THE EFFECTS OF GREYWATER IRRIGATION ON VEGETABLE CROPS AND SOIL

LOYISO LLOYD MZINI

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Department of Environmental and Geographical Sciences
Faculty of Science
University of Cape Town
Rondebosch

SUPERVISOR: DR. KEVIN WINTER

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DECLARATION

I, hereby declare that this thesis is my original work, and has not been submitted in partial or entirety for degree purposes to any other university. All the work that was written by other authors and used in the thesis is fully acknowledged.

Submitted for the degree of Master of Science in Environmental and Geographical Science at the University of Cape Town.

Signed by candidate

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L.L. Mzini

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Date

15 August 2013

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ABSTRACT

Research on greywater irrigation has mainly focused attention on the reuse of greywater in relation to its quality and crop biomass but not on quality of edible vegetable crops. Thus a field experiment was established at the Umtata Dam Research Station where combinations of cabbages and onions; spinaches and beetroots; and carrots and lettuce were planted in to coincide with four different planting seasons (from October 2009 to December 2010). Crops were irrigated with greywater generated from bathing and dishwashing. Greywater was collected from a number of households in the vicinity of the Umtata Dam, in the Eastern Cape Province of South Africa. In the field experiment, vegetables were planted in three plots of the same composition of soil properties and then drip irrigated separately either with greywater, potable water, or with diluted greywater at a ratio of 1:1. The greywater quality, yield, aesthetical appeal, plant chemical analysis and soil chemical analysis were measured. Irrigation from diluted greywater showed a significant increase in yield, in the head mass and in appeal of cabbages. Onion yields were significantly higher when irrigated with greywater. Spinach also obtained significantly higher yields when irrigated with greywater, however many leaves from this treatment were infested with leaf-spot disease. Beetroot yield and quality was not affected with greywater irrigation, instead yield was reduced by 47% (4.686 tons/ha). Carrots did not show any significant difference in yield and root girth, but carrots irrigated with potable water were more appealing and longer in length. Lettuce irrigated with dilute greywater was significantly more appealing than other treatments. Sodium (Na) ions were elevated in cabbage, onions and were significantly higher in the case of lettuce and carrots when irrigated with greywater. Crude protein (CP) was observed to be significantly elevated on cabbages and lettuce when irrigated with diluted greywater whereas CP of onions and carrots were significantly lower due greywater irrigation. Significant increases in iron (Fe) were observed on cabbages and spinach when irrigated with diluted greywater, whereas lettuce Fe content was significantly elevated by greywater irrigation. There was no significant difference in cadmium (Cd) caused by irrigating spinach and lettuce with greywater, also those heavy metals that were significantly higher, were within the accepted threshold leaving the conclusion that lower levels of heavy metals posed no health risks to humans. In conclusion, greywater used in this study does not appear to cause an accumulation of salts and heavy metals in plants and soil, which suggests in this instance, that greywater does not pose a threat to plants and soils.

ABBREVIATIONS AND ACRONYMS

GW	Greywater
DGW	Diluted greywater
PW	Potable water
DAF	Department of Agriculture and Forestry
DAFF	Department of Forestry and Fisheries
DWAF	Department of Water Affairs and Forestry
PW	Potable water
WRC	Water Research Commission
FAO	Food and Agricultural Organization
WHO	World Health Organization
TKN	Total Kjeldahl Nitrogen
EC	Electrical Conductivity
CP	Crude Protein
TWQR	Target Water Quality Range
Zn	Zinc
Fe	Iron
Ca	Calcium
K	Potassium
P	Phosphorus

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Under-developed rural areas of the Eastern Cape Province, South Africa, which were once part of the former homelands of the Ciskei and Transkei (also known as 'Bantustans' following the Land Act of 1936), use all the available freshwater resources (DWA, 2012). It is a water stressed region which is the result of a combination of factors including climatic conditions, geophysical form and process, and geographic location. This limited access to freshwater resources in rural areas of the former homelands of South Africa is played out against the developmental history of South Africa. The injustices meted out by the Apartheid system of government meant that the Transkei, as was the case with the other homelands in South Africa, were under-serviced and under-developed. This legacy continues. Today "many ... still do not have access to potable water supply, and ... do not have access to reliable water supply for productive purposes" (DWA, 2012: 5).

In 1994, following the first democratic elections in South Africa and the demise of the Apartheid government, all of the so-called black homeland states were incorporated into nine administrative regions, referred to as the provinces of South Africa. The Transkei was incorporated into the Eastern Cape Province (Figure 1.1). These former homelands were largely under-developed rural areas with, at best, limited infrastructure to support facilities such as basic sanitation and access to safe drinking water (Phaswana-Mafuya & Shulka, 2005). In part this brief historical account explains why present-day subsistence farmers who live in and around small rural villages of the former homelands of the Transkei, continue to face challenges such as access to water and water-related services. The situation is complicated further by widespread, sporadic drought and long dry spells resulting in a general reduction in agricultural output and crop failure (Vetter, 2009). In order to meet water stressed challenges, different means should be looked at including greywater the use of greywater.

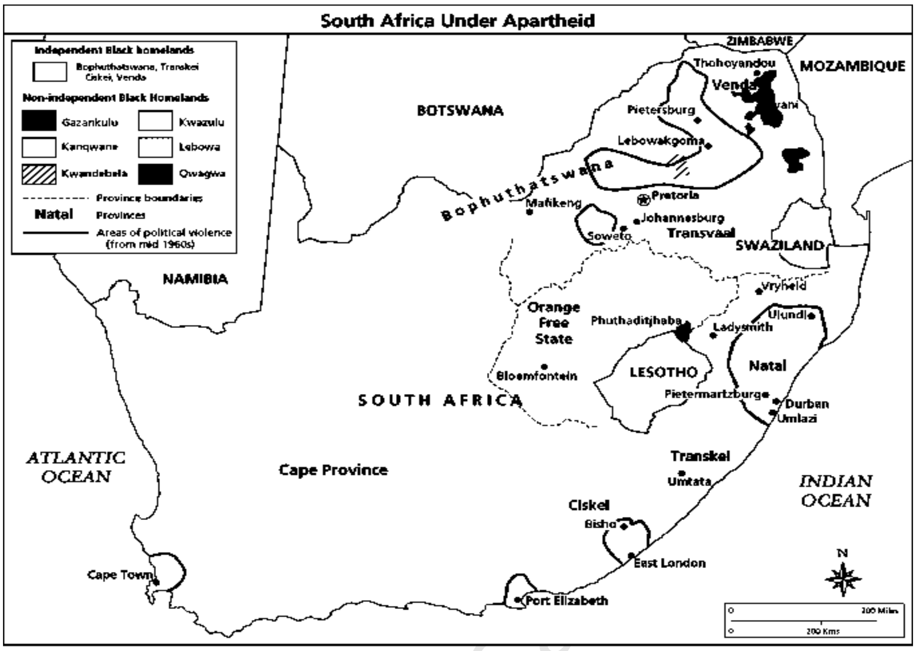

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Figure 1.1 The political demarcation under the apartheid system. Note the position of the Transkei homelands in the eastern part of the country (Source: Facts on File, 2001)

This study investigates the potential to use greywater for irrigating edible crops by conducting field experiments at a site within the former homeland region of the Transkei, but also to investigate the effects of using greywater[1] on the quality of yield and on the soil.

Greywater is widely perceived as ‘waste’ water no longer fit for any purpose. Yet in some water stressed countries, the use of greywater for crop production is common practice (Bino, 2003; Zaidi, 2007; Zavadil, 2009). In South Africa knowledge about the quality and productive use of greywater is largely under-researched and poorly understood. Carden, *et al* (2007a), in a study on the use and management of greywater in informal settlements in South

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[1] Greywater is used as a single word and a common noun although the quality of the ‘greyness’ in water differs considerably and cannot be easily defined, but only broadly described with reference to a range of chemical and physical properties

Africa, showed that the quality of greywater was highly variable and depended largely on the activities that were used in generating the water. Their study also found that people were generally reluctant to use greywater for the irrigation of food crops and cited cultural and religious belief systems, and general perceptions of poor quality, as reasons for this reluctance. By contrast, research in water scarce countries showed that many were prepared to use greywater as an alternative water source for growing food crops and generating an income (Bino, 2004; Zaidi, 2007; Zavadil, 2009). Public concerns and opinions still appear to be major obstacles in the re-use of untreated domestic greywater for irrigating edible crops. For the most, greywater is perceived to be unhygienic and that it poses a health risk (Dixon *et al*., 1999; Khosa *et al*., 2003; Ottoson & Stenström, 2003). This study does not examine the perceptions of greywater or health risks directly rather it seeks to understand how it affects the growth of edible crops and soils in which they are grown.

1.2 Statement of the problem

The rationale for this study is motivated by a number of studies found in the academic literature that shows evidence that the use of greywater for irrigation has an impact on soils. Two studies show that greywater has the potential to contaminate the surrounding water bodies and that it poses an environmental risk when salts and toxins accumulate in the soils (Duttle, 1996; Gross *et al*., 2005). In addition, high sodium (46 to 230 mg/l) and chloride ion concentrations (175 to 350 mg/l) caused leaf damage to crops such as pepper, potato and corn when greywater was sprayed onto the foliage (Ayers & Westcot, 1994; Bauder *et al*., 2007). Little is known about these effects on small scale crop production in the Eastern Cape, and most especially in the context of relatively small backyard gardens in which varying concentrations of greywater are being used to irrigate edible vegetable crops. This study aims to contribute to the research effort by studying the impacts of greywater in a controlled experiment in order to assess the performance of different vegetable crops in response to greywater irrigation (Holtzhausen, 2005; Jackson *et al*., 2006).

1.3 Aims and objectives

The study examines the effects of greywater irrigation on soil and the quality of the crop based on a controlled research experiment in a series of field trials. This aim is met by addressing four main objectives:

- To determine the characteristics of greywater in terms of quality and quantity
- To test the response of different vegetables (leafy, tuber and bulbous vegetables) to two different concentrations of greywater and to compare the response to a control standard of potable water.
- To determine the concentration of nutrients and heavy metals adsorbed by roots, bulbs and leaves of vegetable crops.
- To assess the accumulation of organics and inorganics in the soils immediately surrounding the root and bulbs of vegetable crops.
- To assess the overall quality of crop production from the use of two different concentrations of greywater against the control.

1.4 Research question

Little is known in South Africa about the effects of greywater on soils and on the quality of crops under irrigation. The question is, what are the effects do greywater irrigation have on soils and quality of the crops?

1.5 Study context

Subsistence agricultural activities are found in villages surrounding Umtata, the former capital of the Transkei (Smit, 2003). Typically maize and beans are the staple food crops grown under rain-fed conditions, whereas vegetable production is predominantly grown in backyard gardens (Perret, 2001; Smit 2003). Generally irrigation of vegetable crops around Umtata is negligible (Phillip-Howard & Potter, 1996). Subsistence habits persist in this region because markets are largely inaccessible to rural farmers who are often unable to market their produce because they do not have transport or are unable to produce quality crops for the marketplace. Thus it is often found that large fresh produce retailers in Umtata purchase vegetables from places as far afield as East London, Port Elizabeth and Cape Town rather than from the local region (Phillips-Howard & Porter, 1996). While access to markets might be a factor that accounts for the general decline in vegetable production in this region, dwindling water access and availability, and the general water scarcity resulting from prolonged dry winters, are also contributing factors (Mkile *et al*., 2009). Small scale farmers are unable to afford the expense of pumping and reticulating water from the nearby Umtata Dam in order to irrigate their relatively small scale vegetable gardens (Mzini, 2006).

1.6 Limitations of the study

The study was conducted over four planting seasons; each season was carried through a period of three months. The period of study is limited and is perhaps insufficient to measure the long term effects on soils and to explain the effects of the accumulation of salts and heavy metals in the soils.

The study design and methods were undertaken as field experiments, and as a consequence, variables such as ambient atmospheric conditions and rainfall, could not be controlled. Processes such as the leaching effects of elements due to rainfalls events could not be determined.

The study does not consider the potential health risks of consuming foods that were irrigated with greywater. This is a far more complex study theme and is beyond the scope and means of the current research.

1.7 Thesis structure of the study

The thesis continues from the introduction of the study (Chapter 1) to Chapter 2 which discusses the quality of greywater by drawing, its general use, and emphasises the use of greywater as an augmentation and alternative water supply in the irrigation of edible crops. This is followed by a presentation of the methods used to establish the field trials, the test conditions, sampling techniques and capturing of raw data. The substantive proportion of the thesis is devoted to discussing the results (Chapter 4), and then concludes in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The chapter begins by describing greywater, its generation and reuse in the context of homesteads or households without reticulation. The discussion continues with reference to studies in agricultural sciences which attention being given to water resource management and how crop yields are affected by water quality, and the long- and short term effects of greywater irrigation on soils.

2.2 Greywater perspective in plant growth

Greywater is described by Carden *et al.,* (2007 b) as water that is derived from activities such as bathing, washing of clothes and dishes, but excludes toilet water. Greywater gets its name from its cloudy or grey colour appearance. Ridderrstolpe (2004) regards greywater as any untreated wastewater produced in a household, but excludes toilet waste (urine and faeces) which is sewage or black water and indicates that it contains human waste (Ahmed *et al*., 2001). It is estimated that the volume of greywater generated from a household in an informal settlement varies from between 25 and 75 litres per household per day (l/c/d) (Carden *et al.,* 2007 a). In addition, greywater is a resource often loaded with valuable nutrients and organics, although the variable quality could also create problems when used for growing crops (Toze, 2006).

Varying, inconsistent quality of greywater is one of the challenges in the use of this water source (Ahmed *et al.*, 2001). Greywater often contains excessive salts, total suspended solids (TSS), with elevated biochemical oxygen demand (BOD) and nutrients such as nitrogen (N), ammonia (NH_3) and phosphate (PO_4) (Ahmed *et al*., 2001; Coleman *et al*., 2004). If the quality of greywater content exceeds normal acceptable levels, it should be treated before use, but it is difficult and expensive to test for these and other parameters (Ahmed *et al*., 2001). Without prior treatment, greywater can lead to problems such as elevated levels of soil salinity, lower water infiltration rate, specific ion toxicity (sodium, chloride and boron), and changes in soil properties, elevated pH levels, and the accumulation of heavy metals (Qishlaqi *et al*., 2008) which may impede plant growth (Ayers, & Westcot, 1994; Gross *et al*., 2005; Carden *et al*., 2007 b).

The use of untreated domestic greywater for irrigating crops in small home gardens has several advantages (Holtzhausen, 2005; Al-Zu'bi & Al-Mohamadi, 2008). One is that it saves using fresh water. Studies show that it can reduce household potable water usage by about 30% (Jeppesen, 1996). Further advantages, as shown in several studies, is that greywater irrigation increases plant growth (Day *et al*., 1981; Rusan *et al*., 2007), crop yield (Salukazana *et al*., 2006; Mirsa *et al*., 2009) without any effect on the quality of the crop (Day *et al*., 1981; Zavadil, 2009).

2.3 Greywater quality for crop production

It is the multiple activities used in the generation of the greywater that are responsible for the variable quality. For instance, and most obvious, is the chemical components used in laundry washing machines, washing basins and in cleaning kitchen utensils that results in considerable variation in the physical, chemical and biological characteristics of greywater (Erikson, *et al*., 2002). Grease, oil and food debris are often found in greywater generated from the kitchen (Travis *et al*., 2008), whereas large quantities of sodium (Na) and phosphates (PO_4) are found in greywater from washing machine powders (Friedler, 2004). In the United Kingdom, greywater from household baths were found to contain lower concentrations of fecal coliform and fecal *Streptococci* compared to wash basins and shower water (Jefferson *et al*., 2004). A common finding in greywater studies is that the quality can be improved in a household by excluding water from the kitchen sink, and also by diluting the laundry washing water and finally rinsing the washing water (Friedler, 2004). In all these cases, the source of greywater is a major determinant of the quality of the water, and therefore constrains or limits the intended use.

Bauder *et al*., (2007) found that acceptable water quality for crop production should be approximately at a range of pH 6.5 to 8.4 and EC 0.25 dS/m to 0.75 dS/m and should exclude heavy metals and microbial contaminants. As such, the quality of greywater from dense informal settlements in South Africa was found to be unfit for irrigation because of elevated levels of Na, P and *E.coli* (Carden *et al*., 2007 a). South African guidelines for irrigation set Target Water Quality Range (TWQR) of 1 mg/l for zinc (Zn) (DWAF, 1996) and lead (Pb), according to FAO (1979), and should not exceed 0.5ppm in water used for irrigation. Similarly, in Canada, Finley *et al*. (2009) found that although no heavy metals were detected in greywater, both fecal coliform and fecal *Streptococci* were at elevated levels of $4x10^5$/100 ml and 2,000/100 ml respectively.

Studies to determine the risk of greywater to human health are largely absent in the literature. One study found that because greywater contains a lower bacterium count, such as *E. coli,* compared to sewage water, users tended to use greywater in an untreated state (Holtzhausen, 2005). By contrast, Gross *et al*., (2005) suggests that greywater has the potential to increase health and environmental risks, and that treatment was highly recommended. While the treatment of bacterium in greywater is relatively simple, by adding chlorine and iodine for example, but the organic material in greywater may combine with chlorine to form sediments that will shield total coliforms from disinfection and reduce the chlorine available to act as a disinfectant (Duttle, 1996; Winward *et al*., 2008). Iodine can be very effective at high pH values of greywater by reacting very fast, killing most undesirable bacterium within two minutes of application, and unlike chlorine it is not affected by organic material (Duttle, 1996). Another method is the dilution of greywater with potable water (World Health Organization, 2006). Unfortunately, the studies conducted with greywater dilution at 50:50 were not aimed at improving greywater quality, but rather at crop yield improvement (Day *et al*., 1981; Pinto *et al*., 2010) and water saving efficiency (Dixon *et al*., 1999).

The quality of greywater for use as an irrigation source determines the method of application. For example, greywater containing high Na^+ ion concentration (46-230 mg/l) and chloride ion concentration (175-350 mg/l) causes leaf damage in sensitive crops such as pepper, potato and corn when sprayed onto the crops (Ayers & Westcot, 1994; Bauder *et al*., 2007). The recommended method of applying greywater on crops is drip and surface irrigation systems since these approaches will allow water to accumulate next to the plant root without a direct contact with the leaf structure (Al-Jayyousi, 2004; Holtzhausen, 2005). Moreover, drip irrigation lines placed on the soil surface can significantly reduce the occurrence of crop contamination of microbial organisms during irrigation with black water (Sadovski *et al*., 1978).

2.4 Greywater management and use

The estimated quantity of domestic greywater generation in South Africa varies between 25 % and 75% of the total collected water, but this applies only to the volume of water that is carted from a tap stand to a household in the case of an informal settlement (Carden *et al*., 2007a). Most often this greywater is discarded onto the ground in the vicinity of tap stands, yards and nearby streets, leaving noxious odours. In shallow sandy soils in densely populated informal settlements in Cape Town, the disposal of domestic greywater typically results in standing water bodies and runoffs that pose a human health and environmental risk. In these circumstances it is not feasible to use greywater for food production, but should rather be managed using disposal systems including treatment (Van Vuuren, 2007). In a further case, residents in Kampala, Uganda, dispose their greywater into informal drainage systems, but fail to use this water before disposal (Kulabako *et al*., 2010). In these cases efforts to use greywater are limited although there are isolated case studies, for example, work done by Roman *et al*., (2007) in the capital city of Peru, Lima, where residents in this highly populated shanty town actively grow vegetables using untreated wastewater and greywater.

Peri-urban dwellers in South Africa are obliged to look for alternative water supplies for agricultural activities due to high costs of municipal water (Murphy, 2006). In a peri-urban area of Harare, Zimbabwe, researchers found that greywater was being used for a variety of activities such as toilet flushing, washing of cars and irrigating vegetable gardens, where there was no need for superior water quality (Hoko & Nhlapi, 2002). However the contradictions and contrasting situations differ remarkably elsewhere. In a peri-urban area of Homabay, Kenya, the high bacteriological count was found unfit for use without prior treatment (Ngaga *et al*., 2012), and again confirms the need for treatment of greywater before use. Raude *et al*., (2009) found that high levels of TSS (Total Soluble Solids) and fecal coliform in greywater generated in urban and peri-urban areas of Nakuru Municipality in Kenya necessitated treatment before it could be used for most purposes.

Most rural areas of the former Transkei region of the Eastern Cape lack sanitation and water supply for domestic use (Perret, 2001). Tap stands are available in some villages, but in others the villagers obtain brackish water from underground sources from boreholes or surface water from the rivers and dams. Untreated water from these sources are used by village communities for domestic use, but is often of poor quality, with high levels of salinity, electrical conductivity, nutrients and oxygen demand substances (Fatoki *et al*., 2003; Lehloesa & Muyima, 2000).

Although greywater could be as useful in a variety of ways as mentioned, widespread acceptance is constrained by personal preference and laws governing greywater quality that limits its use for agricultural purposes (Redwood, 2008). In the United Kingdom citizens prefer to use greywater for toilet flushing, and to a lesser extent on washing the car and watering the garden (Jefferson *et al*., 2004), whereas Australians show a willingness to use greywater on a wider variety of activities so long as this avoids direct bodily contact (Marks *et al*., 2006). Australians are more comforted when greywater is used to irrigate public open spaces rather than household use. Both in the Netherlands and in South Africa, researchers recommend that greywater should be used in conjunction with other sources of water because rural and urban dwellers alike consider greywater as unacceptable and unhygienic (Dixon *et al*., 1999; Khosa *et al*., 2003).

Some countries have legislation to govern the re-use of greywater. In USA, each state has regulation guidelines regarding the use of greywater. According to the California Graywater Standards (1995), greywater is perceived to be less contaminated than black water, hence greywater is permitted to be used without treatment for flood irrigation as long it does come into contact with humans. In Australia, greywater is permitted to be diverted in subsoil (garden) by a licensed plumber. This can be done without Council approval except for when greywater is treated and stored for flushing toilets or car washing (Blue Mountain Conservation Society, 2007).

2.5 Greywater impacts on plant growth, yield and quality

2.5.1 Plant growth

Greywater could reduce plant growth due to excessive levels of toxic elements such as boron (B), chlorides (Cl^{-1}), and cadmium (Cd), and cause soil pore clogging from grease, phosphates (PO_2^{-3}) and sodium (Na) (Ayers & Wescott, 1994). These plant nutrients are essential for plant growth but are required in relatively small concentrations (Rusan *et al*., 2007). In addition, Omami (2005) found that salinity affected plant growth in a number of ways: reduced infiltration; caused a deterioration of the physical structure of the soil, which in turn diminishes permeability and soil aeration; and caused an increase in the concentration of certain ions which have an inhibitory effect on plant metabolism. The general response of plants to soil salinity is marked by a reduction in plant growth such as germination (Omami, 2005), root and shoot length, and overall dry mass (Agarwal & Pandey, 2004), and leaf necrosis (Wahome *et al*., 2001).

Studies suggest that caution should be taken when sensitive crops such as pepper, potato and corn are irrigated with greywater that have a high salt concentration because it leads to severe leaf damage and crop failure (Ayers & Westcot, 1994; Bauder *et al*., 2007). The recommended method of applying such highly concentrated greywater on crops is by drip and surface irrigation since this approach allows water to accumulate next to the plant root without direct contact with the leaf structure (Al-Jayyousi, 2004; Holtzhausen, 2005). However, salt and boron tolerant plants such as olives, sugar beet and tomato should not be a problem if irrigated with high salt and chlorine such as is often found in greywater (Bino, 2003, Bauder *et al*., 2007).

Studies have found that diluted municipal greywater at a rate of 1:1 resulted in taller cotton plants with more vegetative growth compared the use of potable water (Day *et al*., 1981). Similarly, in a study by Rusan *et al*., (2007), essential nutrients (N, P, and K) contained in greywater resulted in higher plant biomass in the production of barley. However, there was no significant difference observed on plant growth parameters measured and biomass of lettuce and carrots (Finely *et al*., 2008); and tomatoes (Misra *et al*., 2009) when irrigated with greywater compared to potable water. Also silverbeet irrigated with 100% greywater showed a slight reduction in shoot and root biomass when compared to other treatments, namely greywater diluted with potable water at 1:1 ratio and 100% potable water (Pinto *et al*., 2010). Plant growth in response to greywater irrigation appears to be dependent on the type of crop and nutrient content of the irrigation water.

2.5.2 Crop yield

Greywater used for agricultural purposes worldwide has also been found to increase crop yield due to finite concentrations of essential macro-nutrients such as nitrogen (N) and phosphorus (P) contained in greywater (Day *et al*., 1981; Rusan *et al*., 2007). Cotton yield was improved by using diluted municipal wastewater with groundwater at 50:50 mixtures when compared to groundwater alone from wells in Arizona (Day *et al*., 1981). Also, tomatoes irrigated with greywater obtained higher nutrient uptake and biomass at the flowering stage when compared to tap water (Mirsa *et al*., 2009). The yields found in these studies were due to higher concentration of essential nutrients contained in the greywater compared to control water treatments.

Greywater irrigation increased yields significantly in previous mentioned studies, but in the case of a study in Jordan where tomatoes were irrigated with greywater there was no increase in yield compared to those irrigated with potable water (Al-Zu’bi & Al-Mohamadi, 2008).

Although no study found that there was an observed yield reduction due to greywater irrigation, water containing 1% of NaCl was observed to reduce yields of lettuce, endive and fennel significantly (De Pascale & Barbieri, 1995).

2.5.3 Crop quality

The quality of irrigation water not only affects crop yield, but also internal and external qualities of the product (Zavadil, 2009). Sensory evaluation, being a subjective observation of the properties and defects of plants, varies according to individual judgment but cannot be ignored as a factor. Consumer satisfaction is based solely on sensory evaluation (colour and firmness) which is directly related to product quality (Shewfelt, 1999). For instance, a good quality cabbage head should be fresh, hard, fully developed with an average head size since exceptionally large cabbage heads do not appeal to consumers and consequently lowering its quality and marketability (Wagner *et al*., 1998). According to these researchers, vegetables quality can be assessed by a simply scoring system on a 1 to 5 scale (poor to excellent) by merely looking at the size, uniformity and defects.

Research on the external quality of crops to greywater irrigation is also limited. For instance, Zavadil (2009) discovered that wastewater did not improve crop quality of sugar beet (sugar content) and starch percentage of early potatoes, and Day *et al*., (1981) observed no significant difference between cotton irrigated either with greywater or with groundwater on the quality of the cotton lint. No other research could be found. Most research in greywater irrigation focuses on nutrients that affect the chemical properties of edible crops as a result of greywater irrigation. For instance, Rusan *et al*., (2007) found that lead (Pb) and cadmium (Cd) content in barley crops increased with wastewater irrigation and that the level was highest after a period of 10 years of irrigation. Similarly nickel (Ni) and Pb were elevated on wheat at average concentrations of 23.39 mg/kg and 25.40 mg/kg respectively more than acceptable concentrations, while Cd measured on spinach and lettuce were found to be eight times more than 0.2mg/kg FAO/WHO permissible levels (Qishlaqi *et al*., 2008). Human exposure to even low levels of 2–3 µg Cd/g may result to kidney damage, bone effects and fractures (Järup, 2003). However, Cd uptake by vegetable plants is limited when zinc (Zn) or application of lime or gypsum is present in soils (Wahlquist, 2009).

Lettuce and spinach irrigated with greywater were found to contain more nutritious elements such as Fe and Zn relative to the same using potable water (Rodda *et al*., 2011). Both Fe and Zn were elevated when barley was irrigated with greywater during the first two years of an experiment (Rusan *et al*., 2007). The availability of micronutrients such as Zn and Fe in food crops plays a vital role in the nutrition and health of consumers (White & Broadley, 2005; Zou & Zhang, 2009). Although Zn is nutritious to humans, a maximum Zn tolerance of 20 mg/kg for edible parts of vegetable crops was established (Long *et al*., 2003). Therefore, crops containing 5 mg/kg more Zn and Fe are considered to have a better nutritional quality than those with less (Worthington, 2001).

Zavadil (2009) found that there was significantly higher sodium (Na) content in sugar beet and potato tuber when irrigated with primary treated municipal wastewater. Although higher Na plant content in aforesaid study did not cause any physiological consequences on the plants, it is expected that relatively high Na concentrations may lead to leaf chlorosis (brown patches on the leaf tips) on lettuce as observed by Weil-Shafran *et al*., (2006). Increased Na uptake by a plant due to higher levels of Na in the soil can lead to a decrease in osmotic potential and reduced plant water uptake and therefore reduce the plant total moisture content (Barker-Reid *et al*., 2010). A higher Na content of tomato plant irrigated with greywater was observed when compared to tomatoes irrigated with tap water (Misra *et al*., 2009). In another study, tomatoes and beans were observed to contain an increase in Na content when they were irrigated with greywater than with tap water (Holtzhausen, 2005). In theory, raised levels of Na in crops, as a result of greywater, will eventually cause a reduction in plant quality and productivity (Jacob & Van Staden, 2008). Hence water contained approximately 1% of NaCl was found to significantly reduce the leaf area, moisture and dry matter content of lettuce, and consequently reduced the market value of the crop compared to crops containing no NaCl (De Pascale & Barbieri, 1995).

2.6 Greywater impacts on soil

Greywater has both negative and positive environmental effects on soils depending on how it is managed. In rural areas, greywater is disposed directly on the ground near dwelling places and often results in various health and environmental hazards such as pollution of wetlands, underground water supply and infiltration of salts, oils and grease into the soil (Van Vuuren, 2007). However, the organic matter contained in greywater could help in building up organic matter in the soil over time (Rusan *et al*., 2007). Table 2.1 lists some of the effects of various domestic greywater sources, possible pollutants and effects in the soil in the short term. As shown in the Table 2.1, oil and grease from the kitchen sink found in the greywater accumulated approximately 200 mg kg $^{-1}$ in the soil due to the irrigation of crops and effectively reduces the infiltration rate of the soil (Travis *et al*., 2008). Sources of domestic untreated greywater determine the effects on the health of the soil.

Table 2.1 Effects of domestic greywater generating appliances on soils.

GREYWATER source	**Pollutants**	**Effects on the soil**	**Reference**
Kitchen sink	Grease and oil	Reduction in soil water capillary rise	Travis *et al*., 2008
Washing machine	Surfactants and salts	Modest influence on soil water retention and evapotranspiration	Misra *et al*., 2009
Bath tub	Micro-organisms, such as *E. Coli*	High electrical Conductivity (EC)	Holgate *et al*., 2011

Water discharged from a bath tub had been described as being less polluted than many other forms of domestic greywater sources (Jefferson *et al*., 2004), however this water due to high sodium ion (Na^+) concentration, does induce a high electrical conductivity on soils when used to irrigated food crops (Holgate *et al*., 2011). High electrical conductivity could result in low soil productivity and increase soil salinity (Rusan *et al*., 2007).

In Egypt underground water was found to be contaminated by nitrogen, phosphate, heavy metals and fecal *E. coli* forms on a field that had been irrigated for 75 years with sewage effluent (Farid *et al*., 1993). Sewage effluent contains more organic matter and nutrients compared to domestic greywater, and the water quality for both sewage and greywater contained heavy metal concentrations within the same range of (Eriksson *et al*., 2002). In another long term study conducted over a 10 year period, Rusan *et al*., (2007) claim that there was an increase in salts, organic matter, and plant nutrient in the soil due to greywater irrigation whereas there were no increase in heavy metals in the soil. However, Bolivian researchers Al-Zu'bi & Al-Mohamadi (2008) discovered an increase in heavy metal concentrations for Cd and Ni compared to concentrations before being irrigated with greywater. Although these previously mentioned heavy metals concentrations were not considered hazardous, the accumulation of heavy metals in the soil over long-term should be avoided. Subsequently some researchers, Misra *et al*. (2009) discovered that tomato plants irrigated with greywater removes about 86% more of Fe from the soil compared to the same crop being irrigated with potable water. The removal of these elements by plants may reduce the risk of heavy metal accumulation in the soil in a short term.

The contamination of long-term use of greywater on fields may not necessarily pollute the underground water, although shallow sandy soils that are irrigated with greywater are prone to contaminate the water table by the leaching of nutrients (Duttle, 1996). Gross *et al*., (2005) observed that the accumulation of salts occurred in both fertilized water and greywater irrigated plots, but no risk of salinity was detected over a period of three years. It was assumed that in arid environments, loess soil irrigated with greywater in the long term (beyond three years), may result into raised soil salinity and the presence of surfactants and boron in the soil may cause change the soil properties and soil structure. Furthermore, long term irrigation using greywater with Sodium Absorption Ratio (SAR) greater than four will likely disturb the soil properties (Gross *et al*., 2005). In such cases, flooding soil or rotating greywater irrigation with fresh water is highly recommended to flush the soil pore spaces (Al-Hamaiedeh & Bino, 2010), and to counteract the accumulation of Na and heavy metals in the soil (Al-Jayyousi, 2002; Rodda *et al*., 2011).

There have been no reports in literature that have determined the negative impact on soils due to irrigation of edible crops with greywater, except a few studies where researchers discovered that irrigating with untreated wastewater elevated the pH level by 2 to 3 units and resulted in the build-up of heavy metals on soils being above Maximum Permissible Limits according to Irish standards (Qishlaqi *et al*., 2008). Pinto *et al*., (2010) discovered that EC and soil pH were significantly elevated due to greywater irrigation compared to other irrigation water treatments. However, in the case of the study by Rusan *et al*., (2007), the build-up of pollutants was observed due to greywater irrigation, although soil pH was not affected. Despite these reports on the accumulation of heavy metals and elevation of pH and EC, overall there were no negative effects on soils due to greywater irrigation or those that suggest that it could pose any risks to the health of soils (Faruqui & Al-Jayyousi, 2002; Pinto *et al*., 2010). Further research on the periodic and systematic studies of soil is necessary to ensure long term environmental safety in the sustained used of greywater irrigation (Rusan *et al*., 2007).

CHAPTER 3: RESEARCH MATERIALS AND METHODS

3.1 Introduction

This study seeks to understand the potential to use greywater generated from households in an informal settlement to irrigate a selection of vegetable crops. The Complete Randomized Design (CRD) was built into the design of the field experiments to assess the effects of greywater on the quality of crops and effect on the soils. This chapter describes the method, the study site, experimental design, data collection and analysis.

3.2 Experimental site

Figure 3.1 An experimental site map (Source: Google earth).

The Umtata Dam Research Station (31^{o}30'04"S 28^{o}42'24.5"E) was chosen as the study site. This site receives between 800 and 950 mm per annum of summer rainfall from October to

March (Prinsloo & Schoonbee, 1984). The site is ideal for conducting a field experiment because it is managed by the Eastern Cape Provincial Department of Rural Development and Agrarian Reform, and offers a secure environment from which to conduct the experiment (Figure 3.1). In addition, low wage earners of the Department, who are employees unable to afford to rent in Umtata, have been allowed to build shack dwellings immediately outside the yard of the premises. Together these houses resemble a small informal settlement. Only two water tap stands support these 12 shack dwellings, and there are no toilets. In this instance, the greywater from this small settlement was generated mainly from the washing of clothes and bodies, and from the washing of dishes. Waste material is centrally collected and burnt occasionally, but for most, wastewater is disposed on the ground close to the dwellings typical of many informal settlements in South Africa.

3.3 Experimental design

The experiment uses a Completely Randomized Design (CRD) in the layout of three field plots, with each of the three fields receiving separate treatments namely, potable water from a municipal tap stand, greywater diluted with potable water (1:1), and undiluted greywater collected from the informally constructed houses. The study was replicated six times with single plant replicates. The designated plant in each plot was allocated a number using a randomized number table. In each treatment plot there was a single dripper line without any plants alongside (referred to as an empty dripper) which was used as control. A 1m passage was used to separate the treatment plots (Figure 3.2).

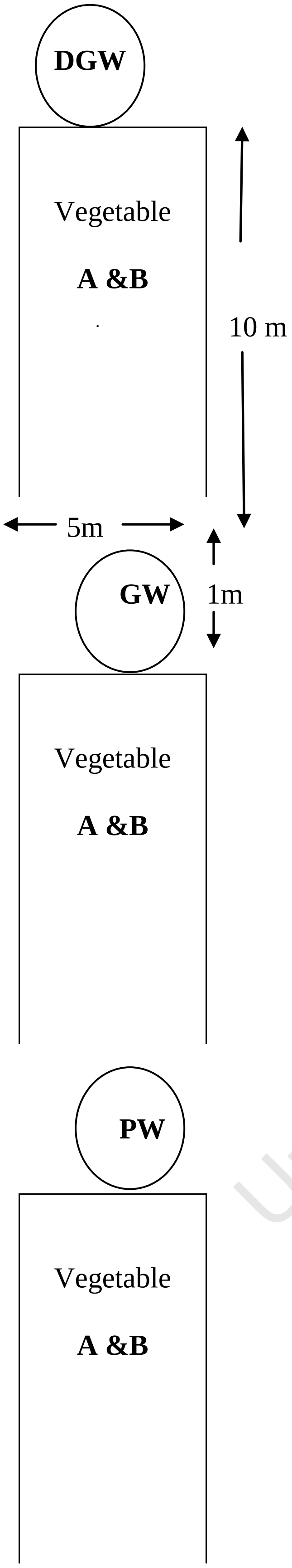

Figure 3.2 Trial layout (where DGW = diluted greywater on 1:1 ratio, GW = greywater, PW = potable water and Vegetable A & B = cabbage and onion /beetroot and spinach/lettuce and carrots).

Vegetable seedlings (cabbage, spinach, beetroot, lettuce and onions) were purchased from a commercial nursery and planted in the designated plots. During the seedling transplant, three drip irrigation systems were installed comprising of 100 l containers that were placed on a stand to gravity feed the water to each plot (Figure 3.3). The water was filtered then reticulated via polyethylene feeder pipe to a 5m pipeline and finally to 10m dripper lines each with end-stoppers. Each of the three garden plots measured 10m x 5m garden (Figure 3.2). Tests conducted on the soils were found to contain Hutton deep red soils that were well drained and had developed from basic dolerite parent material (Soil Classification Working Group, 1991).

All plots were fertilized by broadcasting synthetic fertilizer NPK mixture 2:3:2 (22) + 5% Zn and four weeks after planting the plots were top dressed by broadcasting straight fertilizer Limestone Ammonium Nitrate [LAN(28%)] based on a soil fertility test analysis. All plots were mulched with grass. The grass mulch covered the soil surface next to the each plant to avoid weed invasion and minimize competition for water resources from the main crops. This mulch was taken from grass cuttings, unlike mulch from other studies where a mulch tower (combination of mulch, coarse sand and coarse gravel) have been used to improve greywater quality (Crosby, 2005; Zuma *et al*., 2009) or mulch for soil conditioning (Sheng *et al*., 2008).

Figure 3.3 The drip irrigation system and layout of the experiment

During the first season a combination of onion and cabbage were planted, followed by spinach and beetroot, followed by lettuce and carrots, and then onion and cabbage again (Table 3.1). In every planting, the same row of leafy crops or the root/bulbous crops were used each season. The total plant population was 166 per plot with 133 plants for each leafy or underground crop planted per plot.

Table 3.1 Production plan for combination of a leafy and root/bulbous crops during years 2009 and 2010.

Crop combination	Season started	Season ended
Cabbage and onion	October 2009	December 2009
Spinach and beetroot	February 2010	May 2010
Lettuce and carrots	June 2010	September 2010
Cabbage and onion	October 2010	December 2010

The crop combination (Table 3.1) selection was based on common knowledge of vegetables typically grown in the vicinity. Lettuce and carrots were chosen as vegetable crops based on the possibility that they could be eaten raw.

3.4 Greywater sampling

Greywater samples were collected from the shack dwellings for three consecutive days before the trial initiation. These samples were then analyzed for pH and Electrical Conductivity (EC) using HANNA™ Combo pH and EC, HI 98129a portable meter. These tests indicated the quality of the greywater as well as giving some indication of volume required for the daily irrigation. The mean values for pH and EC, although these were inconsistent, were below 7 pH and ≤0.25 (dS/m) respectively, but were deemed acceptable for irrigation quality (Bauder *et al*., 2007). On commencement of the experiments, four 25 l containers were put around the shack dwellings and these were collected early each morning and returned late in the day. Irrigation took place in the morning at approximately 09h00 using the greywater that was generated overnight. This exercise was repeated daily. Greywater and all other water treatments were sampled fortnightly comprising six samples per treatment in a season (three months) and a grand total of 72 water samples for the duration of field experiment.

3.5 Data collection

3.5.1 Beginning of each season

Both water and soil samples were analyzed for presence of Na, Fe, K, Mn, Cu, Zn, Ca, TKN, P, Mg, Cd, Pb, Ni, Cr and pH (KCl). Water samples were taken from the collection containers situated amongst the informal dwellings as described earlier. A soil auger was used to collect soil samples directly from the rows in which leafy crops were planted, in the rows which bulb/root crops were planted, and along the empty dripper line. Soil samples were taken at different soil depths, namely 0-10 cm, 10-30 cm, 30-60 cm and 60-90 cm making a total of 12 samples per plot and 36 samples per planting season. Both water and soil samples were analyzed at the Döhne Laboratory in Stutterheim. Döhne Laboratory is a member of AgriLasa (Agricultural Laboratory Association of Southern Africa).

3.5.2 At harvest

The average mass (yield) of vegetables that was harvested was established by weighing and also assigning a value based on the aesthetics and appearance of the product according to

Wagner *et al.*, (1998) classification which score a product from 1-5 (where 1= very poor, 2= poor 3 = average 4= good, and 5 = excellent) as explained in Chapter 2. This scoring system was used because leafy vegetables such as cabbage, lettuce and spinach, are not sold by weight but by appearance. Samples of harvested crops were then selected to ensure that five plants per treatment (approximately 6% of the total harvested crops in each case) were selected randomly within a plot, excluding the border rows. Border rows are the first two outside rows which are affected by winds and other factors. Again these samples were sent to Döhne Laboratory to test the chemical contents including heavy metals using graphite furnace/flame atomic absorption and hydride generation techniques (See Appendix A for some detailed account of the methods). The presence of selected bacterium was analyzed from water samples and on the plants, but due to huge variance and inconsistencies, the results were not included in this study.

The soil chemical analysis was performed to check for the possibility of changes in the soil quality and build-up of salts due to successful irrigation water treatments. Also, soil depth was measured to determine whether the water table was likely to be contaminated. Plant chemical analysis was done to determine what elements were likely to be retained in the soil or removed by the plants. Finally, the chemical content of the edible portion was measured to determine the quality of fresh produce and the content of elements that could be ingested if these vegetables were to be consumed.

3.6 Statistical analysis

The differences in water, soil and plant parameters were compared by single-factors analysis of variance (ANOVA) with p = 0.05 for significance, using the GenStat 12 edition (2009).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The chapter presents the analysis of water treatments, and discusses the yield and external crop quality, followed by an analysis the effects of different treatments on crops and soils. A total of 6 water samples per season and

4.2. Water analysis

There was no observed difference in pH and Mg in each of the treatments for potable and greywater (Table 4.1). However, there were significantly higher differences where greywater was used in the experiment (P>0.5) with respect to Cl, EC, HCO_3, Na, SAR and TDS. There were significantly higher concentrations found in $CaCO_3$ hardness of the potable water. As expected, all concentrations were lower when diluted greywater was used compared to the concentrated greywater solution.

Table 4.1 Average values of chemical analysis of 72 water samples taken over a period of four planting seasons.

Treatments	**pH**	**EC (mS/m)**	**$CaCO_3$**	**Cl**	**HCO_3**	**Mg**	**Na**	**SAR**	**TDS**
						(mg/l)			
PW*	6.15 a[x]	6.0 c	39.5a	14.0 ab	43.0 c	2.0 a	1.0 b	0.0 c	50.0 c
DGW*	6.40 a	33.0 b	1.0 bc	7.00 b	140.0 b	1.0 a	9.5 ab	1.8 ab	240.5 b
GW*	6.50 a	50.0 a	2.5 b	16.00 a	223.0 a	1.5 a	15.0 a	2.5 a	358.0 a
LSD (P=0.05)	**NS**	**3.513**	**12.30**	**7.026**	**27.88**	**NS**	**13.72**	**1.45**	**36.04**

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD). * PW – potable water; DGW – diluted greywater; GW – greywater.

From these observations, greywater contained elevated concentrations of Na (15 mg/l) and Cl (16 mg/l) ions although this was below the limit of 100mg/l that is accepted by the South

African Water Quality guidelines (Fatoki *et al*., 2003). Greywater at pH 6.7 falls within an accepted range between 6.5 and 8.4 pH indicating the likelihood that this water is suitable for irrigation (Baunder *et al*., 2007). However, the elevated EC levels could increase the risk to human health, plants or soil as the observed in a range was between 40 to 200 mS/m (Rodda *et al*., 2011). An average of 50 mS/m EC was observed when greywater was used and was recorded in the upper quartile of 70 mS/m at least once in the twenty four samples.

It was surprising that although greywater caused significantly higher bicarbonate (HCO_3^-) which in turn could have caused a rise in pH, there was an insignificant difference in greywater with respect to the observed pH. HCO_3 raises the pH by causing Ca and Mg ions to form insoluble minerals leaving Na ion uncompetitive in the solution (Bauder *et al*., 2007). The presence of high acid food, for example, tomato and cooking oil, in greywater could be the cause of lower pH 6.7 (Al-Jayyousi, 2004). Tomatoes contain about 9% of citric acid, 4% of malic acid, and 2% of dicarboxylic acid (Petro-Turza, 1987 cited by Yilmaz, 2001) and cooking oil contains different kinds of fatty acids (Noureddini *et al*., 1992).

It is interesting to note that Ca in potable water (municipal water from a tap stand) was significantly higher and Mg was slightly higher than other water treatments in which, in combination with Na, were useful in calculating SAR (Sodium Absorption Ratio). Greywater had a significantly higher SAR value of 2.5, but according to Gross *et al*., (2005), this appears not to be destructive to the environment and soil properties in the long term. Although salinity in the diluted greywater was lower than that of greywater, Al-Jayyousi (2004) discovered that greywater salinity was lower than that of potable water since greywater was diluted with rainwater.

Table 4.2 Average of heavy metal chemical content on water analyzed samples.

Treatments	Cd	Cr	Cu	Ni	Pb	Zn
	(mg/l)					
PW	0.283 a[x]	2.2 a	8.2 a	6.6 a	1.0 a	0.085 a
DGW	0.046 bc	25.2 a	16.0 a	25.6 a	16.0 a	0.000 a
GW	0.062 b	42.2 a	18.8 a	16.4 a	46.0 a	0.000 a
LSD (P=0.05)	**0.078**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**

[x] Numbers in columns with different letters are significantly different ($P \leq 0.05$, LSD).

There were no significant differences in heavy metals in the water samples except in the case of Cd (Table 4.2). Heavy metals were less than that found by Surendran & Wheatly (1998) in greywater generated from bath/shower activities. However, Pb, Cd, Cu and Zn were not detected in the aforesaid study from washbasin water. Since the houses where the water was collected were unserviced, most greywater was from the use of washbasins and kitchens, and hence Zn was also not detected in the present study. Water from washbasins was the least polluting compared to dishwasher and washing machine (Friedler, 2004). Zn (0.085 mg/l) in potable water was lower than Target Water Quality Range (TWQR) of 1 mg/l permitted by South African guidelines for irrigation (DWAF, 1996). However, Pb (46 mg/l) and Cu (18.8 mg/l) found in greywater used for irrigation exceeded the permitted TWQR of 0.2 mg/l (DWAF, 1996).

The overall quality of greywater used in this study is comparable with that of the tap water used by Jackson *et al*., (2006) in Ethekwini Municipality in the KwaZulu Natal Province and even better than a tap stand in Nkonkobe Municipality in the Eastern Cape Province (Lehloesa & Muyima, 2000). In South Africa water quality from a tap differs from municipality to municipality. In some cases, greywater generated from municipal water sources might not be fit to irrigate food crops. For this reason, diluting the greywater (with high total soluble salts) with potable water at 1:1 ratio, as in the study done by Day *et al*., (1981), lowers the salt content and improves water quality for irrigation purposes.

4.3 Yield and external crop quality

4.3.1 Cabbage

A significant difference was observed in the yield of cabbages that were irrigated with diluted greywater compared to potable water during the first season (Table 4.3). During the same season, all cabbage external qualities were significantly favoured by diluted greywater than other treatment. It was also observed that cabbages irrigated by potable water had a poor aesthetic appeal: small heads that were pockmarked by insects. During the second season throughout all treatments, the parameters improved such that there was no statistical significant difference between them. These results were due to higher rainfall encountered during the second season in which the irrigation treatments were minimized since less irrigation treatments were applied. Rainfall patterns are not included in these results. Remarkably, potable water doubled the values of yield and average head mass compared to what was obtained in the previous season. During 2010 season cabbage heads were too big in appearance but not hard enough to increase remarkable the average head mass, with which lowered the marketable value in all treatments. According to Wagner *et al*., 1998, a good quality cabbage head should be fresh, hard, fully developed with average head size since exceptionally large cabbage heads has limited appeal to consumers and therefore lowers the market response.

Table 4.3 Influence of irrigation water on yield and cabbage external quality during 2009 and 2010 seasons.

Treatments	**Yield (tons/ha)**		**Head mass (kg)**		**Appeal** [x]	
	2009	**2010**	**2009**	**2010**	**2009**	**2010**
PW	91.4 b[y]	185.0 a	1.90 b	3.86 a	1.8 bc	2.40 a
DGW	160.0 a	177.6a	3.33 a	3.70 a	3.8 a	2.60 a
GW	106.0 ab	158.5a	2.21 ab	3.30 a	2.4 b	2.20 a
LSD (P=0.05)	**68.640**	**N.S**	**1.430**	**N.S**	**1.4**	**N.S**

[x] Assigned a value based on score of 1-5 (where 1= very poor, 2= poor 3 = average 4= good, and 5 = excellent) according to Wagner *et al.*, (1998) classification.

[y] Numbers in columns with different letters are significantly different ($P \leq 0.05$, LSD).

4.3.2 Onions

The yield of onions was the only parameter measured during fields trials in 2009. It was observed that only those onions irrigated with greywater showed a significantly higher yield compared to other treatments (Figure 4.1). Salukazana *et al*., (2006) confirmed these results when it was discovered that onions had a significantly higher yield when irrigated with greywater compared to hydroponic nutrient solution and tap water. The yield was way below the average expected yield of 50-60 tons/ha under normal circumstances (Joubert, 1997). There is no clear explanation for the lower yield, however in the following season different types of irrigation had no observed effect on any of the measured parameters (Table 4.4 and Figure 4.2). Although there was no significant difference from treatments in the second season, onions irrigated with greywater had a slightly higher yield compared to other treatments, while onions irrigated with diluted greywater were marginally better with respect to external quality both in the uniform size and shape.

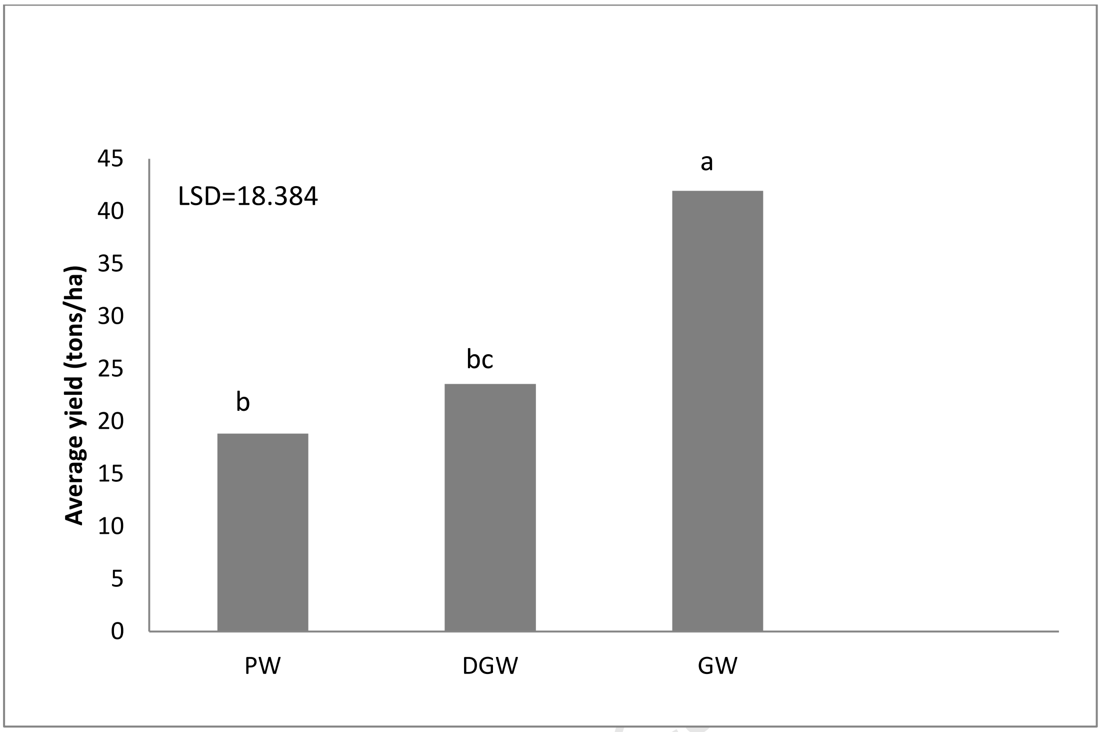

Figure 4.1 The effects of irrigation water on onion yield during the first season in 2009.

Table 4.4 The effect of irrigation water on onions during the second season in 2010.

Treatments	**Yield (tons/ha)**	**Bunch[x] mass (kg)**	**Appeal[y]**
PW	36.0 a[z]	0.750 a	2.30 a
DGW	38.8 a	0.808 a	2.80 a
GW	39.6 a	0.825 a	2.60 a
LSD (P=0.05)	**N.S**	**N.S**	**N.S**

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[y] Assigned a value based on score of 1-5 (where 1= very poor, 2= poor 3 = average 4= good, and 5 = excellent) according to Wagner *et al.*, (1998) classification

[z] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Figure 4.2 The onion 'appeal' influenced by irrigation water during the second season 2010.

4.3.3 Spinach

Spinach yields were significantly better when irrigated with greywater compared to other irrigation water treatments. Although the number of leaves that were infected by leaf-spot disease was higher on plants irrigated with greywater, but this did not reduce the total harvested quality of spinach leaves (Table 4.5). Leaf-spot disease is perpetuated by sprinkler irrigation (DAFF, 2010), but in this study it is not clear what might have caused a high incidence of the disease on the spinach because the crops were all drip irrigated.

Table 4.5 The effects of irrigation water on spinach.

Treatments	Yield (tons/ha)	No. of leaves infested	No. of leaves harvested/sample	Remaining edible leaves
PW	151.6 ab[x]	24a	84bc	60 b
DGW	123.0 b	30a	87b	57 b
GW	218.5 a	33a	109a	76 a
LSD (P=0.05)	**95.52**	**NS**	**22**	**16**

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Spinach irrigated with greywater was unappealing and presented a reduced quality and marketability (Figure 4.3).

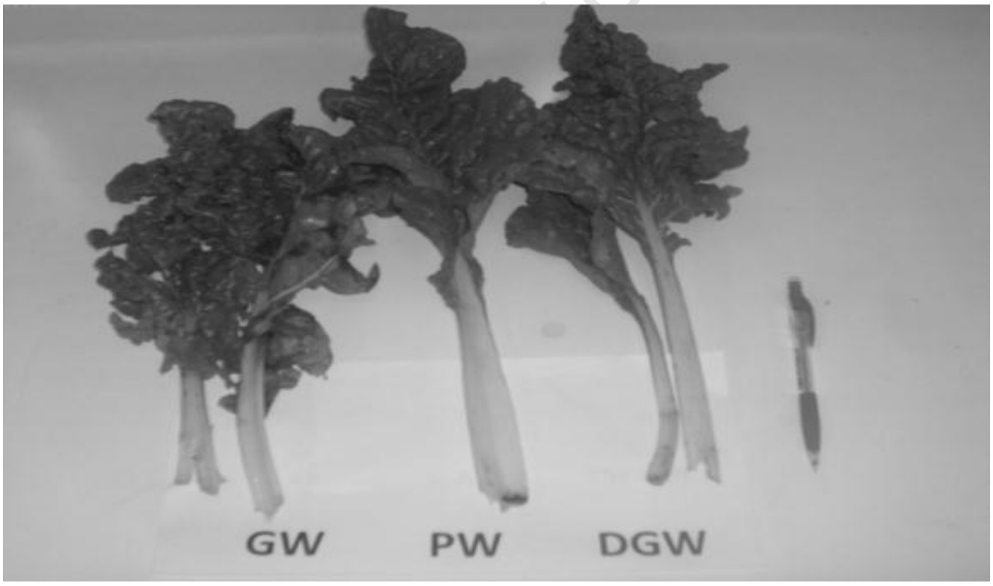

Figure 4.3 The effects of irrigation water on spinach and spinach leaves infested by leaf-spot

4.3.4 Beetroot

There was no significant difference observed in the external quality of beetroot including the yield (Table 4.6). Contrary to the results obtained by Salukazana *et al*., (2005) who found that beetroot had a significantly higher yield when irrigated with greywater compared to hydroponic nutrient solution and tap water. However, although not statistically different, yields were reduced by 47% (4.686 tons/ha) when irrigated with greywater compared to the control in which potable water was used. Salt concentrations in greywater can reduce the yield negatively because beetroot is known to be only moderately tolerant of salts (DWAF, 1996, cited in Rodda *et al*., (2011)). A trend was established where potable water performed best, followed by diluted greywater and greywater performed least in all parameters measured.

Table 4.6 The effect of irrigation water on beetroot during 2009 planting season.

Treatments	**Average circumference (cm)**	**Average mass (g)**	**Yield (tons/ha)**
PW	18.4 a^x	206 a	9.9 a
DGW	16.0 a	164 a	7.9 a
GW	14.0 a	108 a	5.2 a
LSD (P=0.05)	**N.S**	**N.S**	**N.S**

^{x}Numbers in columns with different letters are significantly different (P≤0.05, LSD).

4.3.5 Carrots

There was no significant statistical difference observed in the yield of carrots although greywater had an increase in yield of 40% (3.662 tons/ha) when compared to potable water (Table 4.7). This yield was lower than the average expected yield of 30-40 tons/ha (Joubert *et al*, 1994). The yield was affected by a number of factors, and in the case of this study, it is probable that poor soil moisture content at the planting stage during a very dry period (June) was responsible for this performance. Carrots irrigated with potable water were more appealing than other treatments and significantly longer in length compared to carrots irrigated with diluted greywater.

Table 4.7 The effects of irrigation water on carrots external qualities.

Treatments	**Yield (tons/ha)**	**Appeal**	**Average length (cm)**	**Average girth (cm)**
PW	5.6 a[y]	3.1 a	9.73 a	8.75 a
DGW	6.2 a	2.3 b	6.7 b	7.75 a
GW	9.3 a	1.8 b	8.47 ab	9.13 a
LSD (P=0.05)	**N.S**	**0.8**	**3.03**	**N.S**

[x] Assigned value based on score of 1-5 (where 1= very poor, 2= poor 3 = average 4= good, and 5 = excellent) according to Wagner *et al.*, (1998).

[y] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

There was no significant observed difference between carrots irrigated by greywater and potable water in root length although most of the samples irrigated with greywater were forking and crocked thus limiting the competitiveness of the produce at marketplace (Figure 4.4). The forking and cracking of carrots is due to high soil temperature and humus-rich soils (Joubert, *et al*., 1994). An increase in microbial activities along with an increase in soil temperature is to be expected using greywater irrigation.

Figure 4.4 Carrots irrigated with greywater (GW), potable water (PW) and diluted greywater (DGW)

4.3.6 Lettuce

There was no significant difference in observed data in yields and the head diameter for lettuce under all treatments (Table 4.8). However, lettuce irrigated with diluted greywater was significantly more appealing than other treatments. A yield increase of 22% (6.759 tons/ha) was observed when lettuce was irrigated by diluted greywater compared to the control (potable water), and decrease of 21 % in yield (6.624 tons/ha) was experienced due to greywater irrigation compared to the control.

Table 4.8 The effects of irrigation water on lettuce external qualities.

Treatments	**Yield (tons/ha)**	**Diameter (cm)**	**Appeal**
PW	31.1 a[y]	11.4 a	2.4 b
DGW	37. 9 a	11.4 a	3.8 a
GW	24.5 a	9.4 a	2.4 b
LSD (P=0.05)	**N.S**	**N.S**	**1.4**

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[x] Assigned a value based on score of 1-5 (where 1= very poor, 2= poor 3 = average 4= good, and 5 = excellent) according to Wagner *et al.*, (1998).

[y] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

In general, cabbage and lettuce were the only leafy crops that yielded better results when irrigated with diluted greywater even though, as in the case of lettuce, they were not statistically different with all other treatments. Greywater produced better yields for onions, spinach and carrots, whereas potable water had higher yields for beetroot although it was not statistically significant. These results are also confirmed by Finely *et al.*, (2008) who also found no significant difference in plant growth observed between the greywater and tap water on lettuce and carrots. Greywater had the potential to increase yields due to higher concentration of nutrient mineral as indicated by EC in this study, yet high salt volumes could have "bitter" consequences for the yield as indicated by the levels of Na and Cl ions contained by greywater used in this study. Furthermore, the yield reduction is related to Na and Cl content of the soil as discussed below.

The use of greywater for irrigation purposes compromised the quality of most vegetable crops in this study. Carrots were forked or deformed and spinach was infested by leaf- spots disease. Most other studies thus far only focused on microbial assessment when evaluating greywater irrigation on vegetable crops such carrots, spinach, beetroot and onions (Petterson *et al.*, 2001; Gross *et al.*, 2005; Jackson *et al.*, 2006). The only physical quality test that was performed on cotton by Day *et al.* (1980) where they discovered that there was no effect on the quality due to greywater irrigation.

External qualities are of paramount importance when the vegetables are produced for household food security purposes. FAO (1983) defined food security as, "ensuring that all people at all times have both physical and economical access to the basic food that they need". "Economic access", necessitated that vegetable production must feed individuals and the surplus should be sold to neighbourhood markets so as to afford to buy other food stuff that cannot be produced. Marginal quality could upset the selling price drastically and have a negative impact on acceptance of produce in such market and in doing so food security not realised.

4.4 Crops chemical analysis

4.4.1 Cabbages and onions

During the first season, there was no significant observed difference other than that Total Kjeldahl Nitrogen (TKN) and crude protein (CP) increased significantly due to the irrigation of cabbages from diluted greywater and onions with greywater (Table 4.9). Also, though not statistically different, Na ion content was higher for diluted greywater on cabbages than other treatments, whereas Na was higher on greywater irrigated onions. Nutrient uptake by cabbages was relatively higher than the one absorbed by onions in the same plots. These results suggest that cabbages are heavier feeders than onions.

Table 4.9 The nutrient status of cabbage and onions as influenced by irrigation water quality during 2009 season.

CABBAGES

Treatments	**Ca**	**Mg**	**K**	**Na**	**P**	**Moisture**	**TKN**	**CP**
			(mg/l)			**(%)**	**(mg/l)**	
PW	3.23 a[x]	0.443 a	1.284 a	0.247 a	0.445 a	11.50 a	3.36 ab	21.0 ab
DGW	3.80 a	0.511 a	1.200 a	0.363 a	0.466 a	9.56 a	4.24 a	26.5 a
GW	3.31 a	0.441 a	1.242 a	0.314 a	0.345 a	11.44 a	2.05 b	12.8 b
LSD	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**1.709**	**10.68**
ONIONS								
PW	1.48 a	0.178 a	1.198 a	0.0933 a	0.309 a	10.60 a	0.590 c	3.69 c
DGW	1.43 a	0.186 a	1.116 a	0.1050 a	0.337 a	11.20 a	0.950 ab	5.94 ab
GW	1.90 a	0.219 a	1.204 a	0.1360 a	0.375 a	10.83 a	**0.980 a**	**6.13 a**
LSD (P=0.05)	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**N.S**	**0.1141**	**0.825**

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

During the second season of experiments, there was no significant difference amongst treatment except for Na content which was significantly higher in cabbages when irrigated with greywater. Greywater used on onions was observed to increase most minerals such as Ca, Mg, K and Na significantly (Table 4.10).

Table 4.10 The nutrient status of cabbage and onions as influenced by irrigation water quality during 2010 season.

CABBAGES

Treatments	**Ca**	**Mg**	**K**	**Na**	**P**	**Moisture**	**TKN**	**CP**
	(mg/l)					**(%)**	**(mg/l)**	
PW	3.33 a^{x}	0.36 a	7.35 a	0.19 c	0.58 a	10.10 a	3.29 a	20.56 a
DGW	3.98 a	0.26 a	6.78 a	0.32 ab	0.61 a	9.00 a	3.36 a	20.98 a
GW	3.62 a	0.36 a	5.94 a	0.38 a	0.60 a	9.53 a	2.97 a	18.58 a
LSD	**N.S**	**N.S**	**N.S**	**0.129**	**N.S**	**N.S**	**N.S**	**N.S**
ONIONS								
PW	0.46 c	0.18 b	2.20 b	0.02bc	0.46 a	16.50 a	1.78 a	11.13 a
DGW	1.81 ab	0.16 b	1.68 b	0.11 b	0.38 a	13.37 a	1.69 a	10.56 a
GW	4.69 a	0.59 a	10.84a	0.50 a	0.41 a	9.00 a	1.48 a	9.25 a
LSD	**3.365**	**0.151**	**4.534**	**0.304**	**N.S**	**N.S**	**N.S**	**N.S**

^{x}Numbers in columns with different letters are significantly different ($P \leq 0.05$, LSD).

4.4.2 Spinach and beetroot

Spinach that was irrigated with diluted greywater obtained significantly higher content of Ca and Na ions compared to greywater while potable water realized significantly different levels of P, TKN and CP. Surprisingly, beetroot was not affected significantly by any treatment on any nutrient levels that were measured (Table 4.11).

Table 4.11 The effects of irrigation water on nutrient status of spinach and beetroot.

Treatments	**Ca**	**Mg**	**K**	**Na**	**P**	**Moisture**	**TKN**	**CP**
			(mg/l)			**(%)**	**(mg/l)**	
SPINACH								
PW	2.22 b[x]	1.38 a	1.72	0.630 bc	0.469 a	7.30 a	7.05 a	44.1 a
DGW	4.36 a	2.49 a	1.96	1.118 a	0.297 bc	5.90 a	5.74 bc	35.9 ab
GW	2.79 ab	1.25 a	1.86	0.806 b	0.339 b	7.00 a	5.38 c	33.6 b
LSD	1.288	N.S	N.S	0.1954	0.04842	N.S	1.315	9.93
BEETROOT								
PW	0.61a	0.332 a	1.93 a	0.268 a	0.193 a	9.1 a	3.27 a	20.4 a
DGW	0.60 a	0.368 a	1.75 a	0.323 a	0.273 a	7.0 a	3.54 a	22.1 a
GW	0.66 a	0.296 a	2.22 a	0.326 a	0.344 a	8.1 a	3.72 a	23.2 a
LSD	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

4.4.3 Lettuce and Carrots

The Na content was significantly higher than for other treatments when both lettuce and carrots were irrigated with greywater (Table 4.12). No similar trend was observed for other elements and factors. Ca and Mg content on both lettuce and carrots was not affected by irrigation water, however K was significantly different for carrots irrigated with diluted greywater only, but not for lettuce. As in case of cabbages (leafy crop) and onion (root/bulbous crop), in the combination indicated above, lettuce obtained significantly higher content of TKN and CP on leafy lettuce when irrigated with diluted greywater, compared to when root crop (carrots) irrigated with greywater showed significantly higher concentrations of TKN and CP.

Table 4.12 The effect of irrigation water on nutrient content of lettuce and carrots.

LETTUCE

Treatments	**Ca**	**Mg**	**K**	**Na**	**P**	**Moisture**	**TKN**	**CP**
			(mg/l)			**(%)**	**(mg/l)**	
PW	3.28 a^{x}	0.402 a	4.18 a	0.097 b	0.319 b	14.00 a	27.3 b	170.6 b
DGW	1.40 a	0.303 a	5.30 a	0.190 ab	0.441 a	12.93 ab	36.4 a	227.6 a
GW	1.78 a	0.360 a	5.49 a	0.350 a	0.319 b	11.80 b	32.4 ab	202.6 ab
LSD	**N.S**	**N.S**	**N.S**	**0.2323**	**0.1188**	**1.375**	**8.53**	**53.33**
CARROTS								
PW	0.774 a	0.187 a	2.20 b	0.378 c	0.289 b	3.30 a	13.24 bc	82.8 bc
DGW	0.633 a	0.129 a	4.08 a	0.690 b	0.307 ab	2.50 a	13.75 b	85.9 b
GW	0.895 a	0.190 a	2.38 b	1.013 a	0.433 a	3.20 a	18.70 a	119.2 a
LSD	**N.S**	**N.S**	**1.154**	**0.2266**	**0.1352**	**N.S**	**2.322**	**8.86**

^{x}Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Although higher Na plant content in this study did not cause any physiological consequences, it is expected that relatively high Na concentrations may lead to leaf chlorosis (brown patches on the leaf tips) on lettuce as observed by Weil-Shafran *et al*., (2006). Increased Na uptake by a plant due to higher levels in the soil can result in a decrease in osmotic potential and reduced plant water uptake (Beiker-Reid *et al*., 2010), hence the moisture content was reduced significantly on lettuce that was irrigated with greywater. The nutrient uptake of Na had also been observed in a study done by Misra *et al*. (2009) on tomato plants irrigated with greywater whereby 83% of Na from the soil was removed compared to that of test using tap water. In another study, tomatoes and beans were observed to contain an increase of Na content when they were irrigated by greywater compared to that of tap water (Holtzhausen, 2005). The results from these studies concur with the results of the present study in that greywater, which contains high levels of Na, results in vegetable plants absorbing more thereby reducing the availability to the soil. It is therefore recommended that greywater use in plant irrigation should not be used on compost or be left on the planting surface because residual salts accumulate in the soil.

There were no observed differences in nutrient macro-elements with crops that were irrigated with greywater compared to other treatments. This is consistent with similar observation made by Al-Hamaiedeh & Bino (2010) who found no difference in the absorption of macro nutrients by plants when irrigated with greywater and fresh water. However, crude protein (CP) was observed to be significantly higher in the case of cabbages and lettuce that were irrigated with diluted greywater whereas CP of onions and carrots were significantly increased due to greywater irrigation. Surprisingly spinach showed a positive response to CP when irrigated with potable water. These results are due to significantly higher Total Kjeldahl Nitrogen (TKN) found on the edible portion of the aforesaid vegetable crops. Nitrite reduction on the leaves of spinach is explained by dark-light transition which is a very complicated physiological pattern as discussed in the study by Riens and Heldt (1992). However, it is not clear how spinach that is irrigated with potable water contained higher content of TKN and consequently higher content of CP than its counterparts.

4.4.4 Heavy metals

Heavy metals that were analyzed during the first season were Zn, Cu, Fe and Mn. The results show that both Zn and Fe were significantly higher when cabbages and onions were irrigated with diluted greywater (Table 4.13). However, Mn was not consistent because diluted greywater obtained significantly higher content on cabbages whereas in the case of onions it was significantly favoured by irrigation with greywater.

Table 4.13 Heavy metals content of cabbages and onions as influenced by irrigation water quality during 2009.

CABBAGES				
Treatments	**Zn**	**Cu** **(mg/l)**	**Fe**	**Mn**
PW	23.0 b	11.0 a	184.6 ab	43.4 b
DGW	30.8 a	9.8 a	191.2 a	85.6 a
GW	20.8 b	9.8 a	153.6 b	40.2 b
LSD	**4.206**	**N.S**	**26.15**	**31.71**
ONIONS				
PW	33.0 b	13.0 a	143.0 c	36.0 c
DGW	44.0 a	15.0 a	317.0 a	48.0 b
GW	35.0 b	15.0 a	174.0 b	60.0 a
LSD	**3.206**	**N.S**	**8.58**	**8.48**

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Table 4.14 The heavy metals content of cabbages and onions as influenced by irrigation water quality during 2010.

CABBAGE

Treatments	**Zn**	**Cu**	**Fe**	**Ni**	**Cd**	**Mn**
				(mg/l)		
PW	3.97 a[x]	2.67 a	13.13 b	3.54 a	0.003 a	32.33
DGW	4.33 a	3.33 a	74.37 a	3.04 b	0.012 a	37.00
GW	3.53 a	3.00 a	40.07 ab	2.83 c	0.002 a	37.33
LSD	**NS**	**N.S**	**45.116**	**0.419**	**NS**	**NS**
ONIONS						
PW	3.80 b	4.00 a	49.60 c	3.17 ab	0.007 a	29.00 b
DGW	2.80 bc	3.00 a	68.50 a	1.86 b	0.012 a	26.00 bc
GW	8.00 a	5.00 a	61.50 ab	4.19 a	0.020 a	71.00 a
LSD	**1.309**	**N.S**	**8.173**	**1.309**	**NS**	**13.851**

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

In the second phase of this experiment, heavy metal content of cabbages was not affected by irrigation water with the exception of Fe and Ni that were significantly different due to treatments of diluted greywater and potable water respectively (Table 4.14). Although Fe content was significantly different on cabbages in both growing seasons, due to diluted greywater irrigation, the value seemed to be drastically reduced in the second season. In fact, all elements contained less than the first season on cabbages and onions. A trend was established once again in the second season where Fe and Mn were significantly higher when onions were irrigated with diluted greywater and greywater respectively (Table 4.13 and Table 4.14). No effects on Cu content of onion was observed in both seasons, however, Zn although was significantly higher in both seasons, was due to different treatments, namely diluted greywater during the first season and greywater during the second season.

Table 4.15 The effect of irrigation water on heavy metals content of spinach and beetroot.

SPINACH								
Treatments	**Zn**	**Cu**	**Fe**	**Mn**	**Cd**	**Pb**	**Ni**	**Cr**
				(mg/l)				
PW	52.20bc^{x}	29 b	629.3b	394bc	0.047a	11.666 c	4.153 b	1.079 b
DGW	81.70 a	40 a	757.8a	885 a	0.000b	27.333 a	5.730 a	1.299 a
GW	56.70 b	20 bc	466.1c	450b	0.000b	19.452 b	2.705 c	0.508 c
LSD	**6.688**	**14.75**	**26.50**	**313.7**	**0.0033**	**2.7638**	**0.4030**	**0.1126**
BEETROOT								
PW	28.3c	26.0	734 a	121 a	0.360a	9.657ab	6.101	1.987 a
DGW	37.7 b	16.0	314 c	73 bc	0.078b	11.454a	2.709	2.245a
GW	59.4 a	21.0	556 ab	91b	0.047	7.959 b	3.062	3.330 a
LSD	**8.17**	**N.S**	**211.7**	**26.44**	**0.1170**	**3.226**	**N.S**	**N.S**

^{x}Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Almost all heavy metal elements measured in spinach were significantly higher when irrigated with diluted greywater (Table 4.15). The only exception was Cd which was significantly different when irrigated with potable water. Beetroot obtained significantly higher Zn levels when irrigated with greywater, whereas diluted greywater did not have any effect on heavy metal content of beetroot. Fe, Mn and Cd were observed to be significantly higher from potable water irrigation water.

Table 4.16 The effect of irrigation water quality on lettuce and carrots' heavy metals content.

LETTUCE

Treatments	**Zn**	**Cu**	**Fe**	**Mn**	**Cd**	**Pb**	**Ni**	**Cr**
				(mg/l)				
PW	162 a[x]	8.33 b	284 b	153a	0.214 a	1.511	8.150 a	1.683a
DGW	78 a	11.0 a	290 ab	121a	0.239 a	0.940	8.143 ab	1.473a
GW	79 a	8.0 b	415 a	144a	0.223 a	3.786	5.396 c	1.579a
LSD	**N.S**	**4.207**	**129.6**	**N.S**	**N.S**	**N.S**	**2.5375**	**NS**
CARROTS								
PW	248.8 a	55.0 a	248.8 a	49 b	0.212 a	8.678 c	4.173 ab	1.484 b
DGW	160.3 c	17.0 b	160.3 e	34 c	0.243 a	11.594 b	4.801 a	2.390 ab
GW	196.2 b	14.0 b	196.2c	61 a	0.289 a	33.740 a	3.220 c	2.744 a
LSD	**15.42**	**7.29**	**13.43**	**5.235**	**NS**	**0.3097**	**1.3758**	**1.080**

[x] Numbers in columns with different letters are significantly different ($P \leq 0.05$, LSD).

Significantly higher Fe concentrations were observed in lettuce that was irrigated with greywater (Table 4.16). Although there was no statistical significance difference obtained on plant Zn content but surprisingly lettuce irrigated with potable water obtained more Zn content than other treatment. Carrots on other hand, when irrigated by potable water, possessed significantly higher Zn, Cu, and Fe levels. Carrots irrigated with greywater also had higher Pb and Cr concentrations.

Green leafy vegetables namely cabbage, spinach and lettuce are known to be good source of Fe, ranked second after dried legumes (Peterson & Elvehjem, 1928). Since then, no study has been conducted to oppose this finding. In this current study, a significant increase in Fe was observed on cabbages (Table 4.14) and spinach (Table 4.15**)** when irrigated with diluted greywater, whereas Fe in lettuce (415mg/l) was significantly elevated with greywater irrigation. There was no significant difference in Cd caused by irrigating spinach and lettuce with greywater. This is contrary to results found by Qishlaqi *et al* (2008), who observed there was an increase in Cd in spinach and lettuce when irrigated with wastewater irrigation.

4.5 Soil chemical content

At a soil depth of 0 to 10 cm, there was no significant difference in pH, Al and P whereas K, Mg, Ca and Total cations were significantly higher in the case of potable water irrigated plots (Table 4.17). At 10 to 30 cm soil depth, only P and Mg that were significantly higher due to diluted greywater irrigation whereas in depth of 30 to 60 cm there was no significant difference in all elements. At soil depth of 60 to 90 cm, P once again was significantly higher due diluted greywater treatment, and Mg, Ca, and Total Cations as influenced by potable water treatment. There appeared to be no leaching of all elements from the topsoil to the lower subsoil during experiments. This was confirmed by similar pH values and all chemical elements being contained at similar range between the treatments throughout the profile.

Due to no significance difference in pH of the water treatments used in the study, there was no significant difference observed in pH throughout the soil profile of 0 to 90 cm, whereas in some studies an increase of 1 to 2 units was observed (Qishlaqi *et al*., 2008). In worse scenarios, researchers find the opposite, where pH of soils irrigated with greywater become significantly lower that the freshwater irrigated soils due to probability of enhanced bacterial activities such as respiration (Weil-Shafran *et al*., 2006).

Table 4.17 The soil chemical analysis as influenced by irrigation water quality.

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

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

Although Na was not significantly different in all levels, it was found to be almost three times higher compared than that of potable water irrigated soils. This effect was not surprising since almost all vegetables irrigated by greywater had an ability to absorb more Na from the soil. High Na content in the soil had the effect of disturbing soil structure through swelling and dispersion phenomena (Halliwell *et al*., 2001). Bauder *et al*. (2007) explained this phenomenon by suggesting that Ca flocculate and Na disperses soil particles and that result is a soil crusting which in turn adversely affects infiltration and permeability of water. However, in this study, although the soil structure was not determined, it is evident that there was no disturbance in soil structure due to insignificance levels of Na ions on greywater irrigated soils compared to potable water.

There was no significant difference observed in all heavy metals elements across the 0 to 90 cm soil depth on the soil profile except for Cu at 30 to 60 and Pb at 60 to 90 cm (Table 4.18). It was also observed in a similar study that there was no accumulation of heavy metals on the soil due to greywater irrigation (Al-Zu'bi & Al-Mohamandi, 2008). However, Cr although was not found to be significantly different, was slightly elevated in the soil ranging from 28.34 to 31.66 mg/kg. Kabata-Pendias & Pendias (1992) found that a Cr critical soil total concentration to be in the range of 75 to 100mg/kg, and threshold for Cr in South Africa is 150 mg/kg (Herselman & Steyn, 2001). The highest Cd content obtained on diluted greywater irrigated soils was 0.06 mg/kg, far less than 3-8 mg/kg which is the Cd critical soil total concentration (Kabata-Pendias& Pendias, 1992). However, the Dutch guidelines for Cd range from 0.5 to 10 mg/kg (Mc Laughlin *et al*, 2000) whereas South African threshold is 2 (Herselman & Steyn, 2001). Ni obtained a 22.6 mg/kg on soils irrigated with greywater, which was the highest level obtained amongst treatments. As other elements, Ni content was far less than the South African threshold of 80 mg/l (Herselman & Steyn, 2001).

Table 4.18 The effect of irrigation water on soil heavy metal status

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

[x] Numbers in columns with different letters are significantly different (P≤0.05, LSD).

It is evident that as much as greywater might contribute to soil pollution by adding pollutants such as heavy metals, impurities can be also contained in inorganic fertilizers (Schroeder & Ballassa, 1963; Carnelo *et al*., 1997), agrochemicals such as pesticides, fungicides and herbicides (Gimeno-Garcia *et al*., 1996; Nicholson *et al*., 2003) and corrosion of metal objects such as water pipes, taps and roof materials (Boller, 1997; Sörme & Lagerkvist, 2002) can add toxic elements to the soil.

According to these results obtained from an analysis of soil profiles, it was observed that greywater irrigation had minimal contribution to heavy metal concentration build-up in the soil and therefore greywater does not solely pollute the soil and pose an environmental risk to the soil.

CHAPTER 5: CONCLUSIONS

5.1 Irrigation water quality

Greywater is widely acknowledged in the academic literature as an available water resource for irrigating vegetable crops, and in this study it was found to be ‘fit for purpose’ for irrigating edible vegetable plants. Although Na and Cl ions were significantly higher with the use of greywater, these elements did not cause chlorosis on the leaves probably because drip irrigation methods were used. The levels of nutrients and heavy metals found in the greywater samples were significantly lower compared to the World Health Organization health guidelines (WHO, 2006) and were within the acceptable Water Quality Range (TWQR) permitted by South African guidelines for irrigation (DWAF, 1996). However, it is strongly recommended that greywater must be diluted in order to lower salt content and to improve the irrigation water quality so as to avoid long term risks to the soil and the environment. Furthermore, it is recommended that greywater and potable water dilution rates should be studied further as this study did not determine appropriate dilution rates other than use 1:1 ratio.

5.2 The vegetable response irrigation water

Greywater irrigation increased yields of onions (significantly in 2009 and slightly different in 2010) and spinach significantly, but in the case of other vegetable crops such as cabbages and carrots, there was no effect on the yields. However, greywater reduced yields in the case of beetroot and lettuce. Based on yield results of this study, the response of leafy, root or bulbous vegetable crops remains unclear. As indicated above, greywater increased, reduced or showed no effect on yield on two leafy or root crops planted in different cropping seasons.

Aesthetic appearance was negatively affected in the case of spinach, carrots and lettuce due to greywater irrigation, whilst cabbages, onions and beetroot there was only a minimal effect. The response of vegetable crops in terms of aesthetic appearance on edible parts was not clear but it could be concluded that greywater irrigation does not improve aesthetic appearance of any of the vegetable crops that were tested in this study.

This study reveals that irrigation water quality can be manipulated to achieve particular desired outcomes. For instance, greywater is recommended if a higher yield is desired merely for household consumption. However, if vegetables had to be marketed, it is a better to achieve aesthetic appeal, and hence the use of diluted greywater is highly recommended. Beetroot is not suitable for irrigation by both diluted greywater and greywater, according to the results of this study, although research by Salukazana *et al*., (2005) indicated better results were obtained when greywater was used for irrigation.

Chemical concentrations within vegetables such as cabbages, onions, lettuce and carrots, that are irrigated with greywater, contain higher concentrations of Na ions whereas beetroot and spinach do not show any effect of Na ions in the edible parts of the crop under the influence of greywater irrigation. However, nutritional elements such as Zn and Fe ions were significantly raised in vegetable crops, namely cabbage, onions and spinach irrigated with diluted greywater.

5.3 Soil response to irrigation water

Consistent pH values and all other chemical elements throughout the soil profiles indicate that there is no accumulation of toxins or pollutants that could contaminate the underground water. Besides the foregoing, pollutants in the soil were found to be within the acceptable threshold for South African soils (Herselman & Steyn, 2001). Therefore greywater irrigation does not pose environmental risks to the soil in a short term. This study reveals that greywater irrigation can increase the accumulation of salts in the soil, however, since plant roots absorbed significant amount of Na ions in the soil, the effect was minimised, again a conclusion derived from this relatively short term study. Al-Hamaiedeh & Bino (2010) suggest that soils should be periodically flooded with freshwater to avoid the accumulation of salts and that greywater should be diluted.

Whilst greywater could be considered safe for the irrigation of vegetables under these given conditions, caution must be taken whereby greywater surface runoff and ponding could pose health risks to people and the environment. A drip irrigation method minimizes greywater surface runoff and ponding.

5.4 Recommendations for further studies

The following areas for further investigations were identified through this study:

- Social acceptance of greywater irrigation of edible vegetable crops should be investigated further. The results of this research are futile if they are not going to be practically applicable to the vulnerable and food insecure households.
- The marketability of crops irrigated with greywater needs to be investigated.
- Further research on greywater dilution rates will be useful in establishing an appropriate ratio of greywater to potable water so as to ameliorate irrigation water quality and reduce harsh realities that greywater can cause to the vegetable crops and the surrounding environment.
- The effects of greywater on soil properties (both physical and chemical) in a long term period will probably need to span a period of five years or more in order to thoroughly understand the impacts.

In conclusion, the following effects of using greywater to irrigate vegetable crops had been observed:

- Greywater increased crop yield but reduced crops aesthetic appeal and chemical quality.
- Diluted greywater resulted in an average yield, improved external and internal crop quality and elevated the essential nutrients such as Zn & Fe.
- Greywater irrigation did not have an effect on elevating soil pollutants in the short term.

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APPENDIX A

ELECTRICAL CONDUCTIVITY AND SOLUBLE CATIONS OF THE SATURATION EXTRACT (EC, Ca^{+2}, K^{+2}, Mg^{+2} and Na^{+2})

Apparatus

- Conductivity cell with a known cell constant of ±1cm^{-1}
- Conductivity Bridge
- Buchner funnels, 100 mm in diameter of Richards funnels
- Whatman no 50 filter paper for Buchner
- Suitable test tubes for receiving filtrate
- Spatulas
- Suction flasks, 300cm^3 capacity
- Vacuum system
- Flame spectrophotometer
- Burette
- Porcelain dishes

Reagents

Ammonia buffer, pH 10: Dissolve 67,5 g ammonium chloride in 200cm^3 de-ionised water. Add 570 cm^3 concentrated ammonia solution and dilute to 1 dm^3 with de-ionised water.

Sodium hydroxide, pH 12: Dissolve 200 g sodium hydroxide in 400 cm^3 de-ionised water and dilute to 1 dm^3.

EDTA solution, 0, 01 mol dm^3: Prepare from commercially available standard solution. Standardized against standard solution of calcium and magnesium respectively.

Potassium cyanide, 1% solution: Dissolve 1g KCN in 100 cm^3 de-ionised water.

Hydroxylamine solution, 5%: Dissolve 5g hydroxylamine hydrochloride in 100cm^3 de-ionised water.

Triethanolamine (TEA): Dilute 1:1 with de-ionised.

Indicator, Ca: Mix together in a motor 0,2g calcein, 0, 12 g thymolphthalein and 20 g potassium chloride (AR).

Indicator, CA and Mg: dissolve 0,5g methyl red in 300 cm^3 ethyl alcohol and make up to 500cm3 with de-ionised water. Dissolve 0, 2 g Eriochrome Black T in 50cm^3 ethyl alcohol. Stable for 3 weeks.

Procedure

Preparation of the saturated soil paste and saturation extract

By hand

A 250g air-dry soil sample is placed in a suitable container and moistened with de-ionised water while mixing with a spatula. Consolidate the mixture from time to time by tapping the container on the work bench. Test for the properties of a saturated paste and add more de-ionised water if necessary. Allow to stand for at least an hour and test whether it still has saturation properties. If left overnight cover the container. Special care should be taken to ensure that water doesn't collect and that the paste doesn't dry out too much. Add more de-ionised water if required. If too much water was added, repeat procedure. Note the total volume of water added (w).

Properties of a saturated paste

- In a saturated soil paste all the pores are filled with water
- It has the following characteristics: the surface is shiny, the paste flows slightly when the container is tilted; free water doesn't collect when a small trench is drawn on the surface and it doesn't cling to the spatula (with the exception of clayey soil).

Determination

Determination of EC of the saturation extract

- Calibrate the conductivity cell with 0, 01 mol dm^3 KCl solution. This solution has an electrical conductivity of 141,18 mSm^{-1} at 25^0 C
- Rinse the conductivity cell with saturation extract
- Determine the conductivity of the saturation extract and calculate the electrical resistance from this value
- Temperature control is necessary because the conductance increases with temperature. Conductivity of the saturation extract is expressed in mSm^{-1}

Determination of water soluble cations in the saturation extract

Calcium

Take 5cm3 saturation extract and dilute to 100m3. Pipette a 20 cm^3 aliquot of the diluted saturation extract in a 500 cm^3 Erlenmeyer flask, add 2 cm^3 sodium hydroxide solution, 1 cm^3 1% KCN solution, 1 cm^3 hydroxylamine solution, 1 cm^3 TEA and calcium indicator. Titrate with 0,01 mol dm^3 EDTA. The end point is indicated by a change of colour from pink-green to pink. Record the volume EDTA titrated (a cm^3).

Magnesium plus calcium

As for calcium but use ammonia buffer solution (10cm^3) instead of NaOH. Use 1.5 cm^3 methyl red and 0,5 cm^3 Eriochrome Black T as indicator. Titrate with 0,01 mol dm^3 EDTA from purple to green. Record the volume EDTA titrated (b cm^3)

Sodium and potassium

Sodium and potassium are determined by flame emission spectroscopy against standard solution prepared with de-ionised water.

APPENDIX B

EXTRACTABLE ZINC, COPPER, MANGANESE AND IRON: AMBIC-1

APPARATUS

- Plastic bottles with silicone rubber stoppers, 100 cm3 capacity.
- Whatman no 42 filter paper
- Funnel and racks
- Balance accurate to 0,1 g
- Continuous flow analyser (eg Auto Analyzer)
- Atomic absorption spectrophotometer

Reagents

Ambic-1 extraction solution; 0,25 mol dm3 NH4HCO +0,01 mol dm^{-3} (NH4)2 EDTA +0,01 mol dm^{3} NH4F + Superfloc (N-100 or 127): Prepare the Superfloc by slowly adding 0,5 g Superfloc (N-100 or 127) to 250 cm^{3} luke-warm water while stirring at 400 rpm. The final solution should be viscous and gel-like. Dissolve 197,65 g ammonium bicarbonate, 32,6 g anhydrous di-ammonium EDTA and 3,7 g ammonium fluoride in about 5dm^{3} de-ionised water. Add the Superfloc solution. Mix well and make up to 10dm^{3} with de-ionised water. Leave overnight. Mix throughout and adjust pH to 8.1± 0,1 with concentrated ammonia solution.

Ascorbic Acid reagent: Dissolve 17,6 g ascorbic acid in 440 cm^{3} de-ionised water and 50 cm^{3} acetone (AR). Finally add 0,5 cm^{3} phosphate free wetting agent.

Micro-element standard stock solutions: Commercially available standard solution for Zn, Cu, Fe and Mn are diluted in a 1 dm^{3} volumetric flask to the mark with de-ionised water, to contain 1000 mgdm^{-3} of each micro-element.

Procedure:

Extraction:

- Measure 5,0 g finely ground (≤ 1mm), air dry soil into a plastic bottle or a centrifuge tube of 100 cm^3 capacity with stopper
- Add 50 cm^3 extraction solution to the soil. The extraction solution must have a temperature of 20±2˚C
- Swirl container gently to expel air bubbles
- Allow to stand for 20 minutes
- Swirl again
- Seal with Cu and Zn free Stopper
- Shake horizontally on a reciprocating shaker for 30 minutes at 180 oscillations per minute at an ambient temperature of 20±2˚C
- Carefully remove extraction
- Filter solution through Whatman no 41 filter paper or alternatively centrifuge at 5000 rpm for 5 minutes and decant clear solution into a suitable container
- Transfer a 25 cm^3 aliquot of this solution into a 50 cm^3 volumetric flask. Add exactly 2,5 cm^3 concentrated HCl and a swirl flask gently
- Allow for precipitation of organic material overnight
- Make up the volume with de-ionised water and shake well
- Filter the solution through Whatman no 41 paper into a suitable container
- The extract must be analyzed for Cu, Zn, Fe and Mn within a week.

Determination

Working standards: prepare working standards with AMBIC as matrix.

Ranges to be covered are:

Copper : 0,5 to 2 mg dm^{-3}

Zinc : 0,5 to 2,5 mg dm^{-3}

Iron : 10 to 30 mg dm^{-3}

Manganese : 3 to 12 $mgdm^{-3}$

Use the undiluted extract for these analyses.

Measure absorption with a suitable atomic absorption spectrophotometer against the standards. An air acetylene flame is used. Iron standards should not be kept for extended periods. Rubber and some plastics may contain zinc and therefore, glass or Kartell plastic and silicone rubber stoppers should be used.

Calculations

5g soil is extracted with 50 cm^3 AMBIC solution

Let concentration of micro-element as read from the calibration curve be w mg dm^{-3}

$$\text{mg kg}^{-1} \text{ element in the soil} = \frac{w \times 50}{5}$$

APPENDIX C

DETERMINATION OF pH (KCl)

Apparatus

Balance, accurate to 0,1 g

Beakers, 50 m^3 capacity

Measuring cylinder or automatic dispenser, $25m^3$

Glass rods

pH meter, reading producible to 0, 05 pH units

A combined glass-calomel electrode system or separate glass and calomel electrode

Reagents

Potassium chloride, 1 mol dm^{-3}: Dissolve 74, 5 g KCl (AR) in $1dm^{-3}$ de-ionised water

Buffer solutions: Use commercially available buffer solution, pH = 4, 0 and 7, 0 or 8, 0

Procedure:

- The pH meter is calibrated at a given constant temperature with commercial available standard buffer solutions
- Re-calibrate hourly to compensate for drift
- Place 10g dried soil (≤ 2 mm) in a glass beaker
- Stir the contents rapidly for 5 seconds with glass rod
- Stir again after 50 minutes and allow to stand for 10 minutes
- Determine pH with calibrated pH meter with the electrodes positioned in the supernatant
- Results are reported as pH (KCl)