-Centred Environmental Sanitation (HCES) and this project

The vast majority of the world population lack adequate water, sanitation, drainage and solid waste disposal services. Most of the affected population reside in the developing countries. (Eawag, 2005) states that the conventional planning approaches are partly responsible for this situation because they are unable to make a significant contribution. To reverse the situation, the Household-Centred Environmental Sanitation (HCES) approach is advocated by Sandec as a planning tool.

The HCES approach is based on the Bellagio Principles that recommend that people and their quality of life should be at the centre of any sanitation system. It places the household and its neighborhood at the core of planning process. It also attempts to avoid mistakes of purely "bottom up" and "top down" conventional approaches while overcoming constraints of non-sustainable planning and resource management practices (Eawag, 2005).

The HCES approach recognizes greywater management as an integral part of sanitation improvement. The objective of the approach is to create and maintain conditions whereby:

- People lead healthy and productive lives; and
- The natural environment is protected and enhanced (Eawag, 2005).

It is upon this basis of HCES approach, and to contribute to its stated objectives, that this research work on greywater was undertaken.

1.1.2. Maji na Ufanisi (NGO), Sandec and this project

Maji Na Ufanisi is a Non-Governmental Organization (NGO) operating in Nairobi, Kenya. The name of this organization is Kiswahili (Kenya's national language) word for "Water and Development''.

The NGO has extensive experience in managing developmental activities in low-income high density areas in Nairobi. It has been involved in several water and sanitation projects in urban areas of Nairobi. A good example is Kiambiu water and sanitation project, a project that involved an informal urban settlement in the eastern part of Nairobi.

Sandec is the Department of Water and Sanitation in Developing Countries. It operates from Dubendorf, Switzerland. It is implementing the HCES planning approach in Waruku, Kenya among other case studies in Costa Rica, Burkina Faso and Togo. The issue of greywater management and reuse can form part of HCES approach of solving sanitation problems as close as possible to the point of source.

1.1.3. Problem description of the case study area of Waruku in Nairobi

The Waruku area is a non-sewered informal settlement situated in the north-western part of Nairobi, about 15 km from the city centre. Currently, it has about 10,000 inhabitants with a population density of about 500 people/ha (MnU, 2007).

In Waruku, greywater management entails disposal of untreated greywater onto open ground or to few existing stormwater drains, from where it flows into Nairobi River. Due to lack of sound greywater management in the area, this greywater disposal practice has resulted in adverse impacts on public health, local economy and poor living conditions for the Waruku residents.

Ironically, the problems associated with unplanned greywater disposal in Waruku are expected to be further aggravated following improved water supply provision. The water supply services in the City of Nairobi, being provided by the privately-run Nairobi Water Company, have been considerably improving. This will result in increased greywater generation in the coming years, which if not properly managed, will further compound the current negative health and environmental consequences. There is therefore an urgent need to develop options that can reverse this situation and convert greywater from a nuisance to a positive opportunity for the Waruku residents.

A viable option for managing unplanned greywater disposal is to reuse it in urban agriculture. Urban agriculture is, to some extent, being practiced in the Waruku area by some residents mainly using surface water from the Nairobi River. They mainly grow vegetables such as cabbages and tomatoes, for both their domestic use and commercial purposes. Also, in the neighbourhood of the slum area, there are large tracts of vacant land, which are privately owned that could provide further impetus for greywater reuse. Therefore, there exists huge opportunity for reuse of greywater in the urban agriculture in Waruku. Proper utilisation of greywater in urban agriculture can result in many positive effects on the Waruku residents. It can contribute to poverty reduction, food security and improved living conditions, while at the same time reduce aquatic pollution of the Nairobi River.

However, despite the possibility of greywater reuse in urban agriculture in the area, there are a number of issues that need to be addressed. The perception of residents with respect to greywater reuse is not properly understood. In addition to the above issue, the possible long-term impacts of greywater disposal on soil properties remain unclear.

Although the slum area has been in existence for over 20 years, impacts of greywater disposal have not been monitored. There is therefore no baseline data upon which to develop a clear vision of the long-term effects of greywater disposal on soil characteristics in the area. In order to enhance the possibility of sustainable greywater reuse in urban agriculture, it is imperative to establish whether the extended period of greywater disposal in the area has impacted adversely on the soil characteristics.

Also, no previous research study has been undertaken in Waruku to establish the characteristics of greywater generated in the area that could provide insights on the possible effects of greywater disposal on the soil characteristics. In addition to this, no data is available on the quantity of greywater being generated in the area that could be used to assess the potential of this resource as irrigation water in urban agriculture.

Therefore, this research study that was carried out in Waruku attempted to address the above concerns and issues and to provide an important scientific basis for adopting greywater reuse in the informal settlement as a solution to the current greywater disposal problems.

1.2. Goals and objectives

1.2.1. Overall goal and specific objectives

The overall goal of this research project is to improve the greywater management through greywater reuse in urban agriculture in unplanned urban settlement in a developing country, using Waruku, Nairobi (Kenya) as a case study. Specific objectives are:

1. To investigate existing greywater disposal and reuse practices and the residents' perceptions of greywater reuse in urban agriculture in the study area.
2. To quantify greywater generation in the informal settlement and conduct greywater characterisation.
3. To investigate impacts of long-term greywater disposal on soil properties.
4. To predict potential impacts of greywater on reuse possibilities in urban agriculture based on the greywater characterisation dataset.

1.2.2. Research questions

The main research questions are:

1. What are the greywater disposal practices and reuse options, and what are the residents' perceptions of greywater reuse in urban agriculture in Waruku?
2. How much greywater is generated and what is the sodium load being applied to the soil environment?
3. What are the characteristics of greywater in Waruku?
4. To what extent has greywater disposal altered soil properties in the informal settlement of Waruku, Nairobi and would this adversely affect urban agriculture?
5. What are the potential impacts of the existing greywater quality in Waruku on salinity and soil properties? Is greywater generated in Waruku suitable for reuse as irrigation water in urban agriculture?

1.2.3. Reasons for the selection of Waruku as a case study

Waruku area is a non-sewered urban informal settlement that is located in the middle of Nairobi, which has been inhabited for more than 20 years. The site is selected as case study for the following reasons:

- The site had been selected by Sandec and the local NGO for it had satisfied certain 'enabling environment' criteria conducive for the implementation of HCES approach. These included political support (government support) and existence of institutional arrangements that suited decentralization.
- It offers the possibility of understanding the long-term impacts of greywater quality on soils properties, which gives some indications on the possible effects of applying greywater in urban agriculture over an extended period of time.
- It helps to gain insights on the viability of greywater reuse in urban agriculture as a vital strategy in greywater management in Kenya's urban informal settlements.

- It allows for the determination of a greywater return factor and greywater characteristics, which could be used in the design of greywater treatment and reuse systems in other urban informal settlements in Kenya, which have similar characteristics.

1.3. Scope of the research

This MSc. research is focused on studying the impacts of long-term greywater disposal on soil properties in low income urban area of Waruku, Nairobi in Kenya. It also predicts potential effects of greywater quality on reuse in urban agriculture based on greywater characterization.

The scope of this research excludes excreta and solid waste management. The thesis also does not cover the greywater impacts on groundwater quality nor aspects of microbiological health risks due to greywater disposal or reuse. Greywater treatment methods are not covered in detail because conventional biological treatment systems such as trickling filters, activated sludge, waste stabilization ponds and constructed wetlands have insignificant removal of dissolved solids (salts) to affect chemical (sodium) loads in land application.

1.4. Funding for this project

This research project was funded by SANDEC, Department of Water and Sanitation in Developing Countries, operating from Dubendorf, Switzerland. The scholarship programme was arranged by Dutch government through the Netherlands Fellowship Programme (NFP).

2. Literature Review

2.1. Greywater definition

Greywater can be defined as domestic household wastewater that includes wash water from baths, hand basins, dishwashers, kitchen sinks, etc but which excludes input from the toilet.

However, some researchers exclude in their definition the contribution of wastewater from kitchen sinks and food waste grinders due to its high organic content of oil and food particles (Asano *et al.*, 2007); (Christova-Boal *et al.*, 1996). It is important to recognise this difference as it partly explains profound differences in the greywater quantities and characteristics reported in the literature.

In this research project, the former definition is assumed. It is not practical to separate kitchen waste from other greywater streams in the low income area of Waruku as there are no water plumbing systems in the dwelling structures. In the study area of Waruku, the toilet wastewater stream (blackwater) is discharged separately into mostly pit latrines while the other wastewater streams from household processes (e.g. washing dishes, laundry and bathing) are disposed onto ground outside the dwellings/ open drains or directly to the Nairobi River.

2.2. Greywater quantity generation

In order to evaluate possibilities of greywater reuse, or in the design of suitable greywater treatment technologies, quantification of greywater production in an area is paramount.

Many studies have been undertaken to quantify greywater production and a wide variation is observed. In the studies, data for both greywater production rates and return factors are usually reported. Greywater return factor refers to the proportion of the greywater production to the total freshwater consumption usually expressed as a percentage. Table 2-1 shows greywater return factors and freshwater consumption in some selected studies conducted in developing countries.

Table 2-1: Greywater return factors and freshwater consumption in some developing countries.

References	Fresh water consumption (L/cap/day)	Greywater return factor	Greywater production (range) (L/cap/day)	Country
(Prathapar *et al.*, 2005)	195	82%	160	Oman
(Jamrah *et al.*, 2007)	151	80 – 83%	121- 125	Oman
(Idris *et al.*, 2005)	Not known	83%	Not known	Malaysia
(Carden *et al.*, 2007a)	37	68%	25	South Africa
(Al-Jayyousi, 2003)	Not known	50 – 80%	Not known	Jordan
(Stephenson *et al.*,2006) cited by (Carden *et al.*, 2007a)	29	87%	25	South Africa

Table 2-1 shows that the greywater return factor is relatively similar for different studies even if fresh water consumption varies widely.

The greywater production is directly influenced by water consumption in a household, which is dependent on a number of factors. These include:

- Quantity of water supplied
- Duration of supply (intermittent or continuous)
- Quality of water
- Price of water
- Pressure in the distribution
- Awareness of health and environmental risks (Carden *et al.*, 2007b).

The water consumption is also directly related to the standard of living. Therefore, it is obvious that greywater production per capita is much lower in low-income areas of developing countries than in developed countries. In this literature review, the focus is on developing countries, in particular to the low-income areas.

The variation in greywater production reported is also partly due to different methods used in the quantification. For instance, (Jamrah *et al.*, 2007) used qualitative data on water-related activities through a survey to estimate greywater quantities while (Carden *et al.*, 2007a), in a study conducted in non-sewered areas of South Africa, used direct measurements. In this research study, direct measurements were made to estimate greywater production.

To my knowledge, there is no data available on the greywater production in Kenya. Nonetheless, estimates for water consumption for urban and rural areas are available in the (Water design Manual, 2005), which may be used to give rough estimate of greywater production if greywater return factor could be established or assumed.

2.3. Greywater characterisation

This section assesses the characteristics of greywater. These are important to consider when evaluating the greywater reuse possibilities because they are directly related to the quality of greywater used.

2.3.1. General comparison with mixed domestic wastewater

Greywater differs from mixed municipal wastewater as follows:

- It has much lower pathogen content
- It has much lower ammonia nitrogen (no urine)
- It has lower phosphorus content (no urine and faeces)
- It has no input from industrial wastewater

According to the data by (Ridderstolpe, 2004), greywater contains less than half the concentration of nitrogen and phosphorus compared with mixed wastewater as shown in Table 2-2.

Table 2-2: Amounts of different compounds of greywater compared to mixed wastewater in Sweden (Ridderstolpe, 2004)

Substance	Specific load	Concentration	Amount compared with mixed wastewater
BOD7	20-30 g/pd	150-400 mg/l	60-70%
Nitrogen (N)	0.8-1.2 g/pd	0.5-15 mg/l	5-10%
Phosphorous (P)	0.2-1 g/pd	1-10 mg/l	10-50%

2.3.2. Greywater physical characteristics

The physical parameters that are of relevance to greywater reuse in agriculture include temperature, turbidity and total suspended solids (TSS). Turbidity and TSS may reduce soil surface permeability or may cause clogging of conveying and micro-irrigation systems. According to (Al-Jamani, 2006), concentration of TSS in irrigation water of more than 50 mg/L can have physical and possibly chemical impacts on irrigating systems as such clogging and precipitation.

The impacts of greywater on conveyance and irrigation systems are outside the scope of this research.

2.3.3. Greywater chemical characteristics

The chemical parameters that are important in greywater characterisation include biological and chemical oxygen demand (BOD, COD), nutrients such nitrogen and phosphorus, pH and alkalinity. Other important substances include heavy metals, bleaching agents, surfactants or organic pollutants in detergents.

2.3.3.1. Biological and Chemical Oxygen Demand

Biological and Chemical Oxygen Demand (BOD, COD) indicate the amount of organic matter in a sample. Oxygen is necessary for plant growth and it must be present in the root zone or the plants become stressed. However, anaerobic conditions may occur if irrigation water contains high organic matter concentrations and very low dissolved oxygen. Also, anaerobic conditions may occur when soils remain 100% saturated over a long time. The BOD and COD values of up to 60 and 120 mg/L respectively are not considered harmful to plants or soils (Al-Jamani, 2006).

The literature reviewed showed wide ranges of COD concentrations of greywater. Table 2-3 shows greywater COD concentrations and per capita production reported.

Table 2-3: Greywater characteristics in terms of COD concentrations and per capita production

References	Country	COD concentration (mg/L)	Greywater production (L/cap/d)	COD per capita production (gCOD/cap/d)
(Carden *et al.*, 2007a)	South Africa (non-sewered areas)	1470 - 8490	4.7 - 28	40 - 41
(Munch, 2007)	Germany	560	60	33
	USA	150	260	39
(Al-Jayyousi, 2003)	Jordan	700	50	35
(Jefferson *et al.*, 2004)	United Kingdom	450	85	38
Average				37

The large variation in concentrations reported is due to differences in greywater production, which is directly influenced by water consumption that varies significantly from country to country. Despite large differences in concentrations reported, the per capita COD productions are remarkably similar. Therefore, it may be misleading to report only the concentrations to express strength of wastewater, due to large variations in flow rates. Thus per capita mass production (in g/cap/day) should be used for comparison.

The ratio of COD/BOD is a measure of biodegradability of wastewater. A COD/BOD ratio of 2.0 or less indicates that wastewater is easily biodegradable (Metcalf and Eddy, 2003). Different studies report different values of the COD/BOD ratio for greywater as given in the Table 2-4.

Table 2-4: Greywater COD/BOD ratio from different studies

References	Type of wastewater and country	COD/BOD ratio
(Jamrah *et al.*, 2007)	Greywater - Oman	1.04
(Lens *et al.*, 2001)	Greywater - The Netherlands	4
(Jefferson *et al.*, 2004)	Greywater - United Kingdom	3
(Surendran & Wheatly, 1998) cited by (Eriksson *et al.*, 2002)	Kitchen waste – Not known	1.75
(Metcalf and Eddy, 2003)	Mixed domestic wastewater – developed countries	1.25 -3.33

The difference in COD/BOD ratio reported could be due to the composition of the greywater, which depends on the household's activities. According to (Lens *et al.*, 2001) storage also affects greywater quality. The authors reported that rapid decrease in organic strength is observed when greywater is stored. Although there is limited literature on the effect of storage on reuse, a study by (Jefferson *et al.*, 2004) confirmed that the ratio of COD/BOD decreases with storage, indicating that waste becomes more biodegradable with storage. The decrease could be attributed to chemical and biological degradation of the chemical compounds during storage, possibly due to anaerobic degradation to methane. Therefore possibilities of odour generation are likely upon storage, which may influence greywater reuse possibilities in urban agriculture in low income areas.

2.3.3.2. Surface-active agents and household chemicals

The surface-active agents (surfactants) are the main components of household cleaning products. The surfactants in greywater mainly originate from the detergents used for laundry and dishwashing (Morel and Diener, 2006). The amount and type of detergents used in a household determine the amount of surfactants.

The contribution of detergents to greywater characteristics is considerable. (Eriksson *et al.*, 2002), in a study in United Kingdom, observed that 60% of measured greywater COD was contributed by detergents. In supporting this position, (Wiel-Shafran *et al.*, 2006) claimed that, on average, surfactant concentrations in greywater is higher than in raw domestic wastewater. The authors observed greywater surfactant concentrations ranging from 0.7 to 70 mg/L.

In a further study on the household chemicals, (Eriksson *et al.*, 2002) carried out a detailed greywater characterisation of Xenobiotic organic compounds (XOCs). However, XOC measurements are beyond the scope of this thesis.

2.4. Overview of soils properties affected by wastewater irrigation

This section gives an overview of soil properties that are relevant in understanding the impacts of greywater on soil characteristics.

2.4.1. Soil texture

Soil texture refers to the weight proportions of separate particles that are smaller than 2mm in diameter. It is determined from laboratory particle-size distribution. The soil texture classes are used to classify the physical properties of soil based on the relative percentages of clay, sand and silt.

There is no universally accepted scheme of classifying particle sizes (Hillel, 1998). Some of the reported soil texture classification schemes include USDA (US Department of Agriculture), ISSA (International Soil Science Society), MIT (Massachusetts Institute of Technology), etc. In this research study, USDA soil texture classification was adopted and the chart used is given in Appendix 4.

2.4.2. Soil structure

Soil structure refers to the aggregation of soil particles. Soil particles are aggregated by chemical and biological processes to form natural structure. The soil structure affects the rate at which water and air move through it. It also affects root development and the nutrients supply to plants (USDA, 1993).

Wastewater with high sodium content can cause loss of the soil structure but addition of organic matter and inorganic chemicals such as gypsum (calcium sulphate) restore it.

2.4.3. Soil cation exchange capacity (CEC)

CEC is the total negative electrical charge per mass of soil. It is a measure of the capacity of the soil to absorb and retain cations on the soil particles. The CEC of the soil is measured in the laboratory by the use of an ammonium acetate extraction procedure.

Detailed studies of the CEC show that it is correlated positively with the content of organic matter and with the pH of the soil if an unbuffered solution containing NH_4^+ as the index cation is used in the measurement. This indicates that application of organic matter (humic substances), which increases CEC of the soil, can be used to restore soil structural stability associated with application of sodic wastewater.

(Certini and Scalenghe, 2006) observed that although organic matter comprise 0.1 to 10% of the total soil mass it has major influence on soil physical quality by aggregating mineral particles and thus contributing to a favourable soil structure. It is negatively charged, has a high CEC (60 to 400 meq/100g); it can therefore retain cations such as Ca^{2+}, Mg^{2+} and Na^+ on its negative charged sites to mitigate sodic effects.

2.4.4. Exchangeable sodium percentage (ESP)

Exchangeable sodium percentage (ESP) is the proportion of the sodium adsorbed onto clay mineral surfaces to the total cation exchange capacity. It indicates the potential for soil sodicity to adversely affect either the structural stability of soil aggregates or the osmotic potential of the soil moisture on biological activities (Patterson and Chapman, 1998)

ESP (%) is determined by using expression given below, where the units of the concentrations are in milliequivalents (meq/100g).

$$ESP = \frac{Na}{CEC} x\ 100$$

The soil ESP can also be estimated based on SAR of the soil solution using equation below:

$$ESP = \frac{100[-a + b(SAR)]}{\{1 + [-a + b(SAR)]\}}$$ where a = 0.0126 and b= 0.01475 (USSL, 1954). A graphical representation of the equation is given by (Landon, 1991).

According to (Asano *et al.*, 2007), soil permeability problems are expected to occur when soil ESP is greater than 15% and the soil salinity is less than 4 dS/m (4000 µS/cm). (van de Graaff and Patterson, 2001) noted that soils that have more than 6% ESP are considered to have structural stability problems related to potential dispersion. However, the authors cautioned that ESP should not be taken as the only factor that causes potential problem as other factors such as soil pH may influence soil dispersibility. Clay soils at a given ESP are more dispersible at high pH.

2.5. Greywater quality parameters with agronomic significance

This section describes the greywater quality parameters that are relevant to greywater reuse in urban agriculture.

2.5.1. Salinity

Salinity is the presence of soluble salts in soil or in water. Salinity is the single most important parameter in determining the suitability of the water to be used for irrigation (USEPA, 2004). The accumulation of salts in the soil (soil salinisation) is a major concern in the degradation of agricultural land. It is mainly caused by use of saline wastewater. High levels of soluble salts in the soil may result in reduced plant productivity or in the elimination of crops or loss in native vegetation (ANZECC, 2000).

Water salinity can be reported either as electrical conductivity (EC), measured in dS/m or µS/cm or as total dissolved solids (TDS). To assess irrigation water quality with respect to salinity, the salt content or electrical conductivity of water must be known. The greywater used for irrigation can be classified in terms of salinity using Table 2-5.

Table 2-5: Classification of irrigation water according to salinity (Pereira et al.*, 2002)* (1dS/m =1000 µS/cm)

	Non saline	Slightly saline	Medium saline	Highly saline	Very highly saline
Total dissolved solids, TDS (mg/l)	< 500	500 to 2000	2000 to 4000	4000 to 9000	> 9000
Electrical conductivity, EC (dS/m)	< 0.7	0.7 to 3.0	3.0 to 6.0	6.0 to 14.0	> 14.0

Table 2-5 gives salinity ratings that can be assigned to irrigation water based on EC values but cannot be used on its own to define suitability of irrigation water. Other factors such as soil characteristics, climate, plant species and irrigation management must be considered. (ANZECC, 2000) gives a detailed procedure of determining suitability of irrigation water, where interactions of all these factors are considered. The flow diagram of the procedure is given in Appendix 9.

The literature reviewed showed wide range of greywater salinity (See Table 2-6).

Table 2-6: Greywater salinity measured in terms of electrical conductivity for developing countries

References	Country	Electrical conductivity (µS/cm)	Salinity classification
(Morel and Diener, 2006)	Developing countries	300 - 1500	Slightly saline
(Kallerfelt & Nordberg,2004) cited by (Carden *et al.*, 2007a)	South Africa (Non-sewered areas)	830 - 1320	Slightly saline
(Carden *et al.*, 2007a)	South Africa (Non-sewered areas)	280 -15300	Non-saline to very highly saline
(Eriksson *et al.*, 2002)	United Kingdom	320 -2000	Slightly saline

The major sources of salinity, that may explain variations reported, include drinking water characteristics (especially hardness and naturally occurring salts) and also salts added through household activities e.g. table salt in kitchen/dishwashing greywater stream and in laundry detergents.

2.5.1.1. Effects of greywater salinity on soil properties and crop productivity

The impacts of high salinity on soils properties and crops productivity (yield) are frequently reported in the literature. According to (WHO, 2006), the guidelines on wastewater use in agriculture, greywater of threshold value of 3 dS/m (3000 µS/cm) may result in loss of soil structure. Also, crop productivity can reduce substantially for sensitive crops when conductivity of the irrigation water ranges between 700 and 3000 µS/cm. The sensitivity of agricultural crops is reported in terms of salt tolerance. A complete list is given in (Westcot and Ayers, 1985) cited by (Asano *et al.*, 2007). (ANZECC, 2000) also gives a comprehensive list of plants, their salt tolerance threshold values and the expected crop yield declines for increased soil salinity.

2.5.2. Sodium adsorption ratio (SAR)

Sodicity is a condition where sodium is the dominant cation in the soil solution and irrigation water. The most reliable index of the sodium hazard of irrigating water is the Sodium Adsorption Ratio (SAR). The sodium adsorption ratio is defined as shown below, where ion concentrations are expressed in meq/L.

$$SAR = \frac{Na^{+}}{[(Ca^{2+} + Mg^{2+})/2]^{0.5}}$$

High concentrations of sodium in the irrigation water can lead to the degradation of the soil structure (dispersion of clay particles). Because the relative proportions of exchangeable cations in a given soil are determined by the relative concentrations of cations in the soil solution, the composition of irrigation water can influence soil sodicity (Asano *et al.*, 2007).

The three main problems that are caused by sodium-induced dispersion are

- Reduced infiltration
- Reduced hydraulic conductivity
- Surface crusting

Of the literature reviewed, only a few reported SAR values of greywater. This could possibly be due to low attention that is currently given to the chemical loading contribution of greywater.

Table 2-7: Greywater SAR values in developing countries

References	Country	Sodium Adsorption Ratio (SAR)	Sodium concentration (mg/L)
(Gross *et al.*, 2005) cited by (Morel and Diener, 2006)	Developing countries	2 – 10	Not given
(Carden *et al.*, 2007a)	South Africa	Not given	96 – 1700
(Gross *et al.*, 2005)	Israel (for comparison)	2.8 – 6.0	Not given

The wide range in greywater SAR may depend on the type of detergents that are used in the households. (Patterson, 2001) reported that sodium salts, that are commonly used in laundry powdered detergents as "filler" because of benefit of solubility, contribute significantly to the production of saline greywater and hence to chemical loads in wastewater. The author observed that most liquid soaps have low concentrations of sodium and thus by simply changing to liquid detergents the sodicity of greywater can be reduced without any negative impact on the household operations.

2.5.2.1. Effects of greywater SAR on soil properties

The SAR value can be used to predict permissible sodicity levels in irrigation water to maintain soil structural stability. According to (Lazarova and Bahri, 2005), threshold value of SAR less than 3 indicates no restriction on the use of recycled water for irrigation while severe damage on soil structure can be observed when SAR is above 9 especially for surface irrigation.

Although the irrigation water SAR has an important effect on soil properties, both SAR and EC of irrigating water must be used in combination when evaluating soil potential problems. More serious consequences result from using water of high SAR when soil salinity is low. (Suarez *et al.*, 2006) reported that for a particular value of wastewater SAR, adverse impacts on soil hydraulic conductivity are reduced at increased high salinity.

Similarly, soil suffers from severe reduction in infiltration rate (reduced water entry) at high SAR but low salinity. (Oster *et al.*, 1992) found out that infiltration problems are unlikely for SAR values in the range of 3-6 when the EC is greater than 1.0dS/m. The infiltration problems are likely when EC is less than 0.4dS/m. The high electrolyte concentration reduces the tendency of exchangeable cations to diffuse away from the clay surface thus mitigating the sodicity effects (Qadir and Schubert, 2002). This position is confirmed as shown in Figure 2-1:, adopted from (Hanson *et al.*, 1999) cited by (Asano *et al.*, 2007).

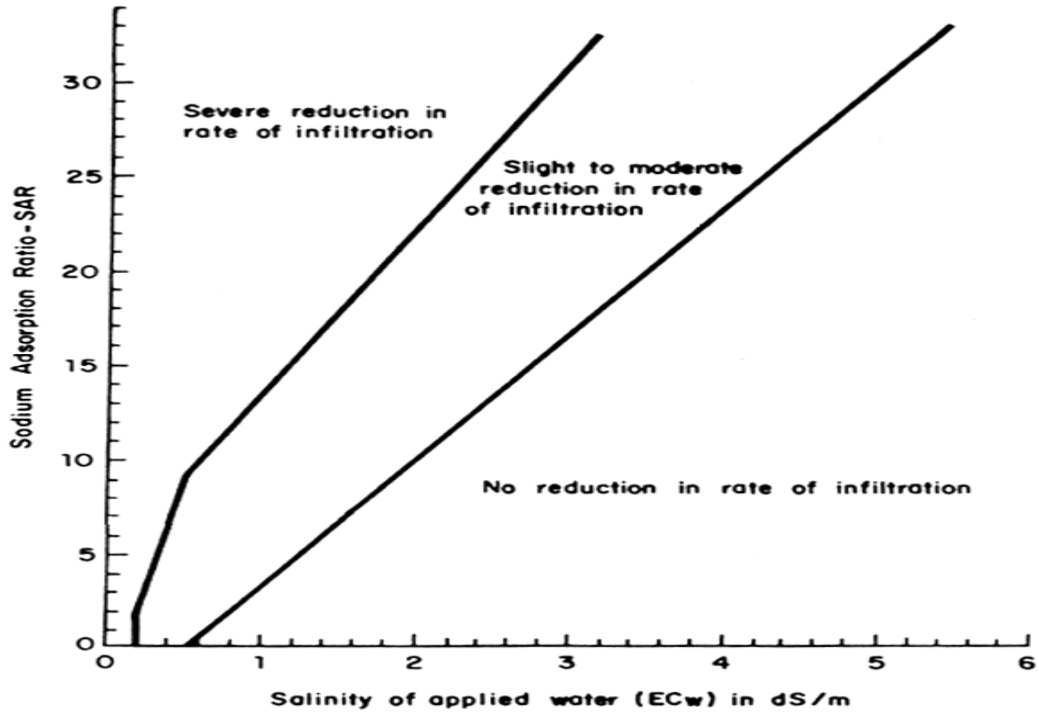


Figure 2-1: Water infiltration rate as affected by irrigation water SAR and salinity (EC) 1dS/m = 1000 µS/cm (Asano et al., 2007).

It is therefore important to control greywater sodium content if possible negative sodic consequences of the soil are to be avoided. The soil sodic problems are more likely to occur after rainfall, which may leach accumulated salts below the root zones thereby reducing soil salinity.

2.6. Guidelines for greywater reuse in agriculture

2.6.1. Wastewater reuse guidelines

The national guidelines for reuse of greywater in agriculture in Kenya are not available. However, (NEMA, 2006) gives microbiological quality guidelines for use of wastewater for irrigation and also sets out standards for irrigation water with main thrust being on heavy metals permissible limits. Nonetheless, the national guidelines spelt out the upper limit of irrigation water SAR of 6.0, which is an important environmental requirement.

Literature reviewed showed that in several states of United States (US) and Australia, where greywater reuse is widely practiced, guidelines for reuse of greywater have been established. However, as clearly pointed out by (Wiel-Shafran *et al.*, 2006), most of these regulations are mainly concerned with public health issues and less with potential environmental impacts.

For example, (USEPA, 2004) sets out guidelines for water quality and treatment requirements prior to reclaimed water reuse. These guidelines are very restrictive. They give strict requirements regardless of the type of reclaimed water use stipulating minimum levels of disinfection that must be done to avoid adverse health consequences.

On the other hand, (WHO, 2006) guidelines for the safe use of wastewater, excreta and greywater are significantly less restrictive compared to the guidelines adopted by various states of the United States. These guidelines are therefore more appropriate to the developing countries. Other less restrictive guidelines, and therefore useful to this research work that is carried out in a developing country, Kenya, include Food Agricultural Organisation (FAO) guidelines. Based on the work of (Ayers and Westcot, 1994), FAO provides guidelines for the evaluation of water quality for irrigation as shown in Table 2-8.

Table 2-8: Guidelines for evaluation of water quality for use in irrigation (Ayers and Westcot, 1994)

Problems	Water characteristic	No restrictions	Slight to moderate restrictions	Severe restrictions
Salinity effects on water availability	EC (dS/m)	< 0.7	0.7 to 3,0	> 3.0
	TDS (mg/l)	< 450	450 to 2000	> 2000
Salinity effects on soil infiltration	SAR < 3	EC > 0.7 dS/m	EC: 0,7 to 0,2 dS/m	EC < 0,2 dS/m
	3 to 6	> 1.2	1.2 to 0.3	< 0.3
	6 to 12	> 1.9	1.9 to 0.5	< 0.5
	12 to 20	> 2.9	2.9 to 1.3	< 1.3
	20 to 40	> 5.0	5.0 to 2.9	< 2.9
Toxicity	Sodium			
	Surface irrigation: SAR	< 3	3 to 9	> 9
	Sprinkle/spray (me/l)	< 3	> 3	
	Chloride concentration			
	Surface irrigation (me/l)	<4	4 to 10	> 10
	Sprinkle/spray (me/l)	<3	> 3	
	Boron (mg/l)	< 0.7	0.7 to 3.0	> 3.0
	Trace elements	Variable		
Sprinkle/spray irrigation	Bicarbonate (me/l)	< 1.5	1.5 to 8.5	> 8.5
Plant nutrition	pH	Normal 6.5 - 8.5		

These FAO guidelines would be used to assess quality of greywater generated from Waruku for its suitability as irrigation water as they also have extensive application. (Suarez *et al.*, 2006) confirm that the guidelines given in Table 2-8, adopted from (Ayers and Westcot, 1994) are currently being used throughout the world for evaluation of water quality for irrigation.

As an example, greywater from non-sewered areas of South Africa which was reported to have an average EC value of 895.5 mS/m (8.95dS/m) (Carden *et al.*, 2007a) has "severe restriction'' on salinity. This implies that the use of that greywater as irrigation water would cause severe problems of salinity effects on water availability to plants. Or in simpler interpretation, it implies that the water user is likely to experience soil and water cropping problems or reduced yields for salt sensitive plants as a result of using this poor quality water. Thus special management practices are needed to allow successful production with water of the quality indicated. A possible remedy would be to shift to more salt tolerant plants or embark on special management practices such as application of leaching fraction (LF) to mobilize excess salts from the root zones.

2.7. Long-term impacts of greywater on soil properties

This section describes briefly procedures of determining long-term impacts of irrigating water on soil properties.

2.7.1. Methods to determine the long-term effects of irrigating water on soil

For the evaluation of long term effects of irrigation water on soil characteristics, (WHO, 2006) proposes two methods that are considered relatively accurate to determine the effects on the soils. These are:

i) To measure the initial soil characteristics and monitor them over time or
ii) To compare similar soils irrigated under similar conditions with either wastewater or freshwater.

In this research project, the first method cannot be adopted since the research period is limited (only six months) and therefore there would be no enough time to monitor the soil regularly in a greywater disposal site in Waruku after the base data (initial conditions) are established.

Therefore, the second method would be adopted to evaluate possible impacts of long-term greywater disposal by selecting two sites; greywater disposal site and a control site, both within the study area of Waruku that have similar soil conditions but irrigated differently.

2.7.2. Previous studies on the long-term effects of greywater on soil

Although it is an established fact that use of saline greywater over longer period of time may lead to increased salinity of the topsoil (Morel and Diener, 2006), there is limited scientific data available on this observation.

(Faruqui and Al-Jayyousi, 2002) investigated the impacts of greywater irrigation on the Jordanian soils (soil classes not specified). In that study, soil samples were collected, at one point in time i.e. not monitored over the time, from different locations in the fields where greywater had been applied for 3 years. The study findings are reported in Table 2-9.

Table 2-9: Soil sample analysis results from soil irrigated with greywater for 3 years (Faruqui and Al-Jayyousi, 2002)

Soil Parameter	Greywater irrigated (Range observed and average [in blacket])	Non-greywater irrigated (average)
SAR	1.71 - 5.59 (3.7)	2.84
EC (dS/m)	1.01 - 6.78 (2.76)	2.57
pH	7.6 - 8.0	-

The authors reported that there were no negative infiltration impacts observed (no measurements for infiltration were provided). Although effects on soils would depend on many factors such as physical and chemical properties of soils, climate, quality and quantity of water used for irrigation etc, there is a possibility that 3 years could have been a short time for greywater dissolved solids (salts) to accumulate in sufficient quantities to have adverse effects on soils.

In a similar study to determine environmental impacts of greywater on soil, (Gross *et al.*, 2005) conducted a comparative study between native soil properties (not irrigated) and nearby plots irrigated with greywater and freshwater for a period of 3 years. The type of soil was native loess and rocky colluvium situated on a limestone rock formation. The study findings are reported in Table 2-10.

Table 2-10: Comparative study to investigate effect on soil irrigated with greywater for 3 years (Gross et al., 2005).

Soil parameter	Soil irrigated with greywater (Mean ± SE)	Soil irrigated with freshwater (Mean ± SE)	Control (dry plot; not irrigated) (Mean ± SE)
SAR	1.01	0.6	0.8
EC (dS/m)	2.5 ± 0.8	0.7 ± 0.1	1.6 ± 0.7
pH	8.2 ± 0.1	8.1 ± 0.1	8.1 ± 0.1
Organic matter (OM) (%)	0.9 ± 0.06	0.6 ± 0.04	0.5 ± 0.03

Accumulation of salts was notable in the plot irrigated with GW but the authors report that salinity had not reached high levels to affect plants growth. The average SAR in the GW irrigated plot was 1.01, followed by dry plot at 0.8 and freshwater plot at 0.6. The author reported that relatively high concentration of calcium in the farm soil reduced SAR and minimised potential negative harm to the plants.

It is important to recognise that on plot irrigated with freshwater both SAR and EC of the soil were lower than non-irrigated (control) dry plot. This could be attributed to the leaching effect of the freshwater. Thus using freshwater in control area as suggested by (WHO, 2006) in the investigation of the effects of greywater could exaggerate the effects of the irrigation water on the soil. Thus in this research project a dry (non-irrigated) plot was selected as the control.

In a study to determine potential off-site effects of effluent on land applications, (Patterson and Chapman, 1998) conducted a detailed study on soil which had been irrigated with wastewater for more than 30 years. Since no previous soil monitoring had been carried out in that study area located in Australia, the authors conducted one time soil measurements. The authors reported that soil ESP levels in the disposal area compared to a control area were significantly beyond threshold values of 5%, which indicated potential problems to soil structural stability. The authors further observed that sodium concentrations were changing with increasing distance from the point of effluent discharge.

3. Research Methodology

This chapter details the research methodology used to collect the necessary data for this research study. The field research study was undertaken in Waruku informal settlement in Nairobi from November 2007 to January 2008.

The field research data collection applied a combination of the following methods:

- Field observations
- Questionnaires and interviews
- Greywater sampling and analysis
- Soil sampling and analysis

3.1. Field observations and base data collection

I started the field work by conducting site visits to familiarise myself with the study area of Waruku before carrying out detailed greywater and soil sampling. During the site visits, I identified, photographed and documented the following site characteristics:

- Existing greywater management and disposal practices
- Current urban agriculture practices
- Sources of water supply
- Physical surroundings and topography.
-

In addition to the information gathered from the field observations, baseline data for the study area was collected from relevant government offices/institutions. Table 3-1 shows baseline data collected and its source.

Table 3-1: Baseline data for the Waruku study area and their sources

Data obtained for Waruku	Document/ information	Source
-Population size -Population density -Area in Sq. km	Census report	-National Central Bureau of Statistics of Kenya -Maji na Ufanisi HCES report of Waruku
-Soil type	Kenya soil map	-Kenya Agriculture Research Institute (KARI)
-Annual precipitation data	Rainfall patterns and evaporation details	-Kenya Meteorological Department, Nairobi
-Social organisations	Administrative/social arrangement	-Division administration (DO) office, Kangemi
-Environmental guidelines	National standards guideline documents	- National Environmental Management Authority (NEMA)

3.2. Questionnaires and interviews

In order to identify existing greywater disposal and reuse practices and to establish the residents' perception of greywater reuse in urban agriculture, questionnaires and interviews were conducted. The questionnaires were administered on the residents of Waruku from 12th to 24th November 2007.

Greywater management and reuse possibilities are affected by sociological factors, which necessitate the collection of data on a range of issues. The data help to understand the local practices relevant to water use, existing greywater reuse practices and residents' perception of greywater reuse.

The data collection methods used to gather this data are a combination of questionnaires and direct interviews. Questionnaires were administered to the residents under the following topics:

a) Household characteristics – Household size, occupation, monthly expenditures (incomes), house ownership, etc
b) Water supply: service level and consumption patterns – Water sources, distance to water source, water uses, frequency of water supply, etc
c) Greywater quality – Type of detergents being used, Amounts of detergents, etc
d) Greywater disposal and reuse practices
e) Urban agriculture
f) Perceptions of greywater reuse and risk levels.

In order to clearly establish the residents' perception of greywater reuse, open-ended questions were administered. The questionnaires were administered with the help of research assistants, who had past experience on conducting social surveys in similar localities. The list of the survey assistants who participated in the exercise is given in the Appendix 2.

In order to improve the quality of data collected through the questionnaires, I first conducted a session, in the NGO's office (Maji na Ufanisi), with the research assistants to expound on the purpose of the study and clearly explain technical terms such as greywater, urban agriculture, treated greywater, etc. The assistants, based on their experience on social surveys, suggested redrafting and reorganisation of some of the questions to make them suitable for the exercise. After this, a preliminary survey was carried out on a few households in Waruku to pilot-test the questionnaires and evaluate the outcome. Based on the pre-test exercise, the questionnaire was reformulated to make it more responsive for the intended purpose. The final version of the questionnaire is presented in the Appendix 1.

It was important to ensure that representative data on greywater was collected from the area under study. To realise this, and in recognition that greywater is an important part of the urban water cycle, some of the following aspects were considered important in identifying households for inclusion in the study:

- Water consumption (litres per person per day)
- Population density (people per hectare)
- Water supply (piped water inside the yard or off-site water supply)
- Monthly household income
- Dwelling type (informal dwelling units or permanent structures)

Detailed information on all the above items, specifically for Waruku, was not available from the Census report (Kenya Census Data, 1999). The Census Report gives data for wider geographical area and for this case it had aggregated the data for Waruku with other geographical locations that had different socio-economic characteristics. I considered the census data outdated as it could not have reflected the current position of the study area due to the long time lapse since the last national census was conducted. The Kenya national censuses are conducted every 10 years; the next is due in 2009.

In order to obtain representative data on greywater management and reuse, three possible selection criteria were identified for characterising the households to participate in the social survey. The three criteria were selected based on their likelihood to influence greywater generation. These included;

i) Water supply service (piped water inside yard or off-site)
ii) Annual income (household expenditure); (below Ksh 72,000[Euro 780] or above Ksh 72,000)
iii) Dwelling type (informal dwelling unit or permanent structures)

The data on the annual income specifically for the households in Waruku area was not available in the household income survey data provided by the Kenya Bureau of Statistics and hence it was not possible to use this criterion to categorise different households for the study.

A similar study conducted in non-sewered informal settlements in S. Africa, (Carden *et al.*, 2007a) observed a high degree of correlation between water supply, income and dwelling type, suggesting that any of the three criteria can be used as " data filter'' when attempting to differentiate the settlements for a social survey in an informal settlement area. In this study, I therefore decided that dwelling type to be used as the criteria for characterising households to participate in the socio-economic survey (informal or permanent). The data on the classification of Waruku in terms of the identified dwelling types was available in a report (MnU, 2007), based on the study conducted by the local NGO, Maji na Ufanisi.

To ensure that the collected data was representative of Waruku as a whole an appropriate sampling plan was followed and an adequate sample size was taken, as described below:

3.2.1. Sampling Plan for the households interviewed

A stratified method of random sampling was adopted for the socio-economic assessment. Using this method, the area under study was divided into two clusters with distinct qualities. The two clusters (heterogeneous) were developed depending on the type of dwelling units; informal dwelling units (mud and tin houses) and permanent units (brick and masonry houses). Each of the two clusters was subjected to a sample size relative to its relative size.

Within each cluster (category), the households were taken to have homogenous (similar) characteristics and thus sampling within each cluster was done randomly.

Figure 3-1:Typical cluster 1 dwelling type in Waruku; Informal dwelling unit (mud and tin houses)

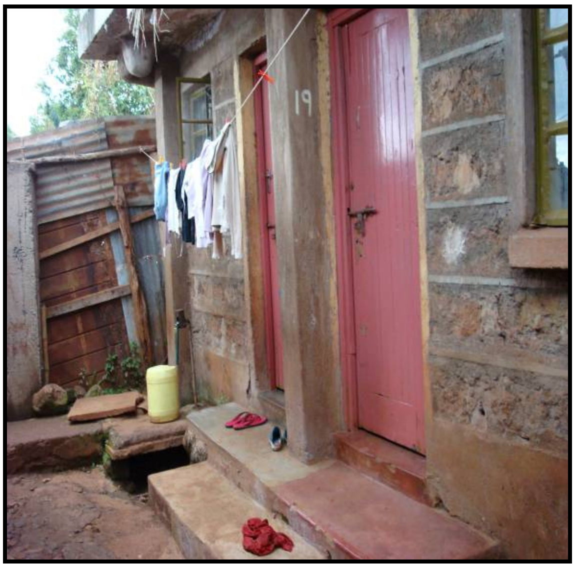


Figure 3-2:Typical cluster 2 dwelling type in Waruku; Permanent structure (brick and masonry houses)

Informal dwellings (mud and tin houses) formed 70% of the housing structure types in Waruku slum area according to the study conducted by the local NGO, Maji na Ufanisi (MnU, 2007).

3.2.2. Sample size of the households

The sample size adopted was aimed at achieving 95% confidence interval (CI) with 10% error margin. The following statistical formula was used:

$$n = k^2 r(100 - r) * \frac{1}{e^2} \qquad \text{(Bernstein, 2004)}$$

Where n= the required sample size, k =1.96 (95% CI), r= 50 (maximum safe upper limit taking survey population as completely heterogeneous) and e = the margin of error (or sampling error) in %. For 95% Confidence Interval and at 10% error margin, the number of samples required for Waruku households survey was **96**.

Table 3-2 gives the sample size (no. of households) per cluster based on the relative number of dwelling types in Waruku that was used in the study.

Table 3-2: Sample size based on the predefined clusters used in the household survey

Cluster	Cluster description	Percentage of dwelling type	Sample size required (No. of households for each cluster)	Sample size taken
1	Informal dwelling type (mud and tin houses)	70%	67	77
2	Permanent dwelling type (brick and masonry houses)	30%	29	33
Total		100%	**96**	**110**

3.2.3. Interview procedure

The Waruku area was divided into four sampling zones and each zone was subjected to a sample size as determined in the Table 3-2 depending on the relative settlement density as determined from an aerial map of the area (the map is given in the Figure 3-10). This was done to avoid taking biased data which could have resulted from sampling only limited areas.

In each zone, the household to be involved in the study was selected randomly and with the help of a member of the local Community Based Organisation (CBO), WACODEP the pre-selected household was visited and where the owner of the house was available she/he was requested for an interview. Otherwise, another household in the neighbourhood was selected and the interview conducted and recorded.

The members of the local CBO were involved in the study in the initial part of the exercise in order to win quick and valuable support of the Waruku residents. The community (CBO) representatives were acting as translators and intermediaries during the survey process if required. This approach enabled the administration of the questionnaires to progress smoothly thereby saving a lot of time for the interviewing team.

The survey team always included a person who was fluent in the predominant language of the settlement to facilitate first-hand communication with the residents and act as an intermediary where necessary.

The Figure 3-3 shows a simplified procedure used for the interview method to collect socio-economic data for the research.

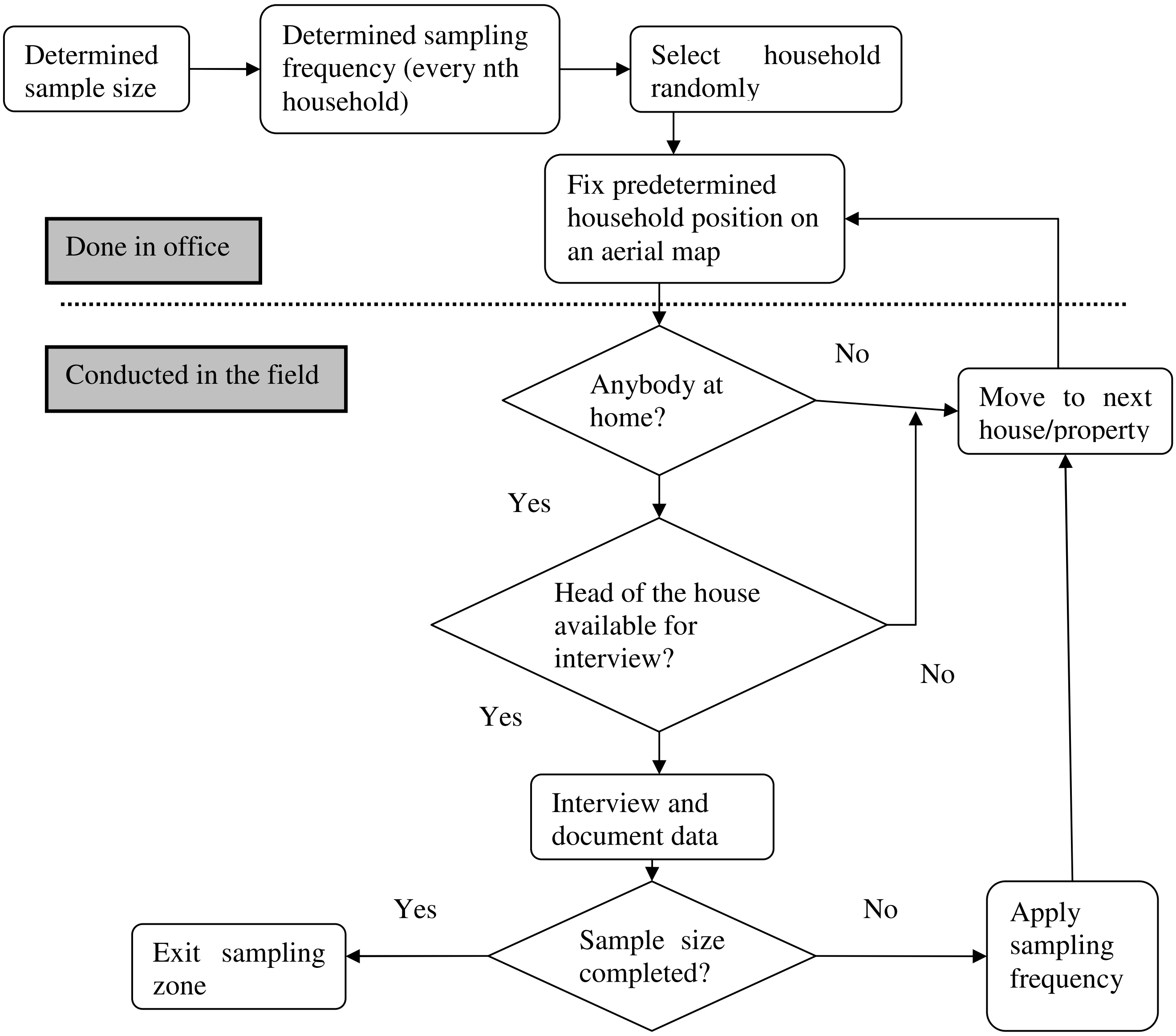


Figure 3-3: Schematic of the interview procedure used in the social survey

In addition to the information obtained using the survey questionnaire form, photographs were taken to record the observations in the settlement related to greywater. Detailed notes were taken to identify the position of the photograph taken.

3.2.4. Semi-structured detailed interview

In addition to the questionnaires, several direct detailed interviews with some relevant stakeholders in the area such as institutions responsible for water supply and sanitations such as Nairobi Water Company, Community based organisations (CBOs) and relevant NGOs were conducted. The interviews helped to verify and cross-check the statements of the individual residents.

3.2.5. Analysis of the Questionnaire exercise results

The data gathered using the questionnaire method was further analysed using Excel software and relevant findings regarding the greywater disposal practices and reuse, the residents' perceptions of treated greywater reuse, etc were drawn. The results of the detailed survey questionnaire analysis are provided in Appendix 3.

3.3. Quantification of greywater generation

One of the objectives of this research study was to quantify the greywater generated in Waruku informal settlement. This section details the method adopted to quantify greywater generation rate in Waruku.

3.3.1. Greywater production determination

The determination of greywater production from households in Waruku low-income settlement was important for the computation of pollutant loads to the land application e.g. sodium loads to the soil environment (see Section 5.4).

The generation of greywater is directly related to water consumption in a household and is dependent on a number of factors including the level of water service provision. In Waruku area, most of the households do not have individual water meters which make it difficult to obtain actual household water consumption figures. Most of the households have shared standpipes. In addition, the greywater generated from the households is generally disposed of outside onto the open ground or to the few existing stormwater drains and this makes it also difficult to obtain the actual greywater generated.

However, to overcome this problem in the measurements of the actual greywater production, the method used by (Stephenson *et al.*,2006) cited by (Carden *et al.*, 2007a), for the low-income non-sewered settlements in South Africa was adopted as described below:

Based on the two clusters described in Section 3.2, and the questionnaires administered, seven households were selected randomly. For the households that were willing to participate in the greywater quantification exercise, I provided them with 200-litre drums for the disposal of their greywater to allow for the direct measurements of daily greywater production.

In order to get a representative greywater quantity data, the seven selected households were further analysed on the basis of the number of persons in a household (household size). The household size has a direct influence on the household water consumption and thus directly affects greywater production.

Table 3-3 and Table 3-4 show the number of households that participated in the greywater quantification exercise in both categories (clusters) and the procedure for their determination based on the household size.

Table 3-3:No. of households that participated in the greywater quantification exercise in cluster 1

Cluster 1: Informal dwelling units (mud and tin houses)			
No. of persons	No. of Interviewed households	Percentage (%)	Households participated in GW quantification exercise
1 - 3	50	65	**3**
4 - 6	26	34	**2**
More than 6	1	1	
Total	77	100	**5**

Table 3-4: No. of households that participated in the greywater quantification exercise in cluster 2

Cluster 2: Permanent dwelling units (block and masonry houses)			
No. of persons	No. of Interviewed households	Percentage (%)	Households participated in GW quantification exercise
1 - 3	12	36	**1**
4 - 6	19	58	**1**
More than 6	2	6	
Total	33	100	**2**

After taking the daily actual measurements of greywater generated from the participating households, I was emptying the drums and gave them back to the participants for the day storage of greywater. The amounts of greywater production were being checked against water consumption in the selected households to ensure that accurate data was obtained. The water consumption data was estimated from the number of water jerry-cans (water fetching containers) used daily by the households participating in the study.

Figure 3-4: A cluster 1 participant putting greywater into the provided drum

Figure 3-5: A cluster 2 participant disposing laundry water into the provided greywater collection drum

In addition to the actual greywater measurements, the data on the number of persons in the household that had contributed to the greywater generation was taken. This exercise was conducted for four weeks, from 26th November to 21st December 2007.

The water consumption and greywater data obtained from the study were analysed using Excel software and the greywater return factor calculated. Greywater return factor refers to the proportion of the greywater production to the total freshwater consumption expressed as a percentage. In addition, per capita greywater production for the Waruku area was computed.

3.4. Greywater sampling and analysis

The establishment of greywater characteristics in Waruku area was another objective of this research study. To realise this objective, greywater sampling and analysis were conducted.

3.4.1. Greywater sampling

Based on the detailed household survey conducted in the study area, a detailed greywater sampling plan was developed. The greywater samples were taken from the drums provided to the seven households that had earlier been selected statistically for greywater quantification exercise as detailed in Section 3.3.1.

Since greywater characteristics are directly influenced by greywater production that is further dependent on the per capita water consumption, the greywater sampling was conducted concurrently with the greywater quantification exercise.

The samples were taken at certain times in the day with an overall aim to obtain realistic average for a 24-hour period. For this research, greywater quality hourly variations were not important, only the 24-hour averages.

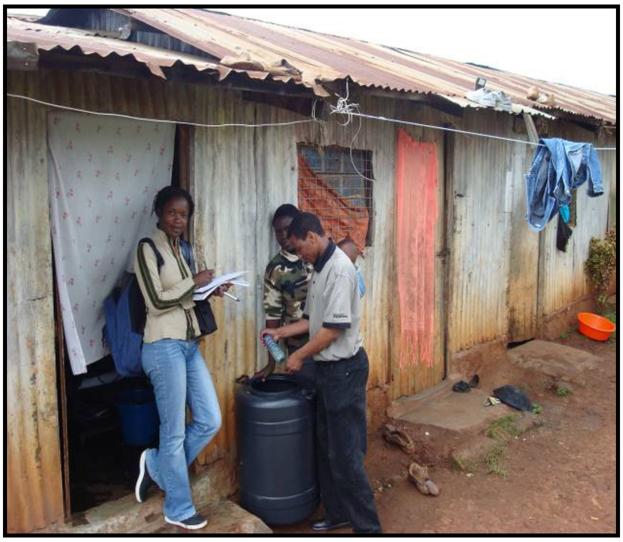


Figure 3-6:The author sampling greywater from a drum provided to a participating household in cluster 1

Figure 3-7: The author performing a field test from a drum provided to a cluster 2 participant

- Before each sample was taken, the greywater collected in the drum was adequately stirred and the sampling plastic container rinsed at least three times. This was done to ensure that a representative sample was collected. Then samples were accordingly labelled indicating sample number, date and time of collection and place of collection. All the samples were taken to the laboratory within a span of 2 hours for analysis.

The greywater cation analysis was carried out at the Mines and Geology Laboratory in Nairobi. Eighty greywater samples were collected during the exercise, which was spread over a period of four weeks, from 26th November to 21st December 2007.

In addition, twelve greywater samples were collected and taken to the Central Water Testing Laboratory in Nairobi for COD, BOD, FC and TSS analysis under a commercial arrangement. I did not participate in the analysis of these samples but I filtered the samples at the Laboratory through a 0.45μm filter paper after prewashing them with one-litre distilled water to obtain 12 greywater samples, which were later tested for DOC, SUVA and TN at the IHE laboratory.

3.4.2. Greywater analysis

All chemical analysis were analysed by standard procedures (Standard Methods for Examination of Water and Wastewater, 1998). The samples were analysed for sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations using Flame Atomic Absorption spectrophotometer; model SpectrAA-10; 5-day Biochemical oxygen demand (BOD_5); Chemical oxygen demand (COD) by dichromate digestion and Faecal Coliform (FC) by pore plate method.

In order to reduce on the cost of greywater analysis, the samples were analysed in the field for electrical conductivity (EC) with a WTW LF340 meter and for pH with WTW pH 340i meter. Both meters were provided by the IHE laboratory.

The samples were also analysed for specific UV adsorption (SUVA) at 254 nm using UV- Spectrophotometer model Shimadzu UV-2501PC; Dissolved organic carbon (DOC) and Total nitrogen (TN) using Shimadzu TOC-V_{CPN} carbon analyser.

Based on the laboratory results, further analyses were done to compute greywater SAR and other relevant ratios using excel software. To obtain more representative assessment of greywater constituent concentrations, the greywater flow-weighted average was computed using the following equation:

$$\overline{C} = \frac{\sum_{i=1}^{n} Qi.Ci}{\sum_{i=1}^{n} Qi}$$

where: $\overline{C}$ = Flow-weighted average constituent concentration

Ci = 24-hr average concentration of the constituent for i_{th} tested sample during the four weeks of sampling

Qi = 24-hr average household greywater production

n = number of tested samples

From the analysis, an excel-based model was developed, which together with SALF PREDICT[1] software, was used to assess suitability of the Waruku greywater quality as irrigation water.

In addition, the greywater quality data obtained in the study was assessed against literature values to predict possible impacts of greywater on soil properties. Important greywater effects on soil characteristics evaluated include:

- Soil infiltration rate
- Soil structural stability

3.5. Soil sampling and analysis

In order to investigate the impacts of the long-term greywater disposal on soil properties and to assess whether the disposal practice could affect urban agriculture in Waruku area, soil sampling and analysis were conducted.

3.5.1. Soil sampling

To investigate to what extent greywater disposal over an extended period of time in Waruku informal settlement had altered the soil properties, soil sampling was carried out. The soil sampling was done in December 2007 to January 2008.

The study was confined to two sites within Waruku area. The first site (marked as Site A in the Figure 3-10) is an open parcel of land located in the middle of the settlements, to where greywater has been draining over an extended period of time. This area is referred to, in this report, as "greywater disposal site''. It had been drained with greywater from the adjacent settlements for more than 20 years, according to the Waruku residents. The disposal site can thus be considered as a full-scale field laboratory for the study of the long-term effects (20 years) of irrigation with untreated greywater. It therefore provides an opportunity to investigate the impacts of long-term greywater reuse on soil properties.

The greywater disposal site is a privately-owned plot that measured 45 m x 90 m (4050 m²). The authority to use the piece of land for this research work was granted by the owner, who had also participated in the household survey conducted under this study. The owner had resided in Waruku for thirty years.

Figure 3-8 and Figure 3-9 show the greywater disposal site.

[1] SALF PREDICT software is a steady-state software that predicts the effects of irrigation water on soil root zone salinity, leaching fraction and plant salinity response, based on soil properties and salt balance. The software was provided by the Department of Natural Resources, Queensland, Australia.

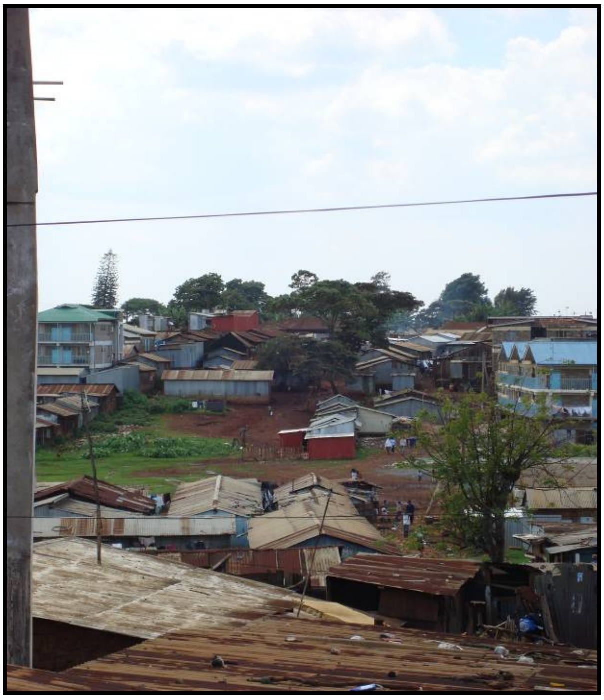


Figure 3-8: Greywater disposal site located in the middle of the informal settlements

Figure 3-9: Greywater disposal site photo taken at a close range

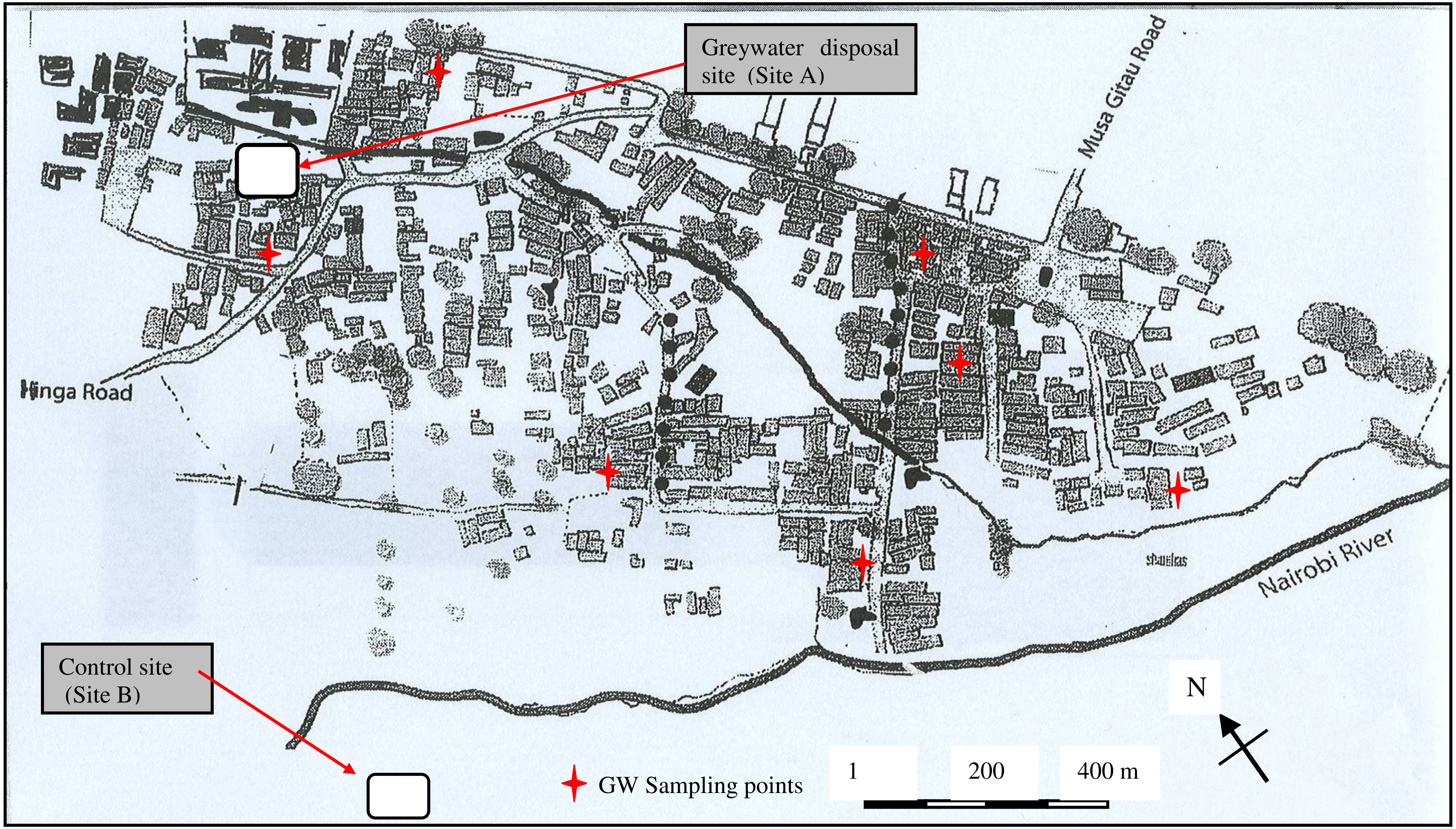


Figure 3-10: Map of the study area of Waruku, Nairobi

The greywater disposal site had not been monitored earlier. Thus, the present study had no base data upon which to develop a clear vision on the long-term effects of greywater disposal on soil characteristics for the site. In order to obtain comparative effects of greywater disposal on soil in the disposal site, a second site (control) was identified. The control site (non-greywater irrigated site) was studied to provide background information on soil characteristics in a site unaffected by greywater disposal.

The second site, which was taken as control and marked as site B in the Figure 3-10, was situated in an area within Waruku which has had no greywater irrigation in the known history. The area was identified with the help of Mzee Thuo Kinyanjui, an 82-year old Waruku resident. Mzee Kinyanjui has resided in Waruku for more than 50 years. The site is located on a privately owned unbuilt land which made it reasonably possible that it had not been cultivated nor irrigated with greywater in the last 20 years.

The criteria for the selection of the control site was its locality in the same neighbourhood as the disposal site (located in Waruku area), had similar geologic (soil) and climatic conditions and was unlikely to have been influenced by greywater disposal as would have occurred on the disposal site. The two sites are assumed to have had similar soil characteristics before the greywater disposal site was affected by human interventions.

To collect representative soil samples, composite samples were made from an approximately one metre diameter circle around the sampling point pegged on the ground. 1000g of thoroughly mixed composite sample was collected, bagged and marked accordingly. Root materials and stones were discarded at sampling.

As the project had a working budget for the laboratory analysis, a total of five horizontal profiles were selected, each with three sampling points. The horizontal profiles, designated with the letters A-E based on the downhill distances as shown in Figure 5-13, were spaced at approximately 15-20m depending on the local surface conditions. Therefore, from the greywater disposal site, a total of 15 soil samples were collected. The soil samples were taken to a depth of 150mm. From the control site, a total of six samples were collected to the same depth as for the first site.

In order to understand the effect of greywater on soil hydraulic conductivity (permeability), six undisturbed core samples were taken from the control site. The samples were collected by driving steel tubes of 50mm diameter and 50mm height to about 10cm into the soil. The steel tubes were then carefully removed from the soil, the open sides trimmed and then the tubes were covered with a plastic lid ready for delivery to the laboratory. The sampling steel tubes were provided by the Kenya National Soil Survey Laboratory, which is located in the neighbourhood of the study site of Waruku.

After soil sampling, the soil samples were taken to the Kenya Agricultural Research Institute (KARI), Soil Survey Laboratory for the soil analysis.

In addition to the soil sampling, a topographical survey of the greywater disposal site was carried out. In the survey, data on the relative heights of all the soil sampling points were obtained. The toposurvey was done using theodolite survey equipment hired from a private land surveyor. All levels were based on a local datum (taken arbitrary as 100m).

3.5.2. Soil laboratory analysis

In the laboratory, the soil samples were transferred to plastic trays for air-drying at room temperature and then were sieved through a 2mm sieve. Clods, not passing through the sieve were carefully crushed by a pestle and mortar and sieved again. The fraction less than 2mm (air-dry fine earth) was homogenised and constituted the sample that was subjected to the laboratory analysis. Each sample was accordingly labelled.

With assistance from experienced laboratory technical officers, I performed the analytical tasks at KARI Soil Survey Laboratory. All the tests were conducted under the normal quality protocols using reference methods acceptable for Kenyan conditions.

All the soil samples were analysed using the standard soil testing methods. The soil samples were analysed for Organic carbon by Walkley-Black method (Walkley and Black, 1934) using UV spectrophotometer model PU8670. Then organic matter was computed by multiplying organic carbon fraction by a factor of two (van Reeuwijk, 2002).

For the exchangeable cations determination, Ammonium acetate extraction method adjusted to pH 7.0 was used. Exchangeable Na^+ and K^+ were measured using Flame emission spectrophotometer (FES); Corning Flame photometer 410 model while exchangeable Ca^{2+} and Mg^{2+} were measured by flame atomic absorption spectrophotometer (AAS).

For the determination of the soil sample CEC, the same sample used for the cations determination was leached again with 4 portions of 25ml of 98% alcohol followed by potassium chloride. From the leachate, the measurements for the CEC were taken using the Skalar segmented flow analyser; model SA9000 on-line process analyser.

The soil samples were also analysed for soil pH measured in the supernatant suspension of a 1: 2.5 soil to water mixture. In addition, the samples were analysed for EC and ECe (electrical conductivity of water extract obtained from the saturated soil paste) and measurements taken using conductivity meter model WTW LF91.

Further to the chemical analysis, the soil samples were analysed for soil texture using hydrometer method, from which the clay content (%) was determined. The soil textural classification was based on (USDA, 1993), the classification chart is provided in Appendix 4.

For the soil hydraulic conductivity tests, the laboratory measurements were done on saturated soil samples. The undisturbed samples were soaked in water for an overnight in order to be completely saturated. Then the samples were transferred to the conductivity rack, from where the hydraulic conductivity test was conducted using greywater under a constant head condition. The soil hydraulic conductivity coefficient, *k* was calculated using the Darcy's law of flow of water in a soil. The test was repeated for different values of greywater SAR and new sets of permeability coefficients, k obtained. The increase in greywater SAR values were realised by adding known concentrations of sodium. Sodium hydroxides pellets were used.

Based on the CEC and exchangeable cations measurements, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) were calculated. Laboratory analytical data were tabulated, graphed and statistically analysed using Excel and SPSS softwares. Contoured map of the disposal site and surface plot of ESP of the disposal site relative to the control area were be made using ArcGIS to display greywater impacts and the topographical spread of its constituents.

3.5.3. Precision and accuracy

In order to enhance the accuracy and precision of the laboratory analysis, the following quality control checks were observed:

- A control sample (reference standard soil sample) of known concentration was used in each of the soil batch tested.
- For the batch of the greywater samples tested there was a duplicate sample (acceptance criteria of the duplicates ± 10% of the arithmetic mean).
- Using a reagent blank in each analysis.
- Distilled water was always used for rinsing and making the solutions.

3.6. Limitations of the study

The research findings on the effect of greywater disposal on soil properties were based on one-time soil measurements. The disposal site had not been earlier monitored and due to the time limitations it was not possible to monitor the disposal site over a time after the initial soil measurements were taken. More soil samples taken at different time intervals (e.g after several years) would have been necessary to confirm the results and provide a clear vision on the changes in the soil properties.

The investigation on the greywater characteristics were based on only seven households that were surveyed during four weeks of sampling. Although great effort was made by extending sampling duration to cater for the expected water consumption seasonal variations, the quality of data (accuracy) would have improved if a higher number of households were surveyed. More resource allocation would be required.

4. Background information of the Study area of Waruku

This chapter details briefly the background information of the research case study area of Waruku in Nairobi.

4.1. Waruku, an informal settlement in Nairobi, Kenya

4.1.1. Introduction

The Waruku informal settlement is a non-sewered, low-income area located on the north-western part of Nairobi, the capital city of Kenya. Figure 4-1 shows the map of Kenya, showing the location of the Nairobi city.

It is located approximately 15 km from the city centre and it is part of the larger Kangemi informal settlement area. It is situated ($01^{o}16'$S, 36^{o} 45'E) at an altitude of 1942m.

Figure 4-1: Map of Kenya showing Nairobi, the capital city of Kenya (CIA, 2007)

Figure 4-2 shows the physical location of the study area of Waruku on the map of Nairobi

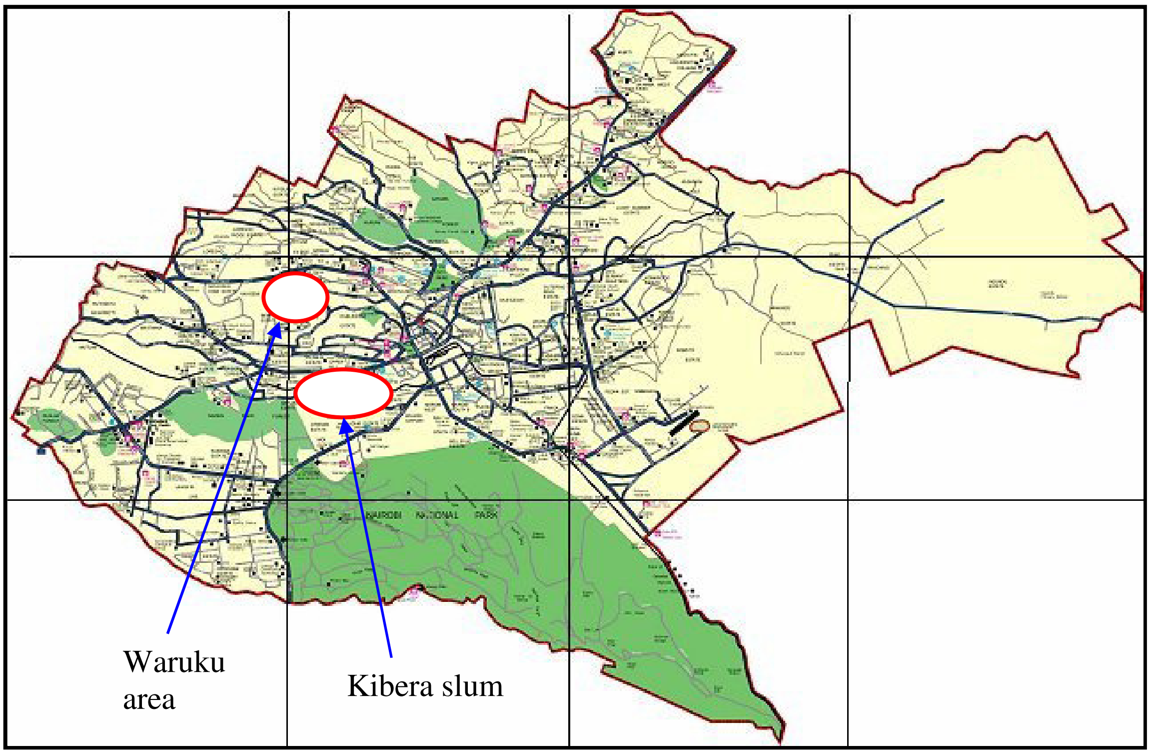


Figure 4-2: Map of Nairobi showing the location of the study area of Waruku (Source: http://www.hassconsult.co.ke)

Figure 4-3 shows the Google earth map of the study area of Waruku.

Figure 4-3: Google Earth image of Waruku, Nairobi (Accessed on 2 November 2007)

The climatic condition of the study area is wet with an average annual rainfall of 1000 mm. The average maximum and minimum temperatures are 24°C and 13°C respectively. The climatic data is based on the meteorological data for Kabete Agromet Station (01°15'S, 36° 44'E), located less than 1 km from Waruku. The average relative humidity ranges from daily minimum of 55% to a maximum of 82% (Kenya Meteorological Department, Nairobi). The complete climatic data provided is given in Appendix 15.

4.1.2. Population

Waruku has an approximate population of 10,000 people with a population density of about 500 persons/ ha (MnU, 2007). The area has people of multi-ethnic background.

It has a blend of the poor on public land and not so poor people settled in their individually owned land. Like most other poor settlements in Nairobi, Waruku people have inadequate and inefficient sanitation systems.

The area is situated along the transit corridor of workers from Kawangware informal settlement to Westlands and Kyuna (these are affluent neighbourhoods where slum dwellers go to work as manual labourers and domestic workers).

4.1.3. Water supply

The main source of water supply in Waruku is the piped water supplied by Nairobi Water and Sewerage Company. According to the residents, although the water supply in the area is regular it has low pressure due to the small diameter of the supply line that is totally insufficient for the water demand.

There is a main water pipeline that passes through Waruku and goes to Karen (a high income settlement area) but the Waruku residents are not allowed to connect. According to the residents, the pipeline has water throughout without any rationing. Most people in Waruku are low-income tenants residing in tinned houses that have yard taps. However, the landlords ration water for the tenants by limiting the number of water jerry-cans they can fetch from the yard taps.

Some land owners provide water to the tenants at only certain times and days of the week. In most cases, the water charges are included in the monthly rent payable to the structure owner, who pays for the services to the water company. In some cases, the tenants are charged by the land owners for exceeding the stipulated amount at a rate of Ksh. 2 to 5 per 20 litre Jerry-can.

In Waruku area, there are no vendors who sell water. The individual landlords act as small-scale independent water providers by selling water to the public in addition to their tenants. The price of water in Waruku ranges between Ksh. 2 to 5 per 20-litre Jerry-can. The prices vary from plot to plot but they rarely fluctuate by season.

Some plot owners have bore-holes (these are few. I noticed only three bore-holes) to supplement water from the water company. The borehole water is normally used for laundry water (not for drinking or cooking).

Figure 4-4:Borehole at private property in Waruku that is used as supplementary source of laundry water

Figure 4-5: Queuing for water at a yard tap connection in Waruku

4.2. Waruku greywater management and urban agriculture

This section describes briefly greywater management and urban agriculture practiced in Waruku as was observed by the author during the field inspection visits, made before detailed collection of greywater and soil data.

4.2.1. Greywater management

Waruku area has an inadequate wastewater management system. The greywater was commonly discharged untreated into the open stormwater drainage channels, on open fields or directly into the Nairobi River.

In some cases, the greywater was discharged to the few existing stormwater drains that are highly clogged by solid waste. In other cases, the greywater was discharged into garbage damping sites. Since the area lacked a proper solid waste management system, the poor disposal of greywater can have a detrimental impact on public health and the environment.

In a few cases, some households discharged untreated greywater into their small household gardens, where they predominantly grow vegetables such as cabbages and kale. The produce from these gardens supplements the families' food needs.

Figure 4-6: Greywater draining to solid-waste filled stormwater drain in Waruku

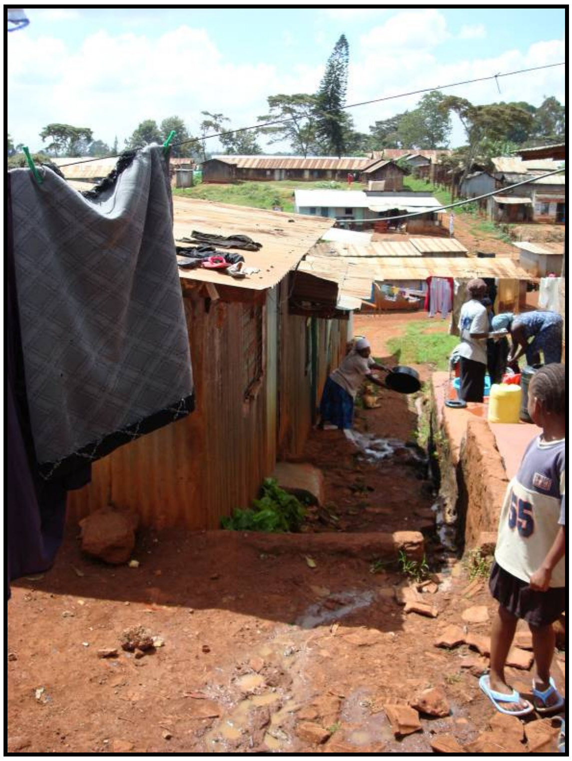


Figure 4-7: A woman discharging untreated greywater outside her house into an open drain

4.2.2. Urban agriculture

Urban agriculture was to some extent practised in the Waruku area, particularly along the highly polluted Nairobi River. It was mainly practiced by the land owners, some of whom are absentee landlords who have rented out the land to tenants. However, the number of Waruku residents, who are chiefly tenants, that practice urban agriculture was low.

The urban agriculture practiced in Waruku mainly centred on subsistence farming producing mostly vegetables such as kale (Brassica campestris[2]), cabbage and spinach. Other crops grown include arrow roots, sweet potatoes, sugarcane, maize and bananas.

The use of highly polluted Nairobi River water to practice urban agriculture as it is done in Waruku raises serious concern on the potential health threats to the local population. The river is highly polluted with untreated wastewater from unsewered areas of the upstream larger Kangemi informal settlement. The farmers taking water from Nairobi River are practising indirect reuse of urban wastewater (Hide *et al.*, 2001), which may have health and environmental consequences.

It was noted that some Waruku tenants also practice urban agriculture by utilising untreated greywater to grow vegetables particularly sukuma wiki (kale), cabbage and spinach.

[2] Commonly known as sukuma wiki in Kiswahili (Kenya's national language). It is extensively used as a vegetable in Nairobi

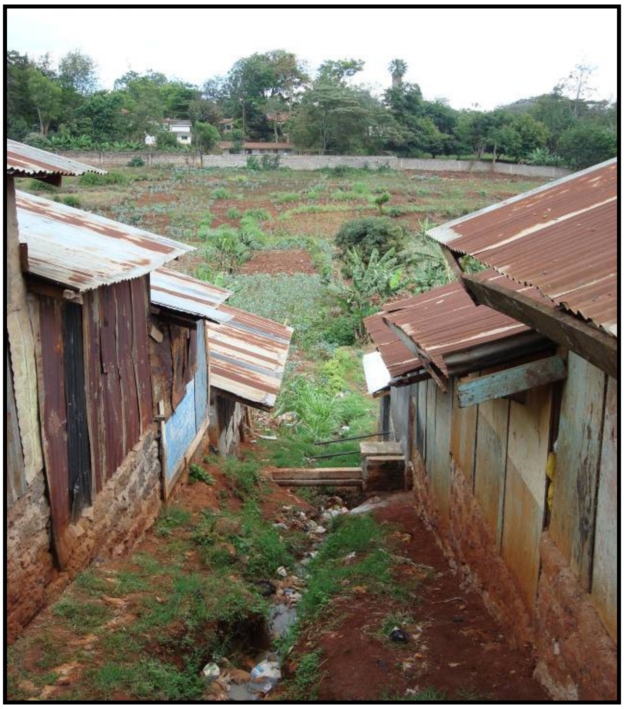


Figure 4-8: Stormwater channel conveying untreated greywater to a farm cultivated with vegetables in Waruku

Figure 4-9: Urban agriculture practiced in Waruku (growing cabbages)

4.2.3. Soil characteristics in Waruku

The soil in Waruku is a humic nitisols developed on volcanic rocks, which are predominantly trachytes i.e. intermediate igneous rocks. The humic nitisols have homogeneous clay-rich horizon with characteristic reddish colour arising from high iron oxide content (Kenya soil map).

The soil in the area is well- drained, very deep, dark reddish, brown to dark red, friable clay locally referred to as the Kikuyu red clay loam (Kapkiyai *et al.*, 1998).

5. Results and Discussions

This chapter presents the results of the research study and the findings are discussed in the context of the research stated specific objectives.

5.1. Greywater disposal practices and residents perception of reuse

5.1.1. Greywater disposal practices and reuse at the household level

Using open-ended questions, respondents were asked to state their main greywater disposal practices, describe the ways in which they deal with different greywater streams and to state their main concerns about the current status of greywater management. A complete questionnaire analysis of the results is presented in the Appendix 3.

In Waruku, the main greywater disposal practice entailed discharging untreated greywater onto open ground outside dwellings/stormwater drains or directly to the Nairobi River, for those households located in its neighbourhood. This mode of greywater disposal route accounts for 79% of the major avenues of greywater disposal identified by the residents (see Question no. D1 in Appendix 3) .

Figure 5-1 shows the major greywater disposal practices in Waruku as identified by 110 households interviewed in this study.

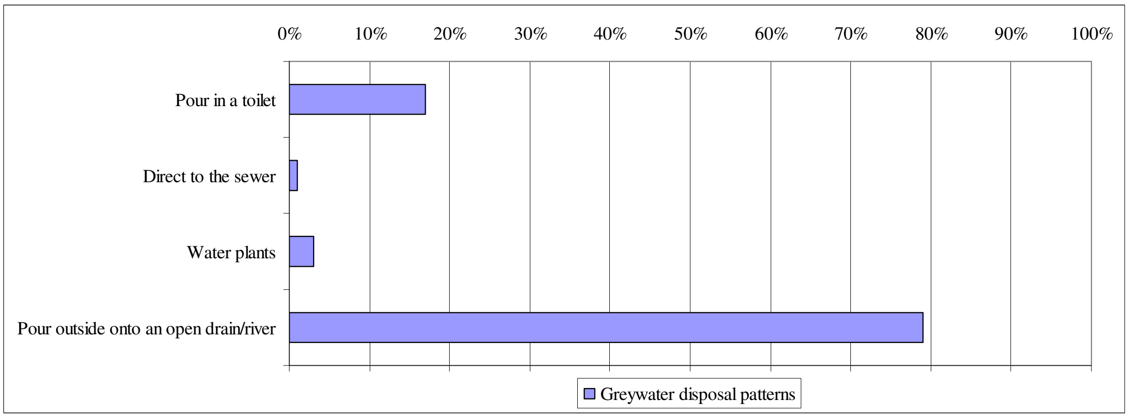


Figure 5-1: Current greywater disposal routes in Waruku area (No. of households sampled, n =110)

The disposal of untreated greywater mainly onto the open drains can be attributed to inadequate greywater management systems in the area. In some parts of the area, lined drains have been constructed, providing quick conveyance of untreated greywater to the Nairobi River, thus further polluting the surface water source.

Another significant greywater disposal route is discharging greywater directly into toilets, of which 53% are pit latrines (see Question no. G1 in Appendix 3). About 17% of Waruku residents discharge greywater directly to their toilets. This may be partly due to inadequte drainage channels in the area or possibly their sensitivity to health risks associated with unplanned greywater disposal. About 78% of the residents consider current greywater disposal practices to be of major health and environmental problems in their neighbourhood (see Question no. F1 in Appendix 3). Of these, 45% of the residents identified health-related concerns particularly malarial outbreaks as their major problem. This is expected considering that the area is in the tropics with an average temperature of 20^{o}C.

Suprisingly, 22% of the respondents were contented with the current greywater disposal practices (see Question no. F1 in Appendix 3). According to them, the existing disposal practices were perceived as of no major health and environmental problems. Public awareness campaigns on the effects of greywater disposal may be necessary.

In addition to the investigation of the greywater disposal practices, the study evaluated the extent of reuse of different greywater streams at the household level prior to final discharge to the identified disposal routes shown in Figure 5-1. The Figure 5-2 shows the results of different reuse or disposal options being practiced in Waruku for different greywater streams.

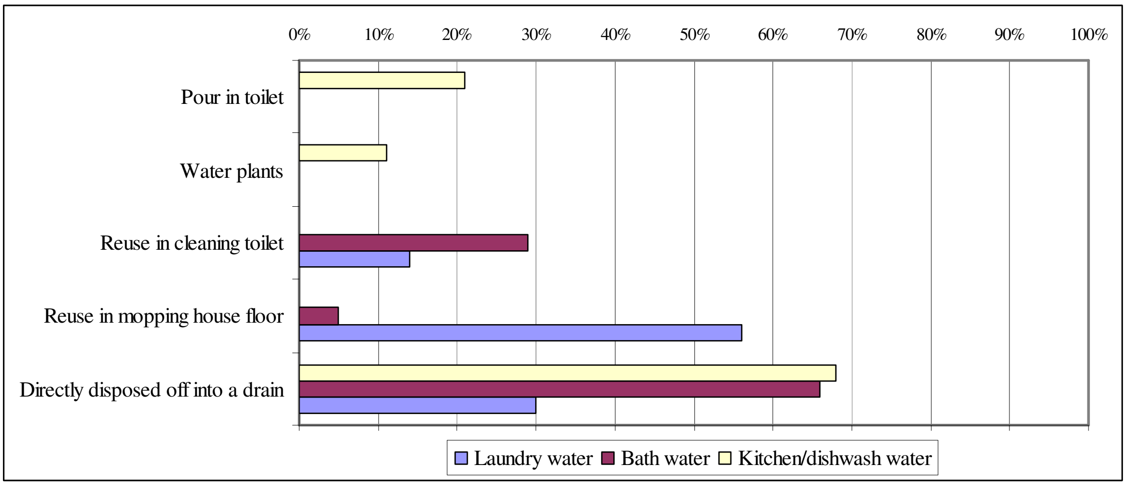


Figure 5-2: Disposal/reuse options of the different greywater streams in Waruku

Laundry water is predominantly reused at household level to clean the house floor. About 56% of the residents reuse it for this activity possibly to save on water and detergents (see Question no. D3a in Appendix 3). Laundry water used for rinsing clothes is perceived to be clean and still contains high concentration of the hydrophilic detergents that are effective in removing dirt from the floors. The internal reuse of this stream therefore contributes to the overall reduction of fresh (clean) water needs at the households level thereby resulting in minimised cost of clean water for the households where it is practiced.

Although the laundry water is highly reused at the household level, it is finally disposed of onto the outside drains. About 30% of the residents dispose of this stream directly to the outside drains. Encouragingly, some of the residents (14%) use this stream to clean their toilets (see Question no. D3a in Appendix 3). This ensures that toilet facilities are kept tidy while also minimising health risks. This reason can partly explain why this disposal route is being practised by some of the residents.

Figure 5-3: Greywater reuse at the household level for toilet cleaning (slab of a pit latrine) in Waruku

Figure 5-4: Greywater (laundry water) reuse at the household level for cleaning the houses floor in Waruku

Kitchen/ dishwash water is the stream of greywater that is limitedly reused at the household level and therefore it is largely disposed of in the outside drains. While 68% of the residents discharge it directly to the drains and 21% of them pour it out in the toilets, about 10% of the residents reuse it to water plants (see Question no. D3b in Appendix 3).

Although only 14% of the residents practice urban agriculture in Waruku, recognition by some of the residents of the value of kitchen water as irrigation water is worth noting (see Question no. E1 in Appendix 3). However, this greywater stream is reused untreated to grow mainly vegetables for domestic nutritional requirements. The motivation for this can be realisation that this greywater stream has high organic matter content that could benefit household gardens, providing important plant nutrients in addition to meeting water needs for the grown crops.

Bath water, like kitchen/dishwash water, is another greywater stream that is also largely disposed of directly onto the outside drains although some of the residents (29%) reuse it to clean the toilets (see Question no. D3c in Appendix 3). Some of the residents have the toilet facilities doubling as bath rooms and this can partly explain the significant contribution of this disposal route for bath water. Bath water is however, rarely used to water plants. It is perceived as harmful to plants possibly due to detergents that residents regard as both harmful to plants and to their health. Actually, when asked during the study whether they could feed on crops grown on treated greywater, of the 16% of the respondents who answered to the negative, 56% of them attributed their response to greywater's high detergents (chemical) content which were perceived as harmful (see Questions no. F4 and F4b in Appendix 3).

From the study, it was apparent that the residents were more concerned about the current greywater disposal practices impact on health and safety issues than direct environmental issues. Only 10% of the residents expressed concern about greywater disposal to the surface water system (Nairobi River) and to the roads (see Question no. F1b in Appendix 3). This perception seems to, a large extent, influence greywater disposal patterns in Waruku. It was therefore not surprising that about 56% of the residents consider construction/renovation of the drains to convey untreated greywater to the river as their preferred solution to the current greywater disposal problems (see Question no. F2 in Appendix 3).

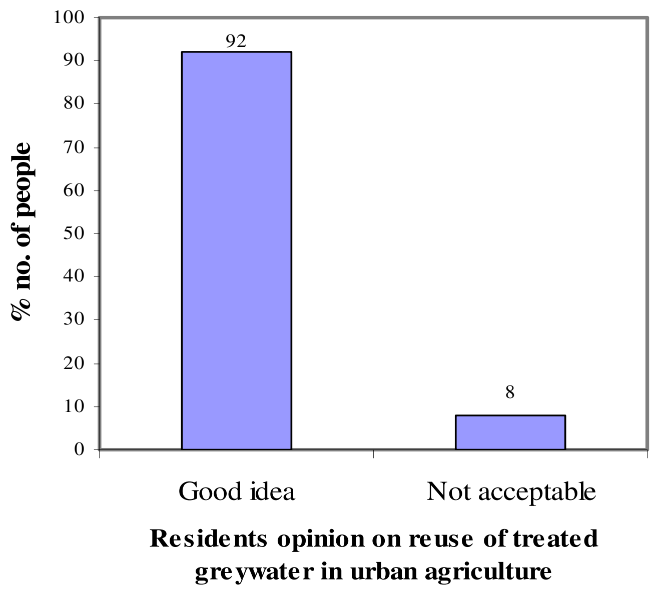
The suggestion by the residents that the current greywater disposal problems could be solved through construction/ renovation of lined drains to discharge greywater to the surface water (Nairobi River), indicated clearly that greywater disposal in Waruku is largely considered a drainage issue (stormwater problem) rather than wastewater problem. From the field observations, the residents' effort to renovate /construct stormwater drains that also convey untreated greywater to the Nairobi River was evident.

Some of the residents (20%) who were dissatisfied with the current greywater disposal practices were of the opinion that their preferred solution to the problem was to direct untreated greywater to the household gardens (see Question no. F2 in Appendix 3). Perhaps, they were unaware of the possible health and environmental consequences of this practice.

5.1.2. Residents perception of the greywater reuse in urban agriculture

To gain insights on the viability of greywater reuse in agriculture as a vital strategy in greywater management in Kenya's urban informal settlements, largely open-ended questions were administered to Waruku residents which led to clear results.

Figure 5-5 shows the residents' response to the question regarding their opinion on the reuse of treated greywater[3] in urban agriculture (see Questions no. F3 & F4 in Appendix 3).



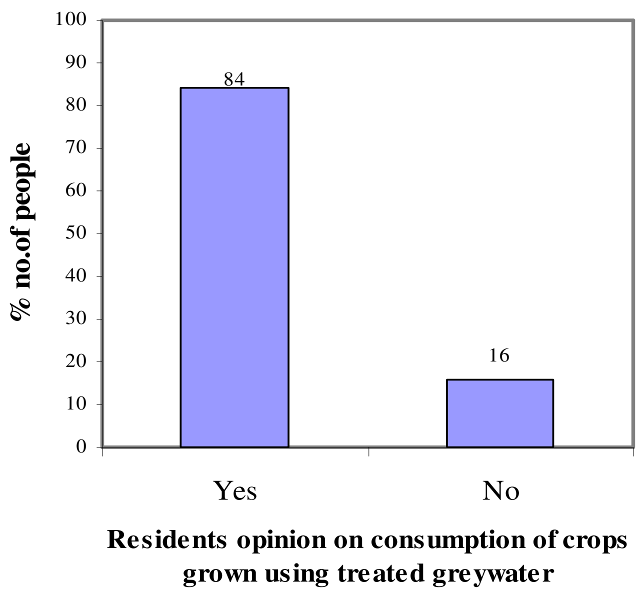


Figure 5-5: Perception of Waruku residents of reuse of treated greywater in urban agriculture

The study revealed that only a small percentage of Waruku residents (14%) practice urban agriculture. They mainly grow vegetables in their backyards and some cultivate along the Nairobi River. Most of those who grow crops at their backyard (40%) reuse

[3] Greywater assumed to be treated to WHO health guidelines for the use of wastewater in agriculture. It is assumed that the greywater has been treated for pathogen and odour potential.

untreated greywater. The figure for those who practice urban agriculture in Waruku is surprisingly lower than that in densely populated Kibera informal settlements in Nairobi. According to the study conducted in Kibera, (Koech, 2006) reported that about 20% of the respondents practiced urban farming using mainly untreated wastewater to irrigate their plots. In Waruku, most people are tenants (85%) who may lack access to household gardens, which can partly justify low urban agriculture practice in the area (see Question no. A3 in Appendix 3).

Figure 5-6: Urban agriculture practiced in Waruku (vegetables grown using untreated greywater)

Despite the low urban agriculture practice in Waruku, from Figure 5-5 it is clear that the residents' perception of the reuse of treated greywater was positive. Over 90% of the residents expressed that reuse of this resource is a positive idea that needs to be encouraged. Even still, 84% of the respondents indicated that they had no problem consuming crops grown with treated greywater.

Only 9% of the residents expressed displeasure with the idea, perceiving the practice as unacceptable and therefore proposing that it should be discouraged. Some of them (16%) indicated that they would not consume crops grown using treated greywater.

For those who supported the idea, some of the reasons advanced were:

- So long as it is well treated and has no smell then we have no problem to use grown vegetables
- It would improve food security and make cost of vegetables cheaper to the community
- It is a good idea because even what we buy (vegetables) we are not sure of how they were grown
- It is fine since crops such as vegetables once they are thoroughly washed are save for human consumption

For those who shared negative perception of reuse of the treated greywater cited some of the following reasons:

- Some believed it is unhygienic as it contains children faeces and doubted whether it could be clean enough to be used for crops meant for human consumption
- Some believed that it is even toxic as it contains harmful chemicals (detergents, shampoos) and therefore it use should be avoided
- Some indicated that they were not wholly opposed to the idea but do not have household gardens to use it to grow crops and/or require to be educated on how use it safely.

From the survey conducted it is apparent that the majority of the respondents (92%) perceive greywater management through reuse of treated greywater in urban agriculture as a positive idea. However, to successfully implement such an initiative, the critical health and safety concerns expressed by the residents must be addressed. The concerns registered included mosquito infestations (malarial outbreaks) due to stagnant water, unpleasant smell due to anaerobic digestion and risks to children falling ill after playing in stagnant greywater. A large number of the respondents (80%) perceived health consequences as their major reason for attributing the current greywater disposal practices as harmful.

5.2. Greywater characterisation

In the previous section, the greywater disposal practices and reuse options in Waruku low-cost area were established and the residents' perception of greywater reuse/disposal to the environment was evaluated.

The environmental effects of the greywater disposal are directly influenced by both quantity of greywater generated and its physico-chemical and biological characteristics. Therefore this section assesses greywater production and greywater characteristics for Waruku area.

5.2.1. Greywater production

The summary of the results of greywater generation obtained from the study of the seven households in Waruku is presented in Table 5-1. A complete analysis of the greywater generation in the households surveyed during the four weeks of sampling is presented in Appendix 5.

Table 5-1: Statistical summary of the results obtained from the actual greywater generation measurements (n = 79)

	Drinking water (Litres/hh/day)	Drinking water (Litres/cap/day)	Greywater (Litres/hh/day)	Greywater (Litres/cap/day)	Greywater return factor
Maximum	240	60	212	55	94
Minimum	60	20	35	12	50
Average	116	34	92	27	80
Standard deviation	41	11	36	10	10
Coefficient of variation (%)	35	33	38	36	12

From the study, the average per capita greywater generation rate in Waruku informal settlement is 27 L/cap/d. The average greywater production per household obtained from the study was 92 L/hh/day. The low greywater production can be attributed to the low quantity of drinking water supplied. The greywater production constitutes 80% of the total clean water consumption in a household. The greywater return factor, i.e. the proportion of greywater production to fresh water consumption of 80% obtained in this study is consistent with values reported in other greywater studies, which typically ranges between 60 and 85% (Carden *et al.*, 2007a); (Jamrah *et al.*, 2007);(Idris *et al.*, 2005). This indicates that greywater as a resource has a large opportunity for reuse as it is the only potential water source, which increases as the population grows and the demand of freshwater increases.

The per capita water consumption in Waruku is 34 L/cap/d. The figure is well within the range reported in other studies in the low-income non-sewered areas in developing countries. A study conducted in non-sewered informal settlements in South Africa, (van Schalkwyk, 1996) reported greywater production estimates ranging from 12 to 50 L/cap/d. The figure obtained in this study was however very low compared to values reported in greywater studies conducted in developed countries where individual household connections are common. The usual range of per capita water consumption in developed countries is 100 L/cap/day and above (Palmquist and Hanaeus, 2005);(Jefferson *et al.*, 2004).

The low per capita water consumption in Waruku can be attributed to the level of water service provision in the area, which is predominantly stand pipes (yard taps). For 79% of the Waruku residents, the main source of domestic water supply is yard connections. In addition to the mode of water service provision which contributes to low water consumption, it was noted that water supply to the residents at the yard connections is rationed by the landlords. About 62% of the residents that use yard tap connections pay for the water monthly to the landlords. The water payments are included in the monthly rent payable to the landlords. Thus landlords ration the water either to reduce wastage or to cut down on the water costs they pay to the Nairobi water company. Some residents draw water only on certain days of the week or at prescribed times in a day.

The measurement of greywater quantities from the seven households involved in the study included all the streams of greywater; laundry, kitchen/dishwashing and bath water. Results of this investigation for the seven households are shown in Figure 5-7.

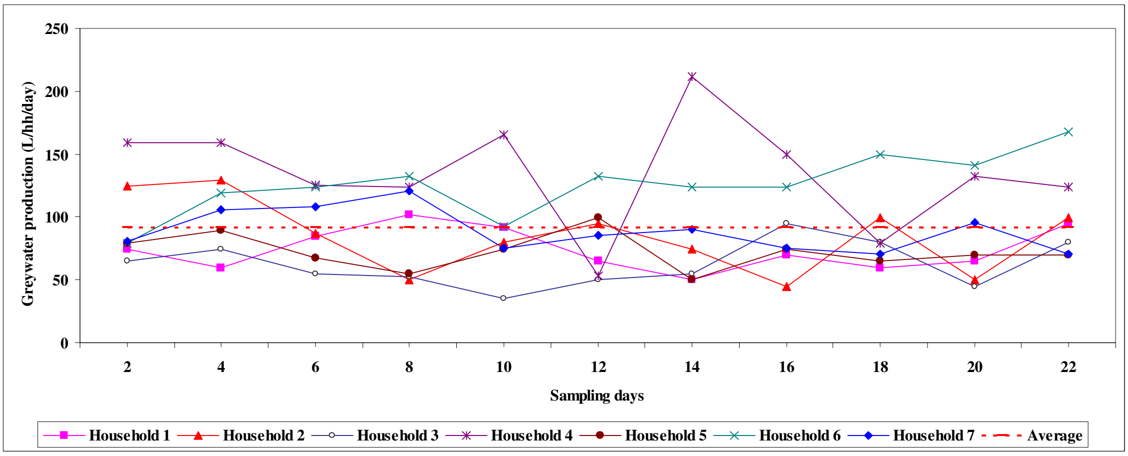


Figure 5-7: Variations in the greywater production in the seven households surveyed in Waruku during the four weeks of sampling

The Figure 5-7 presents the variation in the greywater production in the households surveyed during the sampling period that was spread over four weeks: from 26th November to 21st December 2007. The peaks and lows are dependent on the expected variations in water use in a household depending on the household activities.

Households 4 and 6, which were in cluster 2; Permanent dwelling type, consistently exhibited higher greywater production during the entire sampling period compared to the other five households in the informal dwelling category (cluster 1). This shows that greywater generation rate is directly influenced by the household's standard of living.

Figure 5-8 shows the relationship between greywater generation rate and household size.

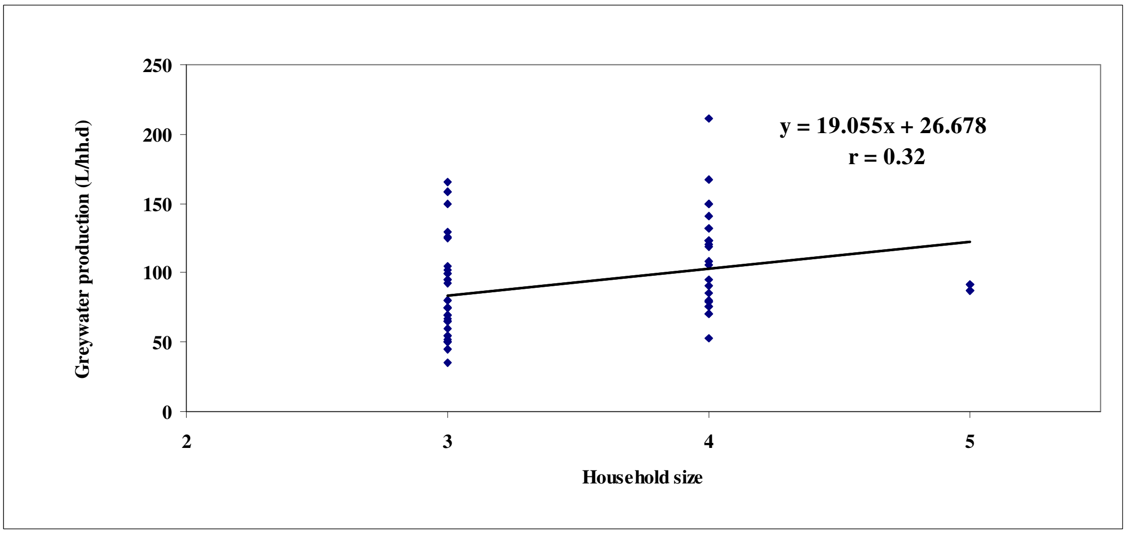


Figure 5-8: Effect of household size on greywater generation in Waruku (L/hh/d indicates litres per household per day)

The Figure 5-8 indicates that greywater generation rate is directly proportional to the household size. The Figure 5-8 shows a positive coefficient of correlation (r) of 0.32 between greywater production and the household size. (Rosner, 2005) stated that if correlation coefficient (r) is greater than zero, then the two variables are positively correlated; as one variable increases the other tends to increase.

Figure 5-9 shows the relationship between greywater generation rate and household size.

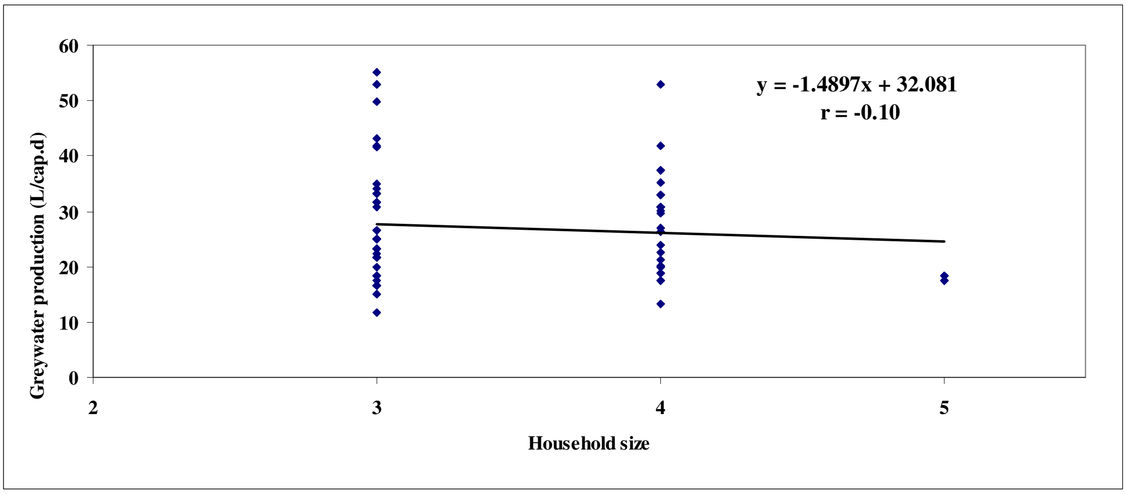


Figure 5-9: Effects of household size on the per capita greywater generation in Waruku (L/cap/d indicates litres per capita per day)

The Figure 5-9 indicates that the per capita greywater generation rate is inversely proportional (r = -0.10) to the household size, which can be explained by the limited amount of freshwater available per household in Waruku. This can be partly attributed to water rationing by the landlords in Waruku. The objective of the Figure 5-9 was to establish whether or not there was a relationship between greywater per capita production and the household size i.e. to establish the relationship between the two variables without considering strength of the trend.

From the study on the estimation of greywater generation in Waruku, it can be observed that there seems to be not much potential to manage the current greywater disposal problems in the area through water demand management. The current water consumption of 34 L/cap/d is already below the intermediate access (average 50 L/cap/d) specified by (WHO, 2003) as the minimum required if the level of health concern in an area is to be regarded as low. Reducing water consumption below the current consumption level might have serious health effects on the residents.

5.2.2. Greywater characteristics

From the seven households involved in the estimation of greywater generation rate in Waruku, the greywater samples were collected and analysed for various physical, chemical and biological parameters.

The results of the greywater analyses (greywater flow-weighted averages) are presented in Table 5-2. The composition of the drinking water collected from Waruku is also presented in this table as a reference. A complete analysis of the greywater characteristics is presented in Appendix 6.

Table 5-2:Physical and chemical parameters of greywater generated in Waruku (n =79)

Parameter	Greywater (Mean ± SE)	Standard*	Drinking water (Average)
pH	8 ± 0.2	6.5 - 8.5	7.0
EC (dS/m)	1.1 ± 0.1		0.2
Sodium (mg/L)	170 ± 14		24
Total Calcium (mg/L)	32 ± 3		8.4
Free Calcium (mg/L)	21 ± 2		-
Magnesium (mg/L)	5 ± 1		2.4
Sodium adsorption ratio (SAR_{total}[4])	8± 1	6.0	1.9
Sodium adsorption ratio (SAR_{free}[5])	9± 1		-

1 dS/m = 1000 µS/cm, SAR is a calculated parameter (see section 2.5.2)
*Standard applies to the Kenya guidelines for irrigation water (NEMA, 2006)

The results presented in the Table 5-2 indicate that the reported parameters have values that are similar to those reported by (Carden *et al.*, 2007a) for the greywater study conducted in the low-income non-sewered area in South Africa. However, the results indicate large variability when compared with greywater characterisation studies in the developed countries (Gross *et al.*, 2005);(Eriksson *et al.*, 2002). This highlights the differences in the quality of greywater from the study area compared to that in developed countries. The high concentrations of many of the reported parameters are partly attributed to the low water consumption in the households. The study area had an average per capita water consumption of only 34 L/cap/day that is very low compared to many developed countries, where it can be about 100 L/cap/day or higher (Palmquist and Hanaeus, 2005);(Jefferson *et al.*, 2004).

The electrical conductivity of the greywater from Waruku area that can be correlated to salinity was 1.1 dS/m (1100 µS/cm). This indicates that the greywater is slightly saline (see Table 2-5). This suggests that the greywater from Waruku would not be expected show serious salinity effects on water availability if reused as irrigation water (see Table 2-8). However, the low salinity of the greywater is likely to induce reduced soil infiltration rate since the greywater SAR is high. At a given SAR, the infiltration rate decreases as the salinity decreases.

The greywater in the area had an average pH of 8.0, which is very consistent with laundry greywater stream which is alkaline and has generally pH values in the range of 8-10 (Eriksson *et al.*, 2002);(Christova-Boal *et al.*, 1996). The high pH value obtained shows that the use of chemical products at the household level have an important influence on the greywater characteristics in Waruku. The pH in the greywater also depends on the pH and the alkalinity in the drinking water supply.

The greywater from Waruku had high SAR_{total} of 8.0. This can be attributed to the extensive use of powdered detergents in the area that may have contributed to the high sodium concentration in greywater that ranged from 156 to 184 mg/L. (Patterson, 1997) found that powdered detergents have higher sodium per wash compared to the liquid detergents.

[4] SAR calculated on the basis of the total calcium (It is the most usual method of calculating water SAR)
[5] SAR calculated on the basis of free calcium (not commonly reported in many literature)

Chemical analyses of piped drinking water supplied to the area, which was drawn from the households' yard taps, had an average SAR value of 1.9 as given in Table 5-2. This confirmed that the elevated greywater SAR values reported, although they are dependent on the quality of the drinking water supply, are largely influenced by the household activities.

Figure 5-10 shows sodium concentration variations in the seven households surveyed in Waruku, during the sampling days. The sampling days was spread over a period of four weeks starting from 26th November to 21st December 2007.

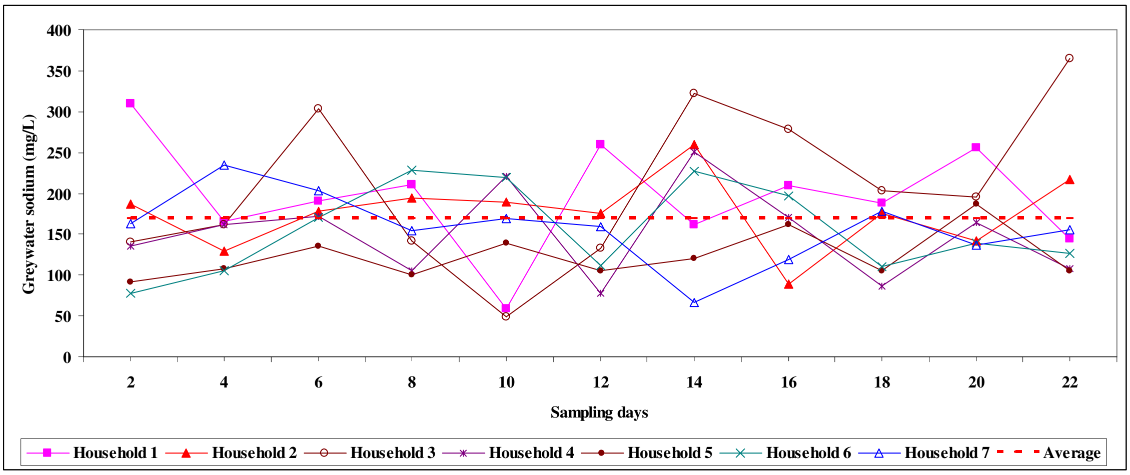


Figure 5-10: Variations in the greywater sodium concentration in the households surveyed in Waruku during the four weeks of sampling

The Figure 5-10 shows the results of the greywater sodium concentration in the households surveyed in the course of the sampling period. The variations in the sodium concentration, as expected, can be attributed to the variation in drinking water use in a household that affects greywater production and its characteristics. Also, differences in amount and the type of detergents and, brand of household chemicals and personal care products, used in the households can also influence greywater sodium concentration variations.

Figure 5-11 shows the variation distribution of average greywater SAR during the four weeks of the sampling period in Waruku.

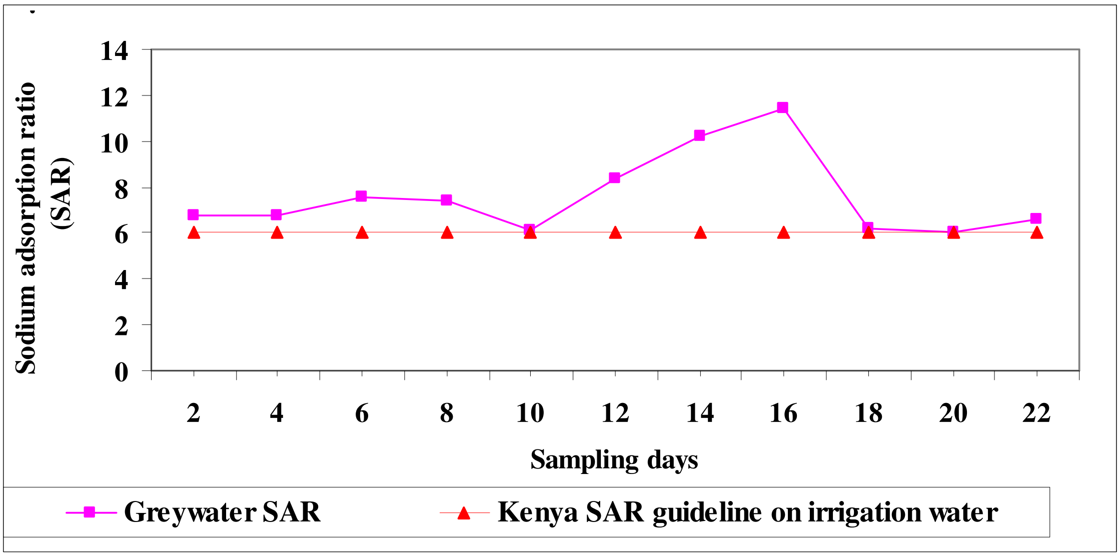


Figure 5-11: Variation distribution of average greywater SAR in Waruku

The Figure 5-11 shows that the average greywater SAR from Waruku consistently exceeded the higher limit of 6.0 specified by the Kenya standards for irrigation purposes. Sodium adsorption ratio of 8.0 has been suggested as the higher limit for irrigation of non-tolerant plants (ANZECC, 1992). The long-term irrigation using water with high SAR can negatively alter soil properties. High sodium concentration leads to soil dispersion (soil swelling).

In this study, free calcium of the greywater was determined using Calcium ion selective electrode (see the procedure for free calcium determination in Appendix 8). The greywater free calcium concentration was 21 mg/L, which was 66 % of the total calcium concentration. This indicates that not all calcium is in free form (reactive part) but considerable part of calcium is in bound form. The calcium can bind greywater proteins, amino acids, acetic acids, etc. The calcium binding affects the greywater SAR. In a detailed study on calcium binding effects on natural organic matter (NOM) source variations, (Chandrakanth and Amy, 1998) found that the magnitude of the increase of calcium association is dependent on the type of NOM source being studied. This means that the greywater SAR reported in a study not only depends on the household activities that influence cations concentrations but also on the type of NOM in the drinking water sources; whether surface water or groundwater.

The determination of the greywater free calcium in this study therefore indicates that greywater SAR reported in the literature, which are usually calculated based on the total calcium concentration, to some extent underestimates greywater SAR value. The free greywater SAR was 9.0 compared to the total SAR of 8.0, indicating an increase of 12.5%.

In this study, other greywater characteristics were investigated which, although they may not have major influence on soil characteristics, they are vital when evaluating the need for pre-treatment and, to some extent, when evaluating possibilities for reuse. These include measurements of the traditional wastewater parameters like BOD, COD and concentration of the nutrients. The results (averages) are presented in Table 5-3. A complete analysis of these greywater characteristics is presented in Appendix 7.

Table 5-3: Physical and biological parameters of untreated greywater generated from Waruku informal settlement (n=12)

Parameter	unit	Greywater (Average)	Standard*
BOD_5	mgO_2/L	213	30
BOD_5 Load	gBOD/cap/day	5.2	
COD	mgO_2/L	2200	50
COD Load	gCOD/cap/day	54	
Total coliform	counts/100mL	4.67E+09	30
Faecal coliform	counts/100mL	4.89E+08	Nil/100mL
TSS	mg/L	922	
SUVA	L/mg-m	0.38	
DOC	mg/L	88	
TN	mg/L	6.8	

*Standard applies to the Kenya guidelines for treated effluent into the environment (NEMA, 2006)

The average greywater BOD_5 obtained was 213 mg/L, which shows that the greywater had similar organic strength to domestic wastewater as reported in (Metcalf and Eddy, 2003). Also, greywater from this area had high faecal content which clearly indicates importance of appropriate treatment of greywater that concurs with the intended use. The high faecal content can be attributed to high bacterial load in laundry greywater stream arising from washing of nappies. It was observed that most of the participating households had babies in the family. The greywater from this area should therefore not be used in urban agriculture without adequate treatment. The greywater treatment system for this resource should include a disinfection stage possibly with chlorine. This is consistent with findings of (Weizhen *et al.*, 2003), who stated that treatment of greywater is needed as a pre-requisite for successful reuse. The greywater from Waruku can be treated using biological treatment systems as it has high biodegradable organic matter as indicated by high BOD and, confirmed by, the low SUVA measurement.

It is clear from the Table 5-3 that greywater had low level of nutrients measured in terms of total nitrogen. It had an average TN value of 6.8 mg/L, which is consistent with other studies conducted on greywater (Jamrah *et al.*, 2007);(Palmquist and Hanaeus, 2005). This shows that unlike toilet waste (urine and safely sanitised faecal matter), greywater has low level of nutrients that are beneficial for plant growth and therefore other sources of these nutrients would be needed to supplement greywater when it is reused in urban agriculture. Nonetheless, the use of greywater in agriculture fits well with the concept of ecological sanitation (ecosan) which attempts to achieve sustainability by managing human urine and faeces as a resource rather than a waste, with recovery and recycling of nutrients (Winbland and Simpson-Hebert, 2004).

It also important to recognise that greywater is rich in phosphorus (not measured in this study), which is another important nutrient required for plants growth. Average values reported in other studies indicate Total Phosphorus (TP) values of 35 mg/L (Eriksson *et al.*, 2002). This attests to the high potential of greywater reuse in urban agriculture which concurs with findings by (Salukazana *et al.*, 2007) that the use of greywater as nutrient source produce increased plant heights and yields similar to that obtained when using chemical fertilisers.

5.3. Greywater effect on soil characteristics

In the previous section, the physical, chemical and biological characteristics of greywater generated in Waruku area were evaluated. The greywater characteristics are important in understanding the effects of greywater when reused in urban agriculture.

In this section, the long-term impacts of greywater disposal on soil characteristics will be examined by assessing the interaction of greywater on the soil environment in a site where greywater had been applied over an extended period of time. The investigation of long-term impacts of greywater on soil properties gives some indications on the possible effects of applying greywater in urban agriculture over an extended period of time.

5.3.1. Soil characteristics at the greywater disposal site

Soil samples collected from the disposal site (Site A shown in the Figure 3-10 and the soil sampling points are shown in Figure 5-13) were analysed using standard soil testing methods for various physical and chemical parameters (see Section 3.5.2 for details). For comparison purposes, the same analyses were done on samples collected from the control site, still located within Waruku area but unaffected by greywater disposal, that provides background data.

The summary of the results (averages) is presented in Table 5-4. A complete table of the soil data analysis of the soil samples obtained from both sampling sites is presented in Appendix 10.

Table 5-4: Summary (averages) of the physical and chemical soil parameters from greywater disposal and control sites

Soil parameter	unit	Greywater disposal site (n=15)	Control site (without GW disposal) (n=6)
Sodium	meq/100g	**4.45**	**0.83**
Calcium	meq/100g	21.72	8.88
Magnesium	meq/100g	0.81	0.98
Sodium adsorption ratio (SAR)	-	**1.62**	**0.38**
Soil EC (soil solution)	dS/m	1.53	0.23
Soil ECe (saturated paste extract)	dS/m	**4.08**	**0.61**
Soil pH	-	7.62	5.54
Organic carbon (OC)	%	**3.52**	2.47
Cation exchange capacity (CEC)	meq/100g	41.28	25.59
Exchangeable sodium percentage (ESP)	**%**	**11.18**	**3.27**
Soil texture	-	clay	clay
Clay content	%	52	61

1 meq/100g = 10 $mmole_c$/kg, 1 dS/m = 1000 µS/cm, ESP is a calculated parameter (see section 2.4.4)

The hypothesis testing at 95% confidence using the data from the two sampling sites, assumed to be two independent samples with unequal variances, indicated that the two sites are significantly different in terms of soil sodium concentration with $p < 0.001$ for significance (see Appendix 11). This therefore indicates that although the two sites are within the same geographical area, with similar geological and climatical conditions, the long-term disposal of greywater at the disposal site had altered soil sodium levels.

The greywater disposal site exhibited an average soil salinity (measured in terms of electrical conductivity) of 4.1 dS/m. It had soil ECe that was 569% higher than control site (ECe =0.61 dS/m). The disposal site can be said to have saline soil according to the criteria given by (USSL, 1954) in which soil ECe of 4 dS/m is used as the boundary between saline and non-saline soils.

The substantial accumulation of salts at the disposal site can be attributed to the long-term disposal of greywater with a high concentration of sodium (see Section 5.2.2) that may have considerably reduced the soil infiltration and hydraulic conductivity properties. This may reduce movement of water in the soil resulting in the salts accumulation in shallow depths of the soil. In addition to the disposal of greywater with high SAR on the site, high rainfall in the area (Waruku has 1000mm annual rainfall) may have further influenced changes in the soil physical properties to cause soil salinity build up. Rain events on a sodic soil cause a reduction in soil electrical conductivity and hence may impact adversely on soil properties. The degree of soil electrical conductivity reduction can be higher under condition of high rainfall than low rainfall due to high level of dilution. The effect of amount of rainfall on soil properties (soil structure) and solute transport mechanisms within the soil profile is influenced by the soil drainage, which is also dependent on the soil type (clay soil unlike sandy soil has low permeability). However, it may not be easy to explain clearly all the mechanisms that caused the disposal site soil salinity build up based on the limited data collected in this study. The soil environment is a complex system and its physical behaviour (properties) can be affected by many interacting factors that include ESP, clay content, clay mineralogy and rainfall.

Nevertheless, the high soil salinity build-up (ECe = 4.1 dS/m) at the greywater disposal site is likely to have adverse effects on the plant growth. In this study, the impact of greywater disposal on the site is assessed on growth of vegetables, being the most predominant crops grown in Waruku. The soil ECe exceeded soil salinity threshold for cabbage of 1.8 dS/m although it was less than threshold value of kale (sukuma wiki) of 6.5 dS/m (DNR, 1997). Thus, it is apparent that the cabbage crop relative yield could reduce to about 75% (DNR, 1997). Unlike the disposal site, the control site soil salinity (ECe = 0.61 dS/m) was well below the salinity threshold values for both cabbage and kale, clearly indicating that uncontrolled greywater disposal in Waruku can have adverse effects on urban agriculture.

The disposal site had an average ESP value of 11.2 % compared to 3.3 % for the control site. Although it may be difficult to strictly classify the soil from the site in terms of soil sodic levels based on the classes suggested by (Sumner *et al.*, 1998), it is clear that it had high ESP value, which can be attributed to the discharge of greywater of high sodium concentration. According to (Sumner *et al.*, 1998), sodic soil have SAR of 3-5 and ESP ranging from 6 to 15. The control site was non-sodic as it had soil SAR< 3 and ESP < 6%. With high ESP of 11.2%, the disposal site is likely to have soil structural stability problems. According to (van de Graaff and Patterson, 2001), the soil with ESP > 6 % are likely to have soil problems in terms of soil structural stability due to potential sodium dispersibility effects.

It was found that soil pH was substantially higher (2.1 units) at the disposal site than at the control site. Increases in soil pH under land application of wastewater have been previously reported. (Qian and Mecham, 2005) reported an increase of 0.3 units from soil tests on golf courses with long-term recycled wastewater irrigation compared with surface water irrigation. In New Zealand, (Schipper *et al.*, 1996) found an increase in soil pH by 0.8 units after applying tertiary-treated domestic wastewater to a forest site for 3 years. The increase in soil pH at the disposal site could perhaps be attributed to high rate of denitrification that produces hydroxyl ions, given high COD of the greywater (see Section 5.2.2). It can also be attributed to high pH (8.2) and buffering capacities of the greywater (greywater alkalinity was not measured in this study). Laundry greywater stream because of detergents can have pH values as high as 10 and alkalinity as high as 200 mg/L as $CaCO_3$ (Christova-Boal *et al.*, 1996).

From the study, it can also be observed that the greywater disposal site had a higher CEC of 41 meq/100g compared to the control site of 25 meq/100g. However, it is recognised that both sites had high organic carbon content, above 2.0 %, which can explain high CEC levels determined. The soil organic matter, expressed in terms of soil organic carbon, is negatively charged and therefore attracts cations on the clay mineral exchangeable sites. The sources of the organic carbon at the disposal site are total solids and soluble organic products of the greywater and the breakdown of plant and microbial products in the dynamic soil environment.

The high organic matter fraction acts to increase the CEC potential. Thus, the soil sodicity effect at the greywater disposal site, measured in terms of ESP, is to some extent dampened by the high organic matter in the soil. Figure 5-12 shows the relationship between soil organic carbon and CEC at the disposal site that exhibits a strong correlation (r =0.84).

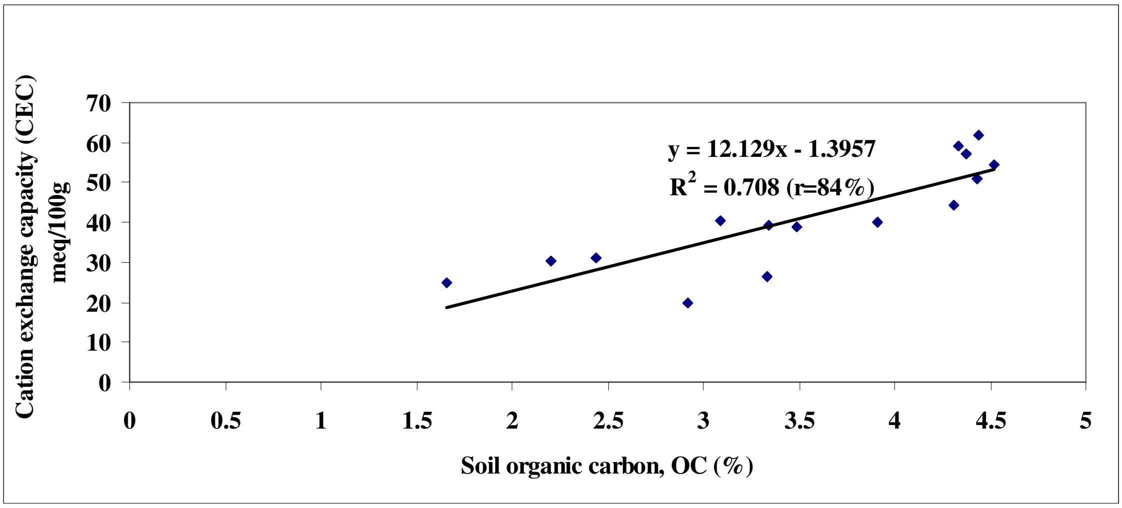


Figure 5-12: Relationship between soil organic matter and CEC at the greywater disposal site in Waruku

Figure 5-12 seems to confirm the fact that organic matter can play an important role in the reduction of sodium effects on the soil due to the considerable improvement of the soil CEC potential. This concurs with findings by (Oorts *et al.*, 2003) who had shown that soil organic matter had an important physicochemical effect on the soils in the tropics (highly weathered lixisol) and that it could even be responsible for upto 77% of the soil CEC.

It was also observed that soil CEC had a strong correlation to the soil calcium (r=0.93, R^2=0.84) compared to the sodium (r=0.79, R^2 =0.64), which showed a relative weaker trend (see the plots given in Appendix 12). This can be attributed to the fact that calcium being a divalent is likely to be retained on the clay surface with force greater than the monovalents (sodium). Therefore, adverse effects of greywater disposal on the soil properties such as reduced water infiltration, low hydraulic conductivity and loss of structural stability, may to some degree mitigated by the high soil calcium content. Calcium has an opposite effect on soil properties to sodium; it causes soil flocculation which enables the soil to retain its structural stability.

Thus, the effects of sodium to impinge negatively on soil properties can be offset by adding calcium salts e.g. gypsum either with greywater or added directly to the soil.

5.3.2. Topographical spread of soil parameters on the disposal site

From the soil samples, taken to a depth of 150 mm, at different locations in the greywater disposal site, surface plots of various soil parameters and a contour map were generated. These plots give a clear representation of the topographical spread of the soil parameters such as soil ESP arising from uncontrolled external discharge of the greywater at the site.

Figure 5-13 shows a contour map of the greywater disposal site produced from a topographical survey carried out on the site and generated using ArcGIS software. The survey was made on the sampling points and the levels indicated are based on a local datum (taken as 100 m). The total area of disposal site was 4050 m^2 (45m x 90m).

The coordinates of the sampling points, used to generate the contour map, are given in Appendix 10. The Profile A (shown in Figure 5-13) represents sampling points that were on the higher elevation (most uphill) of the site. These points were located adjacent to the households that have been discharging greywater onto the site. Profile E, represents sampling points that were 76 m from the profile A, the furthest downhill sampling points considered.

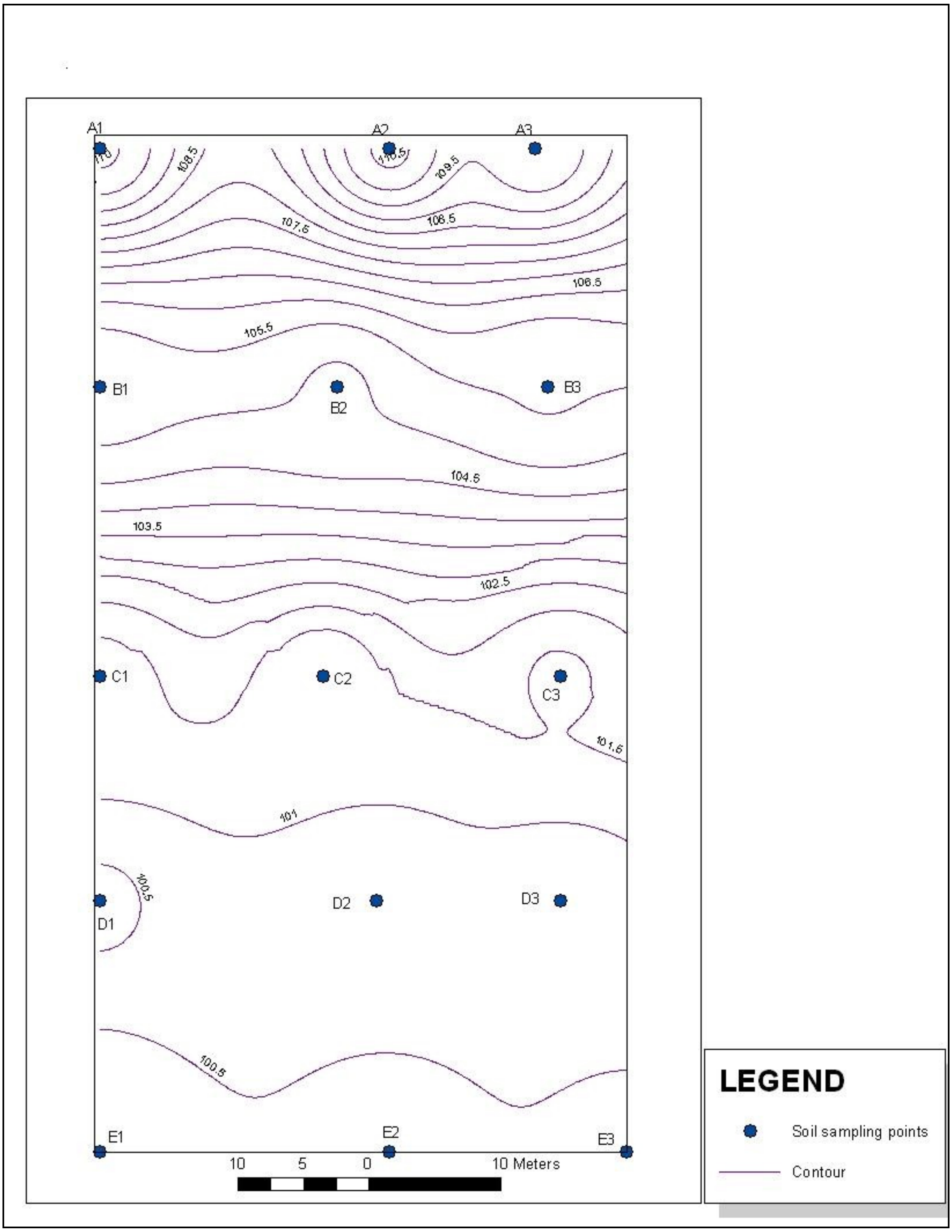


Figure 5-13: Contour map of the greywater disposal site produced from a topographical survey generated using ArcGIS

The Figure 5-13 shows that the upper section of the disposal site (between profile A and C) is a steeper section. The disposal site slopes steeply upto about 40 m from the greywater discharge points (adjacent to profile A). Beyond profile C, the disposal site is generally flat (mild slope) all the way to the Nairobi River tributary. Profile E is about 15 m from the river.

Figure 5-14 shows a surface plot of exchange sodium percentage (ESP) at the greywater disposal site relative to the control site (for the control site an average ESP value was used in the calculation).

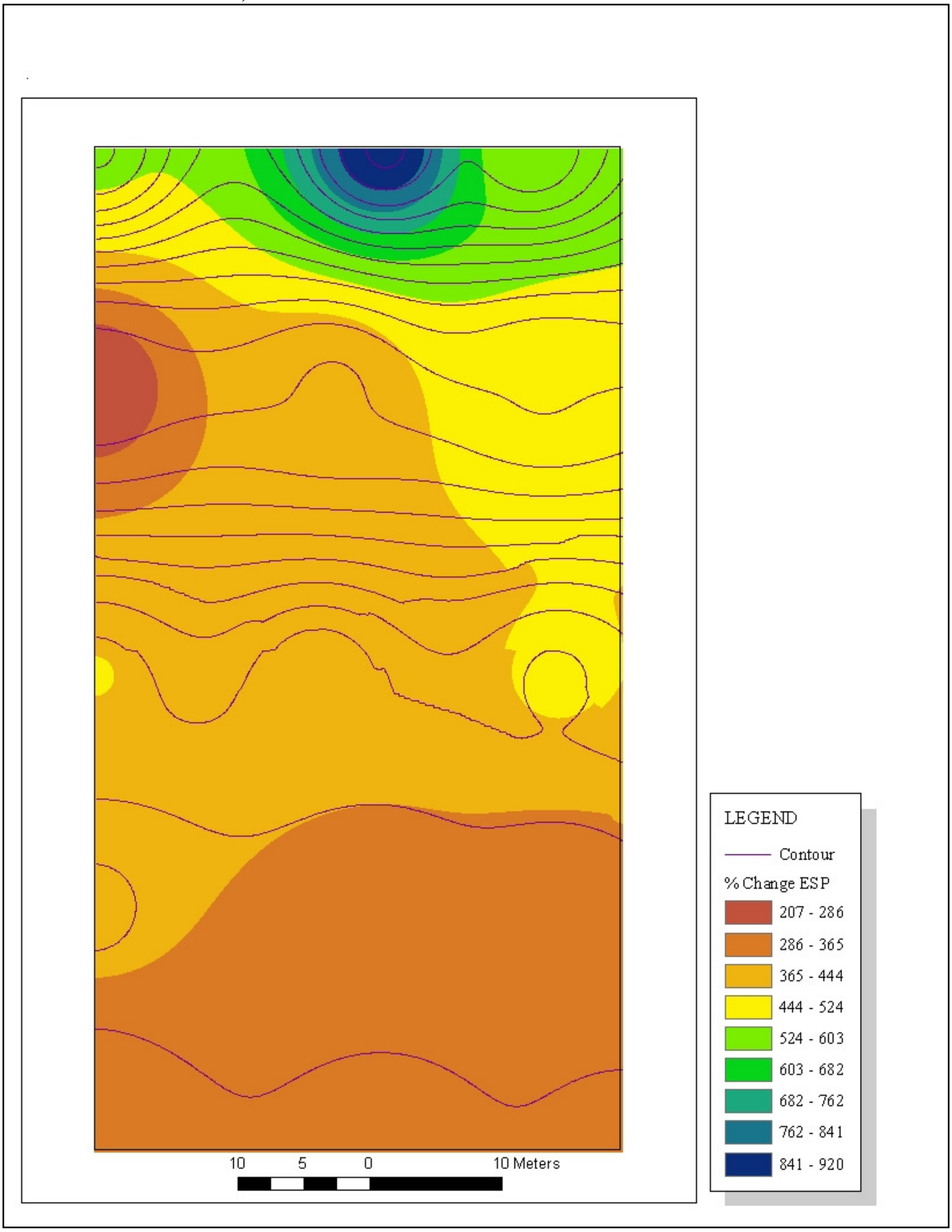


Figure 5-14: Surface plot of the % change of ESP at the greywater disposal site relative to the control site

The Figure 5-14 shows the movement of the sodium salts from the upper part of the disposal site into some distant areas downhill. As expected, the concentrations of the soil sodium are quite high (ESP over 600%) at the upper part of the site (profile A), which is adjacent to the households disposing greywater outside. It is also observed that about a third of the surveyed area, on the upper part of the site, had considerable soil sodium concentrations (ESP above 400%). The sodium spread can be attributed to the fact that greywater sodium salts are soluble and can exhibit high mobility downhill. It is possible that the sodium soluble salts move away from discharge points with drainage (greywater) water and in runoff water following natural rainfall events.

The Figure 5-14 shows that the greywater sodium can spread over a wider area of the disposal area depending on the topography. Thus, adverse effects of sodium on soil properties can be felt over a wider area from the points of greywater disposal and can thereby degrade considerable portion of the land available for productive agricultural activity.

To further investigate, the relationship between the soil sodium and the downhill distance from the points of greywater discharge at the disposal site, box plots of the soil sodium and ESP against the downhill distance were plotted.

Figure 5-15 shows a box plot of the soil sodium against downhill distance from point of discharge at the greywater disposal site, generated using SPSS software.

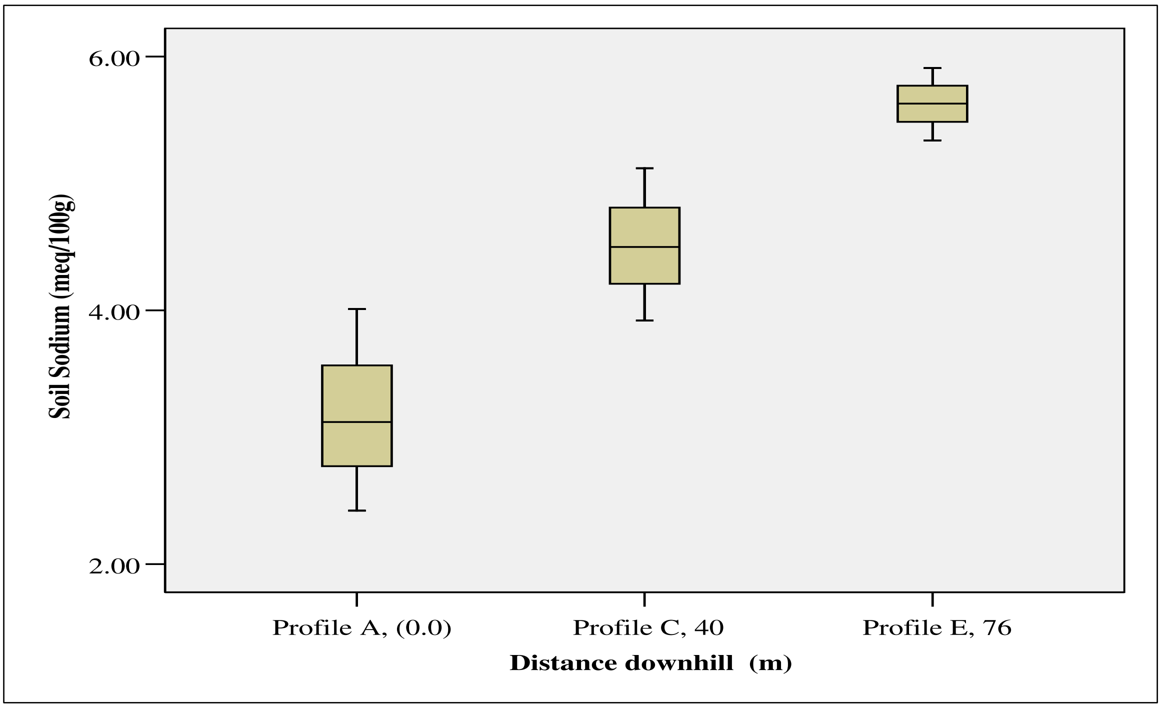


Figure 5-15: Box plot of soil sodium versus distance from the discharge point (profile A) at the greywater disposal site

Figure 5-15 shows that the soil sodium concentration increases with the downhill distance. This can be attributed to the high mobility of soluble sodium salts, which is further influenced by the topography. The increase in the soil sodium from the discharge point (profile A) to 40 m downhill (profile C) may be attributed to the steep topography at that part of the disposal site, which may increase downhill greywater flow velocities. The soil sodium concentration between the discharge points (profile A) and 40 m downhill is however not statistically different at 95% confidence.

However, at 76 m downhill from the discharge points (profile A), the soil sodium levels are significantly different with $p < 0.05$ for significance. The large increase in sodium at the lowest point of the disposal site may not only be associated with sodium mobility since that section of the disposal site is almost flat. There might be another source of sodium that contributes to this substantial increase. A possible source of sodium in that part of greywater disposal site could be human faeces, given that the residents' in the area still throw away human faecal matter away from their houses ("flying toilets") due to limited toilet availability. More than 20 people in Waruku share a toilet (see Section G: Excreta management in Appendix 3). (Palmquist and Hanaeus, 2005), reported blackwater (toilet wastewater without greywater input) sodium level of 98 mg/L, that indicates that where human faecal matter is discharged in a soil environment it can considerably influence soil sodium concentration.

Figure 5-16 shows a box plot of the soil ESP versus distance from the discharge point at the greywater disposal site.

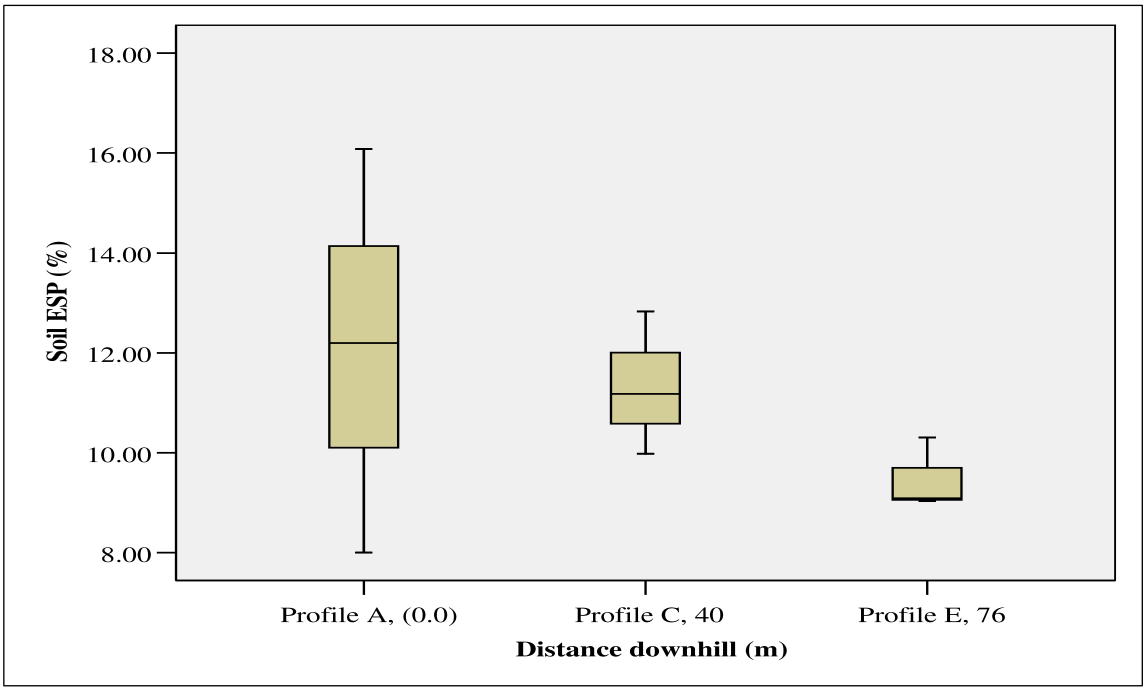


Figure 5-16: Box plot of soil ESP (%) versus distance from the discharge point (profile A) at the greywater disposal site

Figure 5-16 shows that there are no significant differences in soil ESP versus downhill distance. It also shows that all sampling points at the disposal site irrespective of the distance from the disposal point had soil ESP over 6%. According to (van de Graaff and Patterson, 2001), a soil ESP threshold of 6% is considered significant due to negative effects of sodium in terms of the loss of soil structural stability.

The Figure 5-16 also shows that the soil ESP decreased with the downhill distance from the point of greywater disposal despite the downhill soil sodium increase as was observed in the Figure 5-15. The decrease can be attributed to the high soil CEC, which can be due to the high soil organic carbon (above 2 %) at the disposal site. The soil organic carbon can increase the soil CEC to offset the high soil ESP. The higher organic carbon (OC =4.38%) at the lower part of the disposal site than on the upper side partly explain the slight soil ESP dampening observed at that section of the site. This shows that organic matter can be used as a cation barrier (sodium sink) to prevent downhill spread of sodium soluble salts thereby mitigating negative sodium-induced effects on soil properties.

As mentioned above, the high organic carbon at the lower section of the disposal site can be attributed to the ‘flying toilet’ behaviour. Although the behaviour can have serious health consequences and is therefore unacceptable, it may have had beneficial effect on the soil as it improved soil CEC potential thereby reducing soil ESP.

The use of sanitised faecal matter as soil conditioner could act to increase soil CEC, which would be beneficial in not only restricting the movement of sodium and providing a sink of available cations but can also provide an important source of plants essential nutrients. If the use of sanitised faecal matter could be acceptable to the residents (awareness and sensitization campaigns would be required), it can be a positive farm management technique that could contribute to sustainable urban agriculture. The use of sanitised faecal matter is in line with the concepts of ecological sanitation (Winbland and Simpson-Hebert, 2004).

Figure 5-17 shows the relationship of the soil organic matter, in terms of soil organic carbon versus soil SAR at the greywater disposal site.

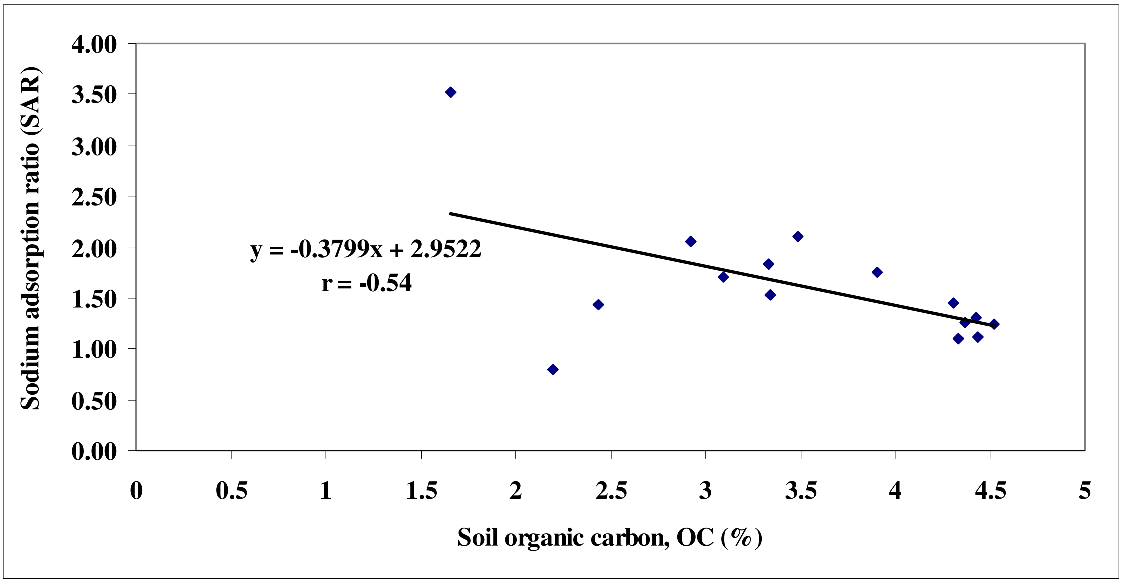


Figure 5-17: Relationship of soil SAR and soil organic carbon (OC) at the greywater disposal site

Figure 5-17 indicates that soil SAR is inversely proportional (r=-0.54) to the soil organic carbon, which can be attributed to the increase in the soil CEC. The soil with high CEC can have high calcium concentration compared to sodium thereby reducing the soil SAR. This suggests that increasing soil organic carbon can mitigate soil sodic effects. Soil organic carbon can be enhanced through application of soil organic matter, which can be added as organic compost (solid waste organic matter) or sanitised faecal matter in line with concepts of ecological sanitation.

5.3.3. Greywater effect on soil hydraulic conductivity

To further investigate the effects of greywater on the soil characteristics, soil hydraulic conductivity tests were carried out on six soil saturated samples collected from the control site (The hydraulic conductivity test procedure is described in Appendix 14).

The Table 5-5 shows the results of the soil hydraulic conductivity tests. The greywater used in the test was obtained from one of the seven households that participated in this study (see Item no. 27 in Appendix 6, sampled on 5th December 2007). It had an initial greywater EC value of 723 µS/cm (0.723 dS/m) and SAR of 3.77. The greywater SAR were adjusted by adding known concentrations of sodium to the test's reservoir filled with greywater.

Table 5-5: Saturated soil hydraulic conductivity for various greywater SAR values based on the laboratory tests

Greywater SAR	Soil hydraulic conductivity (cm/hr)
3.8	0.097
5.0	0.076
7.5	0.058
10.0	0.048
12.5	0.042
15.0	0.037

The results of the soil hydraulic conductivity tests were plotted and fitted using Excel to obtain the best line of fit to represent the short-term effect of the greywater on the soil characteristics. The plot is given in Figure 5-18.

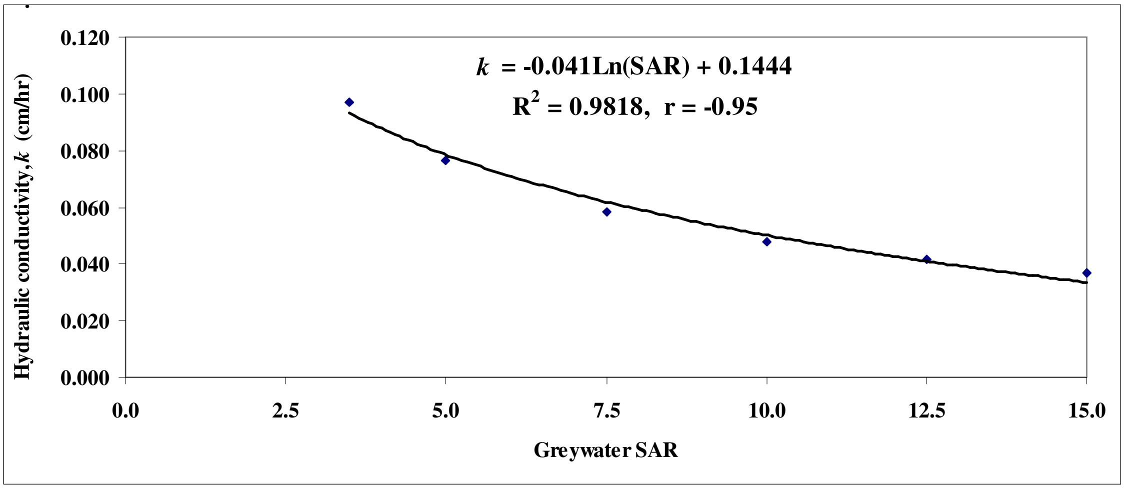


Figure 5-18: Effect of greywater SAR on the soil hydraulic conductivity based on laboratory tests

Figure 5-18 shows a strong negative correlation between greywater SAR and the soil hydraulic conductivity (r = -0.95). The relationship between short-term effects of greywater SAR and saturated soil hydraulic conductivity, *k* is best fitted logarithmically with coefficient of determination, R^2 of 0.98. The results obtained in this study on the negative effect of greywater SAR on soil hydraulic property were in agreement with the findings by (Patterson, 1997) on the effect of wastewater SAR on clay loam Australian soil. The trend observed can be attributed to the sodium-induced dispersion effect on the soil clay minerals, which depends on the electrolyte concentration. The low EC of the greywater (0.732 dS/m) used in the test combined with high SAR created conducive condition for dispersive effect of sodium on the soil.

It can therefore be concluded from the study that the high SAR of greywater has a negative influence on the soil hydraulic properties. The higher the greywater SAR, the greater the impacts on reduction of the soil hydraulic conductivity. The reduced soil hydraulic conductivity can affect movement of water and possibly nutrients to have adverse effect on urban agriculture. However, as it is clearly pointed out by (Shainberg *et al.*, 1991), the response of the soil to sodicity depends on the electrolyte concentration of the water applied; high salts concentrations can prevent the deleterious effect of exchangeable sodium. In this study, due to limited time, the effect of electrolyte concentration on the soil properties was not investigated, which would have established at what electrolyte concentration of the greywater is sodic effects on soil prevented.

The effect of greywater SAR on the soil hydraulic conductivity, shown in Figure 5-18, gives an insight to its possible effects on those wastewater treatment systems, which use soil disposal fields after treatment and those that use soil media for treatment or for effluent quality improvement (see Section 5.6).

5.4. Greywater sodium load to the land application

In the previous sections, greywater production in Waruku and its characteristics on the soil environment were assessed. In this section, the sodium load applied to the land will be estimated in order to gain insights into the magnitude of the problem of unplanned greywater disposal in Waruku. The major mode of greywater disposal practice in Waruku is discharging greywater to land, specifically onto open ground or onto outside drains (see Section 5.1.1).

The greywater sodium load applied to land is estimated as an equivalent sodium chloride (common salt) load. The sodium load calculations are presented in Table 5-6.

Table 5-6: Computation of the greywater sodium load applied to land due to unplanned greywater disposal in Waruku

Description	Units	Value	Additional information
Average greywater sodium concentration	mg/L	170	(see section 5.2.2)
Present population in Waruku		10000	(MnU, 2007)
Greywater production rate in Waruku	L/cap/day	27	(see section 5.2.1)
Total daily greywater production	m^3/day	270	
Sodium load generated in Waruku	$KgNa^+$/day	46	Flow x Concentration
Equivalent sodium chloride load generated in Waruku	KgNaCl/day	117	23g of Na^+ = 58.5g of NaCl
Equivalent annual sodium chloride load generated in Waruku	**tonnes NaCl/year**	**43**	
Equivalent per capita sodium chloride load generation	**KgNaCl/cap/year**	**4.3**	
Sodium loading limit for land application	$KgNa^+$/ha/year	400	Source*
Annual sustainable sodium load expressed as an equivalent NaCl load	KgNaCl/ha/year	1017	
Area of land required to safely dispose greywater in Waruku	ha.	41.9	
Assumed average no. of persons in a Waruku household	No.	4	
No. of households in Waruku	No.	2500	
Area of land required at household level (household garden) to safely dispose greywater to land	**m^2**	**168**	

*(Whitehead and Patterson, 2007)

From Table 5-6, it is estimated that an equivalent greywater sodium chloride load applied to land arising from unplanned greywater disposal is 43 tonnes NaCl/year, which is equivalent to 4.3 KgNaCl/cap/year. This greywater sodium load to be safely disposed onto a household garden, the minimum land area required at the household level is 168 m². Such a household garden area is not available to a typical household in Waruku (a typical plot size (area) for a Waruku household is less than 20 m²) and hence there is a need to change detergents to suit the smaller footprint for irrigation.

These sodium loads end up in the soil environment and if they are concentrated on a small piece of land used for urban agriculture could have adverse effect on the soil properties as described in section 5.3.

The estimated sodium load originates largely from household activities, which mostly is expected to be from laundry water and bath water. The use of largely powdered detergents in the households in Waruku can be the main source of the large sodium load applied to land (see Question no. C1 in Appendix 3). A reduction of the sodium load can be achieved by switching to the low sodium liquid detergents. Powdered detergents in household wastewater have high concentration of sodium per wash compared to the liquid detergents (Patterson, 2007).

5.5. Potential impacts of greywater generated from Waruku on salinity and soil properties

The final objective of this study is to assess suitability of the greywater generated in Waruku as irrigation water based on greywater characterisation dataset.

In section 5.1, the study established that the idea of the reuse of treated greywater[6] in urban agriculture had considerable support in Waruku (see Section 5.1.2). That realisation provided a vital motivation to evaluate the potential impacts of the generated greywater for reuse in urban agriculture.

This section evaluates suitability of greywater as irrigation water based on the available literature, in particular with respect to Food Agricultural Organisation (FAO) standards. The greywater suitability with regard to salinity and a subsequent effect on crop yield is evaluated using an Excel-based model developed from this study, which is assessed against the results of SALF PREDICT software, provided by the Department of Natural Resources, Australia.

5.5.1. Model-based greywater suitability assessment with regard to salinity

Based on the dataset of greywater characteristics (see Section 5.2.2), it can be concluded that the quality of greywater generated from Waruku is well within the usual range of irrigation water (see Table 8-1 in Appendix 9). Therefore, greywater from Waruku should be regarded as an important resource that can be reused in urban agriculture instead of being allowed to go to waste through unplanned greywater disposal practices.

[6] In section 5.5, it is assumed that some form of greywater treatment has taken place to remove organic matter (odour potential) and to reduce pathogen content to WHO health guidelines for the use of wastewater in agriculture **but** greywater has **insignificant** reduction of dissolved solids (salts) since the conventional systems cannot achieve significant removal efficiencies.

Table 8-1 given in Appendix 9 may be insufficient for detailed assessment of the quality of greywater for irrigation use. Thus, to improve on the assessment of greywater for irrigation, using the dataset obtained from this study and information from the literature, an Excel based model (Greywater Reuse Model) was developed. The model can assist the Waruku residents to assess the impact of the quality of greywater generated in that area on crop yield.

Before the development of the model, the dataset of greywater characteristics was further analysed using SPSS software and relevant relationships obtained. Figure 5-19 shows the relationship between greywater SAR versus EC for greywater generated in Waruku.

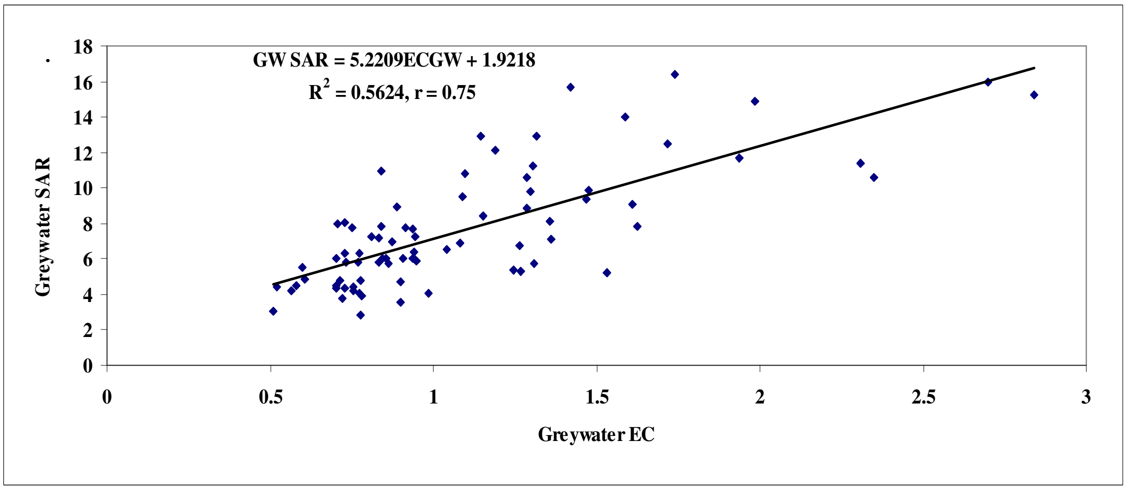


Figure 5-19: Relationship between greywater SAR versus EC from greywater generated from Waruku (n = 79)

Figure 5-19 shows a strong positive correlation (r = 0.75) between greywater SAR and EC. The linear regression model obtained explains a significant part of the total variation i.e. 56% of the greywater EC variation can be explained by the variation of greywater SAR. This means that monitoring of the expensive greywater cations (SAR) can be avoided as the greywater SAR can be estimated from simple and inexpensive greywater EC measurements.

Based on the above findings and the information available from literature, the greywater reuse model, a tool for assessing suitability of greywater for irrigation on salinity was developed (see Appendix 13). The flow diagram given in Appendix 9 (Figure 8-3) was followed during the model development.

The greywater reuse model input and output parameters are shown in Table 5-7.

Table 5-7: Input and output parameters of the greywater reuse model for the assessment of greywater quality with regard to salinity

Model input	**units**
Greywater electrical conductivity (EC)	dS/m
Greywater daily production	m³/day
Annual rainfall (depth)	mm
Land available for irrigation (area)	ha.
Soil electrical conductivity at the bottom of the root zone (ECe)	dS/m
Selection of crop to be irrigated with greywater	
Model output	
Greywater SAR	-
Leaching fraction	-
Predicted soil salinity (ECse)	dS/m
Relative crop yield (100% relative crop yield line indicated)	-

The results of the model for Waruku conditions are shown in Figure 5-20 for cabbage as the selected crop for greywater irrigation. To illustrate how the model works, Figure 5-21 is provided, which is similar to the Figure 5-20 but with a different crop selected; carrot is used as an example.

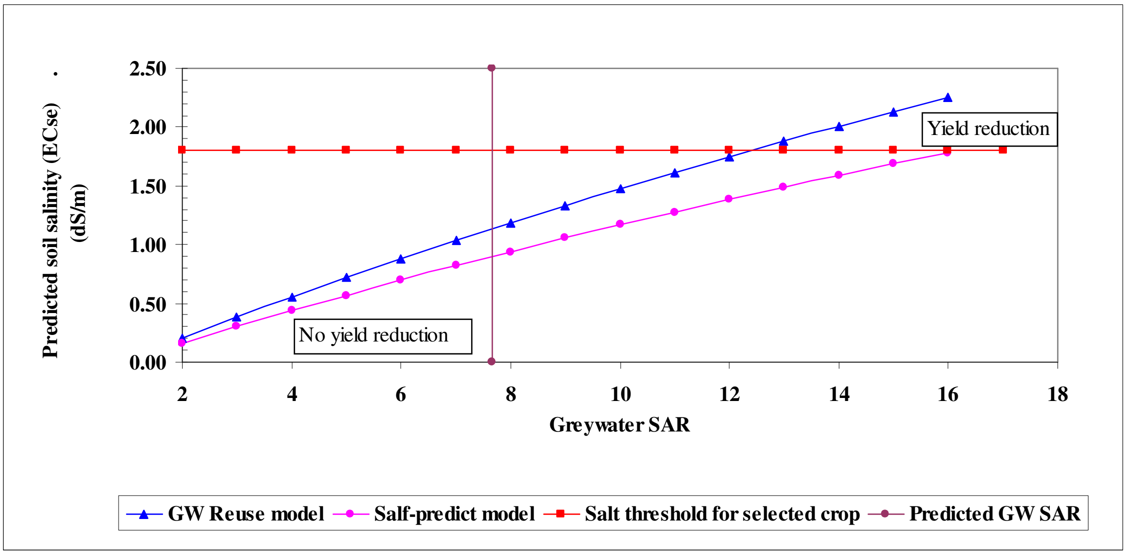


Figure 5-20: Relationship of greywater SAR versus the predicted soil salinity at the root zone, ECse (selected crop - cabbage)

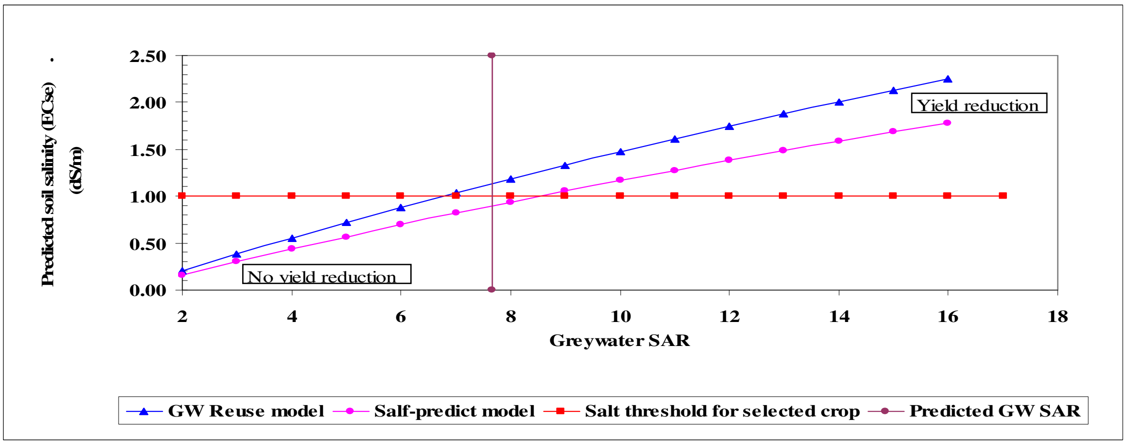


Figure 5-21: Relationship of greywater SAR versus the predicted soil salinity at the root zone, ECse (selected crop - carrot)

The model results given in Figure 5-20 predict that the quality of greywater generated in Waruku would result in soil salinity value that is lower than the salt threshold for cabbage (1.8 dS/m). This indicates that reuse of the greywater would not cause reduction in yield for this most predominant crop in Waruku. Reduction in the yield for cabbage can be expected to occur when greywater SAR is 12 or higher.

However, as shown in Figure 5-21 the greywater from Waruku is expected to cause yield reduction for the carrot, which is a salt-sensitive crop. The predicted soil salinity value is higher than the salt threshold value for carrot (1.0 dS/m).

From Figure 5-20 and Figure 5-21, the greywater reuse model salinity predictions are assessed against the Salf-predict model. It can be observed that the greywater reuse model compared with Salf-predict model exaggerates soil salinity values, particularly at high greywater SAR values. The GW reuse model results are within 10% of the Salf-predict model soil salinity predictions. Salf-predict model is a calibrated model and has been used extensively for salinity prediction in areas with annual rainfall ranging from 200 to 2000mm. Salf-predict model was provided by the Department of Natural Resources (DNR), Queensland, Australia.

The greywater reuse model can be used as an important greywater reuse tool to assist in making quick decision on the likely impacts of greywater quality on soil salinity and how it can affect crop yields for different crops (as demonstrated for cabbage and carrot).

In order to maintain the greywater quality within the "no yield reduction'' zone, for sustainable greywater reuse in urban agriculture, the following strategies are suggested:

- Source control should be practiced at the households to reduce sodium concentrations in the greywater. This can be realised through the use of low sodium detergents and household chemicals.
- Application of gypsum with greywater to reduce greywater SAR. The amount of gypsum required (GR) to reduce hazardous SAR to any desired SAR (SAR desired) can be calculated as follows:

$$GR = \left[\frac{2(Na^+)^2}{SARdesired^2} \left(Ca^{2+} + Mg^{2+} \right) \right] x0.086$$

, GR is in Kg of 100% gypsum per m³ of applied water. Na, Ca and Mg are in milliequivalent (meq/L).

Of the two strategies, the former is the most affordable measure to address greywater effects on salinity. The strategy would protect this resource and increase its beneficial reuse potential.

5.5.2. Possible impacts of the greywater from Waruku on soil properties

This section briefly assesses the likely impacts of the greywater generated from Waruku on the soil properties based on the literature. The soil properties evaluated are infiltration rate and structural stability.

- Soil infiltration rate

The greywater from Waruku is not expected to cause severe reduction in the soil infiltration rate (rate of water entry to the soil media). As shown in Figure 2-1, adopted from (Asano *et al.*, 2007), the greywater from Waruku would have only slight to moderate reduction in the soil infiltration rate. This implies that if reused in urban agriculture, it would not be expected to adversely affect movement of nutrients and water into the soil media. This position is further confirmed by the FAO guidelines, given in the Table 2-8, adopted from (Ayers and Westcot, 1994). The guidelines show that irrigation water of the quality similar to the greywater from Waruku, with respect to salinity effects on soil infiltration, can be used for irrigation with slight to moderate restriction.

Thus, the greywater from Waruku can be reused in urban agriculture as irrigation water without requiring special management practices, such as frequent application of leaching fraction, to achieve successful crop production (without yield reduction).

- Soil structural stability

According to (DNR, 1997), as shown in Figure 8-1 given in Appendix 9, the effect of irrigation water of quality similar to greywater from Waruku on soil structural stability would depend on the soil properties and rainfall. Soil structural stability refers to the ability of the soil to retain its clay aggregate structure that influences movement of water and air in the soil media. The Figure 8-1 indicates that greywater from Waruku is of marginal quality and should be treated with caution with regard to its potential impact on soil structural stability. Due to high rainfall in that area (1000mm annual rainfall), the soil structural problems are likely. The high rainfall can cause reduction in the soil electrical conductivity and since the greywater has high SAR, adverse impact of soil properties in terms of soil structural stability may be likely (see Section 5.3.1).

To mitigate the adverse effect of greywater from Waruku on the soil structural stability measures should be taken to reduce the greywater SAR levels. For instance, through source controls.

5.6. Relevance of the study to the design of wastewater treatment systems in the developing countries

In section 5.3.3, I discussed that greywater characteristics can have substantial effect on the soil hydraulic conductivity. This gives insights to potential effect of wastewater characteristics on wastewater treatment systems that involve wastewater and soil interactions. In this section, the relevance of this study findings to the design of wastewater treatment systems, particularly those that are applicable in developing countries, will be briefly discussed.

5.6.1. Relevance of the study to the design of septic tank systems

The septic tank, an on-site wastewater treatment system, is a conventional wastewater treatment technology in areas without municipal sewerage systems. The septic tanks are followed by effluent disposal system either in the form of soak pits or dispersion trenches. It is the design of these effluent disposal systems (drain fields) that is discussed in relation to the findings of this study.

The design of dispersion trenches or soak pits is based on the percolation tests done on the soil upon which the wastewater is to be drained. The percolation tests are usually done using ordinary tap water to obtain the soil percolation rate upon which the design of the septic tank's drain field is based. The procedure for carrying out percolation tests is detailed in many literature (McGhee, 1991);(Perkins, 1989).

From this study, it was described that the quality of wastewater (greywater) can have a major impact on soil hydraulic properties. The characteristics of wastewater can also affect the infiltration rate from the trenches into the soil. A reduction in the soil infiltration rate and hydraulic conductivity can result in the failure of the system. The failure can cause frequent disludging of the septic tank. Therefore, for the design of the on-site systems and its loading rate, the type of wastewater that is generated in the dwelling should be used in soil percolation tests instead of ordinary water when determining the soil suitability.

A good design of the on-site system should also be followed by sound management of the system in order to realise the full economic benefits. A poorly designed system results in more frequent disludging of the septic tanks thereby increasing the cost of operation of the system. It is therefore important, as part of sound management, that the efforts should be made by households to minimise the inputs of salts, particularly sodium to their septic systems. Frequent use of cleaning solutions or powders(laundry detergents) and household chemicals containing high levels of sodium should be avoided.

To remedy hydraulic failure of septic tank drainfield due to the chemical composition of wastewater (greywater), application of calcium (as an amendment) can be applied together with wastewater. Calcium, being a divalent replaces sodium in the clay exchangeable site thus restoring the soil hydraulic conductivity.

A detailed study on the application of the calcium ameliorant to remedy failed septic tank drainfields is recommended in order to obtain insights on how to optimise these systems (see Section 6.2.2).

5.6.2. Relevance of the study to the design of soil aquifer treatment systems

Soil aquifer treatment (SAT) is a wastewater treatment process involving infiltration (percolation) of wastewater effluent through soil to further improve the quality of wastewater. The wastewater effluent is percolated through the vadose (unsaturated) zone to recharge underlying groundwater aquifer. The SAT renovated water can be recovered and reused for non-potable uses such as irrigation of the agricultural crops.

The SAT process involves three components; surface infiltration, percolation and aquifer storage (and recovery). It is the first two components; surface infiltration and percolation, which are discussed in relation to the findings on this study.

The surface spreading of wastewater effluent in infiltration basins are the most favoured methods of recharge because they allow efficient use of space and require relatively low maintenance. As described in section 5.3.3, wastewater characteristics can affect both soil infiltration rate and hydraulic conductivity and can therefore affect SAT system surface infiltration and percolation components. Wastewater effluent with high SAR and low electrical conductivity (EC) can reduce both soil infiltration and hydraulic conductivity to a point of making surface spreading of wastewater on the existing (available) land use impractical or too expensive. Therefore, the design of wastewater effluent application rates for SAT system must take into account wastewater characteristics for economic use of the available space.

In practice, the problem of reduced soil permeability of the infiltration basins that can be partly attributed to the effect of the wastewater characteristics is overcome through direct subsurface recharge. The wastewater is conveyed and injected directly into groundwater aquifer. However, for direct injection unlike surface spreading, a highly treated reclaimed wastewater should be used to prevent aquifer pollution and this calls for increased cost for wastewater treatment.

A good example where applicability of SAT system has been demonstrated in the developing countries is in Sulaibiya area in Kuwait (Akber *et al.*, 2008). In that area, the tertiary treated wastewater is surface spread by being reused for irrigation (a practice that has been undertaken for 30 years). The SAT renovated water from that project had considerable improvement in quality to the extent that it could be used for irrigation with slight to moderate restriction (as per FAO guidelines given in Table 2-8) and for other non-potable purposes.

However, the water from monitoring wells (after SAT) exhibited an increase in TDS which was attributed to leaching of soluble materials such as carbonates, sulfates, etc as irrigation water infiltrated to the water table. The authors reported that in initial phase of that project, the problem of low infiltration rate (3 cm/d) was experienced in the infiltration ponds, which was solved by drilling holes and filling them with gravel materials to enhance infiltration rates. The authors attributed the low infiltration rates to only low vertical permeability of the soil. Also, the characteristics of treated wastewater may have contributed to the low infiltration rates.

More research is needed to fully understand the implications of wastewater characteristics on SAT system performance. The SAT system has a great opportunity even in the developing countries as it can achieve secondary treatment, if properly operated, and thus can replace more energy intensive secondary treatment systems such as activated sludge system. However, using primary effluent on SAT system may lower the infiltration basin hydraulic loading rates than if higher effluent quality is used. Thus, more research is still required to investigate ways to optimise robust SAT system (see Section 6.2.2).

6. Conclusions and Recommendations

This chapter concludes the findings of this current research and recommends topics for further research. It summarises the conclusions drawn from the investigation of the impacts of long-term greywater disposal on soil properties and reuse in urban agriculture, based on a case study carried out in the Waruku informal urban settlement in Nairobi. The study provides important scientific insights to the long-term potential reuse of greywater in urban agriculture.

The study focuses on the impacts of greywater reuse on soil properties with a focus on sodicity and salinity issues. Possible human health risks from greywater reuse have been dealt with in many other research studies.

The study investigated the greywater disposal practices in Waruku and also evaluated the perception of the residents on greywater reuse and on environmental impacts of unplanned greywater disposal. The methodology used for the investigation was the administration of questionnaires to 110 households in Waruku.

The impacts of greywater on soil properties are expected to be influenced by the greywater characteristics. The research was designed to establish the characteristics of greywater generated in Waruku. To achieve this objective, greywater was collected from seven households surveyed during the four weeks of sampling and the greywater samples were analysed (79 samples were tested) for physical and chemical parameters relevant to the defined focus of the study.

For detailed investigation of the long-term effect of greywater disposal on soil properties, a site in the middle of Waruku settlements that had been drained with greywater for over 20 years was used. Fifteen soil samples (sampled to 150mm depth) were collected from the disposal site and analysed for relevant physical and chemical parameters to provide insight on the soil properties. The same experimental analyses were carried out on the soil samples collected from non-greywater disposal (control) site to provide background data.

6.1. Conclusions

6.1.1. Greywater disposal practices and residents' perceptions

The major greywater disposal route, at the household level in Waruku, is discharge into the outside drains. This disposal method represents 79 % of the major greywater disposal patterns practiced in Waruku. The study also revealed that laundry water is the main greywater stream that is commonly reused within the household. Fifty-six percent of the respondents reuse this stream to clean the floor of their houses. However, like other greywater streams, this stream is finally disposed of into the drains.

The majority of the respondents (84%) perceived reuse of treated greywater in urban agriculture as a viable option that should be encouraged. Despite the overwhelming support, the health and safety concerns about greywater reuse were identified as the key issues that must be adequately addresed for successful reuse of this resource.

6.1.2. Greywater generation and characterisation

The average greywater generation rate in Waruku is 27 L/cap/day or 92 L/hh/day (average household size is 3).

The study found a greywater return factor of 80% i.e. the proportion of greywater production to the total clean water consumption. Greywater as a resource offers large opportunities for reuse in urban agriculture as it is the only water source that increases as the population grows and the demand of freshwater increases.

Due to low per capita water consumption in Waruku (34 L/cap/day), which is the result of water rationing by the landlords, no further reduction in greywater production is possible. The current greywater disposal problems in Waruku cannot be solved by adopting water demand management techniques.

The study also revealed that greywater from Waruku has a high sodium concentration (170 mg/L) that has impacts on soil properties (see Section 5.3).

6.1.3. Effects of long-term greywater disposal on soil quality and urban agriculture

The long-term unplanned disposal of greywater in Waruku can have adverse effects on urban agriculture. The long-term greywater disposal causes high soil sodium accumulation that changes soil properties resulting in high soil salinity build- up which could affect salt-sensitive crops.

Elevated levels of sodium in the soil were evident even several metres from the point of greywater disposal indicating that the soluble sodium salts can move through the soil system with the drainage water. If high sodium concentrations in the greywater are not controlled, widespread adverse sodium-induced effects on soil properties can be expected to degrade large tracts of land available for urban agriculture.

The study has also shown that the soil organic carbon and the soil SAR are negatively correlated ($r = -0.54$), which suggests that a possible way to manage adverse effects of sodium in a soil environment is to boost the soil organic matter which acts to increase soil CEC. The organic matter can be used as a cation barrier (sodium sink) to mitigate sodium mobility in a soil environment.

The organic matter can be applied by using sanitised faecal matter (e.g. after composting) in line with the concept of ecological sanitation (Winbland and Simpson-Hebert, 2004). This method would be cheaper than the application of commercial gypsum. The success of such a strategy would depend on the willingness and participation of the residents. Effective awareness and sensitisation campaigns would be required.

6.1.4. Summary of the study findings

It can be concluded from this study that both opportunities and challenges exist in the reuse of greywater in urban agriculture. Reuse of greywater is a powerful means of water conservation and nutrients recycling, thereby reducing the demands of freshwater and mitigating pollution of surface and groundwater. However, potential challenges associated with reuse of greywater in urban agriculture exist. These challenges include salinity build up and high sodium accumulation in the soil.

Of great concern (apart from health risks due to pathogens which were not included in this study) is the significantly higher soil SAR in site drained with greywater over a long time compared with non-greywater disposal site (taken as control in this study). This provides reason for concern about possible long-term reduction in soil hydraulic conductivity and infiltration rates in soils with high clay content. Salt leaching would become less effective when soil hydraulic conductivity and infiltration rate were reduced. These chemical changes may lead to low crop productivity thus adversely affecting urban agriculture.

The urban farmers/ land managers must be prepared to face new challenges associated with greywater reuse. To mitigate the negative impact and ensure continued success with the reuse of greywater, the following farm management practices would be helpful:

- Regular greywater, soil and plant monitoring
- Selection and use of salt tolerant crops
- Regular application of organic manure (e.g. sanitised faecal matter) or application of soil ameliorants such as gypsum
- Periodic leaching to reduce salt accumulation

6.2. Recommendations

6.2.1. Study recommendations

Currently, there are no limits for Total dissolved solids (TDS) that exist for discharge of greywater in land application or even for discharge of industrial and municipal wastewater in urban sewers.

To mitigate the adverse effects of greywater on the soil environment, it is strongly recommended that source control must be practiced at the household level in Waruku. Source control is the first and the most affordable measure to address the greywater effects on soil salinity. For instance, by simply switching from powdered to liquid detergents, the potential of greywater reuse in sustainable urban agriculture can be enhanced. Liquid detergents compared with powdered detergents have lower concentrations of sodium per wash (Patterson, 2007).

I recommend that a comprehensive study be carried out in Waruku to establish the chemical content (salt content and cations level) of the commonly-used household detergents and chemicals. This would provide the Waruku households with necessary information to take informed decisions in the selection of the household products. It is also recommended that the households be informed about the benefits of switching to liquid detergents as an effective way of minimising the sodium load in Waruku that is applied to the land via greywater.

If source control measures would be difficult to practice at the household level, as recommended above, then some restrictions can be made on the use of high sodium detergents and household chemicals. For instance, the government could ban certain types of detergents.

It is also recommended that the manufacturers of household products be encouraged, (possibly through provision of economic incentives, like subsidies), to use ingredients in the manufacturing of household detergents and chemicals that would promote greywater reuse in urban agriculture. For instance, switching from sodium to potassium, which has similar chemical properties to sodium and also has agronomic significance, would boost opportunities for greywater reuse in urban agriculture. A costs comparison study would be required.

In addition to the above, the manufacturers should be required to provide clear and adequate labelling of their products to enable the households to make informed decisions that could be beneficial to the efforts of undertaking sustainable greywater reuse.

6.2.2. Recommendations for further research studies

The following further research studies have been identified:

i) More extensive soil sampling over longer periods (e.g. several years) to confirm the results of this study.
ii) Investigation of the effects of greywater disposal in non-sewered areas on groundwater quality. This should entail long-term monitoring of groundwater quality parameters and analysis of specific aquifers.
iii) Investigation of the effects of long-term greywater reuse on plant nutrition. Would accumulation of soil sodium due to greywater reuse adversely affect nutrient bio-availability and nutrient uptake by plants and hence reduce crop yields?
iv) Investigation of the required level of greywater treatment and suitable low-cost technologies so that treated greywater disposal would not adversely alter soil properties e.g. soil hydraulic conductivity, infiltration rates. The research should develop suitable design criteria for safe greywater loading (application) rates for on-site disposal systems (septic tanks), SAT systems, etc. to optimise these wastewater treatment systems.
v) Research into strategies required to shape residents' perceptions and how to encourage more and safe wastewater reuse in urban agriculture.
vi) This research showed that organic matter can act as sodium sink (barrier) to mitigate sodium migration on land applied with greywater of high concentration of sodium. More research is needed on the use of organic matter as a low-cost treatment (barrier) to reduce sodium load on land applied with greywater of high sodium concentration. The research should develop suitable design criteria for optimal loading rates, sodium contact time, etc.
vii) Investigation of the greywater disposal in non-sewered areas and its relationship with the long-term environmental effects of detergents. A detailed study on assignment of the financial and environmental cost estimates of greywater disposal problems in non-sewered areas and the financial cost estimates to the management of future impacts.
viii) Investigation of the long-term effects of greywater irrigation on soil microbiology and their important ecosystem functions.

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8. Appendices

Appendix 1: Greywater survey questionnaire details

Form No.

GREYWATER MANAGEMENT AND REUSE: SURVEY

Understanding Greywater Management and Residents' Perception of Greywater Reuse in Waruku, Nairobi

November – January 2008

Name of the interviewer:…………………………………………………………………..

Date of Interview:…………………………… Time ……………………………am/pm

Introduction

"Good morning/afternoon. Can I have a moment of your time? My name is (*name of the interviewer*) and I am conducting a survey for Urban Sanitation Project in Waruku assisted by Maji na Ufanisi (NGO) and Sandec of Switzerland. The project is aimed at improving sanitation situation in Waruku. The purpose of this survey is to help us understand how greywater is being managed and to understand if there are specific problems related to this issue and discuss with residents what they think could solve the problem. I would like to ask you some questions that would assist us to identify what needs to be done. Your opinion is therefore very important to be heard. These questions will take about 20 minutes and all answers are treated confidentially. Moreover, there are no wrong answers because everyone has a different opinion"

…………………………………………………………………………………………………..

A. **Household Characteristics**

A1. House No. /Name of the respondent ______________________________

Position of the respondent

- ☐ Male head of the house
- ☐ Female head of the house
- ☐ Other, please describe ________________________

A2. No. of people in household

Adults		Children	No.	Age
Male	Female	Non-school going		
		School going		

A3. House ownership: -Own house……………………………………….. 1

-Rented (How much do you pay for rent)…………. 2

-Other (specify) …………………………………… 3

A4. Type of House: -Informal (mud and tin) structure………………… 1
-Semi-permanent(brick/masonry) structure………. 2

A5. How long have you lived at the present site: -Less than 5 years……….. 1
-5 – 10 years……………… 2
-11 – 20 years ……………. 3
-More than 20 years ……… 4

A6. Occupation : -Formal……………………………. 1
-Informal (no regular income)…….. 2
-None……………………………… 3

A6. Household monthly expenditure: -Less than Ksh. 6000……………… 1
- Ksh. 6000 -15000……………….. 2
-Ksh.15001 – 20000………………. 3
-More than Ksh.20000……………. 4

B. Water Supply : Service level and consumption patterns

B1. What is your main source of domestic water?
-Piped water (individual house connection)……………………… 1
-Stand pipe (yard connection)…………………………………….. 2
-Water kiosk …………………………………………………… 3
- Water vendor …………………………………………………. 4
-Borehole ………………………………………………………. 5
-Other (Specify) ………………………………………………. 6

B2. Is it the same source for washing? …………..YES
……………NO

If NOT, what is the water source ?
-Surface water (river water)……………………………………… 1
-Borehole,……………………………………………………… 2
-Other (specify)………………………………........................... 3

B3. How much do you pay for the water per 20 litres Jerry-can
-Ksh 2 …………………………………………… 1
-Ksh 3 – 5 ……………………………………….. 2
-Ksh 6 – 10 ……………………………………… 3
-Ksh 11 – 20…………………………………….. 4
-More than Ksh 20 ……………………………….. 5

Or do you pay monthly for water? To whom?
- Nairobi water company ……………Ksh………/month …………1
-Water vendor ………………………Ksh………/ month…………2
- Water kiosk owner …………………Ksh………./month……… 3
- Other ……………………………….Ksh………./month……….. 4

How many 20 litre-Jerry cans do you use per day?..

B4. How regular is the water supply?
- Less than 5 hours/day …………For less than 3days/week……….1
- For 6 – 12 hours/day………….For 3 – 5 days /week…………… 2

-For 12 – 24 hours/ day…………For 7 days/week……………….. 3
-Other ……..hours/day………….For …..days/week…………….. 4

In case of water shortage, what is the source of your water supply?

- Surface water (river water)………………………………………..1
- Borehole …………………………………………………………..2
- Buy from water vendor. How much per 20 litre-Jerry can?…..……..3
- Other (specify)……………………………………………………4

B5. What is the distance from your house to the water point?

-Less 10 m (Includes people with piped water)…… 1
-10-50 m ……………………………………………2
-50-100 m………………………………………… 3
-100-200 m…………………………………………4
-More than 200 m……………………………………5

B6. What is your daily water usage in your household? (Estimate from containers used and frequency of fetching for non-piped residents or from water bills for connected customers)

-Less 20 litres ……………………………………. 1
-20-50 litres ……………………………………. 2
-50-100 litres ……………………………………. 3
-100-150 litres ……………………………………. 4
-More than 150 litres……………………………… 5

B7. How much water do you use for the following purposes in a day? (Estimate from 20 litre Jerry-can)

-Cooking & Drinking ……………………litres
-Bathing/personal hygiene..………………litres
-Laundry …………………….litres
-Kitchen: washing dishes…………………litres
-toilet washing ……………………………litres
-Other uses(Specify) ……………………..litres

(Piped water available : Go to B7, No piped water; Go to B9)

B8. What type of containers and in what capacity do you use to fetch water?

-Bucket ………………….L
-Jerry can ………………..L
-Drum ……………………L
-Other ……………………L

How many of those containers do you fill per day?.......................................

B9. What much water do you keep in the house? (To determine frequency of supply)

-Less 20 litres……………………………………… 1
-20-50 litres …………………………………….. 2
-51-100 litres …………………………………….. 3
-101-150 litres…………………………………….. 4
-More than 150 litres ……………………………… 5

B10. Other purposes of water storing containers?

-Laundry ………………………………………….. 1
-Cooking…………………………………………….. 2
-Dish washing……………………………………… 3
-Other (specify)……………………………..………4

B11. How often is laundry done for your households? Which days of the week?
-Daily ………………………………………………………….. 1
-Once a week ………Which day?……………………………….. 2
-Twice a week ………Which days?……………………………… 3
-More (specify)……… Which days?……………………………… 4

B12. How often do you/members of the family take a shower ?
-Daily………………………………………………..1
-Twice a day…………………………………………2
-Other (specify)……………………………………. 3

C. Greywater quality

C1. What type of detergents or soap brands do you use for the following activities?
Washing dishes …………………Powdered? …. ..Liquid?...........Bar soap?................
Laundry……… ……………… . Powdered? …. ..Liquid?...........Bar soap?...............
Bathing……… ………………… Powdered? …. ..Liquid?...........Bar soap?...............
Cleaning the house ..…………….Powdered? …. ..Liquid?...........Bar soap?...............

In what other activities do you use detergents and which ones do you use? …………

C2. How many grams of detergents do you use per week?
- 0-500g……………………………………………………………1
-501-1000g ………………………………………………………..2
-1001-2000g……………………………………………………….3
- Above 2000g……………………………………………………..4

D. Greywater disposal and reuse practices

D1. When do you think you use most water?
-Morning (8.00 -11.00am)……………………..1
-Afternoon (12Noon -4 pm)……………………..2
-Evening (From 5pm)………………………… 3

D2. What do you do with used water or where does it eventually go?
-pour onto ground outside dwelling/drain………… 1
-water plants …………………………………….. 2
-pour in toilet ……………………….………………3
-Other (specify)…………………………………. 4

D3. How do you dispose or reuse the following used water? Or where does it go? If you reuse, give examples of activities for which it is reused.
Dish washing water : Reuse………………………Dispose……………………
Laundry water : Reuse………………………Dispose……………………
Bathing: Reuse………………………Dispose……………………
Kitchen water : Reuse………………………Dispose……………………
Other (specify) …………………………………………………………

E. Urban agriculture

E1. Do you grow crops where you live? (If No go to F1) No ……..YES……..

If YES, which crops do you grow? …………………………………………

- Cabbages……………………………………………….………1
- Tomatoes………………………………………………………2
- Kales ……………………………………………………….3
- Other (specify)………………………………………………4

E2.Which water do you use to irrigate your crops and how much?

- Surface (river)water …………………………………..………1
- Greywater …………………………………………………2
- Rainwater ……………………………………….…………3

E3. Which type of fertilizers do you use for your crops?

- Commercial fertilisers……………………………………..1
- Animal manure ………………………………………2
- Compost manure ………………………………………3

F. Perception of greywater reuse and risk levels

F1. Do you think greywater disposal is a major health and environmental problem in the community?

……………………………..YES

……………………………..NO

If YES, in what sense? Give examples, starting with the **most important** concern:

………………………………………………………………………………

………………………………………………………………………………

F2. If it is a problem, what would you suggest as the **best** way of solving the problem of greywater disposal?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

F3.What is your opinion about use of treated greywater in urban agriculture? Should it be encouraged or should not be used? Give your reasons; which is the **most important**?

………………………………………………………………………………

………………………………………………………………………………

……………………………………………………………………………….

F4.Would you consume products irrigated with treated greywater ?

…………………YES

…………………..NO

If NOT, give reasons as to why you consider it unacceptable? (Which is the **most** important reason?) ……………………………………………………….

G. Excreta management

G1. What kind of toilet facility does this household use? (*Observe*)

-Pit latrine …………………………………………………… 1

-VIP latrine………………………………………………….. 2

-Flush toilet with septic tank…………………………………… 3

- Flush toilet with sewer connection……………………………. 4
-Have no own toilet; use neighbours' ………………………….. 5
-Public toilet (which type)……………………………………… 6
-Other (Specify) ………………………………………………… 7

(If no own toilet; Go to G3, Otherwise Go To G2)

G2. How many people share your toilet in a typical day?

-1 to 5…………………………………………. 1
-6 to 10………………………………………… 2
-11 to 20……………………………………….. 3
-More than 20…………………………………. 4

G3. How far is the toilet facility from your living quarter?

-Less 10m…………………………………….. 1
-10 to 50m……………………………………. 2
-More than 50m ……………………………… 3

G4. Where are the children faeces disposed off?

-Dropped into toilet facility………………….. 1
-Defaecate outside (open defaecation) ……… 2
-Disposed into solid waste/trash……………… 3
-Others (specify)……………………………… 4

Appendix 2: List of the survey assistants

Name	Gender		Field survey experience
	Male	Female	
Mwanjuma Kheri Kwamboka			Experienced in household surveys. Done 4 previously in Kibera informal settlement
Mutisya Joshua Mutinda			Experienced in household surveys. Done 3 previously in Kibera informal settlement
Ndichu Judy Mukami			Experienced in household surveys. Done 2 previously in Kibera informal settlement
Kibiwott Gilbert			Experienced in household surveys.

- This team was provided by the local NGO, Maji na Ufanisi. The aim was to have a gender balanced team which had extensive experience in household social surveys in similar localities.

Appendix 3: Waruku socio-economic survey questionnaire analysis

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
	A. Household characteristics						
A1	Position of the respondent (mark one)	Male head of the house	15	19	10	30	23
		Female head of the house	62	81	23	70	77
		Other	0	0	0	0	0
			77	100	33	100	100
A2	No. of people in household	1-3	50	65	12	36	56
		4-6	26	34	19	58	41
		> 6	1	1	2	6	3
			77	100	33	100	100
A3	Dwelling unit ownership	Own	12	16	5	15	15
		Rented	65	84	28	85	85
		Other	0	0	0	0	0
			77	100	33	100	100
A5	Length of time at present location	< 5 years	44	57	15	45	54
		5-10 years	21	27	13	39	31
		11-20 years	6	8	4	12	9
		> 20 years	6	8	1	3	6
			77	100	33	100	100
A6	Type of occupation	Formal	18	23	10	30	25
		Informal (no regular income)	59	77	23	70	75
		None	0	0	0	0	0
			77	100	33	100	100
A7	What is your monthly household expenditure?	< Kshs 6000	48	62	8	24	51
		Ksh. 6000 - 15000	26	34	18	55	40
		Ksh. 15001 - 20000	2	3	6	18	7
		> Ksh. 20000	1	1	1	3	2
			77	100	33	100	100

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
	B. Water supply: service levels and consumption patterns						
B1	What is your main source of domestic water?	Piped water (house connection)	0	0	2	6	2
		Stand pipe (yard tap)	60	78	27	82	79
		Water kiosk	17	22	4	12	19
		Borehole	0	0	0	0	0
		River	0	0	0	0	0
			77	100	33	100	100
B2	Is your main source of domestic water the same source for washing (laundry water)?	Yes	77	100.0	33	100.0	100
		No	0	0.0	0	0.0	0
B3	How much do you pay for water per 20 litre-jerrycan?	Ksh 2	0	0.0	0	0.0	0
		Ksh 3-5	22	28.6	4	12.1	24
		Ksh 6-10	0	0.0	0	0.0	0
		Ksh 11-20	0	0.0	0	0.0	0
B3 b)	Or to whom do you pay monthly for water ?	Nairobi water company	8	10	8	24	15
		Water kiosk	0	0	0	0	0
		Landlord (included in rent paid)	47	61	21	64	62
			77	100	33	100	100
B4	How regular is the water supply?	Less than 3 days/week	10	13	1	3	10
		3-5 days /week	20	26	4	12	22
		7 days /week	47	61	28	85	68
			77	100	33	100	100

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
B4 b)	In case of water shortage, what is your alternative water source?	River water	0	0	0	0	0
		Borehole	8	10	4	12	11
		Buy from vendors	69	90	29	88	89
			77	100	33	100	100
B5	What is the distance from your house to the water point?	< 10 m (on-site piped water)	43	56	23	70	60
		10-50 m	30	39	8	24	35
		51-100 m	4	5	2	6	5
		100 - 200m	0	0	0	0	0
			77	100	33	100	100
B6	What is your daily water usage in your household?	< 20 Litres	0	0	0	0	0
		20-50 Litres	17	22	0	0	15
		51-100 Litres	36	47	6	18	38
		101 - 150 Litres	18	23	20	61	35
		> 150 Litres	6	8	7	21	12
			77	100	33	100	100
B7	How often is laundry done in your household?	Daily	29	38	13	39	38
		Once a week	13	17	4	12	15
		Twice a week	21	27	11	33	29
		Three days a week	14	18	5	15	17
			77	100	33	100	100

		Waruku study area household survey analysis					
		Cluster type	**Cluster 1: Informal dwelling units (Mud and tin houses)**		**Cluster 2: Permanent dwelling units (Block and masonry houses)**		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
	C. Greywater quality						
C1	What type of detergents do you use for laundry?	powdered/ bar soap	77	100	33	100	100
		Liquid	0	0	0	0	0
C1 b)	What type of detergents do you use for washing dishes?	powdered	0	0	0	0	0
		bar soap	77	100	33	100	100
		Liquid	0	0	0	0	0
C2	How much detergents do you use in your household per week?	0-500 grams	32	42	13	39	41
		501 - 1000 grams	27	35	15	45	38
		1001 -2000 grams	18	23	5	15	21
		> 2001 grams	0	0	0	0	0
			77	100	33	100	100
	D. Greywater disposal and reuse						
D1	What do you do with used water or where does it eventually go?	dwelling/drain	62	81	25	76	79
		water plants	1	1	2	6	3
		direct to the sewer	0	0	1	3	1
		pour in a toilet	14	18	5	15	17
			77	100	33	100	100
D3 a)	How do you dispose or reuse laundry used water?	Directly dispose off into a drain	26	34	7	21	30
		Reuse in mopping house floor	38	49	24	73	56
		Reuse in cleaning toilet	13	17	2	6	14
		water plants	0	0	0	0	0
			77	100	33	100	100

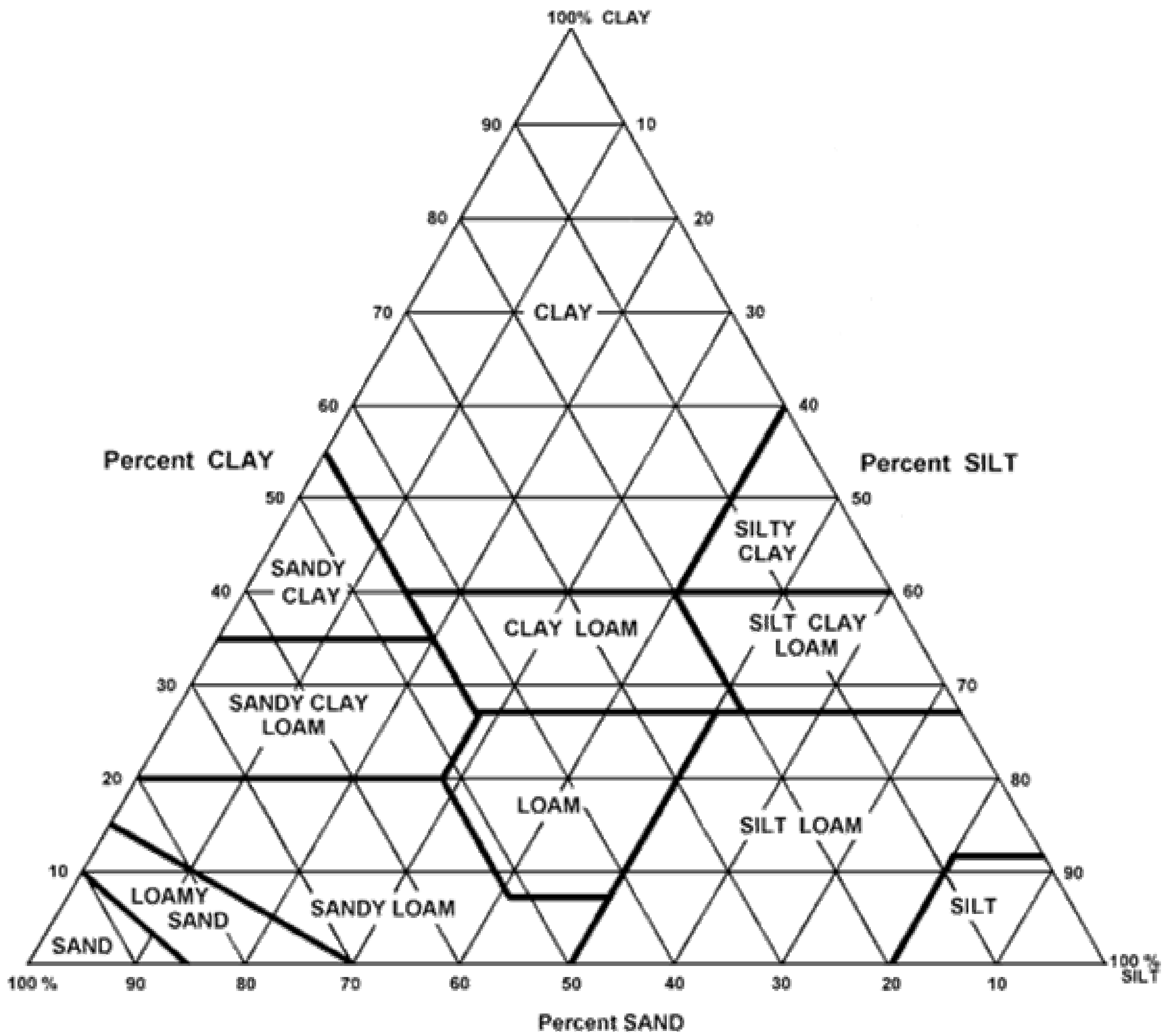
		Waruku study area household survey analysis					
		Cluster type	**Cluster 1: Informal dwelling units (Mud and tin houses)**		**Cluster 2: Permanent dwelling units (Block and masonry houses)**		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
D3 b)	How do you dispose or reuse Kitchen or dishwashing used water?	Dispose of into a drain	51	66	24	73	68
		Reuse in mopping the house floor	0	0	0	0	0
		Reuse in cleaning toilet	0	0	0	0	0
		water plants	10	13	2	6	11
		pour in a toilet	16	21	7	21	21
			77	100	33	100	100
D3 c)	How do you dispose or reuse bathing used water?	Dispose of into a drain	56	73	17	52	66
		Reuse in mopping the house floor	4	5	1	3	5
		Reuse in cleaning toilet	17	22	15	45	29
		water plants	0	0	0	0	0
			77	100	33	100	100
	E. Urban agriculture						
E1	Do you grow crops where you live?	Yes	10	13	5	15	14
		No	67	87	28	85	86
			77	100	33	100	100
E2	If you practice urban agriculture, which crops do you grow?	Cabbages / Sukuma wiki	9	90	5	100	93
		Arrow roots	1	10	0	0	7
		Bananas	0	0	0	0	0
		Others	0	0	0	0	0
			10	100	5	100	100

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
E3	If you practice urban agriculture, which water do you use to irrigate your crops?	Surface (river) water	2	20	1	20	20
		Rainwater	3	30	2	40	33
		Greywater	5	50	1	20	40
		Piped water	0	0	1	20	7
			10	100	5	100	100
E4	Which type of fertilizers do you use for your crops?	Commercial fertilizers	4	40	1	20	33
		Animal manure	3	30	2	40	33
		Compost manure	0	0	1	20	7
		None	3	30	1	20	27
			10	100	5		100
	F. Perception of greywater reuse and risk levels						
F1	Do you think greywater disposal is a major health and environmental problem in your neighbourhood?	Yes	58	75	28	85	78
		No	19	25	5	15	22
			77	100	33	100	100
F1 b)	If greywater disposal has detrimental effects in which ways in your opinion is it harmful?	Breeds mosquitoes/malaria outbreak	35	60	15	54	58
		Releases unpleasant smell (odour)	10	17	9	32	22
		diseases (typhoid)	7	12	2	7	10
		Destroys access roads	4	7	1	4	6
		It pollutes the river	2	3	1	4	3
			58	100	28	100	100

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
F2	In your opinion,what do you think should be done to solve greywater disposal problems?	Construct/renovate drain to the river	34	59	14	50	56
		Direct it to the sewer	8	14	4	14	14
		Drain it to the farms/ reuse in farms	11	19	6	21	20
		I have no idea	5	9	4	14	10
			58	100	28	100	100
F3	What is your opinion regarding the use of treated greywater in urban agriculture?	Good idea, it should be encouraged	69	90	32	97	92
		It should not be used	8	10	1	3	8
			77	100	33	100	100
F4	Would you consume crops irrigated with treated greywater?	Yes	62	81	30	91	84
		No	15	19	3	9	16
			77	100	33	100	100
F4 b)	If you would not consume crops grown with treated greywater, what are the reasons why you consider it unacceptable?	It is unhygienic; contains children faecal matter	5	33	1	33	33
		Not safe (has harmful chemicals)	9	60	1	33	56
		Religious reasons	1	7	1	33	11
			15	100	3	100	100

		Waruku study area household survey analysis					
		Cluster type	Cluster 1: Informal dwelling units (Mud and tin houses)		Cluster 2: Permanent dwelling units (Block and masonry houses)		
		Total no. of respondents	77		33		
Que' no.	Variables	Responses	No Resp1	% Respondents	No Resp1	% Respondents	Overall Respondence (%)
	G. Excreta management						
G1	What kind of toilet facility does this household use?	Pit latrine	46	60	12	36	53
		Pour flush with septic tank	26	34	19	58	41
		Pour flush with sewer connection	1	1	2	6	3
		Public toilet	4	5	0	0	4
			77	100	33	100	100
G2	How many people share the toilet that your household use?	1-5	3	4	5	15	7
		6-10	5	6	2	6	6
		11-20	3	4	12	36	14
		> 20	66	86	14	42	73
			77	100	33	100	100
G3	How far is the toilet facility from your living quarter?	< 10 m	50	65	23	70	66
		10 - 50 m	21	27	9	27	27
		> 50 m	6	8	1	3	6
			77	100	33	100	100
G4	Where are the children faeces disposed off?	Dropped into toilet facility	53	69	21	64	67
		Defaecate outside	5	6	0	0	5
		Dispose into solid waste/trash	4	5	5	15	8
		To the river /flying toilet	11	14	2	6	12
		Not applicable (no children)	4	5	5	15	8
			77	100	33	100	100

Appendix 4: Basic soil textural classes chart (USDA, 1993)



Type of the soil in Waruku study area is humic nitisol, popularly known as Kikuyu red loam soil (red coffee soil). Based on the above soil textural classes, the study area of Waruku had clay soil.

Appendix 5: Analysis of Waruku greywater generation from the seven households surveyed during four weeks of sampling

Item No.	Household identification	Drinking water Litres/hh/day	No. of persons in a household	Drinking water Litres/cap/day	Water depth mm	Diameter mm	Greywater Litres/hh/day	Greywater Litres/cap/day	Greywater return factor	Sampling day & date
1	21/1	180	3	60	300	460	149.50	49.83	83.05	1 (26/11/07)
2	21/2	150	3	50	250	460	124.58	41.53	83.05	
3	21/3	90	3	30	130	460	64.78	21.59	71.98	
4	21/4	90	3	30	130	460	64.78	21.59	71.98	
5	21/5	180	3	60	240	530	158.76	52.92	88.20	
6	21/6	90	3	30	150	460	74.75	24.92	83.05	
7	21/7	90	3	30	150	460	74.75	24.92	83.05	
8	21/8	120	4	30	160	400	80.38	20.10	66.99	
9	22/2	150	3	50	260	460	129.56	43.19	86.38	2 (27/11/07)
10	22/3	90	3	30	150	460	74.75	24.92	83.05	
11	22/4	90	3	30	150	460	74.75	24.92	83.05	
12	22/5	180	3	60	240	530	158.76	52.92	88.20	
13	22/6	120	3	40	210	460	104.65	34.88	87.21	
14	22/7	160	4	40	90	530	79.38	19.85	49.61	
15	22/8	120	4	30	210	400	105.50	26.38	87.92	
16	26/2	100	5	20	105	460	87.21	17.44	87.21	4 (29/11/07)
17	26/3	60	3	20	110	460	54.81	18.27	91.36	
18	26/4	150	3	50	190	530	125.69	41.90	83.79	
19	26/5	90	3	30	135	460	67.27	22.42	74.75	
20	26/6	160	4	40	135	530	119.07	29.77	74.42	
21	26/7	120	4	30	215	400	108.02	27.00	90.01	
22	27/1	120	3	40	205	460	102.16	34.05	85.13	6 (3/12/07)
23	27/2	60	3	20	100	460	49.83	16.61	83.05	
24	27/3	60	3	20	105	460	52.32	17.44	87.21	
25	27/5	60	3	20	110	460	54.81	18.27	91.36	
26	27/6	160	4	40	140	530	123.48	30.87	77.18	
27	28/3	60	3	20	70	460	34.88	11.63	58.14	8 (5/12/07)
28	28/4	160	4	40	140	530	123.48	30.87	77.18	
29	28/5	90	3	30	150	460	74.75	24.92	83.05	
30	28/6	160	4	40	150	530	132.30	33.08	82.69	
31	28/7	160	4	40	240	400	120.58	30.14	75.36	
32	29/1	100	5	20	110	460	91.36	18.27	91.36	10 (7/12/07)
33	29/2	90	3	30	160	460	79.73	26.58	88.59	
34	29/3	60	3	20	100	460	49.83	16.61	83.05	
35	29/4	180	3	60	250	530	165.38	55.13	91.88	
36	29/5	120	3	40	200	460	99.66	33.22	83.05	
37	29/6	180	3	60	140	530	92.61	30.87	51.45	
38	29/7	120	4	30	150	400	75.36	18.84	62.80	
39	30/1	90	3	30	130	460	64.78	21.59	71.98	12 (10/12/07)
40	30/2	120	3	40	190	460	94.68	31.56	78.90	
41	30/3	60	3	20	110	460	54.81	18.27	91.36	
42	30/4	80	4	20	60	530	52.92	13.23	66.15	
43	30/5	60	3	20	100	460	49.83	16.61	83.05	
44	30/6	160	4	40	150	530	132.30	33.08	82.69	
45	30/7	120	4	30	170	400	85.41	21.35	71.17	

Item No.	Household identification	Drinking water Litres/hh/day	No. of persons in a household	Drinking water Litres/cap/day	Water depth mm	Diameter mm	Greywater Litres/hh/day	Greywater Litres/cap/day	Greywater return factor	Sampling day & date
46	3/1	60	3	20	100	460	49.83	16.61	83.05	
47	3/2	90	3	30	150	460	74.75	24.92	83.05	
48	3/3	120	3	40	190	460	94.68	31.56	78.90	
49	3/4	240	4	60	240	530	211.69	52.92	88.20	14
50	3/5	90	3	30	150	460	74.75	24.92	83.05	(12/12/07)
51	3/6	160	4	40	140	530	123.48	30.87	77.18	
52	3/7	120	4	30	180	400	90.43	22.61	75.36	
53	4/1	90	3	30	140	460	69.76	23.25	77.52	
54	4/2	60	3	20	90	460	44.85	14.95	74.75	
55	4/3	90	3	30	160	460	79.73	26.58	88.59	
56	4/4	160	4	40	170	530	149.94	37.49	93.72	16
57	4/5	90	3	30	130	460	64.78	21.59	71.98	(14/12/07)
58	4/6	160	4	40	140	530	123.48	30.87	77.18	
59	4/7	80	4	20	150	400	75.36	18.84	94.20	
60	5/1	90	3	30	120	460	59.80	19.93	66.44	
61	5/2	120	3	40	200	460	99.66	33.22	83.05	
62	5/4	160	4	40	90	530	79.38	19.85	49.61	18
63	5/5	90	3	30	140	460	69.76	23.25	77.52	(17/12/07)
64	5/6	160	4	40	170	530	149.94	37.49	93.72	
65	5/7	120	4	30	140	400	70.34	17.58	58.61	
66	6/1	90	3	30	130	460	64.78	21.59	71.98	
67	6/2	60	3	20	100	460	49.83	16.61	83.05	
68	6/3	60	3	20	90	460	44.85	14.95	74.75	20
69	6/4	160	4	40	150	530	132.30	33.08	82.69	(19/12/07)
70	6/5	90	3	30	140	460	69.76	23.25	77.52	
71	6/6	160	4	40	160	530	141.12	35.28	88.20	
72	6/7	120	4	30	190	400	95.46	23.86	79.55	
73	7/1	120	3	40	190	460	94.68	31.56	78.90	
74	7/2	120	3	40	200	460	99.66	33.22	83.05	
75	7/3	90	3	30	160	460	79.73	26.58	88.59	22
76	7/4	160	4	40	140	530	123.48	30.87	77.18	(21/12/07)
77	7/5	90	3	30	140	460	69.76	23.25	77.52	
78	7/6	200	4	50	190	530	167.58	41.90	83.79	
79	7/7	80	4	20	140	400	70.34	17.58	87.92	
Sum		9160.00	269.00	2690.00	12250.00	37220.00	7298.76	2147.23	6306.52	
Average		115.95	3.41	**34.05**	155.06	471.14	92.39	**27.18**	**79.83**	
Standard deviation		41.12	0.54	**11.15**	47.44	42.00	35.52	**9.88**	**9.77**	
Count		79	79	79	79	79	79	79	79	
Coefficient of variation (CV) %		35	16	33	31	9	38	36	12	
Maximum		240	5	60	300	530	211.69	55.13	94.2	
Minimum		60	3	20	60	400	34.88	11.63	49.61	

Appendix 6: Analysis of Waruku greywater characteristics from the seven households surveyed during four weeks of sampling

Item No.	Sample No.	GW (Q) L/hh/day	Parameters																						Sampling day and date
			Sodium (Na+)		Sodium load (Na+)xQ		Magnesium (Mg2+)		Magnesium load (Mg2+)xQ		Total Calcium (Ca2+)		Total Calcium load (Ca2+)xQ		SAR_{total}	Free Calcium (Ca2+)		Free Calcium load (Ca2+)xQ		SAR_{free}	EC	EC	ECxQ	pH	
			mg/L	meq/L	mg/hh/day	meq/hh/day	mg/L	meq/L	mg/hh/day	meq/hh/day	mg/L	meq/L	mg/hh/day	meq/hh/day		mg/L	meq/L	mg/hh/day	meq/hh/day		µS/cm	dS/m	dS/m.hh/day		
1	21/1/GW	149.50	390.00	16.96	58303.21	2534.92	9.00	0.74	1345.46	110.28	74.00	3.70	11062.66	553.13	11.38	41.44	2.07	372.96	18.65	14.31	2310	2.31	345.33	8.83	
2	21/2/GW	124.58	187.00	8.13	23296.37	1012.89	5.30	0.43	660.27	54.12	18.80	0.94	2342.09	117.10	9.81	10.53	0.53	55.80	2.79	11.73	1297	1.30	161.58	8.07	
3	21/3/GW	64.78	140.00	6.09	9069.39	394.32	5.50	0.45	356.30	29.20	27.50	1.38	1781.49	89.07	6.37	15.40	0.77	84.70	4.24	7.79	940	0.94	60.89	7.85	
4	21/4/GW	64.78	136.00	5.91	8810.26	383.05	5.90	0.48	382.21	31.33	28.50	1.43	1846.27	92.31	6.05	15.96	0.80	94.16	4.71	7.39	937	0.94	60.70	7.85	1 (26/11/07)
5	21/5/GW	158.76	91.50	3.98	14526.97	631.61	3.80	0.31	603.31	49.45	14.40	0.72	2286.21	114.31	5.54	8.06	0.40	30.64	1.53	6.66	597	0.60	94.78	7.59	
6	21/6/GW	74.75	97.00	4.22	7250.53	315.24	5.70	0.47	426.06	34.92	27.30	1.37	2040.61	102.03	4.41	15.29	0.76	87.14	4.36	5.37	756	0.76	56.51	7.23	
7	21/7/GW	74.75	78.00	3.39	5830.32	253.49	10.70	0.88	799.80	65.56	32.60	1.63	2436.78	121.84	3.03	18.26	0.91	195.34	9.77	3.58	511	0.51	38.20	7.05	
8	21/8/GW	80.38	163.00	7.09	13102.59	569.68	6.70	0.55	538.57	44.15	23.10	1.16	1856.87	92.84	7.68	12.94	0.65	86.67	4.33	9.16	937	0.94	75.32	6.23	
9	22/2/GW	129.56	129.70	5.64	16804.28	730.62	3.10	0.25	401.64	32.92	15.90	0.80	2060.05	103.00	7.79	8.90	0.45	27.60	1.38	9.54	914	0.91	118.42	6.07	
10	22/3/GW	74.75	162.20	7.05	12124.08	527.13	3.10	0.25	231.72	18.99	27.90	1.40	2085.46	104.27	7.77	15.62	0.78	48.43	2.42	9.80	750	0.75	56.06	8.12	
11	22/4/GW	74.75	162.30	7.06	12131.55	527.46	2.60	0.21	194.34	15.93	26.40	1.32	1973.34	98.67	8.06	14.78	0.74	38.44	1.92	10.23	728	0.73	54.42	8.12	
12	22/5/GW	158.76	108.00	4.70	17146.59	745.50	2.90	0.24	460.42	37.74	26.80	1.34	4254.89	212.74	5.29	15.01	0.75	43.52	2.18	6.68	1267	1.27	201.15	8.56	2 (27/11/07)
13	22/6/GW	104.65	105.30	4.58	11019.31	479.10	6.00	0.49	627.88	51.47	26.50	1.33	2773.14	138.66	4.80	14.84	0.74	89.04	4.45	5.83	712	0.71	74.51	7.75	
14	22/7/GW	79.38	235.00	10.22	18654.85	811.08	7.10	0.58	563.61	46.20	36.30	1.82	2881.58	144.08	9.33	20.33	1.02	144.33	7.22	11.43	1468	1.47	116.53	8.47	
15	22/8/GW	105.50	99.90	4.34	10539.85	458.25	5.70	0.47	601.37	49.29	35.90	1.80	3787.59	189.38	4.08	20.10	1.01	114.59	5.73	5.06	775	0.78	81.77	6.50	
16	26/2/GW	87.21	178.00	7.74	15522.61	674.90	6.00	0.49	523.23	42.89	29.00	1.45	2528.96	126.45	7.85	16.24	0.81	97.44	4.87	9.59	839	0.84	73.17	9.40	
17	26/3/GW	54.81	304.00	13.22	16663.75	724.51	9.00	0.74	493.33	40.44	30.00	1.50	1644.45	82.22	12.50	16.80	0.84	151.20	7.56	14.88	1716	1.72	94.06	8.23	
18	26/4/GW	125.69	172.00	7.48	21618.46	939.93	6.00	0.49	754.13	61.81	33.00	1.65	4147.73	207.39	7.23	18.48	0.92	110.88	5.54	8.89	945	0.95	118.78	8.80	4 (29/11/07)
19	26/5/GW	67.27	135.00	5.87	9081.85	394.86	6.00	0.49	403.64	33.09	28.00	1.40	1883.64	94.18	6.04	15.68	0.78	94.08	4.70	7.35	843	0.84	56.71	7.85	
20	26/6/GW	119.07	171.00	7.43	20361.57	885.29	7.00	0.57	833.51	68.32	40.00	2.00	4762.94	238.15	6.55	22.40	1.12	156.80	7.84	8.08	1040	1.04	123.84	8.66	
21	26/7/GW	108.02	203.00	8.83	21927.25	953.36	14.00	1.15	1512.22	123.95	90.00	4.50	9721.44	486.07	5.25	50.40	2.52	705.60	35.28	6.52	1532	1.53	165.48	8.16	
22	27/1/GW	102.16	210.20	9.14	21473.02	933.61	6.75	0.55	689.55	56.52	62.50	3.13	6384.70	319.23	6.74	35.00	1.75	236.25	11.81	8.52	1264	1.26	129.12	7.65	
23	27/2/GW	49.83	194.50	8.46	9692.29	421.40	3.20	0.26	159.46	13.07	26.50	1.33	1320.54	66.03	9.49	14.84	0.74	47.49	2.37	11.93	1090	1.09	54.32	7.61	
24	27/3/GW	52.32	142.25	6.18	7443.00	323.61	2.50	0.20	130.81	10.72	27.20	1.36	1423.20	71.16	6.99	15.23	0.76	38.08	1.90	8.90	873	0.87	45.68	8.01	6 (3/12/07)
25	27/5/GW	54.81	100.70	4.38	5519.87	239.99	5.75	0.47	315.19	25.83	24.70	1.24	1353.93	67.70	4.74	13.83	0.69	79.53	3.98	5.74	900	0.90	49.33	8.58	
26	27/6/GW	123.48	228.20	9.92	28178.97	1225.17	5.25	0.43	648.29	53.14	41.50	2.08	5124.57	256.23	8.86	23.24	1.16	122.01	6.10	11.12	1287	1.29	158.92	7.23	
27	28/3/GW	34.88	49.00	2.13	1709.23	74.31	1.55	0.13	54.07	4.43	10.25	0.51	357.54	17.88	3.77	5.74	0.29	8.90	0.44	4.68	723	0.72	25.22	8.78	
28	28/4/GW	123.48	105.50	4.59	13027.52	566.41	4.50	0.37	555.68	45.55	21.75	1.09	2685.77	134.29	5.38	12.18	0.61	54.81	2.74	6.56	1246	1.25	153.86	7.35	
29	28/5/GW	74.75	139.20	6.05	10404.88	452.39	3.25	0.27	242.93	19.91	31.25	1.56	2335.87	116.79	6.33	17.50	0.88	56.88	2.84	8.01	772	0.77	57.71	8.61	8 (5/12/07)
30	28/6/GW	132.30	219.70	9.55	29067.17	1263.79	2.20	0.18	291.07	23.86	27.50	1.38	3638.36	181.92	10.83	15.40	0.77	33.88	1.69	13.86	1097	1.10	145.14	9.57	
31	28/7/GW	120.58	154.20	6.70	18592.82	808.38	17.00	1.39	2049.79	168.02	75.25	3.76	9073.34	453.67	4.18	42.14	2.11	716.38	35.82	5.07	756	0.76	91.16	5.65	
32	29/1/GW	91.36	58.70	2.55	5362.73	233.16	1.60	0.13	146.17	11.98	17.70	0.89	1617.04	80.85	3.58	9.91	0.50	15.86	0.79	4.56	901	0.90	82.31	9.29	
33	29/2/GW	79.73	189.00	8.22	15069.14	655.18	1.60	0.13	127.57	10.46	15.70	0.79	1251.77	62.59	12.14	8.79	0.44	14.07	0.70	15.38	1188	1.19	94.72	9.18	
34	29/3/GW	49.83	133.00	5.78	6627.63	288.16	2.50	0.20	124.58	10.21	21.70	1.09	1081.35	54.07	7.20	12.15	0.61	30.38	1.52	9.07	833	0.83	41.51	9.18	
35	29/4/GW	165.38	221.00	9.61	36548.95	1589.08	1.70	0.14	281.15	23.04	19.30	0.97	3191.83	159.59	12.93	10.81	0.54	18.37	0.92	16.48	1316	1.32	217.64	10.15	10 (7/12/07)
36	29/5/GW	99.66	105.20	4.57	10484.61	455.85	3.20	0.26	318.92	26.14	17.70	0.89	1764.05	88.20	6.04	9.91	0.50	31.72	1.59	7.43	907	0.91	90.39	9.50	
37	29/6/GW	92.61	111.75	4.86	10349.47	449.98	1.90	0.16	175.96	14.42	11.70	0.59	1083.57	54.18	7.98	6.55	0.33	12.45	0.62	9.88	706	0.71	65.38	8.60	
38	29/7/GW	75.36	169.75	7.38	12792.36	556.19	3.40	0.28	256.22	21.00	21.80	1.09	1642.85	82.14	8.92	12.21	0.61	41.51	2.08	11.07	888	0.89	66.92	6.05	
39	30/1/GW	64.78	520.00	22.61	33686.30	1464.62	12.00	0.98	777.38	63.72	68.00	3.40	4405.13	220.26	15.27	38.08	1.90	456.96	22.85	18.82	2840	2.84	183.98	8.21	
40	30/2/GW	94.68	175.00	7.61	16569.07	720.39	4.00	0.33	378.72	31.04	14.00	0.70	1325.53	66.28	10.61	7.84	0.39	31.36	1.57	12.68	2350	2.35	222.50	8.38	
41	30/3/GW	54.81	322.00	14.00	17650.42	767.41	8.00	0.66	438.52	35.94	16.00	0.80	877.04	43.85	16.41	8.96	0.45	71.68	3.58	18.85	1740	1.74	95.38	6.36	
42	30/4/GW	52.92	78.00	3.39	4127.88	179.47	2.00	0.16	105.84	8.68	20.00	1.00	1058.43	52.92	4.45	11.20	0.56	22.40	1.12	5.64	521	0.52	27.57	6.71	12 (10/12/07)
43	30/5/GW	49.83	121.00	5.26	6029.65	262.16	8.00	0.66	398.65	32.68	17.20	0.86	857.11	42.86	6.04	9.63	0.48	77.06	3.85	6.98	701	0.70	34.93	7.22	
44	30/6/GW	132.30	227.00	9.87	30032.99	1305.78	2.00	0.16	264.61	21.69	20.00	1.00	2646.08	132.30	12.94	11.20	0.56	22.40	1.12	16.40	1145	1.15	151.49	9.31	
45	30/7/GW	85.41	159.00	6.91	13579.87	590.43	10.00	0.82	854.08	70.01	37.00	1.85	3160.10	158.00	5.98	20.72	1.04	207.20	10.36	7.18	944	0.94	80.63	6.73	

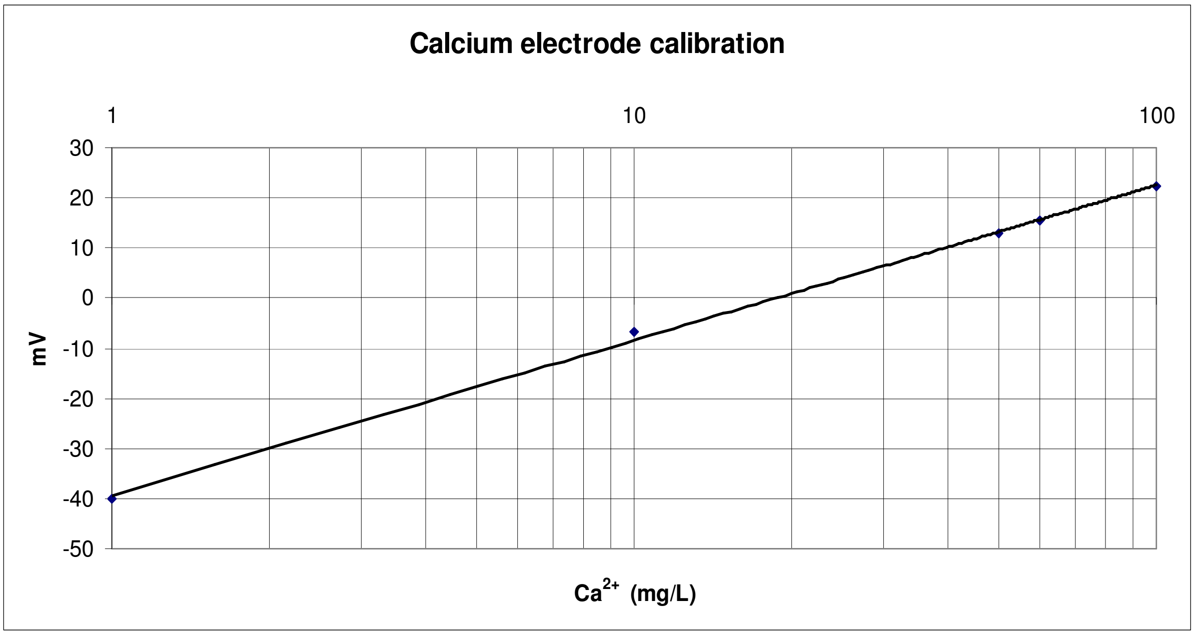
Item No.	Sample No.	GW (Q) L/hh/day	Parameters: Sodium (Na+) mg/L	Sodium (Na+) meq/L	Sodium load (Na+)xQ mg/hh/day	Sodium load (Na+)xQ meq/hh/day	Magnesium (Mg2+) mg/L	Magnesium (Mg2+) meq/L	Magnesium load (Mg2+)xQ mg/hh/day	Magnesium load (Mg2+)xQ meq/hh/day	Total Calcium (Ca2+) mg/L	Total Calcium (Ca2+) meq/L	Total Calcium load (Ca2+)xQ mg/hh/day	Total Calcium load (Ca2+)xQ meq/hh/day	SAR_{total}	Free Calcium (Ca2+) mg/L	Free Calcium (Ca2+) meq/L	Free Calcium load (Ca2+)xQ mg/hh/day	Free Calcium load (Ca2+)xQ meq/hh/day	SAR_{free}	EC µS/cm	EC dS/m	ECxQ dS/m.hh/day	pH	Sampling day and date
46	3/1/GW	49.83	162.00	7.04	8072.75	350.99	4.00	0.33	199.33	16.34	11.00	0.55	548.15	27.41	10.63	6.16	0.31	24.64	1.23	12.49	1287	1.29	64.13	8.98	
47	3/2/GW	74.75	259.00	11.26	19359.65	841.72	6.00	0.49	448.49	36.76	16.00	0.80	1195.96	59.80	14.01	8.96	0.45	53.76	2.69	16.43	1587	1.59	118.62	9.02	
48	3/3/GW	94.68	278.00	12.09	26321.16	1144.40	6.00	0.49	568.08	46.56	14.00	0.70	1325.53	66.28	15.66	7.84	0.39	47.04	2.35	18.18	1420	1.42	134.45	9.40	
49	3/4/GW	211.69	251.00	10.91	53133.25	2310.14	4.00	0.33	846.74	69.41	15.00	0.75	3175.29	158.76	14.87	8.40	0.42	33.60	1.68	17.85	1985	1.99	420.20	9.21	14
50	3/5/GW	74.75	162.00	7.04	12109.13	526.48	4.00	0.33	298.99	24.51	10.00	0.50	747.48	37.37	10.95	5.60	0.28	22.40	1.12	12.78	840	0.84	62.79	8.82	(12/12/07)
51	3/6/GW	123.48	197.00	8.57	24326.28	1057.66	4.30	0.35	530.98	43.52	16.00	0.80	1975.74	98.79	11.28	8.96	0.45	38.53	1.93	13.54	1306	1.31	161.27	8.19	
52	3/7/GW	90.43	67.00	2.91	6058.94	263.43	10.13	0.83	916.08	75.09	26.00	1.30	2351.23	117.56	2.82	14.56	0.73	147.49	7.37	3.30	777	0.78	70.27	6.49	
53	4/1/GW	69.76	209.30	9.10	14601.71	634.86	6.50	0.53	453.47	37.17	43.75	2.19	3052.20	152.61	7.80	24.50	1.23	159.25	7.96	9.71	1626	1.63	113.44	9.34	
54	4/2/GW	44.85	89.50	3.89	4013.95	174.52	4.00	0.33	179.39	14.70	32.25	1.61	1446.37	72.32	3.95	18.06	0.90	72.24	3.61	4.96	780	0.78	34.98	5.65	
55	4/3/GW	79.73	203.30	8.84	16209.29	704.75	3.00	0.25	239.19	19.61	27.00	1.35	2152.73	107.64	9.90	15.12	0.76	45.36	2.27	12.49	1475	1.48	117.60	7.14	
56	4/4/GW	149.94	170.50	7.41	25565.52	1111.54	2.75	0.23	412.35	33.80	26.70	1.34	4003.52	200.18	8.39	14.95	0.75	41.12	2.06	10.63	1154	1.15	173.04	8.69	16
57	4/5/GW	64.78	105.50	4.59	6834.43	297.15	3.25	0.27	210.54	17.26	36.20	1.81	2345.08	117.25	4.50	20.27	1.01	65.88	3.29	5.73	580	0.58	37.57	7.08	(14/12/07)
58	4/6/GW	123.48	109.80	4.77	13558.50	589.50	4.25	0.35	524.81	43.02	32.20	1.61	3976.17	198.81	4.82	18.03	0.90	76.64	3.83	6.04	778	0.78	96.07	5.81	
59	4/7/GW	75.36	119.00	5.17	8967.84	389.91	7.25	0.59	546.36	44.78	53.50	2.68	4031.76	201.59	4.05	29.96	1.50	217.21	10.86	5.06	985	0.99	74.23	5.35	
60	5/1/GW	59.80	188.00	8.17	11242.05	488.78	5.72	0.47	342.05	28.04	71.70	3.59	4287.53	214.38	5.74	40.15	2.01	229.67	11.48	7.35	1310	1.31	78.34	7.70	
61	5/2/GW	99.66	175.00	7.61	17441.13	758.31	5.50	0.45	548.15	44.93	36.50	1.83	3637.72	181.89	7.13	20.44	1.02	112.42	5.62	8.87	1360	1.36	135.54	7.80	
62	5/4/GW	79.38	86.00	3.74	6826.88	296.82	3.25	0.27	257.99	21.15	24.20	1.21	1921.05	96.05	4.35	13.55	0.68	44.04	2.20	5.44	728	0.73	57.79	5.78	18
63	5/5/GW	69.76	187.00	8.13	13045.97	567.22	7.25	0.59	505.79	41.46	38.50	1.93	2685.93	134.30	7.24	21.56	1.08	156.31	7.82	8.89	811	0.81	56.58	8.59	(17/12/07)
64	5/6/GW	149.94	139.50	6.07	20917.25	909.45	3.00	0.25	449.83	36.87	35.50	1.78	5323.03	266.15	6.03	19.88	0.99	59.64	2.98	7.70	854	0.85	128.05	7.64	
65	5/7/GW	70.34	178.00	7.74	12519.81	544.34	12.00	0.98	844.03	69.18	50.70	2.54	3566.04	178.30	5.83	28.39	1.42	340.70	17.04	7.06	770	0.77	54.16	5.80	
66	6/1/GW	64.78	256.30	11.14	16603.46	721.89	4.25	0.35	275.32	22.57	29.50	1.48	1911.05	95.55	11.67	16.52	0.83	70.21	3.51	14.54	1936	1.94	125.42	8.93	
67	6/2/GW	49.83	142.30	6.19	7091.07	308.31	5.25	0.43	261.62	21.44	55.20	2.76	2750.72	137.54	4.90	30.91	1.55	162.29	8.11	6.22	605	0.61	30.15	6.40	
68	6/3/GW	44.85	195.50	8.50	8767.91	381.21	6.00	0.49	269.09	22.06	34.00	1.70	1524.85	76.24	8.12	19.04	0.95	114.24	5.71	10.00	1357	1.36	60.86	7.35	20
69	6/4/GW	132.30	163.80	7.12	21671.38	942.23	3.75	0.31	496.14	40.67	36.20	1.81	4789.40	239.47	6.92	20.27	1.01	76.02	3.80	8.76	1082	1.08	143.15	6.40	(19/12/07)
70	6/5/GW	69.76	105.30	4.58	7346.20	319.40	4.00	0.33	279.06	22.87	37.70	1.89	2630.12	131.51	4.35	21.11	1.06	84.45	4.22	5.50	701	0.70	48.90	6.60	
71	6/6/GW	141.12	126.50	5.50	17852.21	776.18	3.50	0.29	493.93	40.49	30.75	1.54	4339.57	216.98	5.76	17.22	0.86	60.27	3.01	7.26	864	0.86	121.93	6.22	
72	6/7/GW	95.46	136.30	5.93	13010.65	565.68	9.00	0.74	859.10	70.42	54.20	2.71	5173.72	258.69	4.51	30.35	1.52	273.17	13.66	5.58	704	0.70	67.20	5.50	
73	7/1/GW	94.68	144.00	6.26	13633.98	592.78	8.00	0.66	757.44	62.09	76.00	3.80	7195.71	359.79	4.19	42.56	2.13	340.48	17.02	5.31	566	0.57	53.59	7.60	
74	7/2/GW	99.66	216.50	9.41	21577.17	938.14	6.50	0.53	647.81	53.10	32.50	1.63	3239.07	161.95	9.06	18.20	0.91	118.30	5.92	11.08	1610	1.61	160.46	7.60	
75	7/3/GW	79.73	365.00	15.87	29101.77	1265.29	4.50	0.37	358.79	29.41	32.00	1.60	2551.39	127.57	15.99	17.92	0.90	80.64	4.03	19.96	2700	2.70	215.27	9.70	22
76	7/4/GW	123.48	107.50	4.67	13274.49	577.15	3.50	0.29	432.19	35.43	16.00	0.80	1975.74	98.79	6.34	8.96	0.45	31.36	1.57	7.71	730	0.73	90.14	7.40	(21/12/07)
77	7/5/GW	69.76	125.00	5.43	8720.57	379.16	4.00	0.33	279.06	22.87	28.50	1.43	1988.29	99.41	5.81	15.96	0.80	63.84	3.19	7.24	733	0.73	51.14	9.30	
78	7/6/GW	167.58	117.00	5.09	19607.44	852.50	3.00	0.25	502.75	41.21	26.00	1.30	4357.21	217.86	5.79	14.56	0.73	43.68	2.18	7.29	831	0.83	139.26	8.40	
79	7/7/GW	70.34	155.50	6.76	10937.25	475.53	7.00	0.57	492.35	40.36	42.00	2.10	2954.11	147.71	5.85	23.52	1.18	164.64	8.23	7.23	947	0.95	66.61	7.60	
Sum		7298.76	13274.65	577.16	1238126.48	53831.59	423.35	34.70	38225.57	3133.24	2505.35	125.27	230947.33	11547.37	603.85	1403.00	70.15	8948.52	447.43	742.85	86581.00	86.58	8157.22	616.78	
Weighted average			170	7.38			5	0.43			32	1.58			8	21	1.06			9		1.1		8	
Standard deviation			76.73	3.34	9781.81	425.30	2.95	0.24	316.95	25.98	16.77	0.84	1962.65	98.13	3.33	9.39	0.47	130.76	6.54	4.01	478.34	0.48	66.67	1.19	
Count			79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	79	
t95% CI			1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	
Standard error (SE)			14	0.62	1826.90	79.43	1	0.05	59.19	4.85	3	0.16	366.55	18.33	1	2	0.09	24.42	1.22	1	89.34	0.1	12.45	0.2	

Appendix 7: Analysis of additional Waruku greywater characteristics from samples obtained during the sampling period

				Parameters																		
Item No.	Sample No.	Greywater, Q (Litres/hh/day)	Greywater (Litres/cap/day)	BOD mgO2/L	BOD x Q mg/hh/day	BOD per capita production (gBOD/cap/day)	COD mgO2/L	COD x Q mg/hh/day	COD per capita production (gCOD/cap/day)	COD/BOD ratio	Total coliform	Tc x Q	Faecal coliform	Fc x Q	TSS mg/L	TSS x Q mg/hh.day	SUVA L/mg-m	SUVA x Q	DOC mg/L	DOC x Q	TN mg/L	TN x Q (mg/hh/day)
1	5/1/GW	59.80	19.93	230	13754	4.58	2700	161455	54	11.7	2.10E+09	1.26E+11	2.80E+08	1.67E+10	1500	89697.24	0.408	24.398	68.46	4094	2.48	148.18
2	5/2/GW	99.66	33.22	225	22424	7.47	1700	169428	56	7.6	1.10E+10	1.10E+12	1.40E+09	1.40E+11	800	79730.88	0.802	79.930	143.70	14322	12.82	1277.89
3	5/3/GW	66.44	16.61	180	11959	2.99	2900	192676	48	16.1	1.20E+09	7.97E+10	1.20E+08	7.97E+09	800	53152.00	0.966	64.181	234.57	15585	5.02	333.46
4	5/4/GW	79.38	19.85	250	19846	4.96	2850	226240	57	11.4	4.60E+09	3.65E+11	9.30E+08	7.38E+10	400	31752.94	0.178	14.130	47.58	3777	3.53	280.22
5	5/5/GW	69.76	23.25	220	15348	5.12	2600	181388	60	11.8	2.40E+09	1.67E+11	4.30E+08	3.00E+10	800	55811.62	0.353	24.627	98.88	6898	23.86	1664.58
6	5/6/GW	149.94	37.49	160	23991	6.00	1550	232414	58	9.7	9.30E+08	1.39E+11	7.00E+07	1.05E+10	1000	149944.42	0.196	29.389	45.30	6792	2.86	428.84
7	6/1/GW	64.78	21.59	230	14900	4.97	2500	161953	54	10.9	1.20E+09	7.77E+10	1.20E+08	7.77E+09	800	51825.07	0.721	46.707	103.44	6701	7.41	480.03
8	6/2/GW	49.83	16.61	225	11212	3.74	2950	147004	49	13.1	4.60E+09	2.29E+11	9.30E+08	4.63E+10	1100	54814.98	0.312	15.548	22.53	1123	9.56	476.29
9	6/3/GW	44.85	14.95	250	11212	3.74	3000	134546	45	12.0	1.10E+10	4.93E+11	1.50E+09	6.73E+10	2000	89697.24	0.656	29.421	138.66	6219	5.81	260.57
10	6/5/GW	69.76	23.25	230	16046	5.35	2650	184876	62	11.5	2.40E+09	1.67E+11	2.80E+07	1.95E+09	300	20929.36	0.226	15.767	24.11	1682	6.17	430.45
11	6/6/GW	141.12	35.28	240	33870	8.47	1670	235677	59	7.0	1.10E+10	1.55E+12	4.00E+07	5.64E+09	900	127011.74	0.189	26.672	98.58	13912	6.59	929.30
12	7/4/GW	123.48	30.87	180	22227	5.56	1780	219801	55	9.9	2.10E+09	2.59E+11	1.50E+07	1.85E+09	1100	135832.00	0.151	18.646	72.06	8898	1.82	224.12
Sum		1018.83	292.90	2620	216789	63	28850	2247458	657	133	5.45E+10	4.75E+12	5.86E+09	4.09E+11	11500	940199	5.16	389	1098	90003	87.9	6934
Average			24.41	213		5.2	2206		54.7	11	4.66E+09		4.89E+08		923		0.38		88		6.8	
Minimum			14.95	160		3	1550		45	7	9.30E+08		1.50E+07		300		0.15		23		1.8	
Maximum			37.49	250		8	3000		62	16	1.10E+10		1.50E+09		2000		0.97		235		23.9	

Appendix 8: Determination of greywater free calcium concentration using calcium ion selective electrode

Known Ca^{2+} concentration (mg/L)	Meter reading (mV)
1	-40.1
10	-6.7
50	12.9
60	15.4
100	22.2



Item No.	Sample No.	mV	Calcium (Ca^{2+}) (mg/L) Total calcium	Free calcium
1	5/1/GW	5.66	71.70	28.5
2	5/2/GW	-1.69	36.50	16.5
3	5/4/GW	-8.01	24.20	10.3
4	5/5/GW	-1.04	38.50	17.3
5	6/1/GW	-3.23	29.50	14.7
6	6/2/GW	3.30	55.20	23.9
7	6/3/GW	-0.89	34.00	17.5
8	6/5/GW	0.91	37.70	20
9	6/6/GW	-3.32	30.75	14.6
10	7/4/GW	-9.25	16.00	9.4
	Average		**30.84**	**17.27**

Free calcium = 56 % Total calcium

Appendix 9: Figures showing effects of irrigation water SAR and EC on soil properties and crop productivity

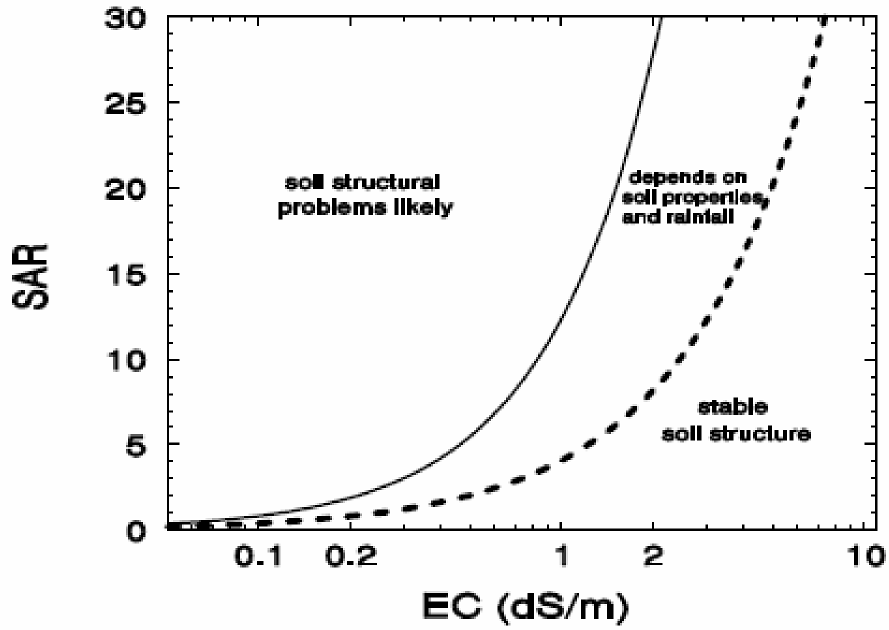


Figure 8-1: Relationship between SAR and EC of irrigation water for prediction of soil structural stability (DNR, 1997).

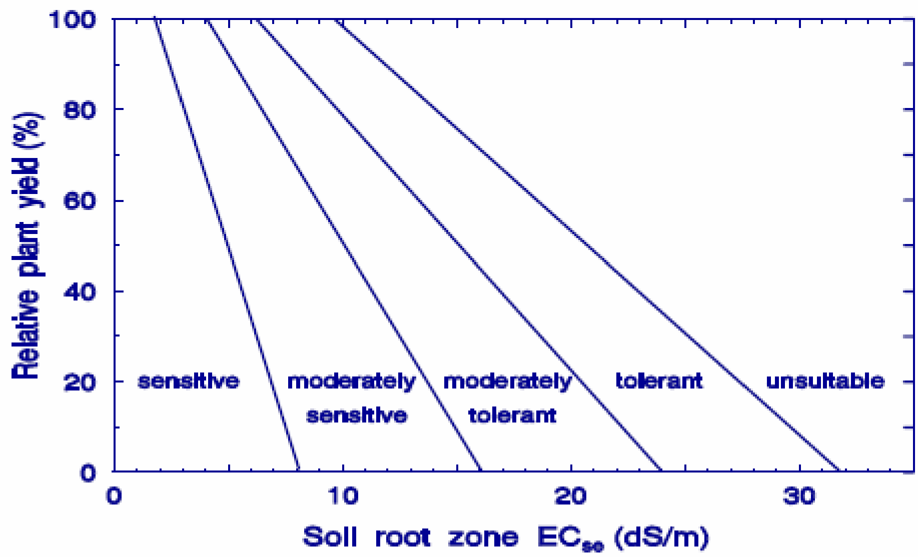


Figure 8-2: Relative crop yield in relation to soil salinity for plant salt tolerance groupings (Maas, 1984) cited by (Morel and Diener, 2006).

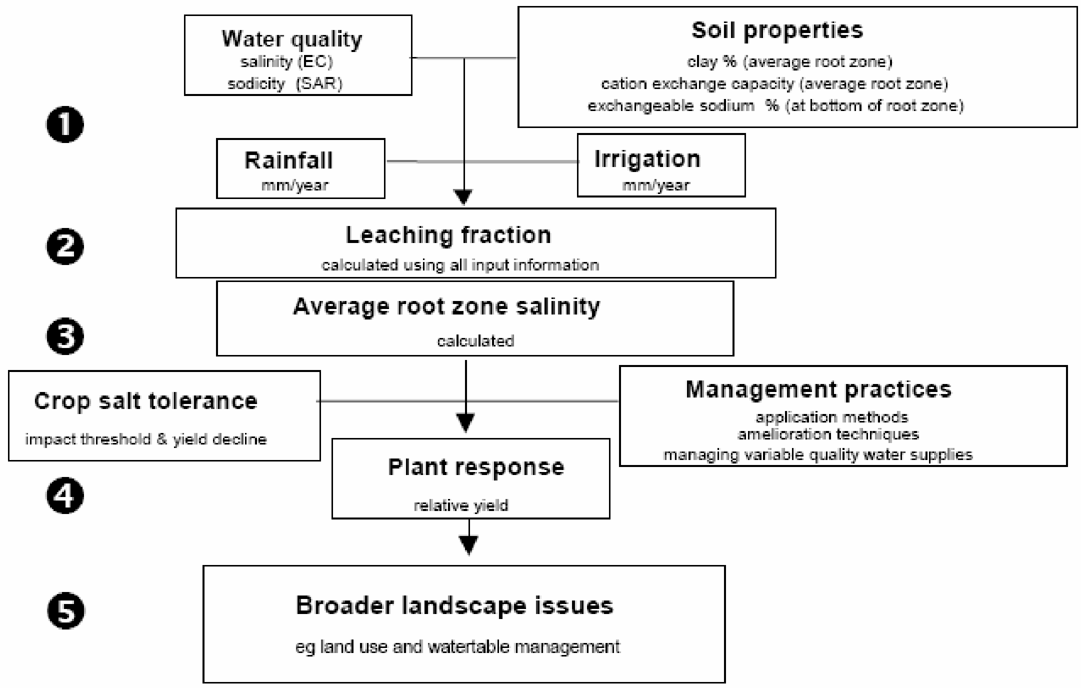


Figure 8-3: Flow diagram for evaluating salinity and sodicity impacts of irrigation water quality (ANZECC, 2000).

Table 8-1: Comparison of greywater quality from Waruku with the usual range of irrigation water

Water parameter	unit	Greywater quality	Usual range in irrigation water*
Salinity			
Electrical conductivity, ECw Cations	dS/m	1.1	0 - 3
Calcium, Ca^{2+}	mg/L	32	0 - 400
Magnesium, Mg^{2+}	mg/L	5	0 - 60
Sodium, Na^{+}	mg/L	169	0 - 900
Miscellaneous			
pH		8.2	6.5 - 8.5
Sodium adsorption ratio, SAR		8.0	0 - 15

* Source (Pettygrove and Asano, 1988)

Appendix 10: A complete analysis of the soil characteristics at the greywater disposal site and the control (non-greywater disposal) site

Soil analysis of the soil samples from the Greywater disposal site

Item No.	Sample No.	Sodium (Na^+) meq/100g	Calcium (Ca^{2+}) meq/100g	Potassium (K^+) meq/100g	Magnesium (Mg^{2+}) meq/100g	Soil SAR	$EC_{1:2.5}$ (dS/m)	ECe (dS/m)	pH	Organic carbon OC (%)	Organic matter OM (%)	CEC meq/100g	ESP %	Clay %	Sand %	Silt %	Soil texture type	Soil sampling point coordinates (x,y,z)
		Parameters																
1	A1	2.42	2.32	3.07	0.46	2.05	1.50	3.80	6.22	2.92	5.84	19.84	12.20	60	22	18	clay	(0,76,110.10)
2	A2	4.01	2.41	1.87	0.18	3.52	0.75	1.35	6.82	1.66	3.32	24.94	16.08	76	16	8	clay	(22,76,110.63)
3	A3	3.12	4.18	5.35	0.22	2.10	1.85	5.30	7.64	3.49	6.98	39.02	8.00	58	24	18	clay	(33,76,109.97)
4	B1	2.02	12.47	1.81	0.59	0.79	0.35	0.55	7.37	2.20	4.40	30.14	6.70	54	16	30	clay	(0,58,105.20)
5	B2	4.10	15.66	2.95	0.84	1.43	0.68	1.15	7.38	2.44	4.88	31.28	13.11	50	22	28	clay	(18,58,104.93)
6	B3	4.30	10.45	2.23	0.50	1.84	1.60	4.50	6.97	3.33	6.66	26.56	16.19	42	36	22	clay	(34,58,105.53)
7	C1	4.50	12.71	2.81	1.09	1.71	1.06	2.97	7.81	3.09	6.18	40.25	11.18	56	22	30	clay	(0,36,101.30)
8	C2	3.92	12.31	2.55	0.90	1.53	2.00	4.00	7.43	3.34	6.68	39.28	9.98	48	24	28	clay	(17,36,101.13)
9	C3	5.12	15.92	2.13	1.08	1.76	1.80	4.86	8.25	3.91	7.82	39.92	12.83	50	30	20	clay	(35,36,101.43)
10	D1	5.24	24.96	3.43	0.93	1.46	1.50	4.26	7.98	4.31	8.62	44.46	11.79	48	36	16	clay	(0,19,100.40)
11	D2	5.56	34.79	3.29	1.09	1.31	1.90	5.83	8.23	4.43	8.86	50.79	10.95	46	36	18	clay	(21,19,100.53)
12	D3	5.63	39.47	3.67	1.13	1.25	2.10	5.38	7.83	4.52	9.04	54.39	10.35	52	31	17	clay	(35,19,100.73)
13	E1	5.34	45.64	3.47	0.97	1.11	1.65	5.07	8.37	4.33	8.66	59.14	9.03	42	40	18	clay	(0,0,100.01)
14	E2	5.63	49.27	3.34	0.99	1.12	1.99	5.69	8.17	4.44	8.88	61.93	9.09	44	38	18	clay	(22,0,100.12)
15	E3	5.91	43.27	3.53	1.16	1.25	2.20	6.43	7.89	4.37	8.74	57.32	10.31	48	36	16	clay	(40,0,100.27)
Average		**4.45**	**21.72**	**3.03**	**0.81**	**1.62**	**1.53**	**4.08**	**7.62**	**3.52**	**7.04**	**41.28**	**11.18**	**51.60**	**28.60**	**20.33**		
Standard deviation		**1.21**	**16.48**	**0.89**	**0.33**	**0.64**	**0.57**	**1.81**	**0.60**	**0.92**	**1.84**	**13.24**	**2.66**	**8.66**	**8.17**	**6.18**		
Count		**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**		
Coefficient of variation,CV %		**27**	**76**	**29**	**41**	**40**	**37**	**44**	**8**	**26**	**26**	**32**	**24**	**17**	**29**	**30**		

Soil analysis of the soil samples from the control (non-greywater disposal) site

Item No.	Sample No.	Sodium (Na^+) meq/100g	Calcium (Ca^{2+}) meq/100g	Potassium (K^+) meq/100g	Magnesium (Mg^{2+}) meq/100g	Soil SAR	$EC_{1:2.5}$ (dS/m)	ECe (dS/m)	pH	Organic carbon OC (%)	Organic matter OM (%)	CEC meq/100g	ESP %	Clay %	Sand %	Silt %	Soil texture type
		Parameters															
16	**CONTROL 1**	0.82	7.44	0.75	0.90	0.40	0.17	0.53	5.02	2.56	5.12	27.86	2.94	62	18	20	clay
17	**CONTROL 2**	0.73	10.58	1.15	1.11	0.30	0.18	0.52	5.42	2.47	4.94	22.90	3.19	62	18	20	clay
18	**CONTROL 3**	0.93	6.52	1.23	0.93	0.48	0.42	1.01	5.64	2.08	4.16	24.95	3.73	62	16	22	clay
19	**CONTROL 4**	0.80	7.22	0.73	0.87	0.40	0.16	0.51	5.52	2.48	4.96	27.02	2.94	61	19	20	clay
20	**CONTROL 5**	0.83	11.63	1.07	1.08	0.33	0.19	0.55	5.78	2.63	5.26	25.98	3.19	62	18	20	clay
21	**CONTROL 6**	0.90	9.87	0.97	0.97	0.39	0.23	0.53	5.83	2.59	5.18	24.83	3.62	61	17	22	clay
Average		**0.83**	**8.88**	**0.98**	**0.98**	**0.38**	**0.23**	**0.61**	**5.54**	**2.47**	**4.94**	**25.59**	**3.27**	**61.67**	**17.67**	**20.67**	
Standard deviation		**0.07**	**2.09**	**0.21**	**0.10**	**0.06**	**0.10**	**0.20**	**0.30**	**0.20**	**0.40**	**1.76**	**0.34**	**0.52**	**1.03**	**1.03**	
Count		**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	
Coefficient of variation,CV %		**9**	**24**	**21**	**10**	**16**	**44**	**32**	**5**	**8**	**8**	**7**	**10**	**1**	**6**	**5**	

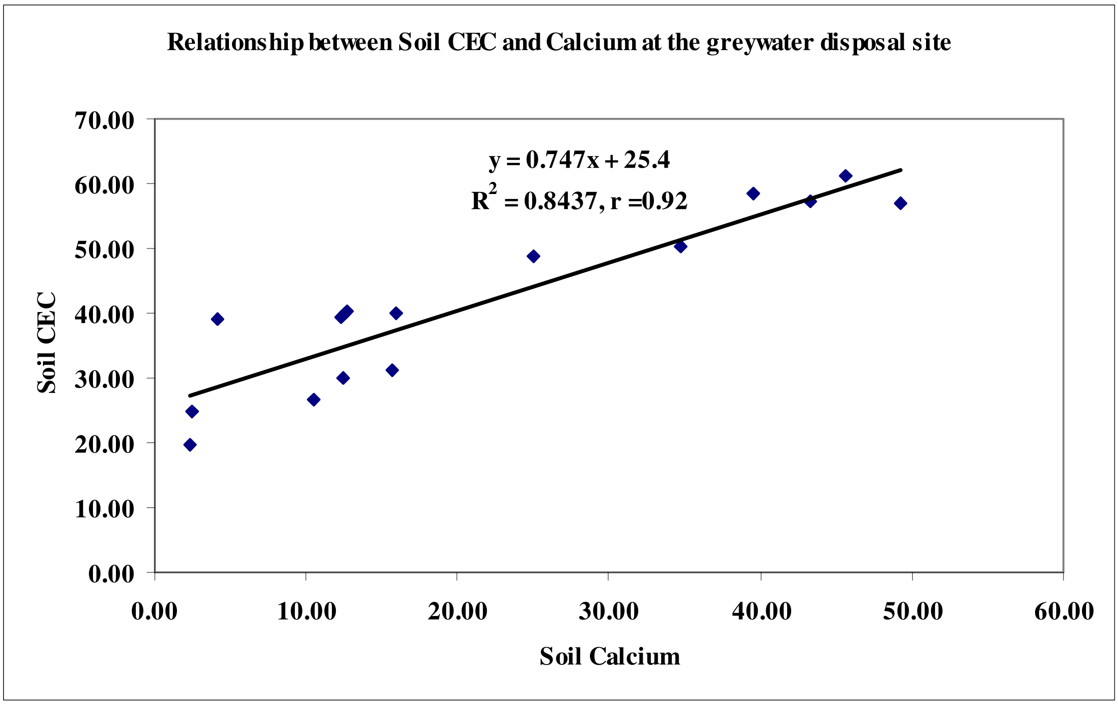
Appendix 11: Comparison of the % changes in soil parameters at the greywater disposal site relative to the control

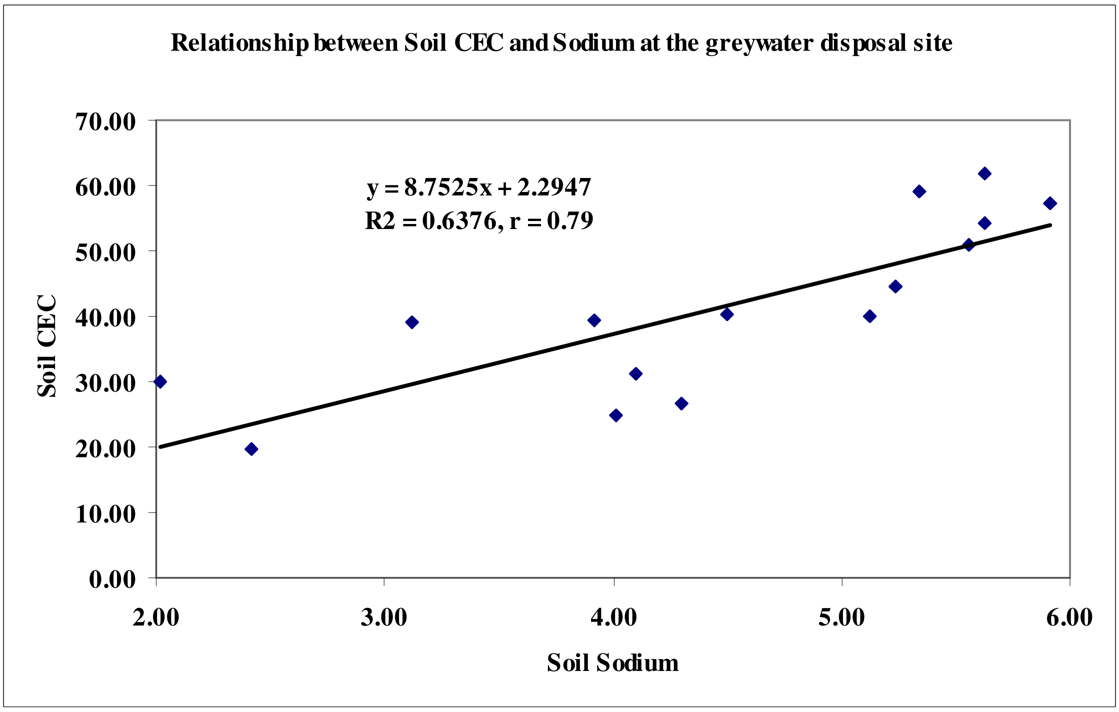
Item No.	Soil sampling point	% change Sodium (Na+) meq/100g	% change Calcium (Ca2+) meq/100g	% change Potassium (K+) meq/100g	% change Magnesium (Mg2+) meq/100g	% change SAR	change $EC_{1:2.5}$ (dS/m)	change ECe (dS/m)	change pH	% change Organic carbon OC (%)	% change Organic matter OM (%)	% change CEC meq/100g	% change ESP (%)	Soil sampling point downhill distances
1	A1	290	26	312	47	373	1.28	3.19	0.69	118	118	78	536	0 m
2	A2	481	27	190	18	492	0.53	0.74	1.29	67	67	97	921	
3	A3	374	47	544	23	245	1.63	4.69	2.11	141	141	152	550	
4	B1	242	140	184	60	205	0.13	-0.06	1.84	89	89	118	207	19 m
5	B2	492	176	300	86	401	0.46	0.54	1.85	99	99	122	373	
6	B3	515	118	227	51	495	1.38	3.89	1.44	135	135	104	480	
7	C1	539	143	286	112	342	0.84	2.36	2.28	125	125	157	448	40 m
8	C2	470	139	259	92	305	1.78	3.39	1.90	135	135	153	399	
9	C3	614	179	217	111	392	1.58	4.25	2.72	158	158	156	459	
10	D1	628	281	349	95	360	1.28	3.65	2.45	175	175	174	381	58 m
11	D2	667	392	335	112	335	1.68	5.22	2.70	179	179	198	343	
12	D3	675	445	373	116	317	1.88	4.77	2.30	183	183	213	326	
13	E1	640	514	353	99	276	1.43	4.46	2.84	175	175	231	289	76 m
14	E2	675	555	340	101	278	1.77	5.08	2.64	180	180	242	293	
15	E3	708	487	359	119	315	1.98	5.82	2.36	177	177	224	328	
16-21	CONTROL	100	100	100	100	100	0.00	0.00	0.00	100	100	100	100	

t-Test: Two-Sample Assuming Unequal Variances for soil exchangeable sodium on both sampling sites

	Exch. Na^+ (GW disposal site)	***Exch. Na^+ (Control site)***
Mean	4.454666667	0.834166667
Variance	1.45928381	0.005224167
Observations	15	6
df	14	
t Stat	11.5560524	
P(T<=t) one-tail	7.57564E-09	
t Critical one-tail	1.761310115	
P(T<=t) two-tail	1.51513E-08	
t Critical two-tail	2.144786681	

Appendix 12: Relationship between soil CEC and soil Calcium/ soil Sodium at the greywater disposal site





Appendix 13: Greywater Reuse Model for predicting soil salinity based on the greywater characteristics and soil properties and relating it to crop yield

Greywater Reuse Model for Assessment of the suitability of greywater quality as irrigation water with respect to salinity

Model input

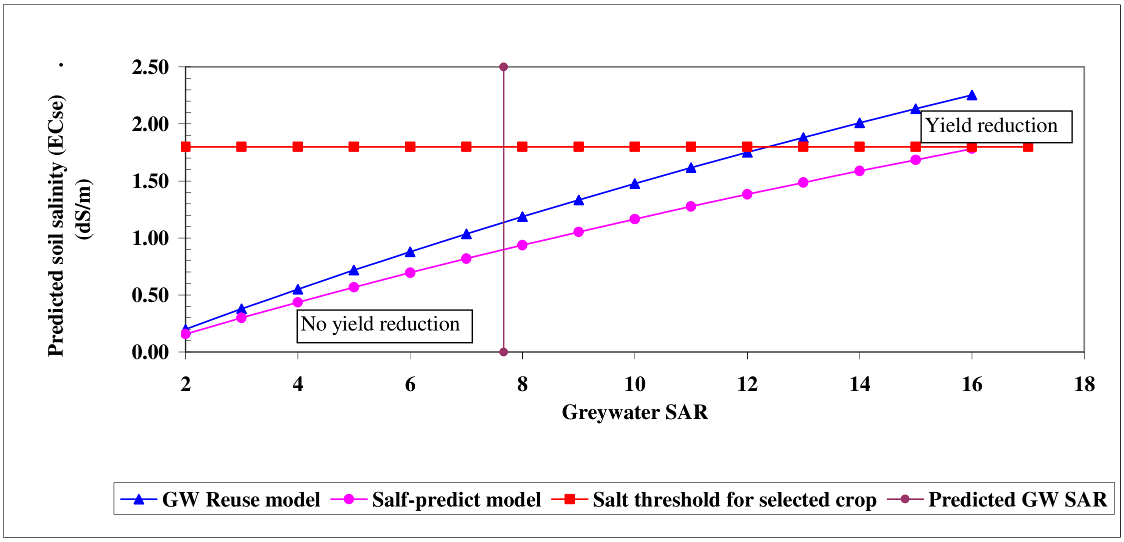
Greywater EC (measured)	1.1	dS/m
Daily greywater production,Q	270	m³/day
Annual rainfall, Dr	1000	mm
Land available for irrigation,A	41.3	ha
Electrical conductivity of soil saturation extract(taken at the bottom of the root zone), ECe	4.08	dS/m
Crop to be irrigated with greywater	cabbage	
Salt threshold for the preferred crop to achieve 100% yield	1.80	dS/m

Model output

Calculated annual irrigation water, Diw	239	mm/year
Calculated greywater SAR	7.7	

Linear regression model: GW SAR = 5.2209 EC_{GW} + 1.9218

GW SAR	EC_{GW} (dS/m)	EC_{GW} (µS/cm)	LF	$LF_{average}$	GW Reuse model	Salf-predict model	Salt threshold for selected crop
2	0.01	15	0.007	0.460	0.01	0.01	1.80
3	0.21	207	0.016	0.469	0.20	0.16	1.80
4	0.40	398	0.025	0.477	0.38	0.30	1.80
5	0.59	590	0.034	0.486	0.55	0.44	1.80
6	0.78	781	0.043	0.494	0.72	0.57	1.80
7	0.97	973	0.052	0.503	0.88	0.70	1.80
8	1.16	1164	0.061	0.511	1.04	0.82	1.80
9	1.36	1356	0.070	0.519	1.19	0.94	1.80
10	1.55	1548	0.079	0.527	1.33	1.05	1.80
11	1.74	1739	0.088	0.535	1.48	1.17	1.80
12	1.93	1931	0.097	0.543	1.62	1.28	1.80
13	2.12	2122	0.106	0.551	1.75	1.38	1.80
14	2.31	2314	0.115	0.559	1.88	1.49	1.80
15	2.51	2505	0.124	0.567	2.01	1.59	1.80
16	2.70	2697	0.133	0.575	2.13	1.69	1.80
17	2.89	2889	0.142	0.582	2.25	1.78	1.80



Appendix 14: Procedure for laboratory measurement of hydraulic conductivity of saturated soil based on constant head method

The procedure detailed below was used to investigate the effect of greywater SAR on the soil hydraulic conductivity.

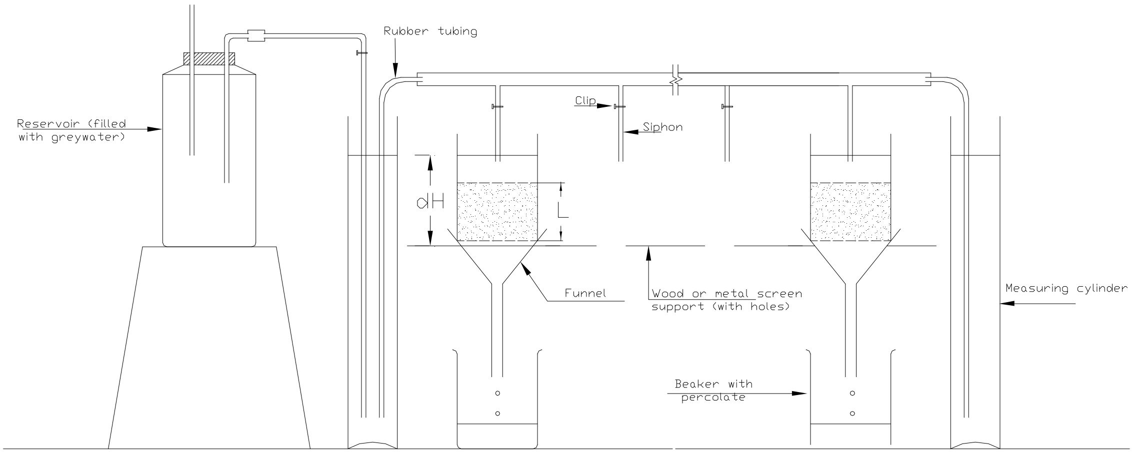


Figure 8-4: Diagram of the constant-head system for hydraulic conductivity measurement

Principle:

Water moves through the soil due to the presence of a hydraulic gradient which is the driving force. According to Darcy's law, the flow of water in the soil may be expressed as $Q = k.A.\frac{dH}{L}$ where,

Q = discharge (cm^3/hr)

k = hydraulic conductivity (cm/hr)

A= cross-section area of the soil column (cm^2)

$\frac{dH}{L}$ = hydraulic head difference between the inflow and outflow boundaries relative to some reference level (cm)

Procedure:

Six undisturbed core samples were collected from the control (non-greywater disposal) site. (For details on the soil sampling procedure, see Section 3.5.1). On one end of the sample (soil sample was contained in a 50 mm high steel tube), a piece of nylon cloth was tied using a rubber band. The core samples were moistened by placing the core samples in a shallow tray of distilled water with the cloth-covered end downwards. The samples were allowed to soak overnight to be completely saturated.

On top of the sample, an identical empty sample cylinder (steel tube) was put and secured carefully in place with waterproof tape so that there was no leak at the joint. A piece of blotting paper was placed on top of the sample.

The samples were then transferred to the conductivity rack. Carefully, water was added into the upper cylinder until it was almost full. Quickly but carefully, the clip was opened while the siphon tip was under the water to maintain constant head on the sample.

After the water level on the sample became constant, time was noted and percolate was collected in a beaker at convenient time intervals. When the discharge would become constant (stabilise), the volume of water, V that had passed through the sample at a given time, t (hours) was recorded. Then the hydraulic head difference, dH (see Figure 8-4) would be measured and since the cross-section area of the sample, A and length of the sample column, L were known, the hydraulic conductivity, k was calculated using the expression below:

$$k = \frac{V}{A.t} \cdot \frac{L}{dH}$$

The hydraulic conductivity, k at a given greywater SAR value was computed for all the six soil samples and an average was calculated.

Then, the same procedure was repeated at different values of greywater SAR. To elevate the greywater SAR value, from the initial value of 3.77, known concentrations of sodium were added. Sodium pellets used in the experiment were provided by the Soil Survey Laboratory, where the soil tests were conducted.

The reservoir filled with greywater was graduated so it was not difficult to calculate, to a reasonable degree of accuracy, the required amounts of sodium to be added to elevate the greywater SAR value.

The experiment was repeatedly run and new sets of hydraulic conductivity were obtained at the set values of greywater SAR. The results of the experiment are presented in Table 5-5.

Appendix 15: Meteorological data for Waruku study area as provided by the Kenya Meteorological Department, Nairobi based on data for Kabete Agromet Station (01^o15'S, 36^o 44'E)

Description	YEAR	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct.	Nov.	Dec.	Total
Rainfall (mm)	**2004**	189.5	45.3	87.2	411.6	190.3	10.4	0.2	0.2	16.1	82	108.9	58.1	1199.8
Temperature (max.) °C		24.5	24.1	25.2	23.5	23	18.3	22.6	22.3	24.5	23.8	22.7	23.8	
Temperature (min.) °C		14.3	14.3	15.3	14.9	14	11.5	10	11	12.5	13.9	14.5	14.4	
Relative Humidity (%); 0600		81	79	82	88	83	83	80	82	80	82	87	83	
Relative Humidity (%); 1200		56	55	50	64	60	55	49	52	43	52	59	56	
Rainfall (mm)	**2003**	28.4	12	51.6	219.2	318.9	30.2	3.1	54.3	27.8	54.7	117.1	14.1	931.4
Temperature (max.) °C		24.3	26.7	26.4	25	22.3	21.3	20.6	21.1	23	24.3	22.8	23.8	
Temperature (min.) °C		13.6	13.6	14.5	15.2	14.6	12.8	11.3	11.5	12.6	13.4	14.4	13.3	
Relative Humidity (%); 0600		77	69	76	82	87	86	79	88	85	82	84	76	
Relative Humidity (%); 1200		49	41	41	52	67	63	63	67	57	52	60	51	
Rainfall (mm)	**2002**	52	69.1	90.2	278.5	134.5	1.6	6.6	59	22.3	59.1	157.2	230.9	1161
Temperature (max.) °C		24.6	26	24.5	22.8	22.8	21.7	22.2	20.7	23.8	24.3	23	22	
Temperature (min.) °C		13.8	13.5	14.4	15.1	14.3	12.2	10.9	12.2	12.3	14.1	14.8	14.3	
Relative Humidity (%); 0600		79	69	86	90	88	86	85	87	80	83	88	86	
Relative Humidity (%); 1200		53	42	55	63	64	59	53	60	46	50	59	62	
Rainfall (mm)	**2001**	371.6	3.2	180.3	106.5	85.7	79.8	16.2	23.4	19.5	95.3	189.5	13.3	1184.3
Temperature (max.) °C		22.9	24.2	24.2	23.1	22.5	21.3	20.3	22.4	24.5	24.3	21.9	22.9	
Temperature (min.) °C		13.6	14	13.9	14.9	14.1	12	11	11.4	12.2	13.4	14	13.8	
Relative Humidity (%); 0600		82	80	82	88	84	86	88	82	82	83	89	83	
Relative Humidity (%); 1200		64	46	49	62	62	60	65	53	47	50	67	59	
Rainfall (mm)	**2000**	5.4	0	41.7	254.4	100.1	57.9	4.4	6.1	53.5	18.4	187.7	111.3	840.9
Temperature (max.) °C		24.1	26.3	26.2	24.4	23.2	21.4	21.1	22.4	23.8	25.1	23.2	23.2	
Temperature (min.) °C		12.6	12	14.2	14.2	13.2	12.1	10.9	11.4	11.2	12.5	14.3	14	
Relative Humidity (%); 0600		74	59	79	84	87	89	90	83	83	76	88	70	
Relative Humidity (%); 1200		46	33	42	52	62	64	60	56	47	43	59	55	
Total Rainfall (mm)														5317.4
Average Rainfall (mm)														**1063.48**

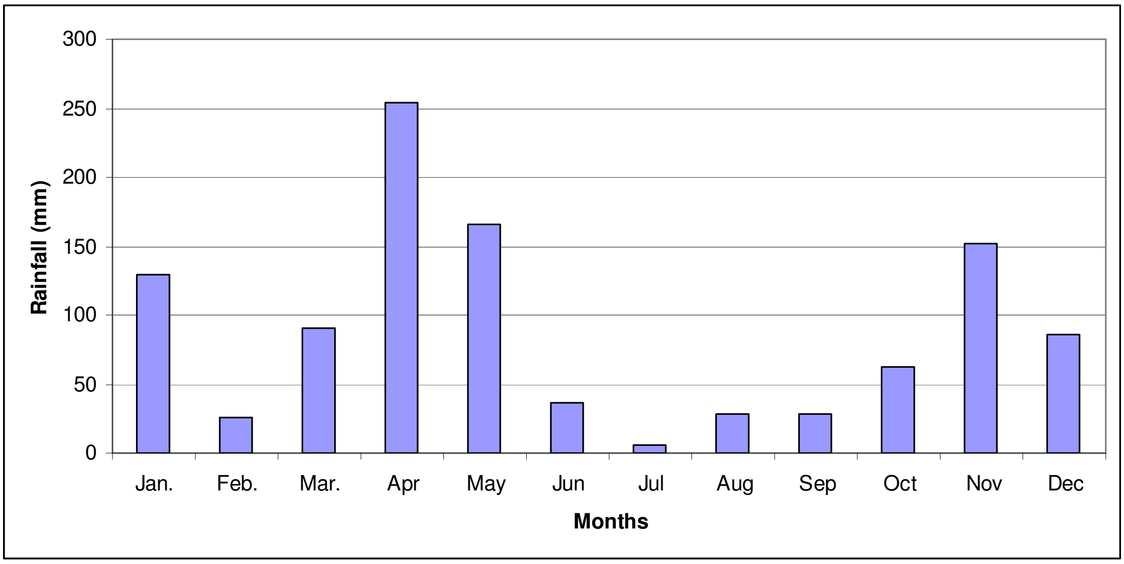


Figure 8-5: Rainfall data of the study area of Waruku (source: Kenya Meteorological Department, Nairobi)