

**AN ASSESSMENT OF pH, TOXIC AND ESSENTIAL PLANT ELEMENTS IN
GREYWATER FROM SELECTED HOUSEHOLDS IN KENYATTA
UNIVERSITY, KENYA**

By

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DECLARATION

I hereby declare that this is my original work and has not been presented for the award of a degree in any other university.

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DEDICATION

This work is dedicated to my wife Milkah and our children Elvis and Levis.

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ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
AC	Activated Carbon
ANOVA	Analysis of Variances
AOAC	Association of Official of Analytical Chemists
APHA	American Public Health Association
AWWA	American Water Works Association
BGW	Bathroom Greywater
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DCC	Dubbo County Council
DHWA	Department of Health of Western Australia
EPA	Environmental Protection Agency
GAC	Granular Activated Carbon
GW	Greywater
ISF	Intermittent Sand Filters
KGW	Kitchen Greywater
KLB	Kenya Literature Bureau
LRGW	Laundry Rinse Greywater
LWGW	Laundry Wash Greywater
MWI	Ministry of Water and Irrigation
NESC	National Environmental Services Center
OC	Ordinary Charcoal
RGW	Raw Greywater
SEI	Stockholm Environment Institute
SPSS	Statistical Package for Social Scientists
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UV-vis	Ultra Violet-visible
WHO	World Health Organization

ABSTRACT

Kenya is experiencing acute water shortage resulting to water rationing, conflict among water users, increased water prices among others. Therefore, there is need for water conservation. One of the water conservation methods available today is greywater reuse. Greywater is domestic wastewater generated from kitchens, bathrooms, and laundry activities. According to World Health Organization (WHO) each household in capital cities of most countries produces an average greywater flow of 356 litres per day. Kenyatta University generates a lot of greywater from its premises including staff quarters, messes, hostels and offices, but all goes to waste because in Kenya, greywater is not adequately utilized probably due to inadequate information about its quality and safety. Greywater contains nutrients especially nitrogen, phosphorus and potassium and its re-use in irrigation would improve food production. However, greywater may also contain toxic elements to plants such as lead and cadmium hence need for its treatment. Greywater treatment methods such as biological, physical and chemical exist, all intended to improve the quality of greywater for reuse in irrigation. Some of these methods are costly to install and unavailable in developing countries like Kenya. Therefore, there is need to study the properties of greywater generated and where possible its treatment done before its application in irrigation using relatively cheap treatment technologies. Greywater sampling was carried out in Kenyatta University staff quarters. The present study determined the levels of plant nutrients (K, Ca, Mg, Fe, Zn, NO_3^- -N and P), toxic metals (Cd and Pb), and pH in the raw greywater and after treatment through sand, activated carbon and ordinary (raw) wood charcoal filtration. The data obtained was analysed using ANOVA. The results in ranges of pH, nutrients and toxic metals were as follows; pH-5.88 to 8.98, K-1.59 to 28.40 mg/L, Ca-6.46 to 51.30 mg/L, Mg-0.92 to 13.24 mg/L, Zn-0.02 to 0.99 mg/L, Fe-0.12 to 4.04 mg/L, P-0.33 to 15.57 mg/L, NO_3^- -N-0.11 to 10.39 mg/L, and Pb-0.01 to 0.19 mg/L. Cadmium was not detected in all the samples. The results of the study indicate that the levels of Pb, Zn, Fe and P in raw greywater were statistically lower from those in activated carbon and ordinary wood charcoal filtrates while those of K, Ca and Mg in raw greywater and the filtrates were not significantly different at 95% confidence level. The NO_3^- -N levels were found to increase significantly with sand filtration, probably due to oxidation of nitrites to nitrate during the greywater filtration process. From this study it can be concluded that both raw and filtered greywater can be used for irrigation since the levels of all the parameters were within the ranges recommended/allowed by WHO for crop irrigation and Kenya Bureau of Standard (KEBS) for drinking water. Therefore greywater can have dual usage as source of plant nutrient and for irrigation, thus preserving freshwater and increasing food production hence enhancing the achievement of Kenya's Vision 2030.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is one of the simplest chemicals of the earth, but one of the most important and most abundant and in which most of life's chemistry takes place and without which that chemistry would be impossible (Scott, 1989). Water resources serve as a cornerstone of human society and its sustainment. Within a household, water may serve many functions beyond everyday household uses such as drinking, cooking, laundry and plumbing needs. Other than household, water uses may include lawn and garden watering, car washing, crop irrigation, fire protection and more. According to WHO (2007), 1.1 billion people lack access to an improved drinking water supply, 88% of the 4 billion annual cases of diarrheal diseases are attributed to unsafe water and inadequate sanitation and hygiene and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94% of these diarrheal cases are preventable through modifications to the environment, including access to safe water.

Kenya with a population of 35 million faces enormous challenges in providing sustainable access to safe water, sewerage systems and basic sanitation for its fast growing population (MWI, 2007). In Kenya, according to MWI (2007) it is estimated that 80% of all diseases are water related, resulting in a huge bill for health care which could be drastically reduced with improved water services. Simple techniques for treating water at home, such as chlorination, filters and solar disinfection and storing it in safe containers could save a huge number of lives each year (WHO and UNICEF, 2005). Therefore availability of water resource is essential for socioeconomic development, yet water is often misused and wasted in today's society (WHO, 2006).

As fresh water becomes increasingly scarce, it is necessary for policy makers, leaders and water users to shift attention to alternative sources of water, particularly for the rural, peri-urban and urban poor as well as arid and semi arid areas. Moreover, widespread water scarcity and the growing stress on water supply resources have prompted considerable interest in water recycling together with other water saving measures. The emphasis is however, mostly on domestic wastewater and on large-scale decentralized options (Bixio *et al.*, 2004). Although there have been a number of studies on greywater recycling focusing on large complexes such as commercial buildings (Nolde, 2000) or sport stadiums (Smith *et al.*, 2000), its potential has not been adequately investigated. This is particularly true for decentralized greywater recycling systems for individual households.

One of the methods of water conservation available today is greywater reuse. Greywater is domestic wastewater that includes water from domestic cleaning operations such as bathing, cleaning dishes and washing clothes (Ahmed *et al.*, 2001; Holtzhausen, 2005). However, it does not include soiled diapers laundry water (Ahmed *et al.*, 2001; WHO, 2006; Wood, 2008). Greywater contributes to over 70% of domestic wastewater (DHWA, 2002). Therefore greywater is no doubt a valuable resource that can be used to alleviate water shortage and increase water conservation in individual households (Long *et al.*, 2005). According to WHO (2006), by reusing greywater the load on wastewater disposal systems is reduced and therefore the life of the wastewater disposal system is prolonged and capital expenditure required for the upgrading and expansion of the systems is delayed.

The appropriate uses of greywater depend on both the source of greywater and the level of treatment (Ahmed *et al.*, 2001). Greywater can be used untreated or it can be treated to varying degree to reduce nutrients and disease-causing micro-organism (EPA, 2007). Greywater treatment is an environmental friendly process as a control of water pollution (Emmerson, 1998; Little *et al.*, 2001; Dixon *et al.*, 1999). Different greywater treatment systems exist which include physical, biological and chemical processes, all intended to improve greywater quality. For example, filtration which is a physical-chemical process refers to the use of relatively deep granular bed to remove impurities from water (Culp *et al.*, 1978).

The filtering media can be of different types such as sand, carbon, sawdust among others. Sand filtration is one of the oldest wastewater treatment technologies known. If properly designed, constructed, operated and maintained, a sand filter produces a very high quality effluent. They are normally used to polish effluent from septic tanks or other treatment processes before it is distributed on the land. Carbon filters on the other hand are employed in commercial home water treatment systems as well as in large-scale municipal treatment facilities. Water contaminants can be reduced to acceptable standards according to Environmental Protection Agency (EPA) National Drinking Water Standards by activated carbon filtration. Charcoal (carbon) is made by pyrolyzing wood or other organic matter such as coconut or rice husks, nut hulls, peat among others. Raw charcoal is industrially activated either physically or chemically (Culp *et al.*, 1978).

Basically, the human mind tends to perceive water quality as being good if desirable water uses are possible, and bad if water quality involves water use problems

(Hulzinger, 1991). Important to the approach of water recycling is the concept of the utility of water whereby water is used of a quality commensurate with its application (Little *et al.*, 2001), allows the use of large water resources that are not necessarily of the highest purity. Water of the highest quality is only needed for drinking and cooking, making up about 5 % of the current total consumption (Little *et al.*, 2001).

Greywater recycling is one aspect of this and relates principally to the reuse of lower polluted water generated within buildings for uses such as toilet flushing or irrigation (Jefferson *et al.*, 2001). In Jordan household wastewater treatment systems have allowed greywater to be used safely for urban agriculture (Friedler *et al.*, 2006). In Israel, Gross *et al.* (2007) have found out that greywater treated with recycled vertical flow constructed wetland had no significant impact on plants or soil while effluent from a pilot plant met the urban reuse quality regulations (Friedler *et al.*, 2006).

Kenya is a water-scarce country. Surface waters cover only 2% of Kenya's total surface area (MWI, 2007). Per capita available water is about 650 m³ per year. Future projections show that by the year 2025, per capita water availability will drop to 235 m³ as a result of population growth (MWI, 2007). Therefore Kenya, like many other developing countries in the world faces serious challenges with regard to providing sustainable access to safe water, sewerage systems and basic sanitation particularly in its poor urban and semi-arid and arid areas due to its fast growing population. Water supply in Kenya is limited, and the lack of new water resources and the level of competition between different water uses like domestic, industrial and agricultural are expected to increase in the near future. Therefore, new methods of water conservation need to be exploited especially in areas where large quantities of greywater are

produced. Such places include higher institution of learning, boarding schools, big hotels and lodgings among others where available greywater treatment techniques are limited or none exists at all.

Kenyatta university (KU) main campus is located at Kahawa in between Nairobi city and Ruiru town. The main source of water for the university is from Nairobi Water Company and its boreholes. Due to its growing population and the national water shortage, KU has been experiencing water shortage to an extent of buying the same from available sources. High water demand due to its growing population, construction works, and irrigation among others water uses, means extra measures are necessary in order to meet water needs. The university with a population of more than twenty thousand people produces an enormous amount of greywater from its premises which is not utilized in anyway but goes into drain as sewage. Therefore, this resource can be tapped and converted into utilizable resource. For example, it's a waste to irrigate with great quantities of drinking water when plants thrive on used water containing small bits of compost.

Based on these problems and on the fact that greywater contains significant amounts of nutrients particularly nitrogen and phosphorus (WHO, 2006) which can be utilized as plant nutrients, the study investigated the pH which is known to affect the uptake of nutrients; lead and cadmium because they are known as pollutants and are toxic to micro-organism, plants and animals; and selected plant nutrients which include K, Ca, Mg, Fe, Zn, N, and P which play various roles during growth and development of the plants such as; K, P and N are involved in photosynthesis and protein synthesis, Ca in nitrogen metabolism and cell division, while Mg, Zn and Fe in chlorophyll formation,

also Zn aids plant growth hormones and enzymes systems. These parameters were analyzed in both raw and filtered greywater in order to establish its quality for use in irrigation, for example, of flowers and grass gardens within the KU main campus compound and enhance its greening the environment programme. Also this under-utilized resource can be used to uplift and minimize food shortage in Kenya and help in achievement of some of Millennium Development Goal.

1.2 Statement of the Problem and Justification

Water supply and scarcity is a thorny issue in many parts of the world. Developing countries, Kenya among them are the most hit by this phenomena. Kenya is a water-scarce country. Surface waters cover only 2% of Kenya's total surface area (MWI, 2007). Per capita available water is about 650 m³ per year (MWI, 2007). Future projections show that by the year 2025, per capita water availability will drop to 235 m³ as a result of population growth (MWI, 2007).

Water conservation measures are therefore essential and should be practiced in order to sustain water demand. Among the strategies the government is taking to fight water scarcity includes building and rehabilitation of water dams, conserving and sustaining water towers such as Mau complex, harvesting of rain water and drilling of boreholes. These measures are costly and may take long to implement. For example, projection cost of dams alone is Kshs 85 billion in the next 10 years (Ngilu, 2010).

Therefore other measures of water conservation like greywater reuse need to be explored and put into practice. In recent years, reduced supply of water has generated

much interest in the reuse of greywater (Ahmed *et al.*, 2001; Gross *et al.*, 2007). Greywater is a feasible resource since it is produced on daily basis on each and every household. Greywater has several applications which include: toilet flushing, car washing, ornamental uses in fountains and waterfalls, and landscaping (Al-Jayyousi, 2002). Greywater reuse succeeds in saving money spent by water authorities, reduces sewage flows and reduces public demand on potable water supplies, prolongs life of the wastewater disposal systems. More importantly greywater can be used in irrigation of crops. Greywater has some pollutants that are considered as fertilizer for the plants. Phosphorous, nitrogen, and potassium are excellent sources of nutrients when reusing greywater for irrigation and therefore can be used to increase food production in Kenya, which is known in experiencing food shortage. Greywater may contain other essential elements to plants such as Ca, Fe, Mg and Zn among others. However domestic greywater does contain chemicals that can be harmful to public health and the environment for example lead and cadmium.

Owing to the insufficient supply of water in Kenyatta University (KU) and large quantities of greywater generated, properties and reuse of greywater need be explored. However, very little, if any, information is available on physical chemical properties of greywater produced, thus the need for this research study.

1.3 Hypotheses

- i) Raw greywater from KU has high pH, Pb, Cd and plant nutrients.
- ii) Activated carbon, sand and raw wood charcoal filtration removes only Pb and Cd in raw greywater from KU.

1.4 Objectives

1.4.1 General Objective

To determine the pH, levels of selected toxic and essential plant elements in greywater before and after filtration

1.4.2 Specific Objectives

a) To determine

- i) The pH values of kitchens, bathrooms, laundries wash and first rinse raw greywater and tap water from selected household in KU staff quarters.
- ii) The levels of Cd^{2+} , Pb^{2+} and K^+ , Ca^{2+} , Mg^{2+} , Fe^{2+} , Zn^{2+} , NO_3^- -N as well as P in kitchens, bathrooms, laundries wash and first rinse raw greywater and tap water from selected household in KU staff quarters.

b) To filter raw kitchens, bathrooms, laundries wash and first rinse greywater from selected household in KU staff quarters using sand, activated carbon and raw wood charcoal.

c) To determine the levels of Cd^{2+} , Pb^{2+} , K^+ , Ca^{2+} , Mg^{2+} , Fe^{2+} , Zn^{2+} , NO_3^- -N, and P as well as the pH values in filtered greywater.

1.5 Significance of the Study

The results of this study will help to shed light on the composition of raw and filtered greywater from KU main campus, and consequently be used for recommendation of greywater dual use as plant nutrient supplement and for irrigation. The study will document levels of K^+ , Ca^{2+} , Mg^{2+} , Fe^{2+} , Zn^{2+} , Cd^{2+} , Pb^{2+} , NO_3^- -N and P as well as the pH values in raw and filtered greywater. The information gathered will be used to sensitize the public about the properties of different types of greywater and its importance. Since most Kenyans cannot afford some of the measures proposed by the

government for water conservation, the research findings will be used to encourage people to use greywater as cheaper and alternative source of water. The findings will also assist in formulation of guidelines on reuse and treatment of greywater and form a baseline for the design and development of greywater treatment systems that optimize greywater quality and its applications.

1.6 Scope and Limitations

The research was limited to analysis of four types of greywater generated from KU staff quarters which included bathrooms, kitchens and laundries wash and laundries first rinse greywater. Only K^+ , Ca^{2+} , Mg^{2+} , Fe^{2+} , Zn^{2+} , Cd^{2+} , Pb^{2+} , NO_3^- -N, and P as well as the pH values were studied because of time and financial limitations. Daily and seasonal variations, lifestyles, water usage patterns, number of occupants and their age as well as study of other essential and non-essential elements to plants were not taken into consideration. In addition other types of greywater such as second laundry rinse greywater and hand wash greywater were not analysed.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Greywater

There are several definitions given to the term greywater as written by various authors, some of them include;

- i) The term greywater refers to the untreated household wastewater which has not been contaminated by toilet waste. It includes the water from bathtubs, showers, hand basins, laundry tubs, floor waste and washing machines; it does not include waste from kitchen sinks, garbage disposal units or dishwashers (Nolde, 2000).
- ii) All household wastewater, except toilet wastewater is greywater; this includes water from showering, bathing and washing clothes and dishes (Ridderstolpe, 2004).

2.2 Quantity of Greywater Generated by Households

The amount of greywater generated by any household will vary greatly according to the dynamics of the household and is influenced by such factors as the number of occupants, the age distribution of the occupants, their lifestyle characteristics, water usage patterns, the cost of water and the climate (NSW Department of Health, 2000). According to WHO (2006), water usage surveys undertaken in capital cities of different countries have identified an average wastewaters flow of 586 L per day for each household as shown in the Table 2.1. As can be seen from Table 2.1, greywater represents about 61% of the total wastewater streams. Therefore greywater is the largest flow of wastewater. Greywater is characterized as high volume low strength stream that constitute about 50-80% of domestic wastewater (DHWA, 2002).

Table 2. 1: Approximate Percentage of Generated Wastewater/household

Wastewater type	Total wastewater		Total greywater	
	Total %	L/day	Total %	L/day
Toilet	32.0	186.0	-	-
Hand basin	5.0	28.0	8.0	28.0
Bath/shower	33.0	193.0	54.0	193.0
Kitchen	7.0	44.0	-	-
Laundry	23.0	135.0	38.0	135.0
Total	100.0	586.0	100.0	356.0

Source: WHO (2006)

Kenya, like many other countries in the world lacks adequate information of greywater reuse. Greywater contributes to over 70% of domestic wastewater in Kenya (MWI, 2007). Its magnitude and effect is quite enormous and could be devastating if not properly disposed off or re-used.

2.3 General Composition of Greywater

Understanding the composition of domestic wastewater is a complex task, because flows are highly variable and its composition is influenced by location and household characteristics such as water supply, household infrastructure and householder lifestyle (Tjandraatmadja *et al.*, 2008). The quality of greywater between households and even within households varies daily depending on activities of the households' occupants (WHO, 2006). Therefore the composition of greywater varies greatly depending on the source. The composition of greywater reported by (WHO, 2006) is given in Table 2.2.

Table 2. 2 : Composition of Greywater

Parameter	Unit	Greywater	
		Range	Mean
Suspended solids	Mg/l	45-330	115
Turbidity	NTU	22-200	100
BOD5	Mg/l	90-290	160
Nitrite	Mg/l	<0.1-0.8	0.3
Ammonia	Mg/l	<1.0-25.4	5.3
Total Kjeldahl Nitrogen	Mg/l	2.1-31.5	12
Total phosphorus	Mg/l	0.6-27.3	8
Sulphate	Mg/l	7.9-110	35
pH		6.6-8.7	7.5
Conductivity	mS/cm	325-1140	600
Hardness (Ca/Mg)	Mg/l	15-55	45
Sodium	Mg/l	29-230	70

Source: Jeppersen and solely (1994)

There are essentially three different greywater streams (DHWA, 2002). They are discussed in sections 2.3.1, 2.3.2 and 2.3.3.

2.3.1 Bathroom Greywater

Bathroom greywater contributes about 55% of the total greywater volume (DHWA, 2002). It may be contaminated with hair, hair dyes, soaps, shampoos, toothpaste, lint, body fats and cleaning products. It also has some faecal contamination through body washing and it is associated with bacteria and viruses. Some of the impurities in bathroom greywater acts as plants nutrients and can be beneficial in the garden. Underground irrigation using bathroom greywater is widely applicable in the United States of America, in Utah, Australia, New Mexico and California State where

international plumbing code to deliver greywater to the garden is legislatively enhanced (Stephanie, 2009). According to Bhausahab *et al.* (2010), the average characteristics of bathroom's and basin's greywater from a residential college campus at Sinnar rural area in Nashik- India are indicated in Table 2.3.

Table 2. 3 : Average Characteristics of Bathrooms and Basins Greywater

Parameter	units	Raw water	Filtered water
pH	pH scale	8.12	7.43
Nitrate	mg/L	0.67	0.21
Phosphates	mg/L	0.012	0.00
Potassium	mg/L	4.52	1.98
Magnesium	mg/L	0.11	0.00
Calcium	mg/L	0.13	0.00

Source: Bhausahab *et al.* (2010)

Murphy (2000) documented the levels of phosphorus in the range of < 0.1 to 14 mg/L with a mean of 2 mg/L for bathwater.

2.3.2 Laundry Greywater

Laundry greywater contributes about 34% of total greywater volume (DHWA, 2002; Karpiscak *et al.*, 2006). This greywater varies in quality from wash water, first rinse water and second rinse water. It is thus important to take these sub streams of laundry greywater into consideration. This study took into consideration only the first two. Laundry greywater can have faecal contamination which is associated with bacteria and viruses, lint, oils, grease, chemicals, soaps, nutrients and other compounds. Laundry greywater of the last rinse is of good quality and can therefore be used for irrigation without further treatment. For example; a study carried out in Kitgum,

Uganda by Kulabako *et al.* (2009) using greywater towers operated in such a way that, greywater from the bathroom and laundry was applied on a daily basis. The results showed that, selected vegetables such as tomatoes and onions could be grown.

2.3.3 Kitchen Greywater

Kitchen greywater contributes about 11% (DHWA, 2002), 10-17% (Karpiscak *et al.*, 2006) of total greywater volume. This greywater is heavily polluted with food particles, cooking oils, detergents and other cleaning products like dishwashing powder. Murphy (2000) reported the levels of phosphorus in the range of 0.87 to 131 mg/L with a mean of 14 mg/L for dishwater.

2.4 Plant Nutrients

The plant nutrients include phosphorus, nitrogen, metals and organic pollutants (Ridderstolpe, 2004). Also according to Beaver (1995), greywater contains significant amount of nutrients particularly nitrogen and phosphorus. Average volume of greywater (356 L/day) will produce approximately 45 g of nitrogen and 3 g of phosphorus per day (Beaver, 1995). Metals originate from the water itself, from corrosion of pipe system and from cutlery and shampoos used in the household (Ridderstolpe, 2004). The metals vary with the detergents used in laundry, dishwashing and bathing soaps; cosmetics and body lotions used. They vary in magnitude depending on the life styles (Arjun *et al.*, 2006). A small number of studies exist on the quality of wastewater collected in domestic catchments at household level in Australia (Connor and Wilkie, 1995). These studies indicate that greywater is the major source of metal contaminants in household wastewater with major inputs of lead and zinc originating from the laundry and bathroom. Organic pollutants are present in many of our ordinary household chemicals such as shampoos, preservatives

and cleaners (Ridderstolpe, 2004). Greywater may also contain other minerals, organic pollutants, heavy metals, pathogens and other micro-organisms (SEI, 2004). Therefore, its composition may vary as stated in section 2.3. If managed properly, these nutrients can be beneficial to the home owners hence reducing the amount of fertilizer needed for gardens and lawns (WHO, 2006).

All plants require nutrients to survive and grow. Plants take nutrients from the air, soil and water (Schepers and Raun, 2008). There are at least a dozen nutrients elements which are important for plant growth. They are classified as macro-nutrients (required in large quantities) which include N, P, K, Ca, Mg, S and micro-nutrients (required in small quantities) which include Co, Fe, Cu, B, Mn, Mo, Zn among others (Davis and Eagle, 1972; Cooke, 1982). These plant elements are used in little amounts, but they are equally important to plant development and profitable to crop production as the major nutrients. Specifically, they work "behind the scene" as activators of many plant activities (Fageria, 1992; Gowariker *et al.*, 2009). Most soils are insufficient in all or nearly all the nutrients required for plant growth (Davis and Eagle, 1972). Each element has its own function in the plant growth and yet is required in vastly different amounts. The present study analyzed the following plant nutrients; NO_3^- -N, P, K, Ca, Mg, Fe and Zn in all the streams of greywater.

2.4.1 Nitrate-Nitrogen

Nitrogen is a major nutrient of important for the growth of micro-organisms, plants and animals (Tchobanoglous, 2003). It plays various functions in the growth and development of plants. For example, nitrogen is essential for plant cell division, plant growth and formation of amino acids. It is directly involved in photosynthesis,

production and usage of carbohydrates. It is also needed for energy reactions in plants. Symptoms of nitrogen deficiency include chlorosis, stunted growth, premature shedding-off of leaves among others (KLB, 2005; Ryoung *et al.*, 2006).

Nitrogen can occur in many forms because of several oxidation states it assumes and the fact that changes in oxidation states can be brought about by living organisms (Tchobanoglous, 2003). The most common and important forms in wastewater are NH_3 , NH_4^+ , N_2 , NO_2^- and NO_3^- . The NO_3^- -N is the most oxidized form of nitrogen found in wastewaters. In an aerobic environment, bacteria can oxidize the ammonia nitrogen to nitrites and nitrate-nitrogen. However, nitrite nitrogen is relatively unstable and is easily oxidized to nitrate. Nitrate may vary in concentration from 0 to 20 mg/l in wastewater effluents (Tchobanoglous, 2003).

Peter *et al.* (2002) reported nitrate concentration in wastewater in the range of 1.0 to 17.5 mg/L and a mean of 1.5 mg/L while Al-Jlil (2009) reported values of 1.88 and 6.66 mg/L in raw and treated wastewater respectively. The results of Bhausahab *et al.* (2010) were 0.67 and 0.21 mg/L for raw and filtered bathroom and basin greywater respectively. The threshold levels of nitrogen recommended by WHO (2006) as maximum concentration for crop production is in the range of 10 to 30 mg/L for safe use of wastewater, excreta and greywater. The primary drinking water standards limit N to 50 mg/L as NO_3^- (KEBS, 2007).

2.4.2 Phosphorus

Phosphorus is a major nutrient of importance to the growth of micro-organisms, plants and animals (Tchobanoglous, 2003). Phosphorus is involved in photosynthesis, seed formation, respiration, energy storage and transfer. It is also involved in cell division as well as promotion of early root formation and growth. Moreover, it improves the quality of fruits, vegetables and grains. In addition it helps plants survive harsh winter conditions, increases water-use efficiency and hastens maturity. Lack of phosphorus leads to increased production of anthocyanin (the pigment that gives plants a purplish colour), stunted plant growth and poor development of root, bark, fruits, seed and metabolizing organs. Excess phosphorus in the soil leads to unavailability of iron, as it is converted to insoluble compounds which cannot be absorbed by plants (KLB, 2005). The usual forms of Phosphorus that are found in aqueous solutions include; orthophosphate, polyphosphate, and organic phosphate. The orthophosphate for example, PO_4^{3-} , HPO_4^{2-} , H_2PO_4^- , and H_3PO_4 are available for biological metabolism without further breakdown.

Raude *et al.* (2007) reported phosphorus levels in the range of 1.2 to 13.1 mg/L; Jerpperson *et al.* (1994) in the range of 0.6 to 27.3 mg/L with a mean of 8 mg/L; Murphy (2000) in the range of 0.87 to 131 mg/L with a mean of 14 mg/L for dishwater, and < 0.1 to 14 mg/L with a mean of 2 mg/L for bathwater. However, the maximum concentration threshold of phosphorus recommended by WHO (2006) for crop production is in the range of 0.1 to 30 mg/L for safe use of wastewater, excreta and greywater.

2.4.3 Potassium

Potassium is a macro-nutrient required by plants. Potassium is useful in carbohydrate metabolism, break down and translocation of starches. It increases photosynthesis, efficiency of water-use and disease resistance. It is also important in protein synthesis, fruit formation, and controls of enzyme reaction rates. Potassium also improves quality of seeds, fruit, and winter hardiness. Its deficiency leads to leaf curling, chlorosis, premature leaf fall and stunted growth (KLB 2005). An excess of nitrogen to potassium renders leaves susceptible to fungal and bacterial diseases and reduces resistance to draught (Ryoung *et al.*, 2006).

The levels of potassium reported by Bhausahab *et al.* (2010) for raw bathroom and basin greywater was 4.52 mg/L from the study of a residential college campus in Nashik- India while Murphy (2000) were in the range of 2.5 to 28 mg/L and a mean of 9 mg/L for dishwater, 0.58 to 30 mg/L and a mean of 5 mg/L for bathwater.

2.4.4 Calcium

Calcium is a macro-nutrient required by plants (Whitney, 1996). It is utilized in continuous cell division and formation, nitrogen metabolism and translocation of photosynthesized food from leaves to fruiting organs. Calcium is essential for nut development, development more erect stem, microbial activity and normal root development. In addition it increases resistance to outside attack. Symptoms of calcium deficiency include stunted growth, dying back of plant tips, root rotting, low fruit weight and low dry matter (Tuna *et al.*, 2005). Excess calcium may however restrict trace element availability and should be avoided (Lampkin, 1990).

Reports of calcium levels in greywater are available. For example, Bhausahab *et al.*

(2010) reported 0.13 mg/L for raw bathroom and basin greywater while those of Murphy (2000) were in the range of 4.4 to 20 mg/L and a mean of 13 mg/L for dishwater, 3.5 to 21 mg/L and a mean of 11 mg/L for bathwater. According to Will *et al.* (1999) desirable levels of calcium for irrigation water is 40 to 100 mg/L. The primary drinking water standards limit Ca to 150 mg/L (KEBS, 2007).

2.4.5 Magnesium

Magnesium is the key element in chlorophyll production. Magnesium improves utilization and mobility of phosphorus and is an activator as well as a component of many plant enzymes. Also it is essential in synthesis of amino acids and cell proteins. In addition, magnesium also increases iron utilization in plants and influences earliness and uniformity of maturity. Its deficiency symptoms include interveinal chlorosis of leaves, anthocyanin pigment developing after chlorosis and later the leaves turn brown and eventually die. In some plants the leaves may curl (Ding *et al.*, 2006).

According to Will *et al.* (1999), desirable levels of magnesium for irrigation water is 30 to 50 mg/l. Documented levels of Mg in greywater by Bhausahab *et al.* (2010) is 0.11 mg/L for raw bathroom and basin greywater while Murphy (2000) were in the range of 0.5 to 4.9 mg/L and a mean of 2 mg/L for dishwater, 0.15 to 1.8 mg/L and a mean of 0.8 mg/L for bathwater. The primary drinking water standards limit Mg to 100 mg/L (KEBS, 2007).

2.4.6 Iron

Iron is a micro-nutrient required by plants. It promotes the formation of chlorophyll and acts as an oxygen carrier. It is also required in reactions that involve cell division and growth. Lack of iron leads to leaf chlorosis (KLB, 2005). Sources of iron in greywater could be as result of corrosion of plumbing pipes and the use of iron and steel wool in cleaning of utensils. The threshold levels of iron recommended by WHO (2006) as maximum concentration for crop production is 5.0 mg/L for safe use of wastewater, excreta and greywater. The primary drinking water standards limit Fe as Fe^{2+} to 0.3 mg/L (KEBS, 2007).

2.4.7 Zinc

Zinc is another micro-nutrient required by plants. It aids plant growth hormones and enzyme system. Zinc is necessary for chlorophyll production, carbohydrate and seed formation. Its deficiency may cause white bud formation and young leaves almost without chlorophyll (KLB, 2005). Zinc is toxic to many plants at wide varying concentrations; however toxicity reduces at $\text{pH} > 6.0$ and in fine textured organic soils (WHO, 2006). Rogan (2008) reported Zn levels ranging from 0.02 to 0.33 mg/L for Motoine river dams. The maximum concentration threshold of zinc recommended by WHO (2006) for crop production is 2.0 mg/L for safe use of wastewater, excreta and greywater. The primary drinking water standards limit Zn as Zn^{2+} to 5 mg/L (KEBS, 2007).

2.5 The pH

The pH is a measure of the concentration of (H^+) hydrogen ions of a solution at a given temperature (Nemerow, 1991). The pH indicates water's acidity or alkalinity

(Meybeck *et al.*, 1998) on a scale of 0 to 14. The pH plays a central role in aquatic chemistry and thus affects the uptake of nutrients in ways that are not fully understood. For example, high pH decreases solubility of phosphorus (Harper, 1992). The main effect of water pH on plant growth is through the control of nutrient availability. For example, the absorption of Pb in soil increases with the increase of pH between 3.0 and 8.5 (Lee *et al.*, 1998). A low pH may be responsible for excess iron and the manganese availability leading to toxicity or calcium and magnesium deficiencies. A high pH may cause iron, manganese and other minor nutrients to become unavailable to plants leading to deficiencies (Will *et al.*, 1999). Generally for most crops, soil pH values of 5.5 to 7.5 are suitable for availability of most nutrients (Muchukuri *et al.*, 2004).

Reports on pH values of greywater have been documented. For example, WHO (2006) reported pH values of 6.6 to 8.7 with a mean of 7.5 while Raude *et al.* (2009) on a study in Nakuru town Kenya was in the range of 5.7 to 8.6. The pH values for Bhausahab *et al.* (2010) were 8.12 for bathroom and basin raw and 7.43 for filtered greywater respectively while those of Peter *et al.* (2002) were in the range of 5.3 to 10.8 and a mean of 7.0. After treatment using soil columns they were in the range of 5.3 to 7.5. However, the pH values recommended by WHO (1997) and KEBS (2007) for drinking water are in the range of 6.5-8.5.

2.6 Toxic Heavy Metals

Many heavy metals are commonly found in wastewaters but in varying quantities. When in excess, these metals affect the activities of natural organisms thus hindering the natural self-purification process and affecting the ecology and diversity of some

organisms. They may pose a threat to human beings who use the water to irrigate food crops. Some of these metals are discussed in sections 2.6.1 and 2.6.2.

2.6.1 Lead

Lead is not an essential nutrient to plants. It is a potential pollutant that readily accumulates in the soil and sediments. The uptake of lead by plants depends on pH, particle size, and cation exchange capacity of soils. Lead causes stunted growth of plants, chlorosis and blackening of root system. It also inhibits photosynthesis, upsets mineral nutrition and water balance. It changes the hormonal status and affects membranes structure and permeability (Pallavi *et al.*, 2005). Lead inhibits chlorophyll synthesis by causing impaired uptake of essential elements such as Mg and Fe by plants (Burzynski, 1987). It damages the photosynthetic apparatus due to its affinity for protein N- and S- ligands (Ahmed and Tajmir-Riahi, 1993). The absorption of lead in the soil increases with the increase of pH between 3.0 and 8.5 (Lee *et al.*, 1998). However Blaylock and coworkers (1997) reported that in soil of pH between 5.5 and 7.5, lead solubility is controlled by phosphate or carbonate precipitates and very little lead is available to plants even if they have the genetic capacity to accumulate it.

High concentrations of lead in the soil environment causes imbalance of mineral nutrients in growing plants. Many of the observed actions of lead appear to be indirect as a result of mineral imbalance within the tissues. Significant changes in nutrient contents as well as in internal ratios of nutrients occur in plants under Pb toxicity (Kabata-Pendias and Pendias, 1992). In most cases Pb blocks the entry of cations (K^+ , Ca^{2+} , Mg^{2+} , Mn^{2+} , Zn^{2+} , Cu^{2+} , Fe^{3+}) and anions (NO_3^-) in the root system. Sources of lead in greywater could be through plumbing systems, paints on the walls and detergents among others. However, Rogan (2008) reported Pb levels ranging from

0.00 to 1.66 mg/L for Motoine river dams. The threshold levels of lead recommended by WHO (2006) as maximum concentration for crop production is 5.0 mg/L for safe use of wastewater, excreta and greywater. The primary drinking water standards limit Pb to 0.01 mg/L (KEBS, 2007).

2.6.2 Cadmium

Cadmium mainly is an unnecessary element to both plants and animals. Cadmium poisons the soil micro-organisms, which dies at very low concentration. It also affects soil structure and inhibits the germination of seeds and root development (Pallavi *et al.*, 2005). Presently this element is of great concern because not only is it highly toxic but its toxicity is cumulative. Rogan (2008) reported Cd levels ranging from 0.00 to 0.01 mg/L for Motoine river dams. The threshold levels of cadmium recommended by WHO (2006) as maximum concentration for crop production is 0.01 mg/L for safe use of wastewater, excreta and greywater. Very few finding of Cd concentration in greywater have been reported. The primary drinking water standards limit Cd to 0.003 mg/L (KEBS, 2007).

2.7 Greywater Treatments

Greywater is relatively harmless from an environmental and hygienic point of view (SEI, 2004). But if not managed properly, greywater can be a strong source of smell due to the high levels of easily degradable compounds. Greywater treatment is an environmental friendly process as a control of water pollution (Emmerson, 1998; Little *et al.*, 2001; Dixon *et al.*, 1999). Treatment of GW targets to reduce bad odours, high levels of organics pollutants, heavy metals, pathogens and other micro-organisms (SEI, 2004). Different greywater treatment systems exist and all are intended to improve greywater quality. They include physical, chemical, and biological systems.

Filtration as a physical method was applied in this research study because it's environmental friendly, affordable and is discussed in the following subsection.

2.7.1 Filtration

The term filtration has different meaning or connotations to various people. However, as most frequently used in water treatment parlance, filtration refers to the use of a relatively deep (1.5-3 ft) granular bed to remove impurities from water or can further be defined as a physical-chemical process for separating suspended and colloidal impurities from water by passage through a bed of granular material (Culp *et al.*, 1978). The role and importance of filtration in wastewater treatment includes:

- a. Removal of particulate and colloidal matter not settleable after either biological or chemical flocculation or both.
- b. Increased removal of suspended solids, turbidity, phosphorus, BOD, COD, heavy metals, asbestos, bacteria, viruses, and other substances.
- c. Improves the efficiency and reduces the cost of disinfection through removal of suspended matter and other interfering substances.
- d. Assures continuous plant operation and consistent effluent quality.
- e. Increases overall plant reliability by overcoming common irregularities in biological and chemical treatment.
- f. Increases aesthetic appreciation by producing an attractive, sparkling, high clarity effluent.
- g. Can be combined with biological denitrification by using the fine grains of the filter bed as an attached growth medium.

2.7.2 Filter Types

There are several ways of classify filters. According to Culp *et al.* (1978, 1974), they can be described according to the direction of flow through the bed, that is downflow, upflow, biflow, radial flow, horizontal flow, fine to coarse, or coarse to fine. They may also be classified according to the type of filter media used, such as sand, coal (or anthracite), coal-sand, multilayered, mixed media, or diatomaceous earth. Filters are also classed by flow rates; slow rate, rapid rate, and high rate filters; pressure or gravity flow filters. The filter types applied in this research study are discussed in subsections 2.7.2.1 and 2.7.2.2

2.7.2.1 Sand Filtration

Sand filtration is one of the oldest wastewater treatment technologies known. Sand filters are designed as single-pass or multi-pass filters and use sand as the media for filtration (NESC, 2008). The sand is usually two to three feet deep and contained in a liner made of concrete, plastic, or other impermeable material. The filter surface may be open or covered. If properly designed, constructed, operated and maintained, a sand filter produces a very high quality effluent. They are normally used to polish effluent from septic tanks or other treatment processes before it is distributed on the land. A sand filter purifies the water in three ways:

- i) Filtration, in which particles are physically strained from the incoming wastewater;
- ii) Chemical sorption, in which contaminants stick to the surface of the sand and to the biological growth on the sand surface;

iii) Assimilation, in which aerobic microbes eat the nutrients in the wastewater. The success of treating wastewater depends on these microbes. Air must be available for these microbes to live.

iv) Types of sand filters include:

- a) **Intermittent Sand Filter (ISF)**, in which wastewater is applied periodically to a 24 to 36 inch-deep bed of sand that is underdrained to collect and discharge the effluent. The bed is underlain by graded gravel and collecting tile. Wastewater is applied intermittently to the bed's surface through distribution pipes. ISFs remove contaminants in wastewater through physical, chemical, and biological treatment processes (EPA, 1999).
- b) **Recirculating Intermittent Sand Filter (RISF)**, which filters wastewater by mixing filtrate with incoming septic tank effluent and recirculating it several times through the filter media before discharging it to a final land application system. This filter's components are similar to the intermittent sand filter components. Sand filters can be free access (open to the surface) or buried in the ground (buried filters).

It's important that the sand particles all be about the same size. If the grain sizes vary greatly, the smaller ones will fill in the spaces between the larger particles, making it easier for the system to clog. The larger the grain size, the faster the wastewater moves through the sand and the more wastewater that can be filtered. Small media slow the water movement and increase the chance of clogging. The grain size also affects how deep the solid particles penetrate the filter and how clean the final effluent is. The advantage of using sand as a filter media is that it is reusable after reactivation

or regeneration. This is done through backwashing or scratching a thin layer of sand just near the greywater source. An onsite using advanced greywater treatment system using sand is shown in Figure 2.1.

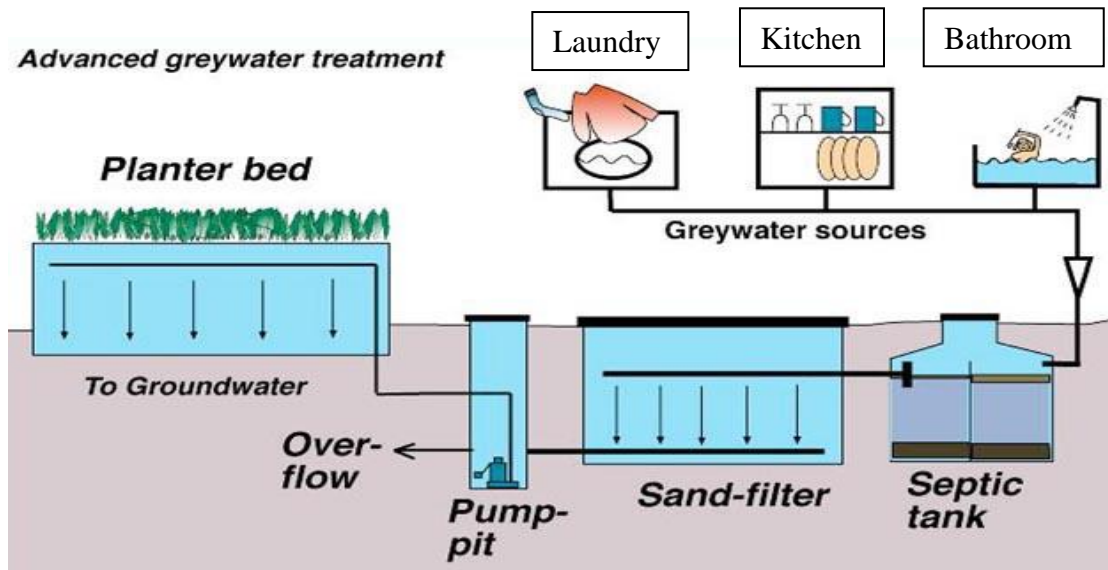


Figure 2.1: Advanced Greywater Sand Treatment System

Source: National Environmental Services Center (NESC) (2008)

A study by Al-Jlil (2009) in Saudi Arabia showed that by using sand filter, activated carbon, sedimentation, aeration and activated sludge COD and BOD reduction was 92.17 and 97.66%, respectively in domestic sewage water.

2.7.2.2 Charcoal Filtration

Charcoal consists of elemental carbon in its graphite configuration. Carbon has been used for water purification for centuries. Carbon filters are employed in commercial home water treatment systems as well as in large scale municipal treatment facilities. For example in Northern Thailand Charcoal filtration has been used as a self reliance water treatment method to remove pesticides in providing safe drinking water to communities (Judith *et al.*, 2004).

2.7.2.2.1 Raw Charcoal Making

Charcoal is made by pyrolyzing wood or other organic matter such as coconut or rice husks, nut hulls, peat, among others in earthen kilns, brick ovens, or underground pits. The process involves heating the base material to temperatures of 600–900 °C in the absence of oxygen (Judith *et al.*, 2004). Although it is not possible to produce high-grade Granular Activated Carbon (GAC) without an industrial process, lower-grade charcoal-derived GAC is readily made in earthen kilns and may exhibit appreciable capacity for aqueous contaminant adsorption. Studies have shown low-grade char from the burning of crop residues to be about one-third as efficient for adsorbing dissolved pesticides when compared with industrial-grade GAC (Judith *et al.*, 2004).

2.7.2.2.2 Activation of Charcoal

Activation of charcoal typically refers to physical or chemical processes designed to increase the reactive surface area of the carbon. Industrial activation processes may use chemicals and/or steam to enhance surface area (Judith *et al.*, 2004). Activated carbon (AC) comes in two sizes: powdered carbon has a diameter of less than 200 meshes, while granular carbon has a diameter greater than 0.1 millimeter (Bruce *et al.*, 1992). Granular carbon is more commonly used in wastewater treatment; powdered carbon is used less frequently because the small particle size creates regeneration and design problems. Activated carbon ability to remove a large variety of compounds from contaminated waters has led to its increased use in the last thirty years (Austin, 1992).

Activated Carbon works by attracting and holding certain chemicals as water passes through it. AC is a highly porous material; therefore, it has an extremely high surface

area for contaminant adsorption. Because contaminants come in all different sizes, they are attracted differently depending on pore size of the filter. The ability of activated carbon to remove some of inorganic materials from wastewater is as shown in the Table 2.4.

Table 2. 4: Some Inorganic Substances that can be Removed by Activated Carbon

Constituents	Potential for removal by carbon
Lead	Good
Iron	Fe ³⁺ good, Fe ²⁺ poor, but may oxidize
Cadmium	Slight
Zinc	Slight
Phosphate	Not sorbed but carbon may induce precipitation of Ca ₃ (PO ₄) ₂ or FePO ₄

Source: Culp *et al.* (1978)

The amount and distribution of pores also plays a key role in determining how well contaminants are filtered. The best filtration occurs when pores are barely large enough to admit the contaminant molecule as shown in Figure 2.2. The advantage of using carbon is that it is reusable after reactivation. The World Health Organization recommends coupling charcoal treatment with chemical (for example iodine, chlorine) or UV disinfection to ensure removal of microbial pathogens. Granular activated carbon (GAC) absorption has been used successfully for the advanced (tertiary) treatment of municipal and industrial wastewater in New York and Virginia to adsorb the relatively small quantities of soluble organics and inorganic compounds such as nitrogen, sulfides, and heavy metals remaining in the wastewater following biological or physical-chemical treatment (EPA, 2000).

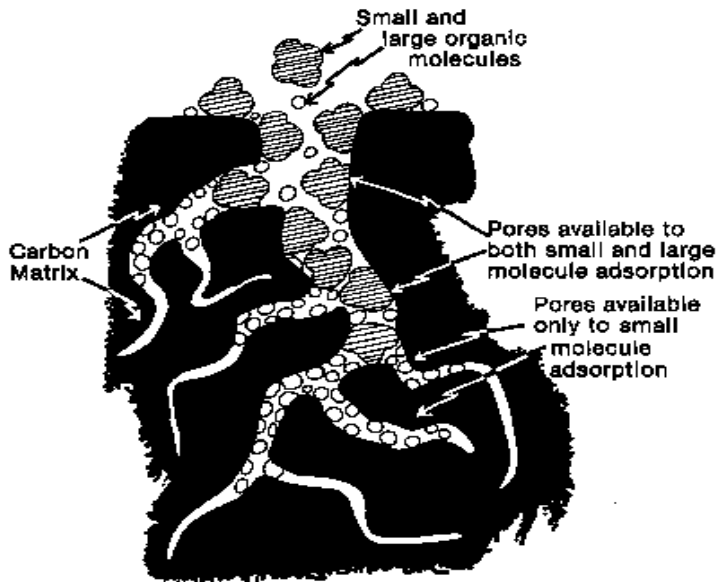


Figure 2.2: Scanning Electron Microscope Image of GAC Showing Molecular Screening in the Micropores of an Activated Carbon Filter
 Source: Culp and Culp (1974)

2.7.3 Filtration Mechanism

Several mechanisms are involved in particle removal by filtration. Some of them are physical while others are chemical in nature. Some of the mechanisms are; sedimentation, impaction, adhesion, flocculation, interception, adsorption, and chance contact. The removal of suspended particles in a filter consists of at least two steps:

- a) The transport of suspended particles to the solid-liquid surface of a grain of filter media or to another floc particle previously retained in the bed.
- b) The attachment and adsorption of particles to the solid-liquid surface.

2.7.4 Filtration Efficiency

Filters are highly efficient in removing suspended and colloidal materials from water. Impurities affected by filtration includes: turbidity, bacteria, algae, viruses, color, oxidized iron and manganese, radioactive particles, chemicals added in pretreatment, heavy metals and other substances (Culp *et al.*, 1978). Filter efficiency is influenced

by variables that exist both in the water applied to the filter, and in the filter itself. In general, filter efficiency increases with smaller grain size and greater bed depth (Tchobanoglous, 2003). A study by Al-Jlil (2009) in Saudi Arabia showed that by using sand filter, activated carbon, sedimentation, aeration and activated sludge COD and BOD reduction was 92.17 and 97.66%, respectively in the domestic sewage water. Other water quality parameters such as TSS, TDS, and PO_4^{3-} showed significant reduction except NO_3^- which increased significantly using different materials in the Wastewater Treatment Plant.

2.8 Significance of Greywater Reuse

Greywater use yields the satisfaction of taking responsibility for the wise husbandry of an important resource. Greywater reuse utilizes an on-site resource which could otherwise be wasted (WHO, 2006). As shown in section 2.2 Table 2.1, greywater constitutes the largest flow of domestic wastewater about 61% WHO (2006), therefore if thoughtfully exploited; it could have several benefits as explained in subsections 2.8.1 to 2.8.6.

2.8.1 Lower Fresh Water Use

Greywater can replace fresh water in many instances thus saving money and increasing the effective water supply in regions where irrigation is needed. Residential water use is almost evenly split between indoor and outdoor (Ludwig, 2000). All except toilet water could be recycled outdoors, achieving the same result with significantly less water diverted from nature. As a result fresh drinking-water supplies are conserved, which in turn enables the water to remain in natural ecosystems. For example underground irrigation using bathroom greywater is widely applicable in the United States of America, in Utah, New Mexico, and California State where

international plumbing code to deliver greywater to the garden is legislatively enhanced (Stephanie, 2009). Also greywater is used in growing of crops in Kitgum-Uganda (Kulabako *et al.*, 2009). Therefore the greywater produced in KU can also be reused to irrigate the grass and flowers.

2.8.2 Less Strain on Septic Tank or Treatment Plant

Greywater use greatly extends the useful life and capacity of septic systems. For municipal treatment systems, decreased wastewater flow means higher treatment effectiveness and lower costs. According to WHO (2006), by reusing greywater the load on wastewater disposal systems is reduced and therefore the life of the wastewater disposal system is prolonged and capital expenditure required for the upgrading and expansion of the systems is delayed. In Australia and some United States jurisdictions recycled greywater from showers and bathtubs are used for toilet flushing and lawn irrigation (Ludwig, 2000).

2.8.3 Highly Effective Purification

Greywater is purified to a spectacularly high degree in the upper, most biologically active region of the soil. This protects the quality of natural surface and ground waters. For sites with slow soil percolation or other problems, a greywater system can be a partial or complete substitute for a very costly, over-engineered system. In Jordan greywater recovery and on-site reuse protects shallow groundwater resources from pollution resulting from the infiltration of septic tanks (Shihab, 2009).

2.8.4 Less Energy and Chemical

Less energy and chemicals are used due to the reduced amount of both freshwater and wastewater that needs pumping and treatment. For those providing their own water or electricity, the advantage of a reduced burden on the infrastructure is felt directly.

2.8.5 Plant Growth and Reclamation of Otherwise Wasted Nutrients

Since greywater contains numerous nutrients, it can be beneficial to homeowners in reducing the amount of fertilizer needed for gardens and lawns. Greywater enables a landscape to flourish where water may not otherwise be available to support much plant growth. Loss of nutrients through wastewater disposal in rivers or oceans is a subtle, but highly significant form of erosion. Reclaiming nutrients in greywater helps to maintain the fertility of the land. According to WHO (2006), a growing world population, unrelenting urbanization, increasing scarcity of good quality water resources and rising fertilizer prices are the driving forces behind the accelerating upward trend in the use of wastewater, excreta and greywater for agriculture and aquaculture. In Jordan greywater recovery and on-site reuse provides households with a considerable amount of irrigation water that can be used to produce supplement food (Shihab, 2009). In Australia and some United States jurisdictions recycled greywater from showers and bathtubs are used for toilet flushing and lawn irrigation (Ludwig, 2000).

2.8.6 Other Uses of Greywater

Other uses of greywater include: Toilet flushing for example in Australia and some United States jurisdictions (Ludwig, 2000), car washing, ornamental uses in fountains and waterfalls, and landscaping (Al-Jayyousi, 2002). Greywater reuse succeeds in

saving money spent by water authorities, reduces sewage flows and reduces public demand on potable water supplies. However it is important to know the quality of greywater before reuse hence the need for this study.

2.9 Challenges of Greywater Reuse

Greywater reuse poses some environmental challenges despite its remarkable benefits. Greywater tends to be slightly alkaline, with a pH range of typically between 6.5 and 9 and the extensive use of it for irrigation could cause the soil to become progressively more alkaline (DHWA, 2002). The use of greywater can potentially introduce excess salts into the soil and groundwater (DCC, 2009). Also greywater reuse can introduce harmful elements to the environment. Therefore there is a need to have them reduced through treatment of greywater.

2.10 Methods of analysis

There are various methods employed in the determination of wastewater properties. These methods include; Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) (EPA, 2007), Atomic Absorption Spectroscopy (AAS) (AOAC, 2000; AWWA, 2005; APHA, 1998, 2005), flame photometry (Lesjean *et al.*, 2006), and potentiometric (Rogan, 2008) among others. In this study AAS, UV-Vis spectroscopy and potentiometric methods were used because of their availability, high specificity, easy sample preparation and ease of operation.

2.10.1 Atomic Absorption Spectroscopy (AAS)

2.10.1.1 Theory of Atomic Absorption Spectroscopy

Atomic Absorption Spectroscopy (AAS) is a single elemental method, in which one element is determined in a series of samples and instrumental parameters optimized for the next element. Atomic absorption is a process involving the absorption by free atoms of an element of light at a wavelength specific to that element. Absorption of light is associated with the process of transition of atoms from one steady state to another (Van loon, 1980). For the case of steady states **0** and **P** (where **0** is the ground state and **P** the excited state), with energies E_o and E_p , where $E_p > E_o$, the $0 \rightarrow P$ transition results in the emission of light with frequency, shown in Equation 2.1

$$\nu_{op} = \frac{E_p - E_o}{h} \dots\dots\dots \text{Equation 2.1}$$

Where; h is the Planks' constant and ν frequency.

The $0 \rightarrow P$ absorption transition is always stimulated by external radiation. For an unexcited atom, each electron is in the ground state, otherwise it is excited. The proportion of excited to ground state atoms in a population at a given temperature is given by the general statement of the Maxwell-Boltzmann law shown in Equation 2.2

$$\frac{N_p}{N_o} = \frac{g_p}{g_o} e^{-\frac{|E_o - E_p|}{kT}} \dots\dots\dots \text{Equation 2.2}$$

Where; N = the number of atoms in state 0 and P,
 g = the statistical weights for states 0 and P,
 T = the temperature (in degrees Kelvin)
 k = the Boltzmann constant.
 E_o = Energy at ground state
 E_p = Energy at excited state

The wavelength at which an atom with its valency electrons in the ground state can absorb radiation are called resonance wavelength (Skoog et al., 1998). To calculate how much light is absorbed by a cloud of atoms, parallel beams of light at the

resonance wavelength for the atoms concerned are considered when striking a cell containing N atoms. If light of intensity I_o enters the cell, the intensity remaining after absorption I_I is given by Equation 2.3

$$I_I = I_o e^{-kl} \dots\dots\dots \text{Equation 2.3}$$

Where l is the cell length and k is the absorption coefficient (i.e. the fraction of energy absorbed per unit length). Taking logarithms of both sides, we get Equation 2.4

$$kl = \log \frac{I_o}{I_I} \dots\dots\dots \text{Equation 2.4}$$

The expression $\log \frac{I_o}{I_I}$ is defined as absorbance. Since the product kl is proportional to the number of atoms in the cell, so is the absorbance. For this reason, absorption is the preferred readout mode of modern atomic absorption spectrometer, giving a linear relationship between absorbance and concentration as in Equation 2.5

$$A = \epsilon cl \dots\dots\dots \text{Equation 2.5}$$

Where; A = absorbance
 ϵ = Molar absorptivity ($\text{Lmol}^{-1}\text{cm}^{-1}$)
 c = Concentration (mol dm^{-3})
 l = Path length (cm)

2.10.1.2 Instrumental Principles

Any atomic absorption spectrophotometer consists basically of:-

- a) **Radiation source** Is a light source which emits the sharp line spectrum of the element to be determined. There are two types of radiation sources, namely;
 - i) **Continuous source** It gives a wide range of radiation and includes deuterium lamp and mercury vapour lamp. It is less sensitive because only a small band of radiation passed by monochromator is absorbed while a large portion falls on the detector.

- ii) **Hollow cathode source** It is commonly used in AAS instrument and is made up of metallic or alloy of element of interest. Hollow cathode lamp consists of a tungsten anode and cylindrical cathode sealed in a glass tube that is filled with neon or argon gas at a pressure of 1-5 torr.
- b) **Atomizer** The two types of atomizers are flame and electro-thermal atomizers. In flame atomizer, temperature is determined by flow rate and the ratio of oxidant and fuel. In flame atomizer, solvent is evaporated to produce solid molecular aerosol during dissolution process. Dissociation leads to atomic gas whereas some of the atoms ionize to give cations and electrons. In electro-thermal atomizers molecules of the solvent are first evaporated at low temperature and then sample ashed at higher temperature in electrically heated graphite. After ashing, the temperature is increased to 2000-3000°C to cause atomization of the sample.
- c) **Monochromators** They are analyzers that present monochromatic radiation to the detector. They are filters, prisms or gratings that disperse or separate radiation so that selected wavelength corresponding to a particular energy of the sample is transmitted. Diffraction gratings are preferred to prisms as they offer accuracy over a wide range of wavelengths.
- d) **Detectors** They are used to convert radiation energy into electrical signal. They include phototube, photomultiplier tube and photodiode array detectors.
- e) **Readout system** These are digital and are interfaced with microprocessors that allow the programming of various aspects, bringing simplicity in operations.

2.10.1.3 Instrumentation of Atomic Absorption Spectrophotometer

Figure 2.3 shows a schematic diagram of atomic absorption spectrophotometer

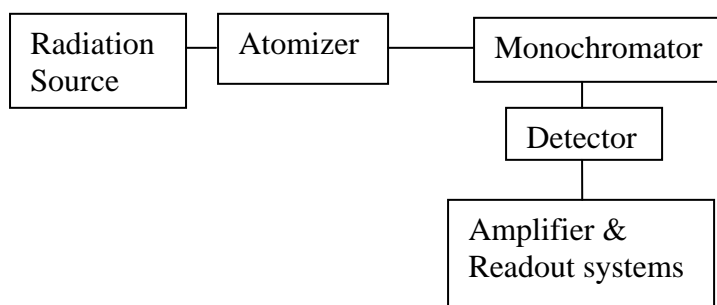


Figure 2.3: Schematic Diagram of Atomic Absorption Spectrophotometer

Source: Skoog *et al.* (1998)

2.10.2 The UV-vis Spectrophotometry

The Ultraviolet and visible spectroscopy (UV-vis spectroscopy) is used to study molecules and inorganic ions in solution. It involves measurement of the amount of radiation absorbed by the molecule or ions. It is preferred for its high sensitivity, reasonably low detection limits and affordable price.

2.10.2.1 Principle

It involves the absorption of Uv-vis radiation by the molecule or ions and getting the difference from the total incident radiation. Absorption of radiation also obeys the Beer-Lambert law given in equation 2.5. The relationship between absorption of incident radiation and its absorption frequency is the basis behind the use of spectroscopy to identify substances as shown in Equation 2.6

$$E_1 + h\nu \rightarrow E_2 \text{ Equation 2.6}$$

Where; E_1 = Low energy state

E_2 = high energy state

h = Plank's constant

ν = Frequency of radiation

Absorption of ultraviolet or visible light electromagnetic radiation causes electron to

moves from lower energy levels to a higher energy levels. Ultraviolet-visible absorption spectroscopy measures the absorption of ultraviolet or visible light. Because the spectrum of an atom or molecule depends on its electron energy levels, UV-vis absorption spectra characteristics are useful for identifying unknown substances.

The UV-vis spectroscopy uses Beer's Law (Beer-Lambert law) to determine the relationship between absorbance and concentration of a substance in a solution. Since absorbance depends on the concentration of the absorbing species, it is possible to quantitatively determine the amount of a given species present (Skoog *et al.*, 1998). In general there is a linear relationship between the increasing amount of substance and a decreasing percentage of light transmitted through the target sample. If there is more of a substance to absorb the UV light then less light will pass through to the detector. Correspondingly, less absorption by the target sample allows increased transmission light through the sample.

2.10.2.2 Instrumentation of UV-Vis Spectrophotometry

Figure 2.4 is a schematic diagram of double beam Uv-vis spectrophotometer

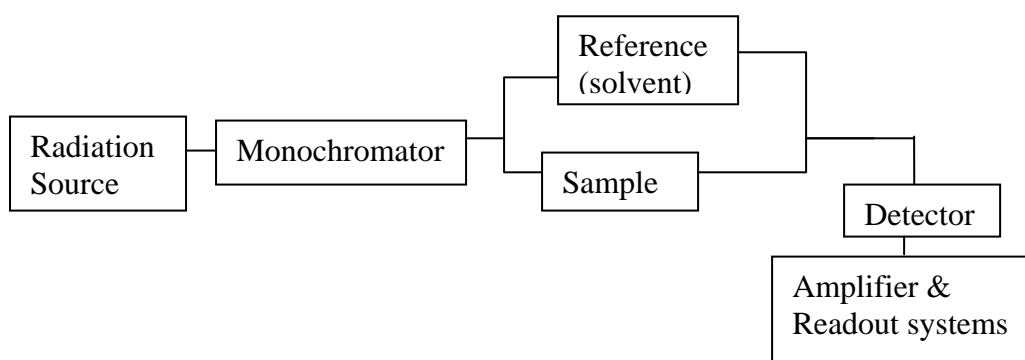


Figure 2.4: Schematic Diagram of Double Beam UV-Vis Spectrophotometer
Source: Skoog *et al.* (1998)

2.10.3 Determination of pH

The pH of a solution is determined using a pH meter, which is a potentiometric method (Brady and Holum, 1993; Busaidi *et al.*, 2005). A pH meter uses a glass electrode for measurement of pH. The electrode is made from a hollow glass tube sealed with a special thin walled glass membrane at the bottom. The tube is filled partway with dilute hydrochloric acid solution and a silver wire coated with a layer of silver chloride dipped into this solution. The potential of electrode is controlled by the difference between the hydrogen ions concentration inside and outside the thin glass membrane at the bottom. Since the hydrogen ions concentration inside the electrode is constant, the electrode potential varies only with the concentration of hydrogen ions in the solution outside. This potential is proportional to the logarithm of the H^+ concentration and therefore to the pH of the outside solution. A glass electrode is always used with another reference electrode whose potential is constant, and this gives a galvanic cell whose potential depends on the pH of the solution into which the electrodes are immersed. The pH meter translates the potential into pH values of the solution (Brady and Holum, 1993; Robert *et al.*, 1990).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

The study was conducted in Kenyatta University's (KU) main campus, Nairobi Kenya. Kenyatta University main campus is located along Thika Superhighway in Kahawa about 20 km from Nairobi city centre. The University occupies about 1000 acres of land and is inhabited by students and University workers both teaching and non-teaching staffs. The university has a population of more than twenty thousand people. The university generates a lot of greywater from its premises such as hostels, hotels/messes, staff quarters, offices among other sources. The greywater produced is an untapped resource since all goes down the drain as sewage. This study targeted the analysis of greywater from staff quarters.

3.2 Research Design

In this study, the research design involved first selection of households where greywater samples were to be collected. Secondly collection of the samples from bathrooms, kitchens and laundry sections of selected households except laundry greywater from soiled diapers. After collection, samples were then taken to Kenyatta University chemistry research laboratory where pH was taken and then pretreated before storage under refrigeration at 4 °C. Some samples were analysed raw and others filtered through sand, activated carbon and ordinary wood charcoal. Both raw and filtered samples were analyzed for cadmium, lead, potassium, magnesium, calcium, zinc, and iron using AAS, nitrate-nitrogen and phosphorus using UV-vis spectroscopy while the pH was measured using potentiometric method. The data was analyzed using ANOVA and results compared.

3.3 Cleaning of Apparatus

All the sampling plastic bottles and glassware used in the study were washed in liquid detergent, and then soaked in 1:1 analytical grade nitric acid for 24 hours to leach out any adsorbed metal ions. They were then thoroughly rinsed with distilled water, dried and sealed tightly.

3.4 Reagents, Solvents and Weighing of the chemicals

All the chemicals used in this research study were of analytical grade (AR). Distilled water was used for dilution. Weighing of the chemicals was done using a research analytical electronic balance (SHIMADZU, model ATY224, Shimadzu Philippines Manufacturing Inc (SPM)).

3.5 Sample Size, Sampling and Sample Pretreatment

The households sample size was determined using the formula reported by Daniel (1999) shown in Equation 3.0

$$n = \frac{z^2 p[1-p]}{d^2} \dots \dots \dots \text{Equation 3.0}$$

Where n = sample size

z = statistic for a level of confidence (for the level of confidence of 95%, conventional value is 1.96)

p = expected prevalence or proportion (in proportion of 80%, p =0.80)

d = precision (in proportion of 15%, d =0.15)

From the Equation 3.0 $n=27$. Thirty households from the staff quarters (upper, lower and Soweto staff quarters) were identified randomly where sampling was done. Four types of greywater (kitchen, bathroom, and laundry wash and laundry first rinse greywater) were sampled from each household except greywater from soiled diapers, giving a total of 120 samples per collection.

Eventually a total of 360 samples were analysed over a period of six months, 120 samples after every two months. At each sampling site, bathroom and kitchen greywater samples were taken directly from an outlet into clean plastic bottles while laundries greywater were taken from wash basins/buckets in duplicate, and then labeled accordingly. Samples were then taken to Kenyatta University chemistry Research laboratory which is few metres from the collection sites. The pH of each sample was taken and samples for metal and phosphorus analysis were acidified to pH 2.0 with concentrated nitric acid. All samples were then kept under refrigeration.

3.6 Column Packing and Filtration of Raw Greywater

Six glass columns 90 cm long and with a diameter of 4.5 cm were used in this study. Two were packed with sand, two with activated carbon, and the remaining two with raw wood charcoal, to about 60 cm high. The columns were first cleaned with 1:1 nitric acid, rinsed with distilled water several times and dried. The filter media (sand, activated carbon and wood charcoal) were soaked in 1:11 HCl acid for 12 hours to remove metal adsorbed on the filter media, then thoroughly rinsed with distilled water to remove traces of the acid. The rinse water was tested with pH meter to ensure that all the acid has been washed. Then, the filter media were dried at 300 °C to remove moisture but sand was heated to 700 °C to remove organic matter. Thereafter, sand and wood charcoal were sieved through sieve mesh No.40 and 30 U.S.A standards make to give particle sizes of 0.42-0.8 mm. The particle sizes for activated carbon were between 30-18 mesh (0.8-1 mm) according to manufacturers' description. The cleaned filter media were packed into the columns as shown in Plate 3.1. The raw greywater samples were then filtered through the columns. The pH values and levels of nitrate-nitrogen for the filtrates were determined after filtration because their values

may change upon storage. However, filtrates for phosphorus and metals were acidified to pH 2.0 with concentrated nitric acid, and then stored under refrigeration awaiting digestion and analysis. After every sample filtration, the filter media were cleaned with a warm solution containing 5 % caustic by weight followed by 3 % HCl acid, then rinsed with hot distilled water to minimize sample matrix.

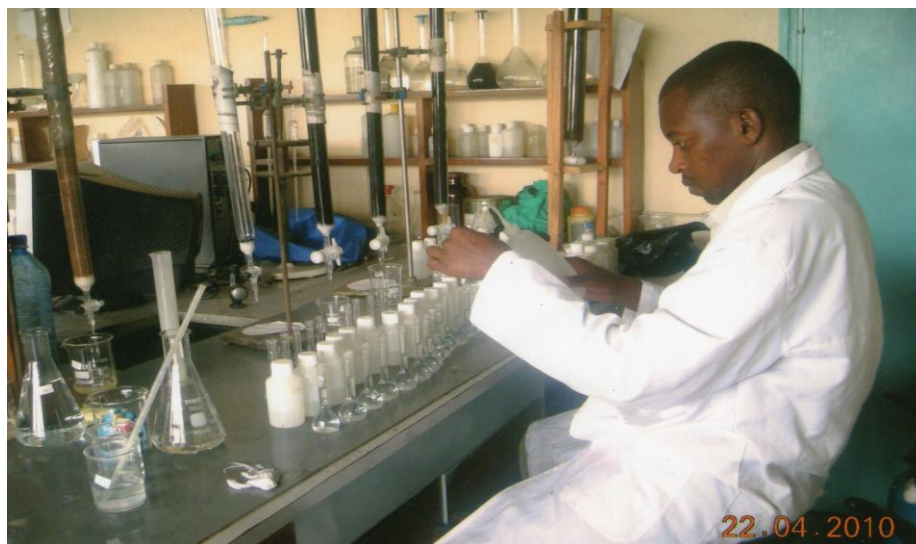


Plate 3.1: Glass Columns for Filtration of Greywater Packed with Sand, Raw wood charcoal and Activated Carbon Used in the Study

3.7 Sample Preparation

3.7.1 Digestion of Samples for K^+ , Mg^{2+} , Ca^{2+} , Zn^{2+} , Fe^{2+} , Pb^{2+} and Cd^{2+} Analysis

Samples were digested using modified methods described by APHA (2005, 1998). Aliquots of 50.0 ml of raw and filtered greywater were put into digestion tubes using a burette, followed by 5 ml of concentrated nitric acid. The samples were then heated on a hot plate and allowed to evaporate to about 5 ml. After cooling, the digestate were then quantitatively filtered into a 50 ml volumetric flask using Whatman filter paper number 541, and then put into clean plastic bottles, labeled and stored under lock and key awaiting analysis.

3.7.2 Digestion of Samples for Phosphorus Analysis

Phosphorus was digested using sulphuric acid-nitric acid method (APHA, 2005; 1998). Portions of 50.0 ml of both raw and filtered greywater were measured, and put into 100 ml beakers. A volume of 5.0 ml of concentrated nitric acid and 1.0 ml of concentrated sulphuric acid added. Samples were then heated on a hot plate and evaporated to a volume of about 1-2 ml, and then allowed to cool before adding 20.0 ml of distilled water. The pH of the samples was then adjusted to 6.5-8.5 using 4M NaOH and 1:1 HCl acid solution. The digestate was then quantitatively transferred into a 100 ml volumetric flask and volume adjusted to the mark, after which it was put in clean plastic bottles, labeled and stored under lock and key awaiting analysis.

3.7.3 Preparation of Samples for Nitrate-Nitrogen Analysis

Modified ultraviolet spectrophotometric screening method (APHA, 2005; 1998) was used to determine the concentration of Nitrate-Nitrogen. Aliquots of 50.0 ml of raw and filtered greywater were put into 100 ml beakers. Then 5.0 ml of 50.0 mg/L aluminium sulphate solution added, stirred and allowed to settle for about 30 minutes for coagulation of organic matter (PYE UNICAM, 1970; Hoather *et al.*, 1965). The sample solutions were then filtered into clean beakers using Whatman filter papers number 541. Then 1.0 ml of 1:1 HCl acid added to the filtered samples and mixed thoroughly. The blank and standard solutions were treated like samples before use.

3.8 Preparation of Standard Solutions

3.8.1 Preparation of Standard Solution for K^+ , Mg^{2+} , Ca^{2+} , Zn^{2+} , Fe^{2+} , Pb^{2+} and Cd^{2+} Analysis

Standard solutions of each metal were prepared by serial dilution of commercial stock solutions of respective metals. For every analysis fresh standard solutions were

prepared.

3.8.2 Preparation of Standard Solution for Phosphorus

Phosphorus stock solution was prepared by dissolving 4.3840 g of di-ammonium hydrogen phosphate (which had previously been dried at 105 °C for 2 hrs) in distilled water in a 1000 ml volumetric flask, and then volume adjusted to the mark. The standard solutions were then prepared by serial dilution of the stock solution. For every analysis fresh standard solutions were prepared.

3.8.3 Preparation of Standard Solution for Nitrate-Nitrogen

The nitrate-nitrogen stock solution was prepared by dissolving 0.7128 g of potassium nitrate salt (which had been dried at 105 °C in an oven for 24 hours) in distilled water and then diluting to 1000 ml mark. The standard solutions were then prepared by serial dilution of stock solution. For every analysis fresh standard solutions were prepared.

3.9 Sample Analysis

3.9.1 The pH Determination

The pH of the raw and filtered greywater samples was measured using a pH meter (model 290A, year of manufacture 2007, USA). The pH meter was calibrated using solutions made from pH 4 and 7 tablets. Aliquots of 30.0 ml each of the greywater samples were put in plastic beakers, pH probe immersed and the pH measured. After each sample measurement, the probe was rinsed with distilled water several times. After every ten measurements, the pH meter was calibrated again to ensure reliability of the data.

3.9.2 Determination of K^+ , Mg^{2+} , Ca^{2+} , Zn^{2+} , Fe^{2+} , Pb^{2+} and Cd^{2+} in Greywater Samples

The AAS spectrophotometer (Varian spectra AA10, Australia, year of manufacture 1985) at Geochemistry laboratory of Mines and Geology Department, Ministry of Environment Nairobi Kenya shown in Plate 3.2 was used to determine the concentration of K^+ , Mg^{2+} , Ca^{2+} , Zn^{2+} , Fe^{2+} , Pb^{2+} and Cd^{2+} . Its operating conditions are listed in Table 3.1. The sample concentrations were obtained from calibration curves (appendix I to VII) for the respective metals. Malfunctioning of the instrument was checked by running the standard and blank in between the samples.



Plate 3.2: The AAS Spectrophotometer Used in the Study

Table 3. 1: The AAS Operating Conditions for the Metals Analyzed

Metal	Wavelength (nm)	Slit (nm)	Detection limit (mg/L)	Acetylene flow L/min	Lamp Current (mA)	Fuel
K	766.5	1.0	3.0×10^{-2}	1.5	5.0	Air/acetylene
Ca	422.7	0.1	5.0×10^{-2}	4.5	1.0	Air/acetylene
Mg	285.2	0.1	3.0×10^{-2}	4.5	1.0	Air/acetylene
Fe	248.8	0.2	5.0×10^{-2}	1.5	7.0	Air/acetylene
Zn	213.9	0.7	2.0×10^{-3}	1.5	2.0	Air/acetylene
Pb	217.0	1.0	1.0×10^{-2}	1.5	8.0	Air/acetylene
Cd	228.9	0.7	6.0×10^{-3}	1.5	2.0	Air/acetylene

3.9.3 Determination of Phosphorus in Greywater Samples

A volume of 10.0 ml of the digested samples were pipetted into separate 50 ml beakers and 25.0 ml of distilled water added. Then 10.0 ml of molybdivanadate buffer was added to each sample (molybdivanadate solution was prepared by dissolving 0.2197 g of ammonium metavanadate in 400 ml of 1:1 nitric acid, and 50.0000 g of ammonium molybdate in 400 ml of distilled water, solutions were then mixed and volume adjusted to one litre with distilled water). The sample mixtures were allowed to stand for at least five minutes before reading their absorbance at 430 nm using T80+ UV/Vis spectrometer PG instruments Ltd (year of manufacture, 2007) shown in Plate 3.3. Standards and blank were treated like samples before use. Phosphorus calibration curve (appendix VIII) was used to obtain the concentration of the samples. Malfunctioning of the instrument was checked by running the standard and blank in between the samples.



Plate 3.3: The T80+ UV/Vis Spectrometer Used in the Study

3.9.4 Determination of Nitrate-Nitrogen in Greywater Samples

The concentrations of nitrate-nitrogen in samples were determined by obtaining their absorbances at 220 nm due to nitrates and 275 nm due to organic matter using T80+ UV/Vis spectrometer PG instruments Ltd (year of manufacture 2007). For samples and standards, two times the absorbances at 275 nm was subtracted from the reading at 220 nm to obtain absorbances due to nitrates. Using corrected absorbances, sample concentrations were obtained from the calibration curve (appendix IX).

3.10 Data Analysis

The data collected was subjected to SPSS statistical Program. Mean values were determined for each type of greywater and one way ANOVA done to test any significance difference between raw and treated (filtered) greywater samples.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Method validation

The reliability of AAS and UV-Vis spectrophotometer used in this study were checked using the linearity of calibration curves and detection limits of the analytes.

4.1.1 Linearity of AAS and UV-vis Calibration Curves

Regression analysis was used to evaluate the linearity of the established AAS and UV-vis calibration curves. The absorbance readings and concentrations of standards were used to calculate correlation coefficient values. The results are summarized in

Table 4.1

Table 4. 1: The Concentration Ranges of Standards Used and Corresponding Correlation Coefficient Values of Calibration Curves of Analytes

Analytes	Instrument used	Concentration (mg/L) range of standards used	Correlation coefficient (r) values
K	AAS	0.0-10.0	0.9989
Mg	AAS	0.0-10.0	0.9994
Ca	AAS	0.0-10.0	0.9994
Fe	AAS	0.0-10.0	0.9994
Zn	AAS	0.0-3.0	0.9994
Pb	AAS	0.0-3.0	0.9994
Cd	AAS	0.0-1.5	0.9984
P	UV-vis	0.0-10.0	0.9994
NO₃⁻-N	UV-vis	0.0-10.0	0.9989

From Table 4.1, it can be seen that the curves were linear within the concentration

range determined from the correlation coefficient (r) values obtained which were close to ideal value of 1 hence the results presented in this study were reliable.

4.1.2 The Detection Limits of the Instruments for the Various Analytes

The experimental detection limits were calculated as the lowest concentration obtained by the instrumental signal equal to the blank signal plus three times the standard deviation of the blank. The results are presented in Table 4.2

Table 4. 2: The AAS and UV-vis Detection Limits of the Analytes

Parameters	Instrument	Experimental detection limits (mg/L)	Theoretical detection limits (mg/L)
K	AAS	3.11×10^{-2}	3.0×10^{-2}
Ca	AAS	5.10×10^{-2}	5.0×10^{-2}
Mg	AAS	3.16×10^{-2}	3.0×10^{-2}
Fe	AAS	5.12×10^{-2}	5.0×10^{-2}
Zn	AAS	2.21×10^{-3}	2.0×10^{-3}
Pb	AAS	1.10×10^{-2}	1.0×10^{-2}
Cd	AAS	6.20×10^{-3}	6.0×10^{-3}
P	UV-vis	2.04×10^{-1}	2.0×10^{-1}
NO₃⁻-N	UV-vis	6.05×10^{-2}	6.0×10^{-2}

From Table 4.2, it can be seen that there was a slight increase in experimental detection limits compared to theoretical ones. The small increase in detection limits could be attributed to flicker noise resulting from the drift in direct current amplifiers (Skoog and Leary, 1992). Therefore, the instruments used in this study were reliable in determination of the selected analytes in greywater.

4.2 Levels of the Analytes/Parameters in Raw Greywater and Tap water

The levels of K^+ , Ca^{2+} , Mg^{2+} , Fe^{2+} , Zn^{2+} , Cd^{2+} , Pb^{2+} , NO_3^- -N, and P as well as the pH values in kitchen (KGW), bathroom (BGW), and laundry wash (LWGW) and laundry first rinse (LRGW) raw greywater (GW) from Kenyatta University staff quarters were determined in duplicates, data analysed using ANOVA and the results for each analyte/parameter are discussed in sections 4.2.1 to 4.2.10

4.2.1 Mean pH Values of Raw Greywater

The mean pH values of different types of raw greywater are presented in Table 4.3

Table 4. 3: The Mean and Ranges of pH Values of Different Types of Greywater

Type of water	Mean pH value Mean±SE n =30	pH ranges (pH scale)
Tap Water (control) TW	7.18±0.10 ^a	6.97 – 7.51
Kitchen greywater (KGW)	7.84±0.08 ^c	6.36 – 8.39
Bathroom greywater (BGW)	7.47±0.09 ^b	6.64 – 7.97
Laundry wash greywater (LWGW)	8.23±0.06 ^d	7.64 - 8.78
Laundry first rinse greywater (LRGW)	7.75±0.06 ^c	7.12 – 8.22

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

From Table 4.3, the mean pH values of greywater were significantly higher than those in tap water ($\alpha=0.05$, $p<0.05$). This could be attributed to the presence of dissolved ions from cleaning products like soaps, detergents as well as from body oils, toothpaste among others. However, the mean pH values of raw laundry greywater, differed significantly from other types of raw greywater ($\alpha=0.05$, $p<0.05$). Laundry wash greywater was on average more basic than other types of greywater, probably

due to ionization of carbonates usually added as builders or water softeners, also it could be due to presence of bleaches. The KGW and LRGW did not differ significantly ($\alpha=0.05$, $p>0.05$), while BGW differed significantly from the other types of GW ($\alpha=0.05$, $p<0.05$). The pH range for the various types of greywater was 6.36 to 8.78 with an overall mean of 7.82 ± 0.04 .

The pH values obtained in this study concurs with those reported in greywater by other researchers including WHO (2006) which were in the range of 6.6 to 8.7 with a mean of 7.5; Peter *et al.* (2002) which were in the range of 5.3 to 10.8 with a mean of 7.0 and Raude *et al.* (2009) which were in the range of 5.7 to 8.6. Bhausahab *et al.* (2010) reported a mean pH value of 8.12 for bathroom and basin raw greywater.

The main effect of water pH on plant growth is through control of nutrient availability. For example, the absorption of Pb in soil increases with the increase of pH between 3.0 and 8.5 (Lee *et al.*, 1998). Blaylock and coworkers (1997) reported that in soil with a pH between 5.5 and 7.5, Pb solubility is controlled by phosphate or carbonate precipitates and very little Pb is available to plants even if they have the genetic capacity to accumulate it. However, for most crops, soil pH values of 5.5 to 7.5 are suitable for availability of most nutrients (Muchukuri *et al.*, 2004). Therefore, from the results of the present study raw bathroom GW would be the most suitable for use in growing of most crops since its pH values are within those of the soil reported by Muchukuri *et al.* (2004) and also would help reduce the uptake of lead by plants according to Blaylock and coworkers (1997). Laundry wash GW could be appropriate for use in acidic soils because it would help in soil neutralization, but would not be suitable for irrigation of acid-loving plants such as azaleas, gardenias, camellias, and

rhododendrons. According to Tchobanoglous (2003) the concentration range suitable for the existence of most biological life is quite narrow and critical and is typically 6 to 9. This then implies that the four types of raw GW analysed in this study can be suitable for irrigation because their pH values are within the required range.

4.2.2 Mean Levels of Lead in Raw Greywater

The average levels of lead in the various types of greywater are tabulated in Table 4.4.

Table 4. 4: The Mean and Ranges of Lead Levels in Different Types of Greywater

Type of Water	Mean±SE mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	0.06±0.02 ^a	0.01 - 0.09
Kitchen greywater (KGW)	0.11±0.01 ^b	0.03 - 0.19
Bathroom greywater (BGW)	0.08±0.01 ^a	0.01- 0.17
Laundry wash greywater (LWGW)	0.13±0.01 ^b	0.09 – 0.18
Laundry first rinse greywater (LRGW)	0.11±0.01 ^b	0.08 – 0.15

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

As can be seen in Table 4.4, the average levels of lead in all the four types of GW analysed were higher than those in tap water. There was no significance difference between the mean levels of lead in tap water and bathroom GW ($\alpha=0.05$, $p>0.05$), however KGW, LWGW and LRGW differed significantly from tap water ($\alpha=0.05$, $p<0.05$). The potential sources of lead in domestic wastewater are household products such as toothpaste, mouth wash, facial cream, powder and liquid detergents, dishwashing products (dishwashing tablets and powders), hair conditioners among others (Tjandraatmadja *et al.*, 2008). Also lead may originate from the plumbing

systems. In addition to use of larger amounts of detergent in laundry activities, soiled clothes could be another source of lead thus high levels in laundry greywater. The concentration of lead in the four types of RGW was in the range of 0.01 to 0.19 mg/L with an overall mean of 0.11 ± 0.00 mg/L. The levels of lead in greywater reported by Skudi (2011) were 0.018 mg/L in kitchen GW, 0.029 mg/L in laundry GW and 0.028 mg/L in bathroom GW.

The lead levels obtained in this study are much lower than the maximum concentration threshold of 5.0 mg/L for lead recommended by WHO (2006) for safe use of wastewater, excreta and greywater for crop production. From the results of this study therefore, it can be concluded that all the four types of raw greywater analysed in this study are recommendable for use in irrigation, since the lead levels are lower than the allowed/recommended levels.

Considering that GW is produced daily, laundry wash GW use should be minimal, as it has high chances of accumulating more lead in the soil and also due to its high pH values it will increase the absorption of lead according to Lee *et al.* (1998) as stated in section 2.6. Regardless of the quantities of lead in RGW, and the problems associated with it to plants for example (In most cases lead blocks the entry of cations (K^+ , Ca^{2+} , Mg^{2+} , Mn^{2+} , Zn^{2+} , Cu^{2+} , Fe^{3+}) and anions (NO_3^-) in the root system (Kabata-Pendias and Pendias, 1992). Lead levels should be minimized to the lowest level possible by treating greywater for example through filtration among other methods.

4.2.3 Levels of Cadmium in Raw Greywater

Cadmium was not detected in any of the samples analysed in this study, probably its levels were below the detection limit of the instrument used. The recommended maximum concentration threshold for cadmium is 0.01 mg/L WHO (2006) for safe use of wastewater, excreta and greywater for crop production. Therefore, all the four types of GW analysed in this study could be recommended for irrigation.

4.2.4 Mean Levels of Potassium in Raw Greywater

The results for the mean concentrations of potassium in the various types of greywater are tabulated in Table 4.5.

Table 4. 5: The Mean and Ranges of Potassium Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	1.76±0.07 ^a	0.37 - 2.13
Kitchen greywater (KGW)	9.74±0.64 ^b	4.99 – 16.46
Bathroom greywater (BGW)	8.60±0.76 ^b	2.77 – 17.80
Laundry wash greywater (LWGW)	15.51±1.24 ^c	6.39 – 28.40
Laundry first rinse greywater (LRGW)	9.45±0.78 ^b	2.59 – 16.23

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

As can be seen in Table 4.5, the mean levels of potassium in greywater were significantly higher than in tap water ($\alpha=0.05$, $p<0.05$). The possible source of potassium in greywater includes uses of cleaning products such as soaps, detergents, oral care products like toothpaste among others thus high levels. However, there was

no significance difference between the mean levels of potassium in kitchen, bathroom and laundry first rinse greywater ($\alpha=0.05$, $p>0.05$).

Also the mean levels of potassium in LWGW were significantly higher than the rest of the GW analysed ($\alpha=0.05$, $p<0.05$) probably due to large amounts of detergents used and soil particles present in cloths among others. Bathroom GW had the lowest mean levels of potassium may be due to small amounts of soaps used. With reference to Table 4.5, the laundry first rinse GW had low levels of potassium compared to laundry washes, showing that rinsing reduces nutrient availability. The mean levels of potassium in the four types of RGW were in the range of 2.59 to 28.40 mg/L with an overall mean of 10.83 ± 0.50 mg/L.

Potassium mean levels in greywater samples found in this study are concurs with those documented by Bhausahab *et al.* (2010) in raw bathroom and basin greywater of 4.52 mg/L, while Murphy (2000) reported K values in the range of 2.5 to 28 mg/L with a mean of 9 mg/L for dishwater, and 0.58 to 30 mg/L with a mean of 5 mg/L for bathwater. From the results of this study, it can be concluded that greywater could be a potential source of potassium, and laundry wash GW offers the highest quantity. Since potassium is one of the fertilizer element (others are nitrogen and phosphorus), greywater can be used to supplement this nutrient.

4.2.5 Mean Levels of Calcium in Raw Greywater

The mean concentrations of calcium in the various types of greywater are given in Table 4.6. The concentration range of calcium of the four types of greywater was 8.94 to 50.00 mg/L with an overall mean of 25.53 ± 0.86 mg/L. As can be seen in Table 4.6, the mean levels of calcium in greywater were significantly higher than in tap water

($\alpha=0.05$, $p<0.05$). The mean levels of calcium in KGW, BGW and LRGW did not differ significantly ($\alpha=0.05$, $p>0.05$). Laundry wash GW differed significantly from the other types of GW analysed ($\alpha=0.05$, $p<0.05$). The higher levels of calcium in greywater from laundry wash GW could be attributed to presence of soil particles in clothes, shoes among other items in addition to detergents used.

Table 4. 6: The Mean and Ranges of Calcium Levels in Different Types of Greywater

Type of Water	Mean \pm SE(mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	5.80 \pm 1.16 ^a	3.09 – 11.41
Kitchen greywater (KGW)	20.94 \pm 1.60 ^b	9.14 – 41.90
Bathroom greywater (BGW)	23.88 \pm 1.23 ^b	19.30 – 37.00
Laundry wash greywater (LWGW)	33.10 \pm 1.72 ^c	20.68 – 50.00
Laundry first rinse greywater (LRGW)	24.20 \pm 1.50 ^b	8.94 – 41.40

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

The mean levels of calcium in greywater reported by Bhausahab *et al.* (2010) were 0.13 mg/L for raw bathroom and basin greywater while those of Murphy (2000) were in the range of 4.4 to 20 mg/L and a mean of 13 mg/L for dishwater, 3.5 to 21 mg/L and a mean of 11 mg/L for bathwater. Also Skudi (2011) reported 165.625 mg/L for bathroom GW, 200.938 mg/L for kitchen GW and 190.049 mg/L for laundry GW.

According to Whitney *et al.* (1996), calcium has no established specific levels of concentration that would be damaging to the soil or plants, however, high levels of calcium would lead to alkaline soils. According to Will *et al.* (1999) desirable levels of calcium for irrigation water is 40 to 100 mg/L. Therefore, from the results of this study all the types of greywater could be recommended for use in irrigation since the

calcium levels are also lower than the maximum level recommended for drinking water by KEBS (2007).

4.2.6 Mean Levels of Magnesium in Raw Greywater

The mean levels of magnesium in greywater analysed in this study are presented in Table 4.7.

Table 4. 7: The Mean and Ranges of Magnesium Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	1.64±0.12 ^a	1.29 – 2.34
Kitchen greywater (KGW)	6.21±0.53 ^b	2.15 – 11.56
Bathroom greywater (BGW)	5.52±0.54 ^b	1.90 – 12.07
Laundry wash greywater (LWGW)	7.53±0.63 ^c	1.57 – 13.24
Laundry first rinse greywater (LRGW)	5.98±0.56 ^b	1.88 – 12.02

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

As indicated in Table 4.7, the mean levels of magnesium for the four types of greywater were in the range of 1.57 to 13.24 mg/L with an overall mean of 6.31 ± 0.29 mg/L. The mean levels of magnesium in LWGW differed significantly from the other types of greywater ($\alpha=0.05$, $p<0.05$). However, KGW, LRGW and BGW did not differ significantly ($\alpha=0.05$, $p>0.05$). The high levels of magnesium in LWGW could be attributed to the use of large amounts of cleaning agents and may be due to presence of soil particles in clothes among other items, while in kitchen GW it could be due to presence of food particles in GW. All the four types of greywater differed significantly from tap water ($\alpha=0.05$, $p<0.05$).

The results of this study showed that GW can provide an appreciable amount of Mg compared to tap water. Therefore, greywater could be used as an effective nutritional supplement for Mg to crops. According to Will *et al.* (1999), desirable levels of magnesium for irrigation water is 30 to 50 mg/l and KEBS (2007) maximum threshold for drinking water is 100mg/L, therefore greywater analysed could be recommended for irrigation

Other reported levels of Mg in greywater by different researchers include 0.11 mg/L by Bhusaheb *et al.* (2010) in raw bathroom and basin greywater, .5 to 4.9 mg/L with a mean of 2.0 mg/L and 0.15 to 1.8 mg/L with a mean of 0.8 mg/L by Murphy (2000) in dishwater and for bathwater respectively, and 4.840 mg/L GW, 5.740 mg/L and 5.364 mg/L by Skudi (2011) in laundry, kitchen GW and bathroom GW respectively

4.2.7 Mean Levels of Zinc in Raw Greywater

The mean levels of zinc in all the four types of RGW analyzed are as indicated in Table 4.8.

Table 4. 8: The Mean and Ranges of Zinc Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	0.25±0.06	0.03 – 0.44
Kitchen greywater (KGW)	0.36±0.03	0.07 – 0.58
Bathroom greywater (BGW)	0.39±0.03	0.08 – 0.66
Laundry wash greywater (LWGW)	0.42±0.03	0.12 –0.99
Laundry first rinse greywater (LRGW)	0.37±0.04	0.07 – 0.63

Referring to Table 4.8, the zinc mean levels in the various types of greywater were in the following order: Laundry wash GW > bathroom GW > Laundry first rinse GW > kitchen GW. The concentration range of zinc in the four types of RGW was 0.07 to 0.70 mg/L with an overall mean of 0.38 ± 0.02 mg/L. As is seen in Table 4.8, the mean levels of zinc in all the types of greywater did not differ significantly from tap water ($\alpha=0.05$, $p>0.05$). However, the mean levels of zinc in grey water were higher than in tap water. The possible sources of zinc in greywater could be bar soaps, liquid and powder detergents, shampoo, sunscreens, and dishwashing products among other household products according to Tjandraatmadja *et al.* (2008) on analysis of household products in Australia. In addition to the use of the mentioned household products, the higher levels of zinc in greywater from laundry activities and bathrooms could be attributed to presence of soil particles in clothes among other items.

The threshold levels of zinc recommended by WHO (2006) as maximum concentration for crop production is 2.0 mg/L for safe use of wastewater, excreta and greywater, while KEBS (2007) is 5 mg/L for drinking water. Therefore, greywater produced in KU could be recommended for use in irrigation since its levels are lower than the recommended/allowed threshold. However, care should be taken since zinc is toxic to many plants at widely varying concentrations, although the toxicity reduces at $\text{pH} > 6.0$ and in fine textured organic soils (WHO, 2006). Greywater analysed in this study was found to have pH values greater than 6.0; therefore, it can be used for irrigation in combination with organic manure to minimize/avoid zinc toxicity.

4.2.8 Mean Levels of Iron in Raw Greywater

The results for the mean levels of iron in greywater analysed in this study are presented in Table 4.9.

Table 4. 9: The Mean and Ranges of Iron Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	0.76±0.11 ^a	0.18 – 1.25
Kitchen greywater (KGW)	1.73±0.16 ^b	0.26 – 3.16
Bathroom greywater (BGW)	1.28±0.12 ^b	0.40 – 2.79
Laundry wash greywater (LWGW)	2.36±0.16 ^c	0.66 – 4.04
Laundry first rinse greywater (LRGW)	1.45±0.12 ^b	0.39 – 2.55

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

With reference to the results in Table 4.9, the mean levels of iron in KGW, BGW and LRGW had no significance difference from each other ($\alpha=0.05$, $p>0.05$), while LWGW differed significantly from the rest ($\alpha=0.05$, $p<0.05$). All the four types of GW differed significantly from tap water ($\alpha=0.05$, $p<0.05$). The mean levels of iron were highest in laundry wash GW (2.36±0.16 mg/L) and lowest in bathroom GW (1.28±0.12 mg/L). The concentration of iron in the four types of greywater ranged from 0.26 to 4.04 mg/L and an overall mean of 1.71±0.08 mg/L. Use of iron wool could be the cause of high levels of iron in kitchen greywater, in addition to cleansing agents used. Apart from detergents, others items that could have contributed to high levels of iron in laundry greywater are soiled clothes among others. Also according to Tjandraatmadja *et al.* (2008), iron is a common element in majority of cleaning and personal products like toothpaste.

The maximum recommended concentration of iron by WHO (2006) for safe use of wastewater, excreta and greywater for crop production is 5.0 mg/L. The mean value of iron in laundry wash GW is almost half (2.36 mg/L) the recommended concentration therefore it has high chances of accumulating excess iron in the soil and could not be recommended for irrigation use. However, it's necessary to note that, iron is not toxic in aerated soils but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum WHO (2006). Bathroom GW which has the lowest iron concentration should be recommended for irrigation use since iron is only required in trace amounts by plants.

4.2.9 Mean Levels of Phosphorus in Raw Greywater

The results for the average levels of phosphorus of the four types of raw greywater analyzed in this study are given in Table 4.10.

Table 4. 10: The Mean and Ranges of Phosphorus Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	0.59±0.13 ^a	0.20 – 0.95
Kitchen greywater (KGW)	4.93±0.41 ^b	1.12 – 8.54
Bathroom greywater (BGW)	3.39±0.51 ^b	0.71 – 9.59
Laundry wash greywater (LWGW)	9.34±0.51 ^c	4.99 – 15.57
Laundry first rinse greywater (LRGW)	4.56±0.26 ^b	2.30 – 7.56

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

From Table 4.10, the mean values of phosphorus in the different types of GW were significantly higher than in tap water ($\alpha=0.05$, $p<0.05$). Equally laundry wash GW

differed significantly from other types greywater, but the mean levels of phosphorus in KGW, LRGW and BGW did not differ significantly ($\alpha=0.05$, $p>0.05$). The concentrations of phosphorus in the four types of greywater were in the range of 0.71 to 15.58 mg/L with an overall mean of 5.56 ± 0.30 mg/L. The following was the order of the concentration of P in GW from the lowest to the highest; BGW < LRGW < KGW < LWGW.

However, the high levels of phosphorus in laundry wash GW could be due to the use of more detergents and washing of soiled clothes, while in the kitchen GW could be attributed to presence of food particles. The phosphorus levels obtained in this study concurs to other documented levels. For example Raude *et al.* (2007) reported P levels in greywater in the range of 1.2 to 13.1 mg/L; Jerpperson *et al.* (1994) in the range of 0.6 to 27.3 mg/L with a mean of 8 mg/L while Murphy (2000) in the range of 0.87 to 131 mg/L with a mean of 14 mg/L for dishwater, and < 0.1 to 14 mg/L with a mean of 2 mg/L for bathwater.

The threshold levels of phosphorus recommended by WHO (2006) as maximum concentration for crop production is in the range of 0.1 to 30 mg/L for safe use of wastewater, excreta and greywater. Therefore all the four types of greywater analysed in this study could be recommended for use for crop production because their mean values are within the recommended range. Also they would provide this vital macro-nutrient needed by plants for various functions such as photosynthesis, energy storage and transfer among others.

4.2.10 Mean Levels of Nitrate-nitrogen in Raw Greywater

The mean levels of nitrate-nitrogen in greywater are shown in Table 4.11.

Table 4. 11: The Mean and Ranges of Nitrate-nitrogen Levels in Different Types of Greywater

Type of Water	Mean±SE (mg/L) n =30	Concentration range values (mg/L)
Tap Water (control) TW	0.53±0.15 ^a	0.32 – 0.66
Kitchen greywater (KGW)	4.99±1.04 ^c	0.76 – 8.84
Bathroom greywater (BGW)	2.55±0.58 ^b	0.46 – 5.16
Laundry wash greywater (LWGW)	3.62±0.54 ^{bc}	1.02 – 5.64
Laundry first rinse greywater (LRGW)	2.87±0.44 ^b	0.72 – 4.11

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$

From the results in Table 4.11, the concentration of nitrate-nitrogen for the four types of greywater ranged from 0.46 to 8.84 mg/L with an overall mean of 3.51 ± 0.38 mg/L. The mean levels of nitrate-nitrogen in the four types of GW and in tap water were in the following order: Kitchen GW > Laundry wash GW > Laundry first rinse GW > Bathroom GW > tap water. There was a significance difference between tap water and all the types of greywater ($\alpha=0.05$, $p<0.05$). Likewise on comparing the four types of greywater, a significance difference existed between kitchen GW and the other types of GW ($\alpha=0.05$, $p<0.05$). However, there was no significance difference between bathroom GW and laundry first rinse GW ($\alpha=0.05$, $p>0.05$).

Kitchen greywater is usually heavily polluted with food particles which could be contributing to high concentrations of nitrate-nitrogen, while in laundry wash greywater it may be due to presence of soil and faecal particle on the clothes. The results also portrays that the levels of nitrate-nitrogen were higher in greywater

compared to tap water. According to Will *et al.* (1999) if nitrate-nitrogen are present in water in significance amounts (for example more than 5 mg/L nitrate), the water should be taken into account in the fertility program. Therefore, all the four types of greywater analysed in this study could be recommended for use in irrigation.

Reports of nitrate-nitrogen levels are available, for example Peter *et al.* (2002) documented levels in the range of 1.0 to 17.5 mg/L with a mean of 1.5 mg/L in raw greywater, Al-Jlil (2009) 1.88 mg/L in raw wastewater while those of Bhausahab *et al.* (2010) were 0.67 mg/L for raw bathroom and basin greywater. Skudi (2011) documented 1.038 mg/L, 3.358 mg/L and 1.873 mg/L for bathroom, laundry and kitchen greywater respectively

4.3 Filtration of Raw Greywater

Greywater in most households especially in Kenyatta University (Kenya) is usually discarded, despite the looming water shortage and high water demand. This is because it is considered waste and noxious. Therefore, there was need for its treatment through filtration to ascertain whether there was any significance difference from untreated (raw) greywater. Filtration is known in producing high quality effluent and reducing water contaminants to acceptable standards according to US-EPA National Drinking Water Standards (1991).

The raw greywater was filtered by passing it through granular beds of sand, activated carbon (AC) and ordinary wood charcoal (raw charcoal) (OC) packed in separate glass columns. Each of the four types of GW analysed was passed through each of the filtering media at a time, and the filtrate collected in separate labeled plastic

containers. Thereafter, the filtrates were analysed for the various analytes/parameters stated in section 1.4.2. The results for filtrate analysis are discussed in section 4.4.

The following observations were made during filtration process:

- i) Some kitchen greywater clogged the filtering media especially the sand. This could be attributed to presence of large amounts of oils and fats in the greywater. This clogging problem was not experienced with activated carbon and raw wood charcoal filtration which could be related to good adsorption of organic compounds in this case fats and oils by carbon.
- ii) Clear filtrates were obtained after filtration. This implied that filtration improves the clarity of greywater. Therefore it should be recommended for treatment of greywater and will help remove the notion that greywater is noxious.

From these observations it can be concluded that sand is not a suitable filtering media for kitchen greywater because of clogging. Carbon (raw or activated) is suitable filtering media for all types of GW since clogging is not a common problem.

4.4 Levels of Various Analytes/Parameters in Filtered Greywater

The sand, activated carbon (AC) and ordinary wood charcoal (OC) filtrates for each of the four types of GW were analysed for pH using pH meter; Pb^{2+} , Cd^{2+} , K^+ , Ca^{2+} , Mg^{2+} , Zn^{2+} and Fe^{2+} using AAS while P and NO_3^- -N using UV-vis spectrometry. The results are presented in sub-sections 4.4.1 to 4.4.9.

4.4.1 The pH Mean Values of Filtered Greywater

The pH mean values for the various filtrates for each of the four types of GW are given in the Table 4.12.

Table 4. 12: The pH Mean Values in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE n =30	BGW Mean±SE n =30	LWGW Mean±SE n =30	LRGW Mean±SE n =30
Raw greywater	7.84 ±0.08 ^b	7.47 ±0.09 ^b	8.23 ± 0.06 ^b	7.75 ±0.06 ^b
Sand filtrates	7.02 ± 0.09 ^a	7.05 ±0.07 ^a	7.37 ± 0.10 ^a	7.11 ±0.09 ^a
AC filtrates	6.88 ±0.08 ^a	6.81 ±0.15 ^a	6.93 ±0.13 ^a	7.10 ±0.12 ^a
OC filtrates	8.18 ±0.06 ^b	8.20 ±0.07 ^c	8.35 ±0.10 ^b	8.07 ± 0.07 ^b

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ within a column

Analysis of pH mean values tabulated in table 4.12, revealed that there was no significance difference between OC filtrates and raw GW ($\alpha=0.05$, $p>0.05$) except BGW which differed significantly at ($\alpha=0.05$, $p<0.05$). However, the mean pH values of all the AC and sand filtrates were significantly lower than in raw GW ($\alpha=0.05$, $p<0.05$). The mean pH values for the AC filtrates decreased when compared with raw GW may due to removal of calcium through precipitation as calcium phosphate. The mean pH values for OC filtrates increased slightly compared to raw GW probably due to high ash content present in the wood charcoal. The mean pH values obtained in this study concurs to those reported by Bhausahab *et al.* (2010) for filtered bathroom and basin GW which were 7.43 and Peter *et al.* (2002) were in the range of 5.3 to 7.5 after treatment using soil columns.

Sand and AC filtrates would offer the best pH values for crop growing, because according to Muchukuri, *et al.* (2004) for most crops, soil pH values of 5.5 to 7.5 are suitable for availability of most nutrients. The OC filtrates would be more suitable for application in acidic soils because of neutralization effect. However, the pH mean

values for all the filtrates were within the ranges of 6.5-8.5 recommended by KEBS (2007) for drinking water and WHO (2006) for irrigation purposes.

4.4.2 Mean Levels of Lead in Filtered Greywater

The results for the average concentration of lead in filtered GW (filtrates) are presented in Table 4.13.

Table 4. 13: The Mean Levels of Lead in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	0.11±0.01 ^b	0.08±0.01 ^b	0.13±0.01 ^b	0.10±0.01 ^b
Sand filtrates	0.08±0.01 ^a	0.06±0.01 ^a	0.09±0.01 ^a	0.08±0.00 ^a
AC filtrates	0.07±0.01 ^a	0.06±0.01 ^a	0.08±0.00 ^a	0.07±0.01 ^a
OC filtrates	0.08±0.01 ^a	0.06±0.01 ^a	0.10±0.00 ^a	0.08±0.01 ^a

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ within a column

From the results presented in Table 4.13, it is noted that the mean levels of lead decreased significantly from raw GW ($\alpha=0.05$, $p<0.05$). The decrease in lead levels is related to factors such as adsorption, sedimentation, straining among others, of lead on filtering media. The results of the present study showed that activated carbon (AC) had the highest ability to remove lead from greywater than the other filtering media used, which could be attributed to its high surface area for adsorption. Therefore activated carbon could be recommended for treatment of GW compared to sand and raw charcoal. However, sand and raw charcoal are cheap, available and known filtering media to both literate and illiterate and could be recommended for use.

4.4.3 Mean Levels of Potassium in Filtered Greywater

The mean levels of potassium in the filtrates of the four types of GW are given in Table 4.14.

Table 4. 14: The Mean Levels of Potassium in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	9.74±0.64	8.60±0.76	15.51±1.24	9.45±0.78
Sand filtrates	8.08±0.60	7.57±0.71	13.66±1.40	8.30±0.83
AC filtrates	8.07±0.71	7.15±0.73	13.52±1.15	8.11±0.86
OC filtrates	9.04±0.71	7.58±0.79	14.00±1.21	8.41±0.78

As is seen in Table 4.14, there was no significance difference between the mean levels of potassium in all the filtered greywater and their respective raw greywater ($\alpha=0.05$, $p>0.05$). However, the potassium mean levels in filtered GW were lower than in raw greywater. Activated carbon removed slightly more potassium than sand and OC. The higher values of potassium in OC filtrates may be attributed to high ash content thus slightly higher values than in other filtering media. Therefore, AC is not the best filtering media as it removes more potassium which is needed by plants in large quantities. Sand and OC would be the filtering media of choice as they have very little effect on this important macro-nutrient needed by plants. The levels of potassium reported by Bhausheb *et al.* (2010) was 4.52 mg/L for raw bathroom and basin greywater, and after treatment through Sedimentation, aeration and filtration was 1.98 mg/L.

4.4.4 Mean Levels of Calcium in Filtered Greywater

The mean concentrations of calcium in the filtrates are presented in Table 4.15.

Table 4. 15: The Mean Levels of Calcium in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	20.94±1.60	23.88±1.23	33.10±1.72	24.20±1.50
Sand filtrates	18.95±1.81	21.40±1.31	30.08±1.80	22.12±1.45
AC filtrates	17.41±1.56	20.74±1.36	30.58±1.80	21.01±1.46
OC filtrates	19.05±1.73	21.44±1.35	30.13±1.78	22.48±1.60

The results in Table 4.15 indicated that there was no significance difference between the various greywater filtrates and their respective raw greywater ($\alpha=0.05$, $p>0.05$). However, the calcium levels in the filtrates are lower than in raw greywater. The decrease of calcium mean levels in filtrates and especially AC and OC could be attributed to precipitation of calcium as calcium phosphate. However, the sand and OC filtrates had almost the same levels of calcium, but higher than in AC filtrates. The high levels of calcium in sand and OC filtrates could be attributed to poor adsorption of the metal on the filtering media. In addition, OC may contain ash thus slightly higher values.

Although the levels of calcium in the filtrates were below those recommended by Will *et al.* (1999) for irrigation (40 to 100 mg/L), treatment of greywater through filtration was necessary as it would help lower the calcium levels, because it's known that, high levels of calcium would lead to alkaline soils (Whitney *et al.*, 1996). However, all the filtrates could be recommended for irrigation use because their calcium levels were

below the maximum limit of 150 mg/L for drinking water recommended by KEBS (2007). The levels of calcium reported by Bhausahab *et al.* (2010) were 0.13 mg/L for raw bathroom and basin greywater and after treatment were 0.00 mg/L.

4.4.5 Mean Levels of Magnesium in Filtered Greywater

The mean levels of magnesium in the filtrates are given in Table 4.16.

Table 4. 16: The Mean Levels of Magnesium in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	6.21±0.53	5.52±0.54	7.53±0.63	5.98±0.55
Sand filtrates	5.24±0.61	4.71±0.47	5.12±0.60	4.26±0.55
AC filtrates	5.23±0.52	4.18±0.50	5.19±0.70	4.03±0.54
OC filtrates	5.33±0.53	4.13±0.60	5.71±0.70	4.93±0.67

From Table 4.16, it can be seen that there was no significance difference between the mean levels of magnesium of the various filtrates and their respective raw GW ($\alpha=0.05$, $p>0.05$). However the mean levels of magnesium in the filtrates of the four types of greywater were abit lower than in raw greywater. The sand and wood charcoal filtrates had slightly higher levels of magnesium compared to AC filtrates, which could be attributed to their poor adsorption properties.

According to Will *et al.* (1999) desirable levels of magnesium for irrigation water is 30 to 50 mg/L and therefore, the results from this study indicate that all the various filtrates could be recommended for irrigation use as they contain considerable amount

of magnesium. The chances of these filtrates damaging the soil are low since the levels are much below the suggested levels by Will *et al.* (1999) and 100 mg/L recommended by KEBS (2007) for drinking water. Documented levels of magnesium by Bhausahab *et al.* (2010) are 0.11 mg/L for raw bathroom and basin greywater while after treatment were 0.00 mg/L.

4.4.6 Mean Levels of Zinc in Filtered Greywater

The levels of zinc obtained in the filtrates of raw greywater are presented in the Table 4.17.

Table 4. 17: The Mean Levels of Zinc in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	0.36±0.03 ^b	0.39±0.03 ^b	0.42±0.03 ^b	0.37±0.04 ^b
Sand filtrates	0.30±0.02 ^a	0.29±0.03 ^a	0.34±0.03 ^a	0.30±0.04 ^a
AC filtrates	0.27±0.02 ^a	0.30±0.03 ^a	0.33±0.02 ^a	0.29±0.04 ^a
OC filtrates	0.26±0.02 ^a	0.28±0.02 ^a	0.31±0.02 ^a	0.26±0.02 ^a

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ within a column

The results in Table 4.17 revealed that the mean levels of zinc in the different types of filtrates were significantly lower than in their respective raw greywater ($\alpha=0.05$, $p<0.05$). The decrease in zinc mean levels was highest in OC filtrates followed by AC and finally sand filtrates for all the four types of greywater analysed. The high removal of zinc by OC could be attributed to high pH levels associated with OC filtration among other factors such as adsorption, chance contact among others of zinc on filtering media. A high pH may cause iron and manganese and other minor

nutrients to become unavailable to plants leading to deficiencies (Will *et al.*, 1999) and zinc is known as one of these minor nutrients.

The zinc levels obtained in all the filtrates are much lower than the maximum concentration threshold of 2.0 mg/L for zinc recommended by WHO (2006) for safe use of wastewater, excreta and greywater for crop production and 5.0 mg/L by KEBS (2007) for drinking water. Therefore, all the filtrates could be recommended for irrigation use since zinc is required in small amounts by plants. Although the levels are below the recommended values, filtration is necessary for taking care of zinc toxicity due to successive accumulation in the soil. According to WHO (2006), zinc is toxic to many plants at widely varying concentrations; however toxicity reduces at pH > 6.0 and in fine textured organic soils. All the filtrates obtained in this research study had pH values above 6.0.

4.4.7 Mean Levels of Iron in Filtered Greywater

The mean levels of iron in the filtrates compared to raw GW are given in Table 4.18.

Table 4. 18: The Mean Levels of Iron in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	1.73±0.16 ^c	1.28±0.12 ^b	2.36±0.16 ^c	1.45±0.12 ^b
Sand filtrates	1.62±0.15 ^{bc}	1.13±0.15 ^{ab}	2.16±0.19 ^{bc}	1.29±0.12 ^b
AC filtrates	1.50±0.15 ^b	1.06±0.09 ^a	2.01±0.17 ^b	0.98±0.08 ^a
OC filtrates	1.16±0.13 ^a	0.99±0.10 ^a	1.62±0.17 ^a	0.91±0.08 ^a

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ in a column

As indicated in Table 4.18, the mean levels of iron decreased significantly on filtration and also varied depending on the type of filtering media used. The results also showed that OC filtrates had the lowest levels of iron followed by AC and finally sand filtrates. The decrease in iron levels may be due to adsorption of iron on the filtering media. The high removal of iron by ordinary charcoal (OC) could be attributed to high pH values of greywater filtered through it. Also according to Will *et al.* (1999), a high pH may cause iron and manganese and other minor nutrients to become unavailable to plants leading to deficiencies. Carbon may also cause precipitation of iron as ferric phosphate (Culp, 1978). Since the iron mean levels obtained in this study for the filtrates were lower than the maximum threshold of 5.0 mg/L of iron for crop production recommended by WHO (2006) for safe use of wastewater, excreta and greywater, all the various filtrates could be recommended for irrigation.

Analysis of iron mean values showed that there was no significance difference between the various sand filtrates and their respective raw GW ($\alpha=0.05$, $p>0.05$). However, it was observed that the various AC and OC filtrates differed significantly from their respective raw GW ($\alpha=0.05$, $p<0.05$).

4.4.8 Mean Levels of Phosphorus in Filtered Greywater

The Phosphorus mean levels in the various filtrates obtained in this study are given in Table 4.19. The results presented in Table 4.19, showed that the mean levels of phosphorus in the filtered greywater (filtrates) were significantly lower than those of raw greywater ($\alpha=0.05$, $p<0.05$). This could be attributed to precipitation of phosphorus as calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) or ferric phosphate (FePO_4) (Culp *et*

al., 1978) as well as decomposition of some organic phosphorus compounds from the greywater by the filtering media and especially carbon. As can be noted from the results in Table 4.19, activated carbon filtrates had the lowest mean levels of phosphorus probably due to its' good adsorption properties towards organic phosphates.

Table 4. 19: The Mean Levels of Phosphorus in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	4.93±0.41 ^b	3.39±0.57 ^b	9.34±0.51 ^b	4.56±0.26 ^c
Sand filtrates	3.82±0.32 ^a	2.69±0.44 ^a	6.91±0.40 ^a	3.43±0.21 ^b
AC filtrates	3.14±0.26 ^a	2.21±0.35 ^a	6.27±0.43 ^a	2.89±0.20 ^a
OC filtrates	3.46±0.29 ^a	2.55±0.42 ^a	6.55±0.39 ^a	3.37±0.21 ^b

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ within a column

The phosphorus mean levels obtained in this study are within the maximum concentration threshold levels of 0.1 to 30 mg/L for crop production recommended by WHO (2006) for safe use of wastewater, excreta and greywater. Therefore all the filtrates analysed in this study could be recommended for irrigation. The phosphorus levels obtained in this study are comparable to those reported by Raude *et al.* (2007) in raw greywater in the range of 1.2 to 13.1 mg/L; Jerpperson *et al.* (1994) in the range of 0.6 to 27.3 mg/L with a mean of 8 mg/L and Murphy (2000) in the range of 0.87 to 131 mg/L with a mean of 14 mg/L for dishwater, and < 0.1 to 14 mg/L with a mean of 2 mg/L for bathwater.

4.4.9 Mean Levels of Nitrate-Nitrogen in Filtered Greywater

The results for the levels of nitrate-nitrogen in the specified filtrates are presented in Table 4.20.

Table 4. 20: The Mean Levels of Nitrate-Nitrogen in Sand, AC and OC Filtrates

Type of Water	KGW Mean±SE (mg/L) n =30	BGW Mean±SE (mg/L) n =30	LWGW Mean±SE (mg/L) n =30	LRGW Mean±SE (mg/L) n =30
Raw greywater	4.99±1.04 ^b	2.55±0.58 ^b	3.62±0.54 ^b	2.87±0.44 ^b
Sand filtrates	6.60± 1.11 ^c	5.09± 0.66 ^c	5.14 ±0.90 ^c	4.13 ±0.87 ^c
AC filtrates	3.49± 1.06 ^a	1.81± 0.47 ^a	1.92 ±0.51 ^a	1.56 ±0.49 ^a
OC filtrates	4.25 ±0.92 ^b	2.36± 0.62 ^b	3.24± 0.52 ^b	2.28± 0.40 ^b

NB: Same superscript means no significant difference and different superscript indicates significant difference at $\alpha=0.05$ within a column

From the results presented in Table 4.20, the mean levels of nitrate-nitrogen were in the following order: Sand filtrates > raw GW > OC filtrates > AC filtrates. Also it can be noted that the nitrate-nitrogen levels in AC and OC filtrates are lower than in raw greywater, while higher in sand filtrates than in raw greywater. This shows that sand filtrates would provide the highest amount of nitrate-nitrogen while AC the lowest. On analysis of nitrate-nitrogen mean values presented in table 4.20, it was found that the nitrate-nitrogen mean values of the various sand and AC filtrates from differed significantly with their respective raw greywater ($\alpha=0.05$, $p<0.05$), while no significance difference between the various OC filtrates and their respective raw greywater ($\alpha=0.05$, $p>0.05$).

The mean nitrate-nitrogen levels in the sand filtrates were significantly higher than in raw GW probably due to nitrification process or conversion of organic form of

nitrogen to nitrate form due to oxidation reaction during the greywater filtration process. Since organic nitrogen is mostly in NH_4^+ form which might have oxidized to nitrite and finally to a more stable form of nitrogen (NO_3^-) (Al-Jlil, 2009). Nitrate is the highly stable form of nitrogen in wastewater treatment system (Al-Jlil, 2009). Activated carbon removed more nitrate-nitrogen than raw wood charcoal which may be attributed to its large surface area for adsorption.

The mean levels of nitrate-nitrogen obtained in this study compares with those reported by Peter *et al.* (2002) for raw grey water with a mean of 1.5 mg/L and after filtering through sandy and sandy loam soils, the mean levels were 9.9 and 12.9 mg/L respectively while those of Bhausahab *et al.* (2010) were 0.67 mg/L for raw bathroom and basin greywater and after filtering through coconut shell, charcoal and bricks were 0.21 mg/L. Also Al-Jlil (2009) reported 1.88 and 6.66 mg/L for raw and treated wastewater respectively.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study the following conclusions can be made:

- a) The pH values of the various greywater samples were within the recommended ranges for drinking water by WHO and KEBS.
- b) All the greywater samples analysed in this study contained low levels of Pb, which were below levels recommended by WHO for greywater reuse. Cadmium was not detected in any of the greywater samples analysed.
- c) The levels of Ca^{2+} , Fe^{2+} , K^+ , Mg^{2+} , Zn^{2+} , NO_3^- -N and P in all types of greywater were within the recommended levels of greywater for crop irrigation by WHO.
- d) Laundry wash greywater had significantly higher levels of all the selected analytes/parameters except nitrate-nitrogen which were highest in kitchen greywater.
- e) Filtration reduced the levels of all analytes/parameters but to varying degree except nitrate-nitrogen which increased significantly upon sand filtration while pH levels increased slightly upon raw wood charcoal filtration.
- f) Activated carbon (AC) removed the highest amounts of toxic metals (lead) from greywater compared to sand and ordinary charcoal (OC).

5.2 Recommendations from this Study

- a) Greywater produced in KU should be tapped and re-used for irrigation because the levels of parameters were within the recommended ranges for drinking water recommended by WHO and KEBS and crop irrigation recommended by WHO.
- b) Greywater can supplement essential elements in exhausted soils and can substitute

commercial fertilizers that are expensive and inaccessible to many.

- c) The greywater filtrates from raw wood charcoal would be suitable for use in acidic soils because of its high pH.
- d) Filtration of greywater should be encouraged since it would help in removing heavy metals and excess nutrients from greywater before land application.
- e) Use of sand and raw charcoal as filtering media compared to activated carbon should be encouraged because they are cheap, available and known to many.

5.3 Recommendations for Further Work

- a) Studies on other essential elements to plants and pollutants in greywater should be done
- b) Other types of domestic wastewater such as hand wash greywater need to be assessed.
- c) Same study to be carried out considering seasonal variation, age, health and lifestyle of occupants.
- d) Other types of filtering/adsorbent material should be investigated.
- e) Effects of raw and filtered greywater use on soil and plants should be investigated.
- f) Filtering media of different particle sizes and height should be assessed to find out its impact on the levels of essential plant nutrients and pollutants.
- g) Types and levels of organic matter in greywater produced in Kenyatta University should be determined
- h) Microbial test for greywater produced in Kenyatta University should be done.

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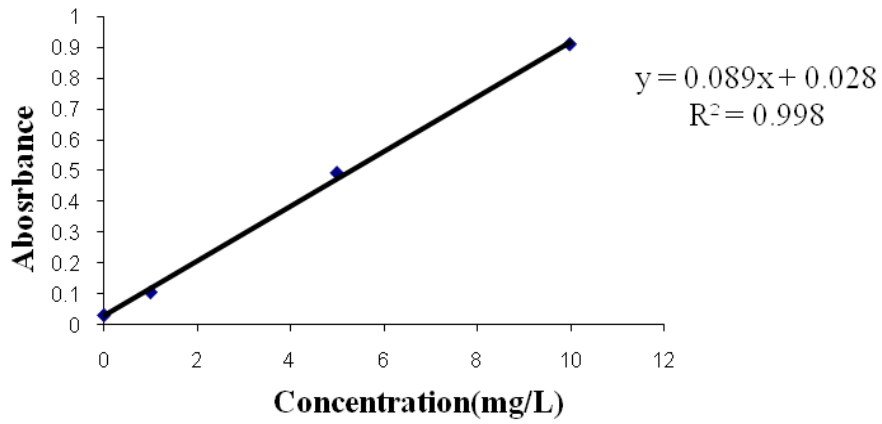
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APPENDICES

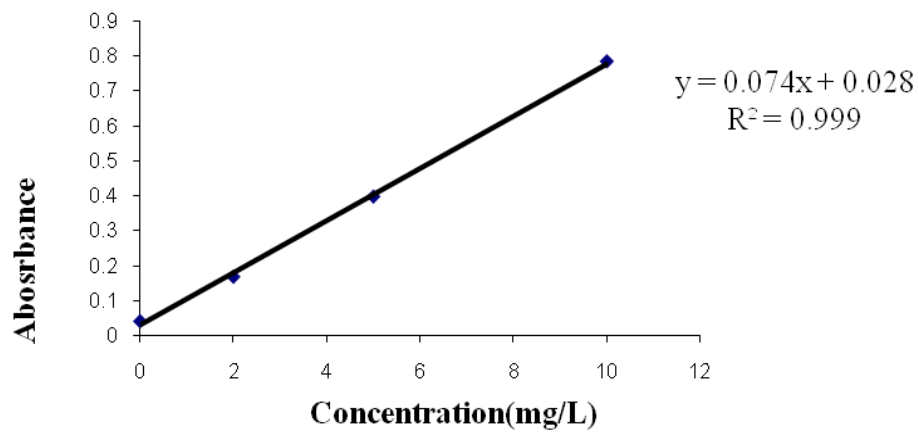
Appendix I

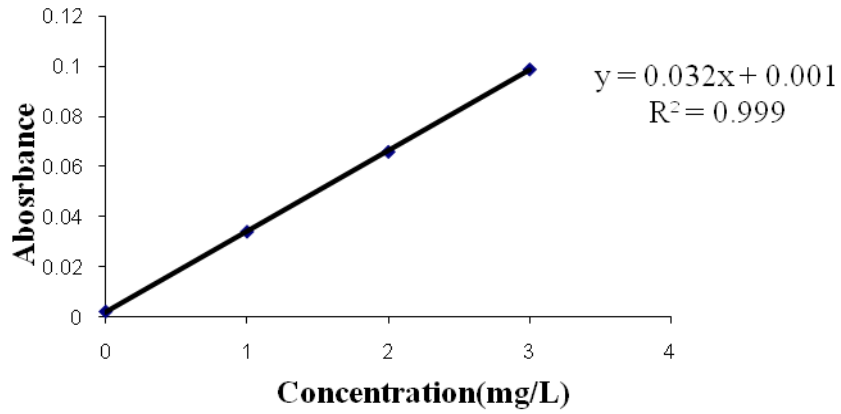
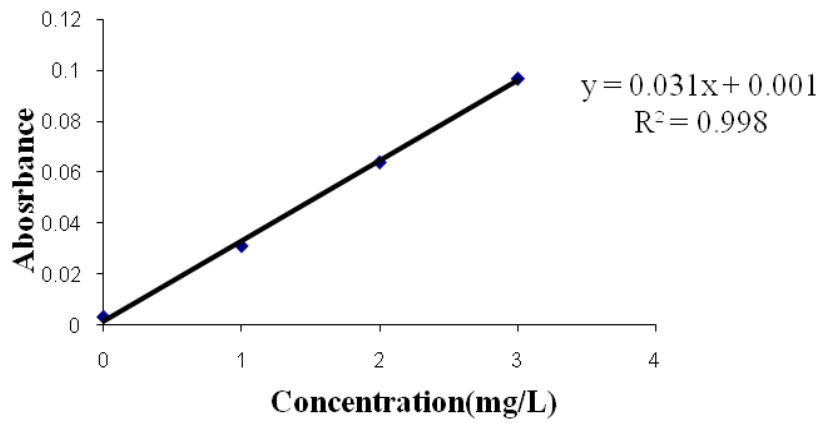
Standard calibration curve for potassium

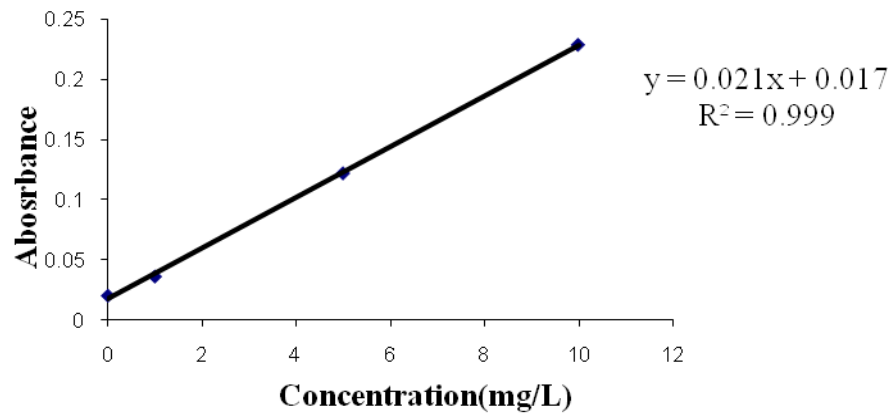
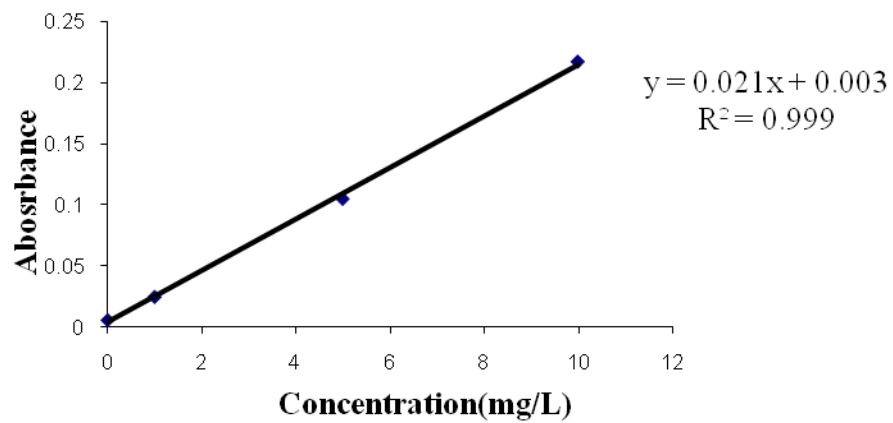


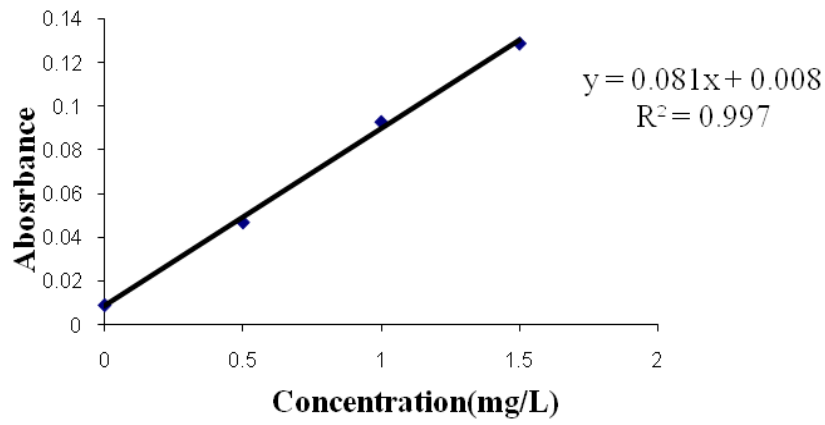
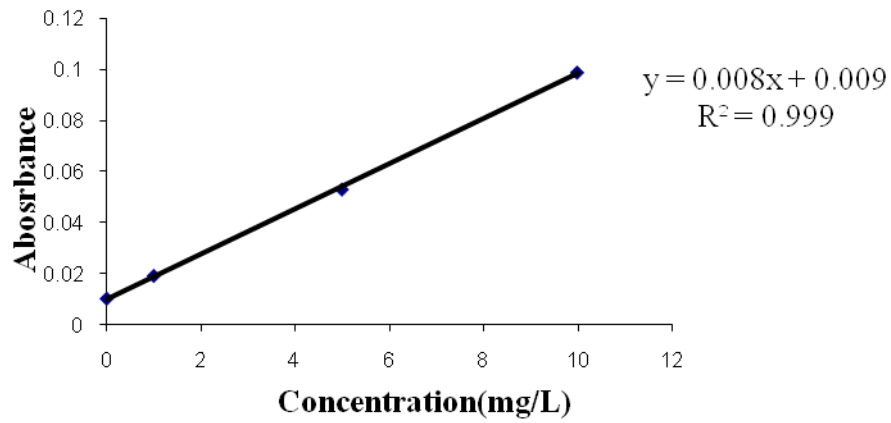
Appendix II

Standard calibration curve for calcium



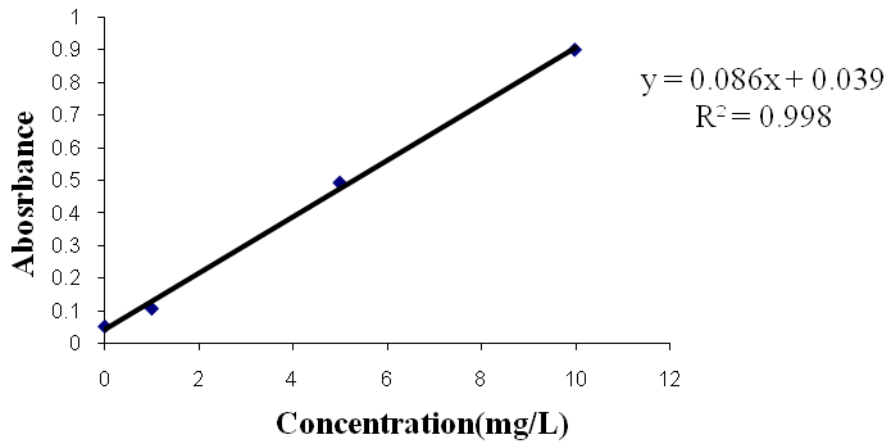
Appendix III**Standard calibration curve for zinc****Appendix IV****Standard calibration curve for Lead**

Appendix V**Standard calibration curve for Iron****Appendix V****Standard calibration curve for magnesium**

Appendix VII**Standard calibration curve for cadmium****Appendix VIII****Standard calibration curve for phosphorus**

Appendix IX

Standard calibration curve for nitrates



Appendix X

Map of Nairobi Province Showing the Study Area (shaded region)

